CENTRAL VALLEY FLOOD MANAGEMENT PLANNING PROGRAM

FloodSAFE CALIFORNIA

# Public Draft

## 2012 Central Valley Flood Protection Plan

# Attachment 9B: Status and Trends of the Riparian and Riverine Ecosystems of the Systemwide Planning Area

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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# 1.0 Introduction

This section states the purpose of this attachment, gives background information (including a description of planning areas and goals), discusses the scope of the status and trends assessment, and provides an overview of the report organization.

## 1.1 Purpose of Status and Trends Report

The purpose of this status and trends report is to summarize the current status and historical trends of riparian and riverine ecosystems in the Systemwide Planning Area for the Central Valley Flood Protection Plan (CVFPP). This area includes lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System. The lands that currently receive protection from the State Plan of Flood Control (SPFC) are entirely within the SPA.

The summary of status and trends in this report is intended to document the need for and support of the development of the Conservation Framework. The Conservation Framework will be a component of the 2012 CVFPP and the Central Valley Flood System Conservation Strategy (CVFSCS). It will describe how environmental stewardship would be an integral part of CVFPP actions to improve integrated flood management in lands currently protected by facilities of the SPFC flood management system in the SPA. The CVFSCS will identify opportunities in the SPA to promote natural dynamic hydrologic and geomorphic processes; increase and improve the quantity, diversity, and connectivity of habitats; and promote the recovery and stability of native species' populations.

This interim report, developed to support the 2012 CVFPP, will be followed by a more complete report to be prepared at a later date, in concert with the CVFSCS, during development of the 2017 CVFPP.

## 1.2 Background

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

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

As a supplement to the CVFPP, this status and trends report is intended to provide SPFC planners and engineers with relevant ecological background on Sacramento Valley and San Joaquin Valley riparian and riverine ecosystems, including an overview of the hydrologic and geomorphic processes that contribute to the structure and function of these ecosystems. It focuses on stressors specifically related to operations and maintenance of the SPFC so that flood system planners and engineers can understand the ecological consequences of previous flood management decisions and consider the potential ecological consequences of management actions considered as part of the 2012 CVFPP.

## 1.3 CVFPP Planning Areas

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

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

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

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

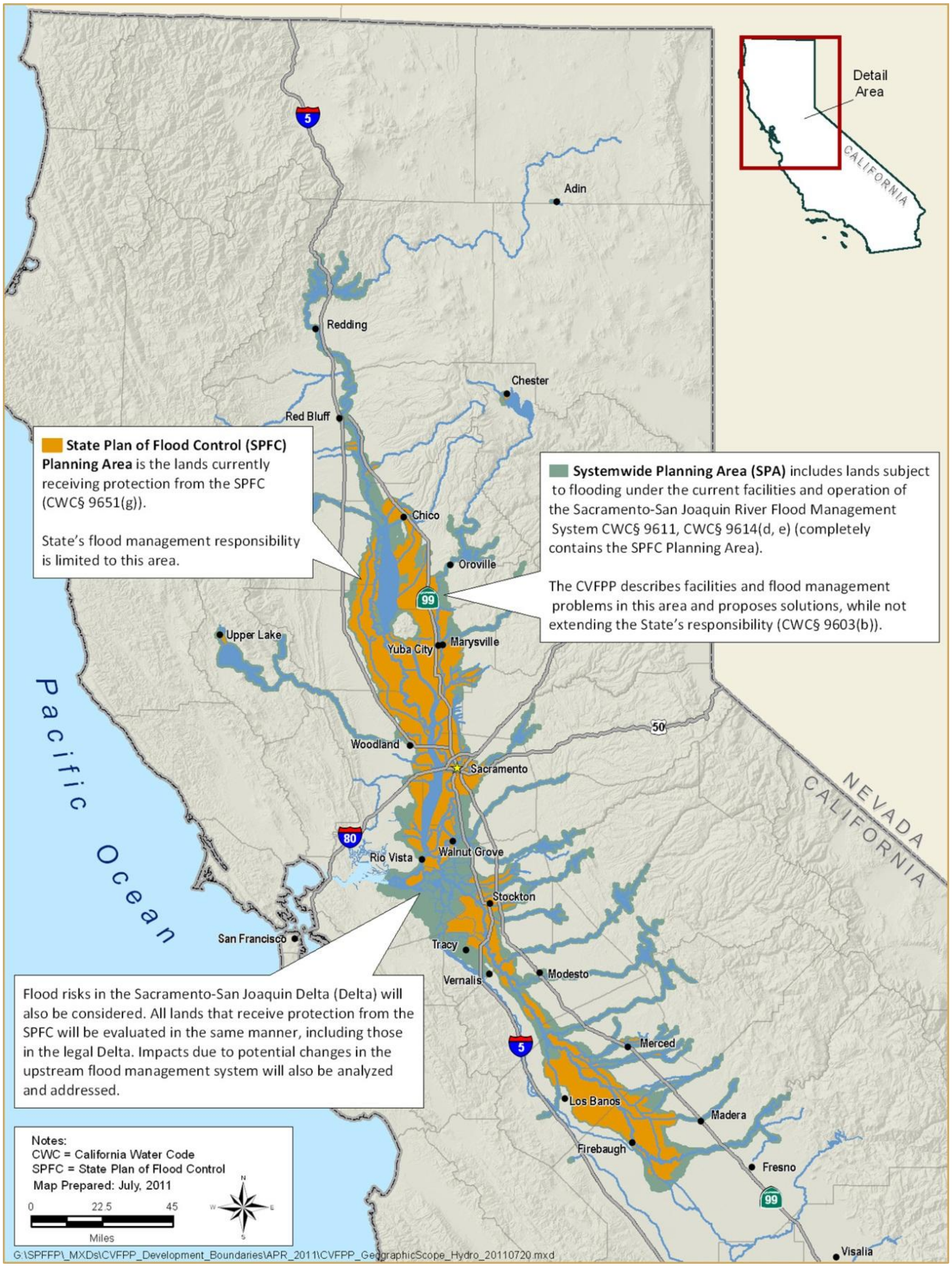



**Figure 1-1. Central Valley Flood Protection Plan Planning Areas**

This status and trends report focuses on the Systemwide Planning Area.

## 1.4 2012 CVFPP Planning Goals

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

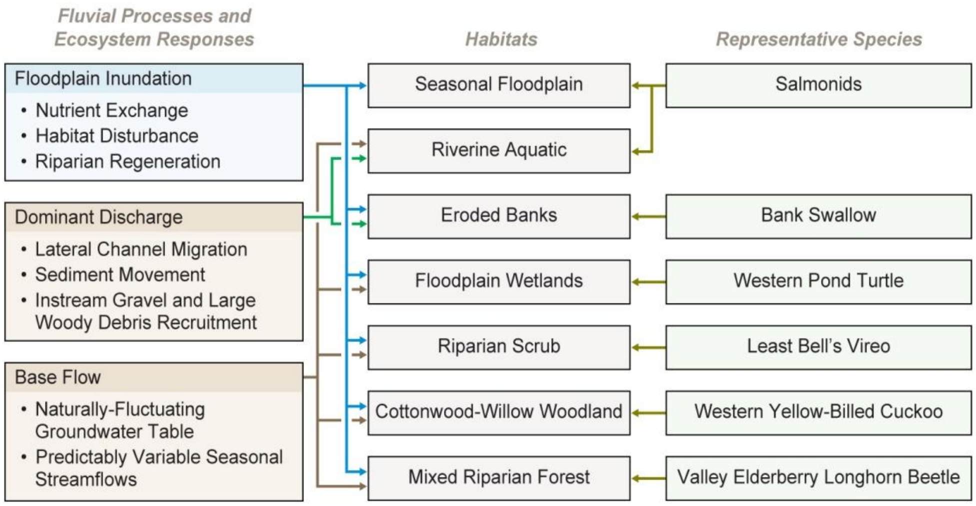
- **Primary Goal**: Improve Flood Risk Management
- Supporting Goals:
  - Improve Operations and Maintenance
  - Promote Ecosystem Functions
  - Improve Institutional Support
  - Promote Multi-Benefit Projects

This attachment provides the important background necessary for achieving the goal of promoting ecosystem functions.

## 1.5 Scope of Status and Trends Assessment

This report is not intended to be an exhaustive description of the SPA's riparian and riverine ecosystems. Rather, it focuses on describing key relationships among the Sacramento Valley's and San Joaquin Valley's river flows, geomorphic processes, and ecosystem responses that are relevant for understanding how these ecosystems function and how key stressors have modified these ecosystems historically and continue to modify them today. It also identifies key data gaps regarding stressors and current status and trends. Documenting these relationships is an important initial step in the development of a CVFSCS.

This report examines only those hydrologic and geomorphic processes that are most strongly linked to ecosystem functions, and it focuses on representative habitats and species that are most indicative of Sacramento Valley and San Joaquin Valley riparian and riverine ecosystems. Similarly, the report assesses the effects of only a limited number of stressors that are thought to have had the greatest effect on hydrologic and geomorphic processes and related riparian and riverine habitats. These stressors are strongly linked to the operations and maintenance of the SPFC because these stressors are most likely to be mitigated through potential modifications to the SPFC adopted as part of the CVFPP. As stated above, it is intended to provide a foundation for a more detailed assessment conducted during development of the CVFSCS. Processes and related habitats, stressors on these processes and habitats, and interrelationships among processes, habitats, and stressors discussed in this ecological status and trends report are shown on Figure 1-2.




*Source: Prepared by AECOM in 2011*

**Figure 1-2. Relationships Among Hydrologic and Geomorphic Processes, Habitats, and Representative Species of Sacramento and San Joaquin Valley Streams**

## 1.6 Report Organization

Organization of this document is as follows:

- Section 1 introduces and describes the purpose of this report.
- Section 2 describes the ecological history of the Sacramento Valley's and San Joaquin Valley's riparian and riverine ecosystems, how these ecosystems historically functioned, and early stressors on these ecosystems that have contributed to their current status and observed trends.
- Section 3 builds from the relationships illustrated on Figure 1-2 and describes the ecological relevance of the hydrologic and geomorphic processes emphasized in this report and the mechanisms by which these processes interact with each other and affect the ecosystem functions of Sacramento Valley and San Joaquin Valley riparian and riverine habitats. Additionally, it describes the mechanisms by which specific

stressors negatively affect hydrologic, geomorphic, and ecosystem processes.

- Section 4 assesses the status and trends of Sacramento Valley and San Joaquin Valley hydrologic processes, geomorphic processes, and related habitats through a series of metrics calculated from readily available data described in detail in Section 4. Each metric is described in a concise summary that identifies the rationale for selecting that metric to illustrate a particular process or habitat status, trend, or stressor; describes how the metric was developed and analyzed; and identifies the primary conclusion that can be drawn from each metric. The assessment relies heavily on graphical representations of each metric (e.g., charts or maps).

- Section 5 summarizes data gaps documented during the analysis of status, trends, and stressor metrics and highlights the potential for conceptual ecological models as a planning tool for the CVFSCS. Key data gaps need to be documented and the utility of conceptual ecological models needs to be highlighted because this report is intended to serve as the framework for a future, more comprehensive report developed as part of the CVFSCS.

- Section 6 contains references for the sources cited in this document.

- Section 7 lists abbreviations and acronyms used in this document.

# 2.0 Historical Conditions and Modifications of Central Valley Riparian and Riverine Ecosystems

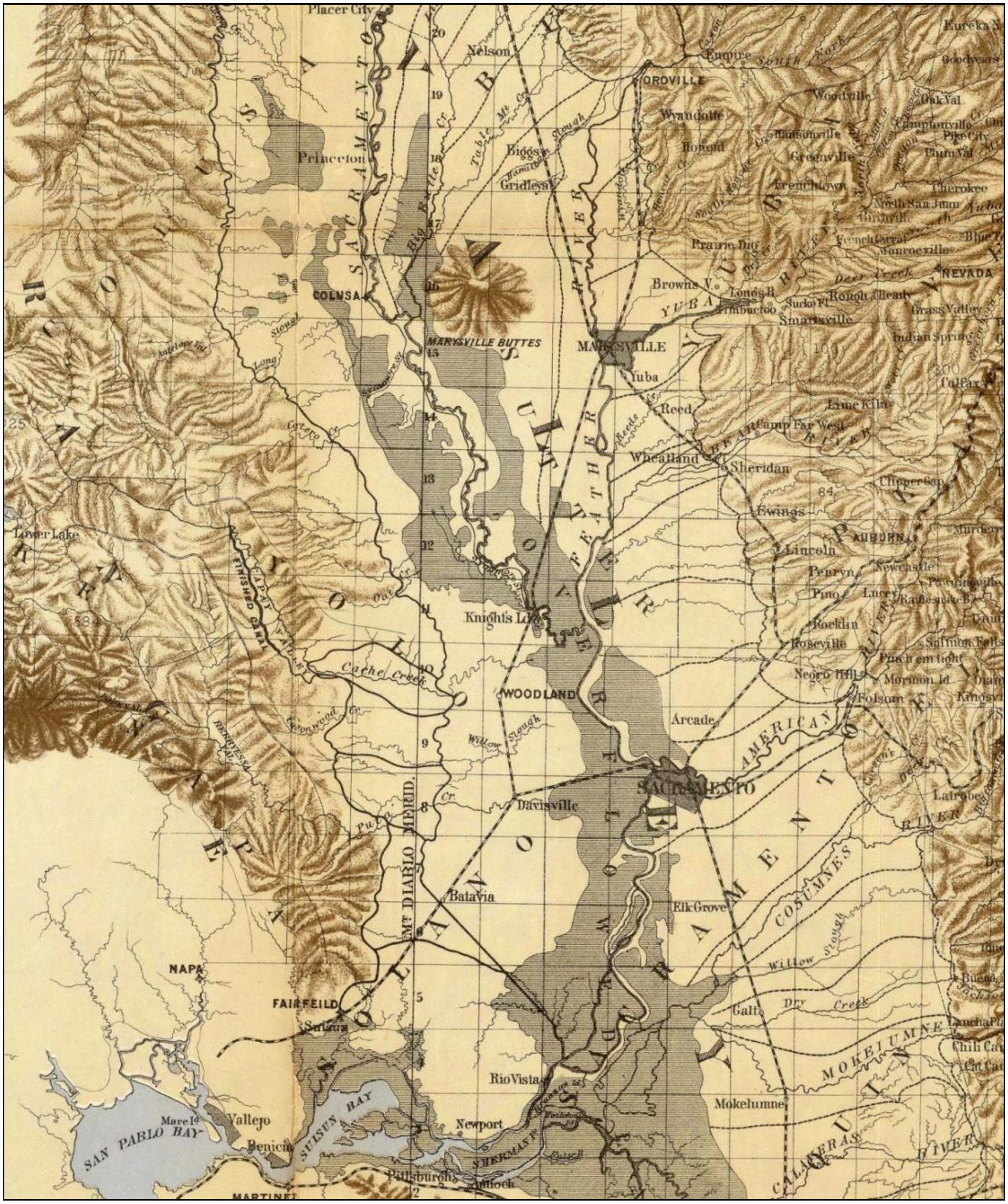
This section describes the historical conditions of the Sacramento Valley and San Joaquin Valley riparian and riverine ecosystems before the Gold Rush and the subsequent modification of these ecosystems associated with settlement and development. The description of historical conditions and modifications provides a framework for understanding the origins of conditions observed today.

## 2.1 Sacramento Valley Ecosystems

### 2.1.1 Pre-1850 Riparian and Riverine Ecosystems

The Sacramento River is more than 400 miles long and drains a watershed of more than 27,000 square miles. Inflow to the Delta in an average water year is approximately 21.3 million acre-feet (URS Corporation, 2007). The Sacramento River is mainly a rainfall river, with discharges that before the construction of major dams on average peaked in February to April (see Section 4). High flow variability and limited channel capacities resulted in frequent flooding of the lowland basins that cover most of the Sacramento Valley floor: the Butte, Marysville, Colusa, Sutter, American, Yolo, and Sacramento basins (Singer et al., 2008). Before the construction of major dams, the Sacramento River carried large amounts of sediment that was deposited along broad natural levees that bordered the river channel during overbank flows (James and Singer, 2008). At flood stages, the river flowed into its flood basins through openings in the natural levees and deposited large amounts of silt. In these flood basins, known as “tulares,” large expanses of freshwater marsh were dominated by common tule (*Schenoplectus acutus*) (Figure 2-1).

In the Sacramento Valley, the Sacramento River and its major tributary, the Feather River, are affected by valley tectonics and geology (Singer et al., 2008). Upstream from Red Bluff, the Sacramento River descends to the Sacramento Valley floor mostly between bedrock bluffs. In this reach, there is little opportunity for the river to meander or to overflow onto adjacent floodplains. Downstream from Red Bluff, the Sacramento River is a broadly meandering, alluvial river until it reaches the city of Colusa.



*Source: Alexander et al., 1874*

**Figure 2-1. Extent of "Overflowed Lands" (Tule Marshes) (Shaded Area) in the Sacramento Valley in 1873**

There, it encounters a buried geologic formation known as the Colusa Dome.

The presence of the Colusa Dome has resulted in the surface expression of a Modesto Formation outcrop, an erosion-resistant Pleistocene alluvial geologic formation commonly encountered in the Sacramento and San Joaquin valleys (Singer and Dunne, 2001). At this point, the river is deflected east, where it passes between the Colusa Dome and the Sutter Buttes, causing a sequestration of water and sediment in the reach upstream from this deflection point and a decrease in downstream channel capacity of approximately 70 percent (Singer et al., 2008).

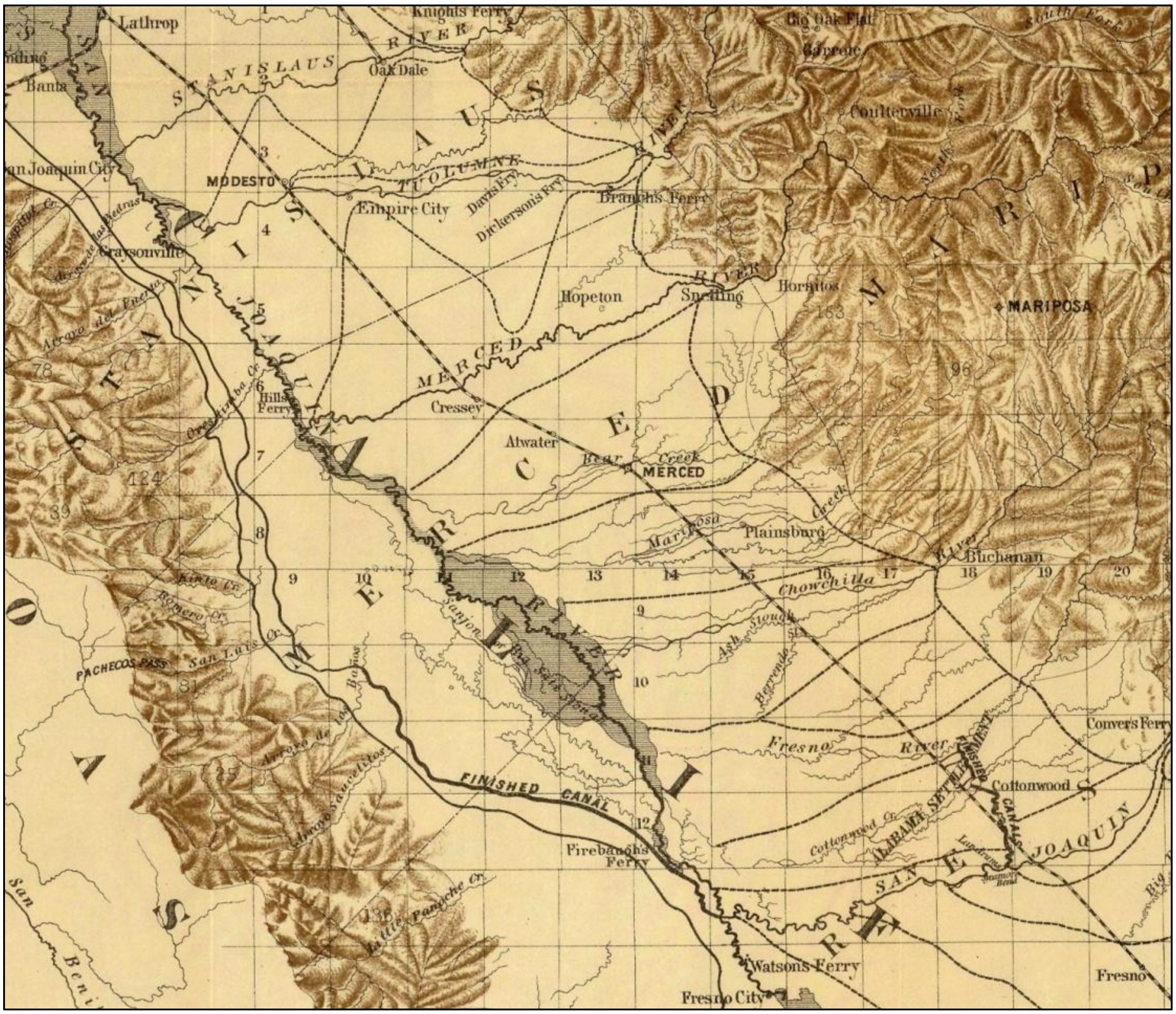
Another major geologic control is formed by the Pleistocene alluvial fan of Cache Creek, a westside tributary. This obstacle causes the river to run eastward to the confluence with the Feather River at Verona. Because backwaters would be created here historically during floodflows, the Knights Landing Ridge Cut was dug through the Cache Creek fan in 1915 to bring floodflows to the Yolo Bypass.

The land surface of the basins in the Sacramento Valley outside the natural levees has historically subsided and is lower in elevation than the floodplains directly along the river corridor (Singer et al., 2008). In some reaches, such as at the south side of the river between Knights Landing and Verona, at the current site of the Fremont Weir, the river frequently broke through the natural levees and deposited “alluvial splays” within the subsided basins.

The pre-1850 vegetation of the Sacramento Valley reflected the valley’s geomorphology. The subsided basins of the valley floor where the rivers deposited silts and clay during flood stage supported extensive tule marshes. The total area of tule marshes and other associated wetlands and open water was estimated by The Bay Institute (1998) by digitizing maps developed by Hall (1887, cited in The Bay Institute, 1998) and Alexander et al. (1874) (Figures 2-1 and 2-2). The total extent of wetlands in 1873 was estimated at approximately 300,000 acres in the Sacramento Valley (The Bay Institute, 1998).

The historical acreage of marshes and other types of wetlands in the riparian zone of the Sacramento Valley was estimated at 87,000 acres, the remainder of the 300,000 acres of wetland was mostly tule marsh in the basins (The Bay Institute, 1998). Riparian forest that occupied the natural levees and adjacent alluvial lands (e.g., splays) along the Sacramento River in the Sacramento Valley has been estimated at 364,000 acres (The Bay Institute, 1998). Because the disturbance regime along the channel and floodplain of the river was highly dynamic, with ongoing meandering processes forming point bars at the inside of bends and eroding steep banks at the outside of bends, the riparian habitat was diverse, with a mosaic of patches of different riparian habitat types (see Section 3). At its upland edges, the riparian forest graded into grassland and valley oak woodland.

The grasslands and woodlands associated with the riparian zone occupied approximately 186,000 acres of the Sacramento Valley (The Bay Institute, 1998).




*Source: Alexander et al., 1874*

**Figure 2-2. Extent of "Overflowed Lands" (Tule Marshes) (Shaded Area) in the San Joaquin Valley in 1873**

Historically, aquatic habitat in the Sacramento River and its tributaries was more diverse and variable than it is under current conditions. Periodically flooded basins provided seasonal rearing habitat for many native fish species, including salmonids (Sommer et al., 2001, 2003). Riparian forest canopies provided inputs of organic material, including large woody material (LWM), which provided abundant instream structure, shade, and reduced water temperatures, important habitat components for migrating salmonids and other native fish species. Salmonid fish species had access to their spawning grounds in the foothills and mountains and were historically much more abundant than today (Moyle, 2002). Historically, the dead Chinook salmon (*Oncorhynchus tshawytscha*) provided an estimated nutrient input of 20 million to 80 million pounds of organic matter per year for the entire Central Valley ecosystem (Moyle and Yoshiyama, 1992, cited in The Bay Institute, 1998). The abundant salmon fed numerous wildlife species, including the now extinct California grizzly bear (*Ursus arctos horribilis*).

Riparian and marsh vegetation of Sacramento Valley floodplains and flooded basins also supported abundant wildlife. The high diversity of riparian forest most likely supported a diverse assemblage of breeding birds. The tule marshes supported large numbers of waterfowl, and other species, such as beaver (*Castor canadensis*), and tule elk (*Cervus canadensis* ssp. *nannodes*) (The Bay Institute, 1998).

### 2.1.2 Historical Modifications of the Riparian and Riverine Ecosystems

In the 1850s, American and European settlers of the Sacramento Valley drained and cultivated the fertile flood basins and dug irrigation canals and ditches to provide their fields with water diverted from the Sacramento River and its tributaries. Floods in the early 1850s led the communities to build protective levees (James and Singer, 2008).

The Sacramento River spilled into its natural flood basins at relatively low flood stages. The construction of levees resulted in increased flood stages and velocities and more serious flooding when floods did occur. To counter the increased flooding severity, levees were built along longer stretches of the river and tributaries and were incrementally increased in height (James and Singer, 2008). Competing levee districts often knowingly exacerbated flooding in neighboring lands by building higher levees on their lands that forced flooding onto adjacent lands. These “levee wars” lasted until 1876, when building dams and levees that endangered others was outlawed in California (James and Singer, 2008).

At the same time, hydraulic mining became increasingly common in the northern Sierra Nevada. This practice produced large amounts of sediment that was delivered in torrents to the Sacramento Valley, starting in the early 1860s. It caused increased flooding along rivers of the Sacramento Valley (i.e., the lower Yuba, Feather, Bear, American, and Sacramento rivers) because it raised channel beds, and decreased channel gradients and flood conveyance capacity (James and Singer, 2008). Hydraulic mining on tributaries to navigable rivers was halted by the Sawyer Decision in 1884, but storage and remobilization of sediment continue to this day (James and Singer, 2008). Sediment delivery from the mountains to the valley was stopped by major dams built from 1928 to 1967 (Table 2-1).

**Table 2-1. Major Human Activities that Affected the Hydrology of the Sacramento River, 1849–2010**

| Year | Activity |
|---|---|
| 1849 | Gold Rush started |
| 1852 | Hydraulic mining started |
| 1884 | Federal injunction banned the use of hydraulic mining unless sediment was controlled (*Woodruff v. North Bloomfield et al.*) |
| 1895 | (Old) Folsom Dam constructed |
| 1902 | Sutter Butte Canal Company started construction of large facilities near Gridley |
| 1912 | Construction of Goodwin Dam completed on Stanislaus River |
| 1914 | Sacramento River Flood Control Project levees constructed for improved flood control and navigation, and to minimize flooding related to increased elevation of riverbed caused by mining debris |
| 1916 | Sacramento Weir constructed (releases to Sacramento Bypass started) |
| 1924 | (Old) Bullards Bar Dam completed on Yuba River |
| 1924 | Fremont Weir constructed (releases to Yolo Bypass started) |
| 1933 | Colusa Weir constructed (releases to Colusa and Sutter basins started) |
| 1944 | Construction of Shasta Dam completed on Sacramento River |
| 1950 | Construction of Keswick Dam completed on Sacramento River downstream from Shasta Dam |
| 1955 | Construction of Nimbus Dam and power plant completed on American River |
| 1956 | Construction of Folsom Dam completed on American River |
| 1960 | Sacramento Ship Channel constructed |
| 1963 | Construction of Whiskeytown Dam completed on Clear Creek (tributary to Sacramento River) |
| 1963 | Construction of Lewiston Dam completed on Trinity River, and Clear Creek Tunnel, which transfers water from Trinity River to Whiskeytown Lake in the Sacramento River watershed, completed |
| 1964 | Construction of Trinity Dam completed on Trinity River |
| 1967 | Construction of Oroville Dam completed on Feather River |
| 1969 | Construction of New Bullards Bar Dam completed on Yuba River |

*Sources: Reclamation, 1997, pp. II-7 through II-14; James and Singer, 2008, p. 132*

In the late 19th century, the state and federal governments' flood control strategy in the Sacramento Valley focused on a single-channel system, with tall, narrowly spaced levees, to encourage bed scour that would remove mining debris and improve opportunities for navigation. After the California Debris Commission was formed in 1893, state-federal cooperation on flood control started, and a systemwide review of the flood control system was initiated. After major floods in 1907 and 1909, the California Legislature and U.S. Congress adopted the Jackson Plan, which proposed a system of flood bypasses and weirs, widening of the Sacramento River channel near Rio Vista, and many miles of levees. The levee system incorporated existing levees and the construction of new levees. About 200 miles of levees along the main river channels below Colusa were narrowly spaced to promote bed scour, 300 miles of levees were located along tributaries and sloughs, and a setback reach was incorporated upstream from Chico Landing. Because federal funding was not immediately available, construction of the Sacramento River Flood Control Project did not start until 1918. The Sacramento River Flood Control Project is a system of levees, weirs, flood relief structures, and bypasses that was designed to route floodflows from the Sacramento River into a system of bypasses, while additional flood control is provided by major dams. By 1944, 90 percent of the project was completed. Major flood control was also provided by Shasta Dam, and additional flood protection was provided with the closure of Oroville Dam in 1968. Five major weirs were constructed between 1916 and 1933 that allowed the river to overflow into bypasses at specific flood stages or overflow into the Butte Basin designated floodways to make their way into the bypass system. These bypasses incorporated to some degree the historical flood basins described above.

In addition to providing flood control, major dams were constructed to manage irrigation water and generate electricity. Multipurpose dams provide flood storage, but were not economically justified for the purpose of flood control alone. The Sacramento River Flood Control Project should, therefore, be considered within the context of the larger water management system of the federal Central Valley Project and the State Water Project. Reservoir operations include consideration of flood management and the supply of water to agricultural, industrial, and municipal water users in the Central Valley, the Delta, Bay Area (Contra Costa, Santa Clara and Napa counties), and Southern California. Reservoir operations also are adjusted for environmental purposes; for example, to maintain prescribed levels of fresh water in the Delta for the benefit of native fish species.

The conversion of tule marshes and other wetlands, grasslands, oak woodlands, and riparian habitats to agricultural lands on much of the valley floor has resulted in changes in water demand. Water diverted from the rivers has been supplemented with groundwater, and groundwater pumping has led to a drop in groundwater levels that locally may affect riparian vegetation. The need for irrigation water in summer and fall also has led to reservoir operations that cause higher base flows during summer and fall than occurred before European settlement. This has resulted in higher than historical groundwater levels during this period (see Section 4).

The riparian and riverine ecosystems of the Sacramento River and its tributaries have been affected by the major changes in land use and the resulting need for flood control, and water management. The primary change is that the area of natural habitat has been greatly reduced. Based on 1993 California Department of Fish and Game (DFG) geographic information system (GIS) data, The Bay Institute (1998) concluded that less than 5 percent of the historically mapped wetlands in the Central Valley remain. Most remaining wetlands today are located on federal and state wildlife areas and on private duck clubs that are managed as waterfowl habitat. They are not directly connected to the river and typically are flooded from October to spring. Katibah (1984) estimated that 102,000 acres of riparian forest remained in the Central Valley, or about 11 percent of the pre-1850 area. He also estimated that of this area, 49,000 acres were in “disturbed and/or degraded” condition. The Bay Institute (1998) concluded, based on the 1993 DFG GIS data, that approximately 56,000 acres of riparian forest remains, or approximately 6 percent of the pre-1850 acreage. Much of this riparian habitat is highly fragmented or occurs as narrow strips along waterways. Habitat quality has been further degraded as the result of invasive plant species occurring in riparian habitats, such as saltcedar (*Tamarix* spp.) and giant reed (*Arundo donax*). These species have become especially abundant in stream reaches where geomorphic processes have been disturbed by sand and gravel mining and other disturbances.

The riverine (aquatic) habitat of today is also modified greatly from the pre-1850 condition. The channels have in many areas been straightened, and 150 miles of bank of the Sacramento River have been lined with riprap (The Bay Institute, 1998). In summer, the water tends to be deeper and of more uniform depth than it was before 1850, when aquatic habitats were much more diverse. Major dams on the main stem of the Sacramento River, the Feather River, and other Sacramento River tributaries has led to a substantially modified hydraulic regime with greatly reduced winter peak flows and increased summer flows that convey irrigation water to downstream diversions. The sediment supply has been altered, first by hydraulic mining and subsequently by dam construction. The reduction of riparian forest acreage has led to the reduced recruitment of woody material to the river and the reduced inputs of organic material into the water. The reduction in riparian tree acreage along streambanks has also led to a reduction in shade and changes in temperature regimes. Bypasses still provide seasonal habitat for native fish species (Sommer et al., 2003); however, the frequency and duration of inundation may be reduced compared to conditions before 1850. Many unscreened diversions along the rivers cause fish mortality, and because of blockage by dams, most potential spawning habitat for salmonids is no longer accessible (The Bay Institute, 1998). Salmon populations, conservatively estimated at 1 million to 2 million spawners in the Central Valley before European settlement, declined to small fractions of these previous numbers as the result of overfishing, blockage and damage of streams by mining, and modifications of flows by dams and water diversions (Yoshiyama et al., 1998). Other native fish species have also been impacted by these stressors, which are described in more detail in Sections 3 and 4.

Although no baseline data are available, the reduction in overall riparian habitat area has no doubt reduced the abundance of wildlife species supported by riparian habitat. For example, the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), a state-listed endangered species and a federal candidate for listing under the Endangered Species Act, breeds in large patches of well-developed, riparian habitat patches that were more abundant historically than today along the Sacramento River (Greco, 2008). California population size at the end of the 19th century was estimated at15,000 breeding pairs (Hughes, 1999, cited in 66 Federal Register 38614, July 25, 2001). Recently, the Sacramento River population of this species has declined from 96 pairs in 1973 to 40 pairs in 2000 (Greco, 2008). A survey conducted in 2010 estimated 38 existing territories that each could be occupied by a pair or individual bird (Dettling and Howell, 2011). To what extent the decline is attributable to loss of Sacramento River riparian habitat is unknown. However, this decline underscores the importance of conserving this riparian habitat-dependent species.

## 2.2 San Joaquin Valley Ecosystems

### 2.2.1 Pre-1850 Riparian and Riverine Ecosystems

The San Joaquin River is 330 miles long and drains an area of 15,558 square miles, or 58 percent of the size of the Sacramento River watershed. Inflow to the Delta in an average water year is approximately 2.8 million acre-feet, or 13 percent of the Sacramento River inflow (URS Corporation, 2007). The San Joaquin River is mainly a snowmelt river, with discharges that peak on average in May and June (see Section 4).

The San Joaquin River is inset between terraces as it descends with a low sinuosity into the San Joaquin Valley and down to Gravelly Ford. Historically, the river was flanked by at least two terraces at 40 feet and 20 feet above the current riverbed (Jones & Stokes Associates, 1998a). A diversity of riparian vegetation types representing different successional stages was supported by the river in this reach before Friant Dam was constructed, including riverwash (bare gravel and sand), riparian scrub, cottonwood-willow riparian forest, mixed riparian forest, riparian forest dominated by valley oak (*Quercus lobata*), and substantial areas of herbaceous wetlands (Jones & Stokes Associates, 1998b, 2002).

At Gravelly Ford, the alluvial fan of the San Joaquin River meets the valley floor. The valley slope increases here, resulting in increased river sinuosity until, near the city of Mendota, the river reaches the confluence with the Kings River North (current James Bypass), which drained the former Tulare Lake. At this confluence, the San Joaquin River bends north and extends along the main axis of the San Joaquin Valley. Before Friant Dam was constructed, vegetation in this reach was characterized by extensive wetlands, riparian scrub, and riparian forest (Jones & Stokes Associates, 1998b, 2002).

After the San Joaquin River moves north, sinuosity declines as the slope of the river decreases. The river historically formed a single channel (Jones & Stokes Associates, 1998a) with diverse riparian habitat. This single-channel reach ended approximately 20 river miles to 25 river miles downstream from the confluence with the Kings River North, at the edge of a historical basin, where the river branched into multiple channels and where large expanses of marshes were supported (Figure 2-2) (see also The Bay Institute, 1998, Appendix A, Map G6). The interconnected channels of the basin historically stored and conveyed floodflows that were collected in Mud, Salt, and Sand sloughs, which join the San Joaquin River above the confluence with the Merced River. The alluvial fan of the Merced River functions as grade control for the San Joaquin River (Jones & Stokes Associates, 1998a). Historically, floodflows backed up upstream from the confluence with the Merced River, and extensive tule marshes were located in this reach (Figure 2-2).

The width of the riparian zone and stretches of marsh varied between the confluence with the Merced and Stanislaus rivers. Downstream from the confluence with the Stanislaus River, the San Joaquin River spread into a broad delta covered with tule marshes (Figure 2-2).

The major tributaries of the San Joaquin River, including the Merced, Tuolumne, and Stanislaus rivers, supported their own riparian zones. The remaining remnant of primary riparian forest at Caswell Memorial State

Park on the Stanislaus River provides a glimpse into the historical riparian forest conditions, with massive valley oak trees growing on natural levees along the river meanders. These riparian forests gradually became oak woodlands and grasslands on higher ground. The Mokelumne, Cosumnes, and Calaveras rivers drain into the San Joaquin River in the Delta, each supporting abundant riparian habitat along its banks (The Bay Institute, 1998, Appendix A, Map G6).

The historical extent of the riparian zone in the San Joaquin Valley was approximately 329,000 acres, about half the extent in the Sacramento Valley (The Bay Institute, 1998). In the San Joaquin Valley, riparian zones were generally present in narrower bands than in the Sacramento Valley. The riparian zone was heterogeneous with patches of forest and woodland in drier spots, surrounded by tule marshes (The Bay Institute, 1998).

The pre-1850 San Joaquin River and its major tributaries supported abundant runs of spring- and fall-run Chinook salmon (Cain, 1997). As described for the Sacramento River, the dead salmon historically provided substantial nutrient input to the San Joaquin River ecosystem and fed numerous wildlife species. As in the Sacramento Valley, the high diversity of riparian forest most likely supported a diverse assemblage of breeding birds. The tule marshes supported large numbers of waterfowl.

### 2.2.2 Historical Modifications of the Riparian and Riverine Ecosystems

Major modifications to the San Joaquin River and its tributaries include the construction of diversion facilities for irrigation, including Friant Dam, which also has a flood management function; construction of flood control levees and channelization (including straightening) of the river; encroachment of agriculture and urban land uses into the floodplain; and aggregate mining in the upper reaches of the San Joaquin River and its tributaries. Table 2-2 lists major modifications that have led to changes in San Joaquin River hydrology.

**Table 2-2. Major Human Activities That Affected the Hydrology of the San Joaquin River, 1849–2010**

| Year | Activity |
|---|---|
| 1849 | Gold Rush started |
| 1871 | Mendota Dam (Weir) constructed |
| 1872 | Miller & Lux Canal constructed along west side of San Joaquin Valley to convey water from San Joaquin River |
| 1912 | Goodwin Dam completed on Stanislaus River |
| 1916 | Newer Mendota Dam constructed on San Joaquin River with a movable section to allow navigation |
| 1919 | Exchequer Dam and Power Plant constructed by Merced Irrigation District |
| 1923 | O'Shaugnessy Dam constructed on Tuolumne River (Hetch Hetchy Reservoir created) |
| 1923 | Don Pedro Reservoir constructed on Tuolumne River |
| 1924 | Melones Dam constructed on Stanislaus River |
| 1929 | Construction of Pardee Dam completed on Mokelumne River |
| 1940 | Water diversions started in Contra Costa Canal |
| 1944 | Construction of Friant Dam completed on San Joaquin River |
| 1951 | Construction of Delta Cross Canal, Delta-Mendota Canal, and Tracy Pumping Plant completed |
| 1958 | Construction of Tulloch Dam completed on Stanislaus River |
| 1963 | New Hogan Dam completed on Calaveras River |
| 1963 | Construction of Camanche Dam completed on Mokelumne River |
| 1959-1966 | Implementation of the Lower San Joaquin River Flood Control System, including construction of bypass system, above Merced River |
| 1967 | Construction of San Luis Canal and Dam completed |
| 1967 | Construction of New Exchequer Dam completed on Merced River |
| 1967 | Construction of State Water Project Delta pumps and California Aqueduct completed |
| 1970 | Construction of New Don Pedro Dam completed on Tuolumne River |
| 1978 | Construction of New Melones Dam completed on Stanislaus River |
| 1992 | Central Valley Project Improvement Act enacted |
| 1998 | Los Vaqueros Reservoir completed |

*Sources: Reclamation, 1997, pp.II-7 – II-14; James and Singer, 2008, p. 132*

The first major changes to the San Joaquin River were facilities built for irrigation, including the Miller & Lux Canal, a major canal built on the west side of the San Joaquin Valley that was completed in 1872 (Table 2-2). Frequently, temporary dams were placed in the river to divert irrigation water. These dams usually failed during floodflows in winter. One of the major examples is Sack Dam, which was originally built from sand bags, but is now a permanent structure, and which diverts water into the Arroyo Canal. A diversion dam at Mendota was first built in 1871 and has been replaced several times since then. The Mendota Pool behind this dam is a major diversion point for irrigation water. The most important changes to the hydrology of the San Joaquin River occurred when Friant Dam was completed in 1944 and when the Delta-Mendota Canal was completed in 1951 (Table 2-2).

Friant Dam intercepts all San Joaquin River water except floodflows and flows needed to maintain water rights downstream from the dam to Gravelly Ford. Almost all water released from Friant Dam is routed into two major irrigation canals. The result is that the reach between Gravelly Ford and the Mendota Pool has been dry during a large part of the year. In some cases, this reach can be dry continuously for several years. The Delta-Mendota Canal brings high-quality Delta water to the Mendota Pool. Some of the water is taken out of Mendota Pool for irrigation, and some of it moves down the river where it is diverted into numerous canals, such as the Arroyo Canal. Near the Sand Slough Control Structure, the flow has become so small that the river passes through a culvert.

The system of sloughs that enter the river upstream from the confluence with the Merced River captures agricultural return water and carries it back into the river. The quality of this water is poor. Groundwater in this reach of the river also appears to be of relatively poor quality because it has high levels of boron and salt (Jones & Stokes Associates, 1998a).

Although local levees have existed along the San Joaquin River since the 19th century, the San Joaquin River Flood Control Project levees were constructed between 1956 and 1972 by the state and federal Lower San Joaquin River and Tributaries Project from the Delta upstream to the Merced River. Additional modifications were completed in the 1980s. In the upper reaches from the Delta to Mossdale in the Stockton Area, the levees are frequently narrowly spaced. Below Mossdale, near the Stanislaus River, they become more set back and often are on just one side of the river. Between the Stanislaus River and Merced River, levees are discontinuous, allowing some overflow during high waters. In this reach, Paradise Cut Bypass carries floodwaters directly to Old River and Delta channels.

Immediately upstream from the Merced River to the beginning of the bypass system near the Sand Slough Control Structure, project levees alternate between being located on only the east side or on both sides of the San Joaquin River. Upstream from this point, between the San Joaquin Flood Control Structure and Fresno Slough, about 45 miles of the San Joaquin River have no SPFC levees or facilities. This reach differs from the downstream reaches in that it is not a single channel, but rather an anabranching river system with Salt Slough, Sand Slough, Mariposa Slough, and the San Joaquin River in parallel channels.

The Chowchilla, Eastside, and Mariposa bypass system intercepts flows from Bear Creek, Owens Creek, Chowchilla River, Ash Slough, Berenda Slough, and the Fresno River in addition to two-thirds of the San Joaquin River's higher flows. Initially, the U.S. Army Corps of Engineers (USACE) recommended that approximately 118,000 acres of grassland floodplain between Friant Dam and the Merced River be retained as flood detention basins, in lieu of flood protection works (Reclamation Board, 1966). Instead, between 1956 and 1966, the state designed and constructed the Eastside Bypass system from the Merced River upstream to the head of the Chowchilla Bypass, isolating about 240,000 acres of floodplain from the San Joaquin River (Mussetter Engineering and Jones & Stokes Associates 2002).

In some areas, the soil may not be suitable for farming – for example, in the reach upstream from the confluence with the Merced River, where a claypan subsoil makes cultivation difficult. Here, higher ground is used as pastureland, and lower areas have been converted to state wildlife management areas, federal national wildlife refuges (e.g., the San Luis National Wildlife Refuge Complex), or private duck clubs (e.g., many acres of private wetlands in the Grasslands Irrigation District). These wetland areas provide important wintering habitat for waterfowl that migrate along the Pacific Flyway.

Flow regulation by Friant Dam has had a dramatic effect on riparian habitats. Without scouring flows, natural succession has progressed uninterrupted in most areas, and early successional stages of riparian vegetation, such as riverwash, riparian scrub, and cottonwood-willow forest, have declined in cover, while the extent of mixed riparian forest has increased (Jones & Stokes Associates, 1998b, 2002). In some reaches – for example, downstream from Mendota Dam – riparian forest flourishes directly along the channel because of continual high base flows. Downstream from Sack Dam, riparian vegetation completely covers the riverbed because floodflows bypass these areas, but they remain wet throughout the summer because of leakage through the dam or agricultural runoff (Jones & Stokes Associates, 1998a).

As described for the Sacramento River, the reduction in overall riparian habitat area has no doubt reduced the abundance of wildlife species supported by riparian habitat. A number of neotropical migrant songbirds breed in riparian scrub, such as the least Bell's vireo (*Vireo bellii pusillus*), which is state- and federally listed as endangered, but riparian scrub habitat for these species has been greatly reduced along the San Joaquin River (Jones & Stokes Associates, 1998b, 2002).

The dry sections of the San Joaquin River form a major obstacle to migration by salmonids. As the result of a legal settlement, the U.S. Department of Interior, Bureau of Reclamation (Reclamation), is restoring a self-sustaining Chinook salmon population to the San Joaquin River between the Merced River and Friant Dam. The Merced, Tuolumne, and Stanislaus rivers each have remnant Chinook salmon runs that spawn below the major dams on these rivers (on the Merced River, salmon are also reared in a hatchery). On each of these rivers, active riparian and riverine habitat restoration projects have been implemented to improve Chinook salmon habitat, including the isolation of instream gravel pits from the river channel. A whole community of native fish, including hitch (*Lavinia exilicauda*), California roach (*Lavinia symmetricus*), hardhead (*Mylopharodon conocephalus*) and others that were present in the 19th century in the San Joaquin River at Friant have been replaced by largely nonnative species such as largemouth bass (*Micropterus salmoides*) and common carp (*Cyprinus carpio*) (Moyle 2002, Table 9). The largest change in fish community composition occurred after the construction of Friant Dam.

The operation of Friant Dam has prevented the regeneration of willows and cottonwoods. Typically, these species germinate in June on bare sand or gravel bars that under natural conditions typically would be deposited by a moderate-sized flood (e.g., 10-year flood) in western rivers (Stromberg et al., 1991; Scott et al., 1997; Shafroth et al., 1998). After seed of these species is dispersed by wind in spring and early summer, they may germinate, but the abrupt termination of almost all flow releases in spring or early summer causes these seedlings to die. Early age classes of willows (e.g., black willow (*Salix gooddingii*) and Fremont cottonwood (*Populus fremontii*) are therefore almost absent from much of the San Joaquin River. A pilot project initiated by the Friant Water Users Authority and the Natural Resources Defense Council in 1999 used water purchased by the CALFED Bay-Delta Program to extend releases from Friant Dam into summer and fall. This project demonstrated that black willow can be established if a gradually declining hydrograph is provided, allowing growing roots to reach the declining groundwater.

The San Joaquin River has been greatly modified by sand and gravel mining, especially in the vicinity of Fresno. Although mining does not occur in the bed of the river, the berms that separate the mining pits from the river frequently are captured by the river at high flows. Sediment transport is affected by these mining pits because the flows may capture coarse sediment, but sand may also “waste” out of these mine pits and be deposited downstream. Sand and gravel mining also occurs along the Merced, Tuolumne, Stanislaus, and Calaveras rivers. To the salmonids that migrate up these rivers, the mining pits become a major potential source of mortality because the warm water in the pits provides ideal habitat for largemouth bass and other nonnative predatory fish that feed on juvenile salmonids.

Although invasive riparian plant species, such as giant reed, are present throughout the riparian habitat along the San Joaquin River, the density of invasive plants is highest in disturbed areas, such as mining pits. Near Fresno, the mining pits have relatively recently become infested by red sesbania (*Sesbania punicea*), and this area is now a seed source for downstream parts of the San Joaquin River and the Delta (Hunter and Platenkamp, 2003). The spread of giant reed, red sesbania, and Chinese tallow (*Triadica sibifera*) reduces habitat area for native plant species, creates lower quality habitat for native wildlife species than native vegetation, and causes flood management problems by increasing the hydraulic roughness of the channel.

# 3.0 Basis for Evaluation of Status, Trends, and Stressors

## 3.1 Scope of Status, Trends, and Stressor Evaluation

This section summarizes hydrologic and geomorphic fluvial processes, ecosystem responses to these processes, and stressors that have modified these processes and resulted in adverse effects on Sacramento Valley and San Joaquin Valley riparian and riverine ecosystems. It provides the basis for the description of specific metrics that are indicators of the processes, stressors, and ecosystem responses presented in Section 4.

This section does not provide a comprehensive account of fluvial processes and stressors. Instead, it presents an overview of hydrologic and geomorphic processes that are capable of producing substantial ecosystem responses in the Sacramento and San Joaquin rivers and their tributaries. Much of the information below describes how these processes interact in a hypothetical "typical" river system. Although the resulting characterization may not accurately reflect actual interactions in the Sacramento and San Joaquin rivers today, it provides a conceptual framework for understanding how these processes interact and for evaluating the extent to which they have been modified from historical conditions.

Similarly, the discussion focuses on stressors that have most affected hydrologic and geomorphic fluvial processes and ecosystem responses in the Sacramento Valley's and San Joaquin Valley's rivers and that are affected by the operations and maintenance of the SPFC. Other stressors, such as historical hydraulic mining, urban and agricultural development, and global climate change, are acknowledged as past and likely future stressors, but they are not discussed in this report because they are not reasonably caused by or could be affected by the operations and maintenance of the SPFC.

## 3.2 Hydrologic Processes

This discussion provides an overview of three ecologically significant categories of flows: floodplain inundation, bankfull, and base flows. The emphasis on these three flows does not imply that other flows (e.g., flows greater than base flow but less than bankfull) are ecologically insignificant. However, these three flows are generally regarded as more ecologically meaningful than other flows (Poff et al., 1997). Table 3-1 summarizes the effects of the three flow categories on geomorphic processes, ecosystem processes, and species in the riverine and riparian ecosystems. These effects are discussed in more detail below.

**Table 3-1. Effects of Different Categories of Flows on Geomorphic and Ecological Processes and Species**

| | Floodplain Inundation Flow | Bankfull Flow | Base Flow |
|---|---|---|---|
| Geomorphic processes | Causes major changes in channel morphology (scouring, erosion, channel cutoffs, new side channels) | Causes ongoing scouring and erosion of banks, formation of point bars, lateral channel migration, and mosaic of different-aged floodplain surfaces | Causes deposition in channel |
| | Mobilizes coarse to fine sediments | Mobilizes moderate to fine sediments | Mobilizes fine sediments only |
| Ecosystem processes | Increases large woody material in river | Increases large woody material in river | Provides perennial flow for fish, birds, and other species and maintains vegetation growth |
| | Increases dissolved oxygen in water | Increases dissolved oxygen in water | Reduces dissolved oxygen in water |
| | Increases aquatic structural diversity and exposes gravels for spawning | Increases aquatic structural diversity and exposes gravels for spawning | Decreases aquatic structural diversity |
| | Enables establishment of early successional vegetation (willows and cottonwoods) | Creates mosaic of riparian vegetation (pioneer to mature) with time | Allows mature vegetation to outcompete early successional species if base flow is prolonged |
| | Provides nutrients, sediment, and plant seeds to floodplain from upstream | Provides nutrients, sediment, and plant seeds to riverbank from upstream | No major effect |
| | Increases primary aquatic productivity | No major effect | Allows accumulation of organic materials, as well as contaminants |
| Species | Provides floodplain habitat to outmigrating salmonids and spawning splittail and increases early successional habitat for plants and animals, potential to strand or isolate fish species | Provides instream fish habitat to channel and maintains diversity of early to late successional habitat for plants and animals | Provides summer channel habitat for fish; causes silts to cover spawning gravels; and facilitates invasion of less-flood-tolerant species, including nonriparian and nonnative species |

Source: Prepared by DWR and AECOM in 2011.

### 3.2.1 Floodplain Inundation Flow

Floodplain inundation occurs when river flows exceed channel capacity, and water overflows onto adjacent land. Typically, floodplain inundation is associated with storms occurring more frequently than once every 2 years (Leopold et al., 1964), although the actual frequency of floodplain inundation is affected by watershed characteristics, channel morphology, and channel incision, in particular, along a given river reach. In the Sacramento and San Joaquin valleys, floodplain inundation can occur at any time during the rainy season roughly from October 1 through May 31. It lasts for a variable duration, from hours to days or weeks, and exhibits a variable rate of flow, depending on precipitation and snowmelt patterns, and reservoir storage capacity.

During floodplain inundation, a variety of physical processes occur. The magnitude of ecosystem responses to these events depends on flow timing, frequency, magnitude, and duration. Changes in channel dynamics and channel morphology resulting from scouring, erosion, and sediment deposition are typically associated with floodplain inundation (see Section 3.3). Additionally, because the energy of floodplain inundation flow is dissipated over a large area (i.e., the floodplain rather than the channel), floodplain inundation flows have a reduced capacity to carry suspended sediments and other debris. Sediments and debris typically are deposited on the floodplain. Floodplain vegetation, which increases hydraulic roughness and further slows flow velocity, can increase the amount of sediment and organic matter that settles on the floodplain during a floodplain inundation flow. The ecological implications of this interaction between the river and its floodplain are described in more detail in Section 3.4.2.

### 3.2.2 Bankfull Flow

The flow that occurs, on average, once every 1.5 years to 2 years is often referred to as the bankfull flow (Leopold et al., 1964), even though a 1.5- to 2-year recurrence interval flow may not represent an actual bankfull condition in many stream reaches. A bankfull flow event can occur at any time during the rainy season. It lasts for a variable duration, from hours to days or weeks, and exhibits a variable rate of flow, depending on precipitation and snowmelt patterns, and reservoir storage capacity.

Because a bankfull flow is often the maximum flow that can be contained within the active river channel, these flows are responsible for most of the force on the channel and bed (Allan and Castillo, 2007). This force has the ability to mobilize most medium and fine gravels, as well as organic and inorganic sediments. It also creates meandering stream patterns through erosion on the outside bends of meanders and deposition on the inside bends of meanders, and creates point bars, undercut banks, and other instream features that increase riverine habitat complexity (Leopold et al., 1964).

Many of these same processes occur with floodplain inundation flows, and the effects of floodplain inundation flows may be slightly greater in magnitude (e.g., mobilization of coarser sediments as bedload – i.e., sediment moving along the stream bed – or creation of chute cutoffs instead of progressive bend meanders), but the cumulative effect of bankfull flows is greater because this flow occurs with greater regularity (TNC, 2007). Although many of these processes have been empirically observed occurring with flows much less than the assumed bankfull flow in parts of the Sacramento River (TNC, 2007 and references cited therein), the bankfull flow likely has the most pronounced effect because it exerts a greater amount of force on the channel than the lower velocity flows. Geomorphic processes related to bankfull flows are described in more detail in Section 3.3.

### 3.2.3 Base Flow

Base flows are typically the annual minimum flows that occur in summer and fall. Historically, base flow conditions were likely observed on the Sacramento and San Joaquin rivers from approximately July through October, following the cessation of snowmelt runoff and before the onset of the rainy season (see Section 4.1). Although local groundwater contributions from perched aquifers and agricultural water discharge can be important drivers of base flows on some tributaries (e.g., Fleckenstein et al., 2004), base flows in the mainstem rivers were primarily sustained by groundwater discharge into tributaries of these streams in the Sierra Nevada, Cascade Range, and Coast Ranges. With the current system of reservoirs and water diversions in the Sacramento and San Joaquin valleys, base flows are elevated above historical conditions on the Sacramento River and its tributaries and greatly reduced on major portions of the San Joaquin River and its tributaries (see Section 4).

## 3.3 Geomorphic Processes

The fundamental geomorphic processes of alluvial floodplain rivers are channel migration, channel cutoff, channel anabranching, bed mobility, and fine and coarse sediment transport. All these processes influence floodplain formation and other floodplain dynamics. The SPA extends along the Sacramento River up to Shasta Dam, however this document focuses on leveed reaches of the Sacramento River.

The following brief description focuses on channel dynamics typically observed on the middle reach of the Sacramento River (River Miles (RM) 143 to 243), between Red Bluff and Colusa. The middle reach is emphasized for two reasons. First, it is the only segment of a major river in the Sacramento and San Joaquin valleys where channel dynamics are still regularly observed. Second, channel dynamics observed on the middle Sacramento River are also likely representative of other meandering alluvial river systems in the Sacramento and San Joaquin valleys. This does not imply that there are not potentially significant differences in channel dynamics between the middle Sacramento River and other rivers in the Sacramento Valley. However, the types of channel dynamics observed on this reach are likely to be broadly representative of these processes on other rivers in the Sacramento Valley.

The middle Sacramento River meanders within a belt of recent alluvium and outcrops of weathered Pleistocene-aged alluvium characterized by claypans and duripans that are resistant to erosion (Helley and Harwood, 1985). The region is tectonically active, with many landscape features formed as a consequence of east-west compression progressing up the valley (Harwood and Helley, 1987). The channel bed of the middle Sacramento River is composed of gravel and sand.

This reach of the river is characterized by an actively meandering channel with point bars on the inside of meander bends and active floodplain and older terraces on the outside of meander bends. The river channel migrates across this floodplain to the limits of the meander belt, constrained only by outcrops of erosion-resistant geologic formations or artificial bank protection. In these actively meandering reaches, a characteristic chronosequence of floodplain surfaces results, with younger surfaces closest to the river and oldest surfaces furthest from the river. Over time, meandering channels naturally tend to maintain roughly constant dimensions as erosion of outside bends is balanced by deposition on point bars, a state known as dynamic equilibrium.

Meander migration is one of the primary processes driving riparian ecosystem functions on large, single-channel alluvial rivers (Hughes, 1997). When not constrained by natural or artificial erosion-resistant banks, large alluvial meandering rivers have a tendency to migrate laterally (Johannesson and Parker, 1989). For example, in bank erosion studies conducted on the Sacramento River, annual migration rates have been observed to vary between 0 meters and 39 meters per year (Larsen et al., 2006a). Channel migration of meandering rivers has been shown to establish and maintain riparian habitats, oxbow lakes, and riverbank ecosystems (Hupp and Osterkamp, 1996; Scott et al., 1996; Ward et al., 2001). These habitat linkages are described in more detail in Section 3.4.

As meander bends grow, they may become unstable and form cutoffs. Three basic types of cutoffs may be observed on meandering alluvial rivers: chute cutoffs, partial cutoffs, and neck cutoffs. Chute cutoffs and partial cutoffs are regularly observed on the middle Sacramento River (Hooke, 1984, 1995a, 1995b; Fares and Herbertson, 1990), although chute cutoffs are more common (Micheli and Larsen, 2011).

Chute cutoffs are a type of channel avulsion that occurs when overbank flows are sufficient to concentrate shear stresses to a degree capable of carving a new channel across the floodplain (Hooke, 1984, 1995a, 1995b). If a floodplain "chute" erodes a secondary channel linking approximately the upstream and downstream inflection points of a bend, the chute may grow, short circuit the former meander path, and become the primary channel (Gay et al., 1998). The abandoned former channel, depending on the degree of remnant hydrologic connection to the river, may function as a slough or, eventually, as an oxbow lake, providing important wetland habitat for a variety of species. In contrast, partial cutoffs tend to develop into side channels, separated from the main river flow by an instream island, rather than offstream wetland features.

Although not currently observed on the middle Sacramento River, neck cutoffs, which result when the sinuosity of a bend increases and the radius of curvature in the bend decreases until the bend essentially doubles back on itself through progressive migration, may have historically occurred (Robertson, 1987). The occurrence of neck cutoffs before European settlement or under a different climatic regime cannot be ruled out, particularly in the lower section of the middle Sacramento River and other low-gradient reaches of other rivers in the Sacramento and San Joaquin valleys.

## 3.4 Ecosystem Responses

This section discusses the ecosystem responses to floodplain inundation flows, bankfull flows, and base flows and their associated geomorphic processes. Major in-channel and floodplain responses are discussed separately.

### 3.4.1 In-Channel Responses

Fluvial hydrologic and geomorphic processes in river channels are associated with flows up to and including the bankfull flow and the geomorphic process of channel meandering. These processes are particularly important for salmonids and aquatic habitat quality, the recruitment and succession of riparian vegetation, and riparian wildlife.

High flows transport significant amounts of fine sediments and, by extension, most of the nutrients, contaminants, and organic matter that accumulate on the riverbed, resulting in improved water quality. During low-velocity flow conditions, fine sediments, organic material, inorganic compounds, pollutants, and similar materials accumulate on the stream bed because the stream lacks sufficient force to suspend these materials and transport them. Organic materials that accumulate on the channel bottom are decomposed by microorganisms, resulting in the consumption of available dissolved oxygen (DO) through increased biological oxygen demand (BOD). The result can be a nutrient-rich, low-DO sludge, which is a poor-quality habitat for most aquatic organisms (TNC, 2007).

The reduction in siltation associated with flushing flows increases benthic algal production, which provides a source of primary production in streams (TNC, 2003) that benefits aquatic organisms. The flushing associated with higher flows can also significantly improve gravel quality for incubating salmonid eggs, salmonid larvae, and salmonid fry by reducing gravel embeddedness (Kondolf, 2000). High water velocities associated with bankfull flows not only flush the fine sediments and accumulated organic matter, resulting in improved water quality and chemistry of the sediments, but they also create broken surface water, which increases the diffusion of atmospheric oxygen into the water column, resulting in increased concentrations of DO.

The recruitment of LWM is also tied to elevated flows and associated geomorphic processes of channel meander and erosion. As meander bends migrate during higher flows, banks are undercut and mature trees fall into the channel, becoming LWM. Although the term “debris” has negative connotations associated with navigation hazards and potential impacts with bridges and other infrastructure during floods, the importance of LWM for salmonids is becoming increasingly recognized (Harmon et al., 1986; Maser and Sedell, 1994), and the continual recruitment of LWM is important to maintain salmonid habitat as existing LWM is transported downriver by floodflows.

In addition to higher flows, base flows contribute to salmonid habitat quality. As discussed in Section 3.2.3, base flows help to maintain perennial water flows and thereby contribute to the suitability of spawning habitat for spring- and fall-run Chinook salmon. Spring- and fall-run Chinook salmon begin spawning in the Sacramento and San Joaquin valleys before the onset of winter rains (TNC, 2007 and references cited therein). Therefore, important Chinook salmon spawning habitat attributes, such as water depth, flow velocity, and water temperature, are closely tied to base flows. In rivers without adequate base flows (e.g., the Cosumnes River and upper San Joaquin River), Chinook salmon numbers have been drastically reduced, in part, because a lack of adequate base flows has resulted in a lack of suitable spawning habitat.

Ongoing channel meandering and associated high flows are also important for the formation and sustainability of riparian habitats. Point bars formed on the inside of meander bends are common locations for recruitment of willow and cottonwood, which establish on newly deposited surfaces in response to specific combinations of flow events (Mahoney and Rood, 1998). Channel meandering creates point bar depositional surfaces of different ages, each of which supports riparian vegetation of a different age class (Greco et al., 2007). As channel migration continues, older depositional surfaces shift from cottonwood and willow dominance to dominance by other species less tolerant of flooding and disturbance, resulting in greater vegetation community structure and increased overall species diversity (Ward and Stanford, 1995). Because riparian forest ecosystems mature relatively rapidly (e.g., within 100 to 300 years), they can transition to upland ecosystems without periodic disturbance related to channel meandering, sediment deposition, and point bar formation (Sands and Howe, 1977; Johnson et al., 1976; Fremier, 2003).

Base flows also affect the establishment and sustainability of riparian vegetation. Most riparian plants require a source of soil moisture to maintain growth and vigor during summer, and conceptual models for riparian recruitment have described zones of successful riparian vegetation establishment in relation to base flow elevations (Mahoney and Rood, 1998). Adequate soil moisture is typically provided by shallow groundwater tied to base flows in adjacent rivers and streams. Similarly, riparian wetlands may require shallow groundwater created by river base flows to maintain perennial inundation and habitat functions associated with perennial wetlands. On rivers lacking sufficient summer base flows, such as many portions of the San Joaquin River, riparian vegetation can be replaced entirely by upland vegetation and invasive plants that are more tolerant of low soil moisture.

This diversity of riparian habitat patches created by meandering rivers and high flows, and sustained by adequate summer base flows, is critically important for a variety of wildlife and supports high levels of biodiversity (Ward et al., 2001). For example, many bird species, such as yellow-breasted chat (*Icteria virens*), prefer early seral stages of riparian habitat subject to regular disturbance (from high-water events, meander migration, and channel abandonment) for foraging and nesting (RHJV, 2004). Bank swallows (*Riparia riparia*), a species listed by the State as threatened, also depend on periodic disturbance, in the form of eroding banks, for nesting substrate (Morken and Kondolf, 2003; RHJV, 2004). These sites must be periodically disturbed through high flows and channel meander migration to maintain their suitability for bank swallow nesting (Garrison, 1999).

### 3.4.2 Floodplain Responses

Many of the processes described previously as occurring in the river channel also occur in adjacent floodplains during higher river flows (i.e., flows above the bankfull stage). As with in-channel processes, these floodplain processes are important for riparian habitats and riparian-associated wildlife, as well as salmonids and other native fish species.

Floodplains are created primarily by lateral accretion of point bars and vertical accretion from suspended sediments in overbank flows (Wolman and Leopold, 1957). Lateral point bar accretion and overbank deposition are readily observed along most meandering and wandering channels carrying a mixed load of gravel, sand, and silt/clay. This results in a characteristic floodplain stratigraphy of channel deposits (gravel and/or sand) overlain by point bar deposits of sand and perhaps gravel, which in turn are overlain by overbank deposits (sand and silt/clay).

Historically, overbank flows were commonly observed in the Sacramento and San Joaquin valleys during winter and spring in response to spring snowmelt, rain-on-snow events, and prolonged periods of heavy rainfall that are characteristic of the region (Kondolf et al., 2000). Floodplain inundation caused by overbank flows can result in widespread disturbances to existing riparian vegetation through scouring and removal of existing vegetation. Floodplain inundation may also result in death of plants from physiological stress related to prolonged inundation, root suffocation from the deposition of fine sediment, and similar factors (TNC, 2007). These disturbances remove existing vegetation and may create suitable conditions for the germination and recruitment of early successional vegetation, leading to increased habitat diversity and increased wildlife diversity, as described in Section 3.4.1.

Cottonwood and willow require moist, bare, mineral soil during periods of seed release. In the Sacramento and San Joaquin valleys, this period of seed release roughly lasts from mid-March through July (see TNC, 2007 and studies referenced therein) and may vary widely by species and geographic location within years and according to annual temperature and precipitation patterns among years. Flows leading to successful recruitment of cottonwoods and willows have been estimated to occur every 5 years to 10 years on meandering alluvial rivers, similar to those found in the Sacramento and San Joaquin valleys, although recruitment events may occur much less frequently on rivers constrained by geology, bank revetment, or levees (see TNC, 2007 and references cited therein).

The geomorphic process of gradual channel meander migration, coupled with overbank flows, may also result in the formation of side channels, sloughs, and oxbow lakes through the cutoff of meander bends and gradual separation of the flow in these habitats from the mainstem of the river (see Section 3.3). The formation and sustainability of off-channel habitats is important for species such as western pond turtle (*Actinemys marmorata*) that prefer slow-moving water, and in many river reaches, these off-channel habitats provide substantial opportunities for recruitment of cottonwood and willows, particularly when in-channel recruitment zones (e.g., point bars) are lacking (TNC, 2007).

Aside from effects on the successional processes of riparian vegetation through disturbance, vegetation recruitment, and the formation of off-channel habitats, overbank flows increase the amount and quality of rearing habitat for Chinook salmon. Studies have shown that juvenile Chinook salmon that have been reared on seasonal floodplains are much larger than salmon that have been reared in river channels (Sommer et al., 2001, 2003). The mechanisms by which seasonal floodplains positively affect salmonid rearing include increased primary production and food availability (Junk et al., 1989, cited in TNC, 2007), lack of predation from nonnative fish that are generally not found on seasonal floodplains, and improved habitat quality relative to river channels (lower velocity flows, greater structural diversity) (Sommer et al., 2001, 2003). Larger juvenile salmon are assumed to have a greater probability of successful outmigration to the Pacific Ocean.

Three main races of Chinook salmon–fall/late fall run, winter run, and spring run–are found in the Sacramento River, and the San Joaquin River supports or historically supported runs of fall/late fall run and spring-run fish. These races historically made extensive use of seasonal floodplains during winter and spring outmigration. Today, substantial areas of seasonal floodplain in the Delta and its vicinity are still found in the Yolo Bypass and along the lower Cosumnes River (Sommer et al., 2001, 2003). The timing, duration, and frequency of floodplain flows that are optimal for salmon rearing have been variously estimated (Williams et al., 2009; USACE, 2002). However, the general consensus from these and other studies (TNC, 2007) is that frequent floodplain inundation (i.e., inundation approximately every 2 years to 4 years on average) of some duration during periods of salmon outmigration from January through May has a positive effect on outmigration success.

## 3.5 Primary Stressors

### 3.5.1 Levees and Bank Revetment

Flood control levees confine floodflows, controlling the width, depth, gradient, and velocity of flows that without levees would spread out on the floodplain. Levees tend to increase the sediment-carrying capacity of the stream, which leads to degradation of the channel thalweg (i.e., the line defining the lowest points along the riverbed) and widening of the channel. Many levees were originally constructed to aid in the movement of sediment resulting from hydraulic gold mining to clear the channel for navigation purposes (see Section 2).

Bank revetment (i.e., the hardening of streambanks by riprap or other material to prevent erosion) generally causes the riverbanks to become narrower and deeper. Bank protection may also increase the incidence of riverbend cutoffs, thus reducing the overall length and sinuosity of the river.

***Effects on Geomorphic Processes***

River channel migration results in bank retreat, which can cause conflicts with adjacent land uses and infrastructure. Efforts to protect against bank retreat often involve lining the riverbank with riprap or large rocks. Likewise, efforts to protect communities and other landscapes from flood risk can involve levee construction. In selected areas of the Sacramento River, as in many places throughout the world, riprap and levees have virtually halted natural river processes such as river channel meander migration and meander cutoffs that create and maintain the complexity of aquatic and riparian ecosystems (Naiman et al., 1993; Lytle and Poff, 2004). In addition, most alluvial reaches of the middle Sacramento River have narrowed during the last century, largely in response to bank stabilization measures (Fischer, 1994).

Riprap and other bank armor solutions are almost always considered only with respect to local channel bank protection and not to downstream consequences. Such site-by-site planning solutions often lead to more problems in both the near and long term, especially in dynamic landscapes, such as riparian corridors. For example, changing bank erosion rates at one site, either by removing vegetation or by hardening the banks, can alter the migration pattern as far as three or four bends downstream (Larsen, 1995). These channel alterations can occur over relatively short periods (less than 5 years) and may affect the timing and location of avulsion events. Clearly, planning and management of infrastructure at a site should consider long-term consequences (e.g., periods greater than 50 years). These consequences may include infrastructure impacts on upstream conditions, as well as downstream effects on river channel and adjacent floodplain conditions.

#### *Effects on Habitat*

The ecosystem benefits of altering channel dynamics (by removing constrictions to channel migration) often can be greater than those associated with changing the flow regime. Larsen (2007) conducted a simulation study comparing removal of revetment to changes in flow regime at three bends in the Sacramento River at Woodson Bridge, Hamilton City, and Ord Ferry. The gain in floodplain area from removing revetment in three individual bends was larger in magnitude (but of a similar order of magnitude) than the effects of changing the flow regime over the entire reach.

Two important aspects of habitat for salmonids and other native fish species are affected by channel migration: shaded riverine aquatic (SRA) cover and LWM.

SRA cover is defined as the overhanging vegetation, in-water cover, and natural banks of the nearshore aquatic area occurring at the interface between a river and adjacent woody riparian habitat (USFWS, 1992). Vegetation in this terrestrial-aquatic transition zone provides plant and animal materials that are used by aquatic and aquatic-dependent species (e.g., birds). Near-shore LWM is part of the in-water cover component of SRA cover, although LWM may also occur away from the shore in the river channel.

LWM is also critically important to aquatic species, contributing to habitat creation (e.g., habitat complexity and refuge habitat) and serving a role in storing sediment and organic matter. LWM is important to salmon populations in the Sacramento River. Bank protection with riprap drastically reduces LWM production and also reduces LWM retention along armored banks. According to the U.S. Fish and Wildlife Service (USFWS) (2004), a substantial reduction of LWM has occurred in the Sacramento River as a result of the Sacramento River Bank Protection Project. Alternative approaches to flood protection that can generate LWM resources are the construction of setback levees, adjacent levees that retain waterside growth, and constructing waterside planting benches in urban or other constrained areas. Levee setbacks have been constructed to provide flood protection and can at the same time provide ecosystem benefits, including LWM (Larsen et al., 2006b).

### 3.5.2 Reservoirs

Storage reservoirs created by large multipurpose dams are located on the Sacramento and San Joaquin rivers and on most of their major tributaries. The dams have major effects on the hydrology and geomorphic processes of the downstream river reaches, and because of those effects, they also have greatly affected the habitats of plants and fish and wildlife species supported by the riparian and riverine ecosystems.

The hydraulic effect depends on the watershed area above the reservoir, the storage capacity of the reservoir, the operational criteria, and the nature of the river downstream from the dam. The larger the watershed above the dam and the smaller the reservoir storage, the less effect the dam has on the streamflow. The dam's operational criteria also affect streamflow. Larger, multipurpose reservoirs affect the magnitude, timing, and frequency of channel-forming flows and consequently have a large effect on the river downstream.

***Effects on Hydrology***

The most important effects of dams on the hydrology of downstream river reaches are decreases in flow peak frequency, magnitude, and duration, and increases in the frequency, magnitude, and duration of low flows (Singer, 2007).

In the Sacramento River, the reduction in median winter and spring flows is accompanied by increased summer and fall flows, some of which originate from diversions from the Trinity River. However, downstream from Friant Dam, on the San Joaquin River, median flows in both winter and summer are reduced because the water captured by Friant Dam is diverted into two major canals for irrigation during summer. Downstream from Mendota Pool, where the Delta-Mendota Canal enters the San Joaquin River, median summer flows used for irrigation are generally higher than in winter. The hydrologic effect of dams therefore depends on interactions of dam operations and the operation of diversion facilities.

The major dams were designed primarily to reduce the largest winter flood peaks and store spring snowmelt runoff (Singer, 2007). A useful index of the effect of dams on downstream hydrology is the impoundment runoff index (IRI), which is the ratio of reservoir capacity to median annual flood runoff volume (Singer, 2007). There are two major ways of operating dams for flood control. Dams with a high IRI (e.g., Shasta, Whiskeytown, and Oroville dams) are likely to cut off flood peaks and store them for subsequent release for irrigation and hydropower generation. Dams with a low IRI (e.g., New Bullards Bar, Camp Far West, and Folsom dams) do not have storage capacity adequate to completely cut off flood peaks, and must instead release high flows early and longer, i.e., lengthen the rising and falling limbs of the hydrograph (Singer, 2007). IRIs have not been published for dams in the San Joaquin River watershed.

#### *Effects on Geomorphic Processes*

Channel-forming flows are mostly responsible for bank erosion, bed degradation, meandering, and sediment transport. These flows generally are winter and spring high-flow events. There is usually a threshold flow in each river reach where bed and banks begin to erode and sediment begins to move. As flow increases above this threshold, the flow velocity and geomorphic effects also increase until a bankfull stage is reached.

Bankfull discharge is considered to be the geomorphic flow that is the most responsible for shaping the channel form and function. In a natural, undammed river, it is defined as the flow that occurs on average approximately every 2 years (2-year event). A bankfull discharge normally fills the channel but does not inundate the floodplain. Post-dam bankfull discharge is also considered to be the flow with an approximate 2-year recurrence interval, but it may have a much smaller discharge and not fill the channel, particularly in watersheds with large multipurpose dams.

Bankfull discharges meet the following two criteria for shaping channel cross sections: the flows are strong enough to erode banks and to transport and deposit sediment, and the flows occur often enough to overcome the effects of larger flows.

Floodflows above bankfull discharge affect the river somewhat differently than the bankfull discharge. Flows that move out of the channel do not erode or deposit sediment in the channel. Velocities in the channel generally do not increase and sometimes decrease because of backwater effects. Many dams decrease the number of floodflows and may, in wet years, increase the number of bankfull discharges.

The installation of a dam on a river disrupts the frequency of an established bankfull discharge.

Sediment transport is also affected by the dams. Unlike most hydraulic parameters that are affected mostly by storage capacity of dams in the watershed, the effect of dams on sediment is controlled more by the location of the dam in the watershed.

Dams trap sediment from the watershed upstream by allowing sediment to settle and become trapped in the reservoir area. The trap efficiency of large dams like Oroville may be higher than 95 percent, only releasing the very fine silts and clays to the river below. All of the bedload of a stream is generally trapped by a dam.

The effect of dams on the downstream channel is a combination of the watershed area above the dam, the flow release, and sediment trap efficiency. The pre-dam and post-dam frequency of bankfull discharge is a useful indicator of the change in the river's ability to move the sediment in the channel below the dam.

A normal, undammed river system is typically in dynamic equilibrium. The river may incise its channel for a number of years, then fill with sediment to reestablish a stable grade. Sediment carried by a stream may conveniently be divided into bedload (moving by saltation, which is to move by bouncing along the bottom of the river) and suspended sediment moving in the water column.

Dams may change this dynamic equilibrium by trapping bedload that would normally replenish bedload washed downstream; larger dams also trap most of the suspended sediment. In addition, larger dams change the magnitude and frequency of flows, affecting sediment transport in the stream below. The river downstream from a dam is sediment starved, resulting in a gradual removal of the finer fractions of sediment in the channel (TNC, 2007). Over time, the channel degrades and becomes entrenched. Riffles become coarser and armored with a surface layer with particles too large for most flows to move. The channel, riffles, islands, and other depositional features become static. Riffles, used by spawning salmonids and other species, become impermeable and too coarse for the species that would use them. In addition, degradation of the channel bed may also cause headcuts to prograde up tributary channels below the dam, and degradation of the bed in these tributaries.

Suspended sediment concentrations are reduced by dams. Suspended sediment is particularly important to floodplain development. During large floods, the sediment is deposited on the floodplain, over the long term replacing the soils lost through bank erosion. Sediment transport in the Sacramento River is driven by the natural characteristics of the river and its watershed and by the engineered features used to manage the river. The sources and degree of sediment transport vary between the upper (above Red Bluff) and lower (below Red Bluff) reaches of the watershed.

Above Red Bluff, the Sacramento River is mostly an incised, narrow bedrock stream and is characterized by conveyor-belt-like bedload sediment transport. This transport generally occurs during winter storm events, with sediment loads generated by western tributaries. Minimal sediment storage is available because large alluvial floodplains are not present. Cottonwood Creek produces the greatest amount of sediment; Dibble, Blue Tent, Reeds, and Red Bank tributaries also supply sediment (Jones et al., 1972). During summer, releases from upstream dams (e.g., Shasta, Keswick, and Whiskeytown dams) dominate streamflow but provide minimal sediment loads, capturing more than 90 percent of all upper watershed sediment (K. Buer, pers. comm., 2011). In wet water years, water levels in the reservoirs may rise to the point where flood releases occur, producing a scenario whereby sediment concentrations may vary as much as three orders of magnitude for a single flow rate.

Below Red Bluff, the Sacramento River has point bars and a widened river corridor, and alluvial floodplains are located adjacent to the river, providing for large amounts of sediment storage and a disruption of the conveyor-belt-like sediment transport of the upper reach. Most of the sediment in the lower reach is produced through bank erosion that occurs when flood releases from upstream dams maintain bankfull conditions for extended periods. Westside tributaries, such as Elder and Thomes creeks, also provide significant amounts of sediment (USACE, 1981). Deposition of this sediment on the Sacramento River floodplain naturally replenishes sediment lost because of bank erosion in the lower Sacramento River. Since the early 1960s, however, the use of bank protection has reduced the amount of sediment locally generated by bank erosion (DWR, 1994). In addition, below Hamilton City, constructed and natural levees constrain the floodplain and reduce sediment deposition on the floodplain during moderate flow events.

Apart from the interruption of sediment transport, geomorphic processes are also affected by the modification of the flow regime. Channels become more stable and narrow when high flows are reduced. The rate that point bars, secondary channels, oxbows, and changes in channel planform (e.g., meander migration) are formed is reduced when the frequency and magnitude of high flows are reduced (Poff et al., 1997; Friedman et al., 1998). The effects of these reductions in flood frequency, magnitude, and duration are difficult to analyze because of the confounding effects that land-use changes and bank revetment have on channel dynamics.

#### *Effects on Habitat*

As was described above, reservoirs may be associated with downstream channel narrowing. Channel narrowing is generally accompanied by an increase in vegetation cover along the channel. This vegetation gradually undergoes succession to mature riparian forest because of a lack of scouring flows and channel migration that would “reset” the successional process to an earlier stage (Friedman et al., 1998). This phenomenon was observed on the San Joaquin River after the completion of Friant Dam when “river wash” (exposed sand and gravel) and early successional riparian communities (e.g., riparian scrub) gradually disappeared in favor of mixed riparian and valley oak riparian forest (Jones & Stokes Associates, 1998b, 2002).

At Friant Dam and other dams with a high IRI, an abrupt drop in dam releases in spring causes the regeneration success of woody riparian species, such as Fremont cottonwood and black willow, to be reduced. Mahoney and Rood (1998) postulated that river stage decline during the period of seed release for cottonwoods had to remain within limits dictated by the root growth rate of the seedlings, which needs to keep up with the decline of the water table and saturated soil zone. This relationship was later confirmed by Stella et al. (2010) with a controlled declining water table in a laboratory setting for three riparian plants species that occur in the San Joaquin Valley. This study showed that the simulated groundwater declines had to be less than 2 inches per day to allow seedling survival.

### 3.5.3 Diversions

***Effects on Hydrology***

Before the development of large-scale water supply dams in the mid-20th century, miners and settlers constructed smaller dams to impound and divert water for mining, irrigation, and grazing in the mid- and late 19th century. Many of these structures still exist or have been replaced by larger, more modern structures. Various agricultural and municipal water districts have also constructed water diversions that pump water directly out of the Sacramento and San Joaquin rivers and their tributaries. An inventory of water diversions estimated that 722 such diversions are present along the Sacramento River and in the San Joaquin River Basin (Herren and Kawasaki, 2001). Many large diversions (greater than 250 inches in diameter) exist on the Sacramento and San Joaquin rivers and their tributaries (Moyle and White, 2002). Forty-four diversions located in the SPFC are controlled by the DWR.

In the Sacramento River, the overall effect of these diversions is difficult to estimate for any one diversion. Cumulatively, their effects are likely substantial but difficult to quantify (TNC, 2007). Aside from their effects as fish passage barriers, discussed separately below, the most serious effect of these diversions is likely not the reduction in flow tied to the amount of water withdrawn but rather the artificially elevated summer base flows routed through the rivers to facilitate these water diversions (see Section 4). Although there are few quantitative estimates of the total number of fish killed at these diversions (Moyle and White, 2002), these diversions are undoubtedly a stressor on salmonids, and the installation of screens to prevent entrainment at these diversions has been considered a major conservation action for these species (Moyle and White, 2002).

Artificially elevated and constant, sustained releases of water to facilitate water diversions likely promote nonnative fish populations over native fish (Marchetti and Moyle, 2001) and inhibit the establishment of woody riparian species (TNC, 2007). Fish species that are native to the Sacramento River system evolved with historically variable flows characteristic of Mediterranean ecosystems, whereas nonnative species (e.g., nonnative predatory species introduced from the eastern United States) evolved and thrive in less variable flow conditions (Marchetti and Moyle, 2001). Maintaining relatively constant summer base flows to maintain water supply for agriculture diversions, therefore, is more likely to promote nonnative fish assemblages over native assemblages. Similarly, flow variability is a driver of early successional riparian vegetation germination and recruitment. Certain rates of water recession in spring and summer are required to keep pace with the root growth of newly germinated Fremont cottonwood seedlings (Mahoney and Rood, 1998; TNC, 2007). Elevated summer base flows may contribute to reduced elongation of roots and thus increased susceptibility to scour in winter floods, and may cause direct “drowning” mortality of newly germinated seedlings through prolonged inundation during the summer months (TNC, 2007).

In the upper San Joaquin River, the nearly complete diversion of water from the river channel has drastically reduced salmonid populations and effectively halted riparian forest succession. With little or no water in the channel, suitable spawning habitat for salmonids is absent in the upper San Joaquin River. Because water supply is cut off in spring or early summer, willows and Fremont cottonwood seedlings that may have germinated earlier in the spring are killed. As a result, early age classes of willows and Fremont cottonwood are almost absent from the San Joaquin River (see Section 2). Reclamation is implementing the San Joaquin River Restoration Program to restore a salmon run to the San Joaquin River upstream from the Merced River by releasing addition flows from Millerton Reservoir and by building infrastructure improvements to facilitate salmon migration.

### 3.5.4 Invasive Species

***Effects on Geomorphic Processes***

Invasive species can alter hydrology and sedimentation rates in riparian and aquatic systems (Cal-IPC, 2011a). Dense stands of invasive species can alter channel morphology by retaining sediments and increasing the hydraulic roughness of the channel that restricts flows and reduces flood conveyance (Bossard et al., 2000). For example, saltcedar traps and stabilizes alluvial sediments, which results in the narrowing of stream channels and more frequent flooding (Bossard et al., 2000). Species with shallow root systems, such as giant reed and red sesbania, promote bank undercutting, collapse, and erosion (Bossard et al., 2000; Cal-IPC, 2011b).

***Effects on Habitats and Native Species***

Invasive plants can alter the structure of the vegetation they invade and thereby significantly degrade wildlife habitat quality and ecosystem health (Cal-IPC, 2011a). They may outcompete native species, suppress native species recruitment, and provide food and cover for undesirable nonnative animals (Bossard et al., 2000). Aquatic invasive plants can degrade aquatic habitat by reducing areas of open water used by waterfowl for resting, shading out algae in the water column that serve as the basis of the aquatic food web, and displacing native aquatic plants used for food or shelter by wildlife species (Bossard et al., 2000). Invasive terrestrial plants can also reduce groundwater availability by transpiring large amounts of water, making less water available for native riparian vegetation (Bossard et al., 2000).

Invasive plants can threaten the integrity of native riparian plant communities by outcompeting native plant species, hybridizing with native plant species, reducing habitat quality and food supply for wildlife, and interfering with wildlife management (Bossard et al., 2000; Cal-IPC, 2011a). Nationally, invasive species are the second-greatest threat to endangered species, after habitat destruction (Cal-IPC, 2011a). Invasive aquatic plants often form dense mats that kill fish by lowering pH, DO, and light levels and increasing carbon dioxide and turbidity (Bossard et al., 2000). Some invasive plants hybridize with natives that could, in time, effectively eliminate native genotypes of some species (Bossard et al., 2000).

### 3.5.5 Fish Passage Barriers

This section is based on an advance administrative draft of the technical memorandum “Fish and Flood Management” (DWR, 2011b).

***Effects on Species Abundance and Distribution***

Fish passage barriers, such as dams, weirs, and water diversions for agricultural and municipal uses, have greatly reduced the amount of salmonid habitat and can result in the direct mortality of fish at diversions. The effects of passage barriers on salmonids differ by species and race as described below.

Most races and species of salmonids have been adversely affected by the construction of dams and similar passage barriers. However, spring-run Chinook salmon and steelhead (*Oncorhynchus mykiss*) have likely been the most seriously affected, in terms of direct habitat loss, by the construction of passage barriers. These fish historically spawned in tributaries of the Sacramento and San Joaquin rivers in the Sierra Nevada and Cascade Range. The vast majority of historical spring-run Chinook habitat in the Sacramento River and all historical spring-run habitat in the San Joaquin

River is now blocked by passage barriers, collectively reducing spring-run spawning and rearing habitat by 80 percent to 90 percent (DWR, 2005). Currently, the only viable, naturally reproducing populations of spring-run Chinook are found in Deer, Mill, and Butte creeks (NMFS, 2009).

Spring-run Chinook salmon have also been subject to hybridization because their habitat overlaps with that of fall-run fish below passage barriers. Historically, the two races would have been spatially segregated, with spring-run fish spawning further into the mountains and fall-run fish spawning on the valley floor and lower foothills. With construction of Shasta Dam and other passage barriers on the Sacramento Valley's and San Joaquin Valley's major rivers, the two races now use the same segments of these rivers for spawning. The larger, more vigorous fall-run fish typically outcompete spring-run fish for redd sites, or construct their redds on top of spring-run redds, and extensive hybridization between fall-run and spring-run fish has been detrimental to the gene pool of the spring-run fish (Yoshiyama et al., 1998).

Steelhead spawning habitat loss from construction of passage barriers has been estimated at 80 percent (Lindley et al., 2006). Currently, spawning and rearing habitat for wild steelhead exists in Mill and Deer creeks, tributaries of the Sacramento River, and the Yuba River (Moyle, 2002). Incidental occurrences of steelhead have also been recorded in Cow, Battle, Clear, and Cottonwood creeks. Opportunities exist for restoration in these creeks, as well as in the Big Chico, Antelope, and Butte creeks and in the Yuba River. The distribution in the San Joaquin River system is limited to a small sport fishery in the Tuolumne River (DWR, 2005). Steelhead are found in other parts of the Sacramento River watershed, but the presence of hatchery fish makes identifying the origin of the fish difficult (e.g., fish originating from the Eel River in the American and Mokelumne rivers) (Moyle, 2002).

To some extent, steelhead may have initially benefited from construction of Shasta Dam and other Sacramento Valley and San Joaquin Valley dams (TNC, 2007). Persistent releases of cool water and, at least initially, readily available spawning gravels below dams may have mitigated extensive losses in the extent of total spawning habitat above the dams by providing suitable steelhead spawning and rearing habitat where it did not previously exist, at least during the first decade following construction of the dams. However, bed coarsening has, over time, reduced habitat suitability.

Additionally, unlike Chinook juveniles, which spend up to several months in their natal rivers before migrating to the ocean and forming schools, juvenile steelhead spend up to 3 years in their natal streams and vigorously defend their territories from other juvenile steelhead. Historically, juveniles hatched in tributaries above present-day reservoirs could disperse throughout their natal streams in search of suitable and available rearing habitat. With construction of dams, available rearing habitat has been greatly reduced, and temperatures in some areas are too high. Competition for rearing habitat has been tied to numerous adverse effects on individual fish and steelhead populations (Keeley, 2001), and competition for suitable sites among 1- and 2-year-old fish is now likely to be at least as limiting on steelhead populations as the lack of spawning habitat (TNC, 2007).

The construction of passage barriers has also been a stressor on winter-run Chinook. Adult winter-run Chinook migrate into the Sacramento River during winter and spring. Historically, these fish held for several months in deeper pools to reach sexual maturity and then spawned during summer in cool-water reaches of streams in the upper watershed of the Sacramento River (e.g., McCloud River, Pit River, upper Sacramento River) and Battle Creek (Yoshiyama et al., 1998). Construction of Shasta Dam has nearly completely eliminated historical holding and spawning grounds for winter-run fish.

Although historical spawning areas have been eliminated, winter-run Chinook have adapted to holding and spawning in cool-water releases from Shasta Dam on the upper portion of the lower Sacramento River. Under current conditions, the total amount of suitable spawning habitat for winter-run fish may actually be equal to or greater than the amount of spawning habitat that was historically available (TNC, 2007). The exact causes of declines in winter-run populations are not known, but it is hypothesized that spawning habitat reduction related to the construction of passage barriers is not one of the primary stressors on winter-run fish (TNC, 2007). This hypothesis does not imply that passage barriers, such as Shasta Dam, have not affected winter-run Chinook. However, the reservoirs impounded by passage barriers and related modifications to river flows and geomorphic processes below reservoirs are likely more significant stressors on winter-run fish (TNC, 2007).

As described for winter-run fish, passage barriers are a stressor on fall- and late fall-run Chinook but may not be a significant stressor compared to other stressors described previously (TNC, 2007). Relative to other salmonids, fall- and late fall-run fish historically spawned much lower in the Sacramento and San Joaquin rivers, generally at elevations below 500 feet to 1,000 feet, as far south as Kings River and as far north as the upper Sacramento, McCloud, and Pit rivers (DWR, 2005; Yoshiyama et al, 2001). Because of their larger size, fall- and late fall-run Chinook are capable of spawning in a wider range of gravel sizes. Therefore, although their historical spawning ranges have likely been reduced, the relative amount of habitat reduction caused by construction of passage barriers is likely less than for other salmonids, particularly steelhead and spring-run Chinook. Current distribution of fall- and late fall-run Chinook on the Sacramento River encompasses all historic habitat on lower foothill and Central Valley streams and spawning occurs upstream as far as Keswick Dam. On the San Joaquin River, distribution reaches up to the Merced River.

Aside from dams and similar passage barriers that have directly blocked historical holding, spawning, and rearing areas for salmonids in the Sacramento and San Joaquin valleys, partial passage barriers, such as intakes for water diversions, are an additional stressor on salmonids. Diversions are discussed further in Section 3.5.3.

# 4.0 Status, Trends, and Stressor Assessment

## 4.1 Status and Trends Metrics

### 4.1.1 Hydrologic Processes

***Description of Metrics***

Hydrology metrics were calculated with the Indicators of Hydrologic Alteration (IHA) software (Version 7.1.0.10), developed by The Nature Conservancy. IHA was used to query historic flow records to identify event-based metrics. The average annual peak discharge (in cubic feet per second (cfs)), average annual frequency, and average annual duration were determined for small floods (conforming to floodplain inundation flows), high pulse flows (conforming approximately to bankfull flows), and extreme low flows (conforming to base flows).

In addition, the median yearly, spring, and monthly flows were calculated. The median yearly flow is the median daily average flow for each year, the median spring flow is the median daily average flow occurring between March 1 and June 30, and the median monthly flow is the median daily average flow for each month.

The hydrologic metrics were calculated at two gages maintained by the U.S. Geological Survey with long-term flow records: Sacramento River above Bend Bridge and San Joaquin River at Friant. These gages were selected because they most clearly represent the effects of changes in flow related to reservoir construction (i.e., they represent the furthest upstream gaging stations on the Sacramento and San Joaquin rivers) and because they both have continuous observations of average daily flows dating from 1891 and 1908, respectively. All metrics were calculated separately for the pre-reservoir and post-reservoir flow periods. On the Sacramento River, a third period representing the period following the construction of Shasta Dam and before the import of Trinity River water from Whiskeytown Reservoir, was also calculated. The specific periods of record analyzed are shown in Table 4-1.

Approximately 12 additional flow gages with long-term average daily flow observations were identified on the Sacramento and San Joaquin rivers and their tributaries; however, because of time constraints, flow metrics were not prepared for these gaging stations. Similar analyses may be completed for these gages as part of the development of the 2017 CVFSCS.

Although the approach used here supports an initial analysis of more general patterns, this analysis has important limitations. In particular, median flows cannot be used to evaluate effects occurring on a finer time scale, such as individual daily flow effects on salmonids. Effects of specific flow management events, such as introduction of the Central Valley Project Improvement Act mandated flows in 1992 and the flow management resulting from several Biological Opinions were also not assessed.

**Table 4-1. Periods of Record for Hydrologic Process Metrics**

| Period of Record | Sacramento River | San Joaquin River |
|---|---|---|
| Pre-reservoir period | 1901[1]–1944 | 1908–1941 |
| Post-reservoir period | 1945–1964 | 1942–2010 |
| Period following initiation of Trinity River imports | 1964–2010 | NA |

*Source: Prepared by AECOM in 2011 for this report.*

Note:
[1] The record was truncated because Excel does not recognize dates before 1901.

Key:
NA = not applicable

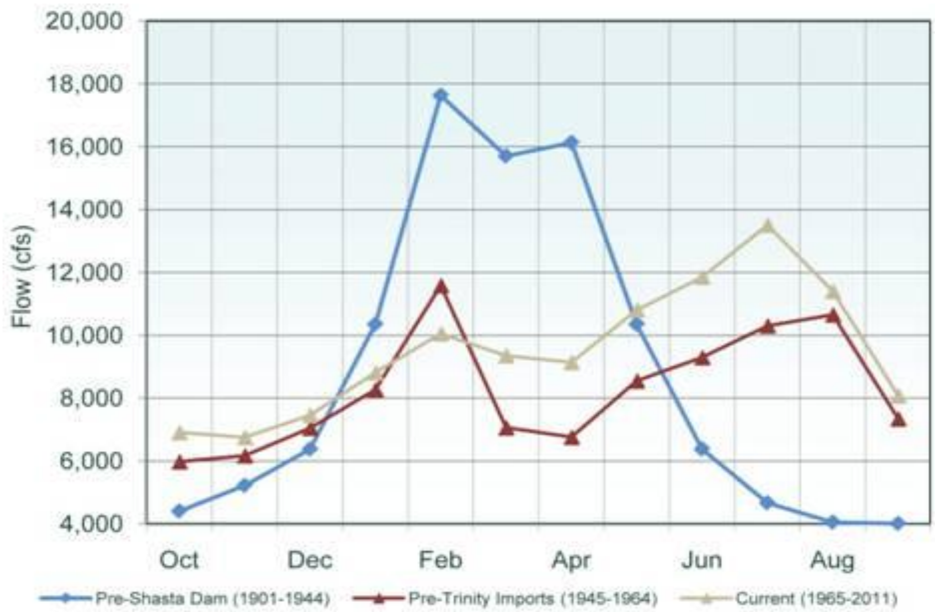
### *Median Flows*

Timing and variability of median flows from pre-reservoir and post-reservoir periods were compared to assess changes in the hydrologic habitat parameters of native species. The life cycles and physiology of native plant, fish, and wildlife species are adapted to the hydrologic regime that predates reservoirs on the major rivers. Major changes in hydrologic habitat parameters would reduce habitat suitability for native species.

**Methodology and Rationale** The median yearly, spring, and monthly flows (in cfs) for the pre-reservoir and post-reservoir periods were determined as a means to compare changes in the pattern of flows, compare the timing of peak and low flows, and visualize overall flow variability under historical conditions and with operation of reservoirs. They provide a concise overview of overall hydrologic conditions while conveying information about the typical timing and intensity of the annual high and low flows and information about flow variability.

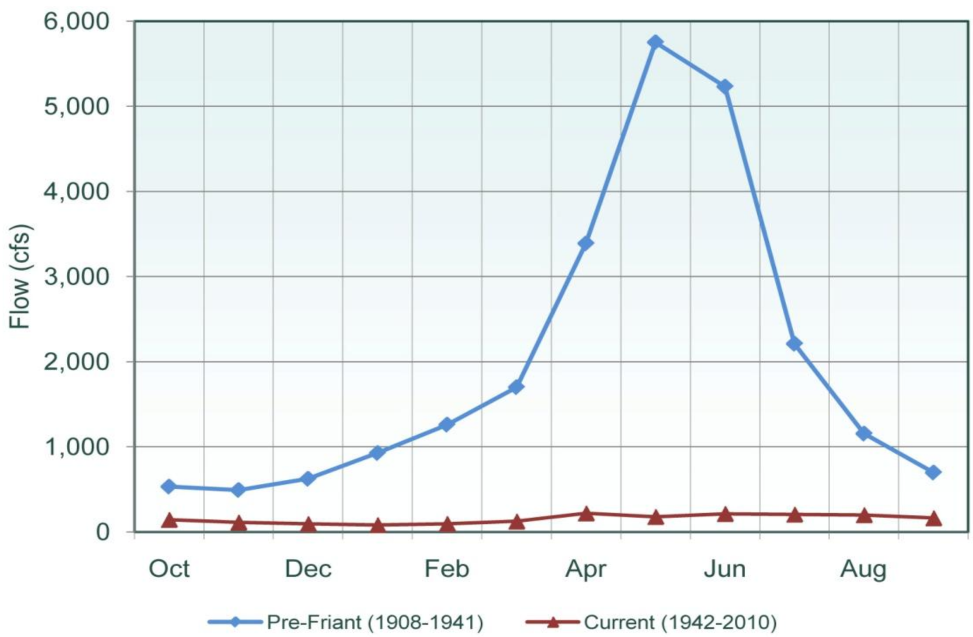
**Metric Summary** Monthly median flows in the Sacramento and San Joaquin rivers are shown on Figures 4-1 and 4-2, respectively. Before Shasta Dam was completed and the Trinity River imports to the Sacramento River were initiated, peak median flows occurred in the

February-through-April period. After Shasta Dam was completed in 1944, peak flows occurred in February and then again in July and August. After imports from the Trinity River were introduced, median summer flows in the Sacramento River increased by 2,000 cfs to 3,000 cfs (Figure 4-1).




*Source: Prepared by AECOM in 2011 based on USGS gage data*

**Figure 4-1. Monthly Median Flows in the Sacramento River at Bend Bridge (USGS Gage 11377100)**




*Source: Prepared by AECOM in 2011 based on USGS gage data*

**Figure 4-2. Monthly Median Flows in the San Joaquin River at Friant (USGS Gage 11251000)**

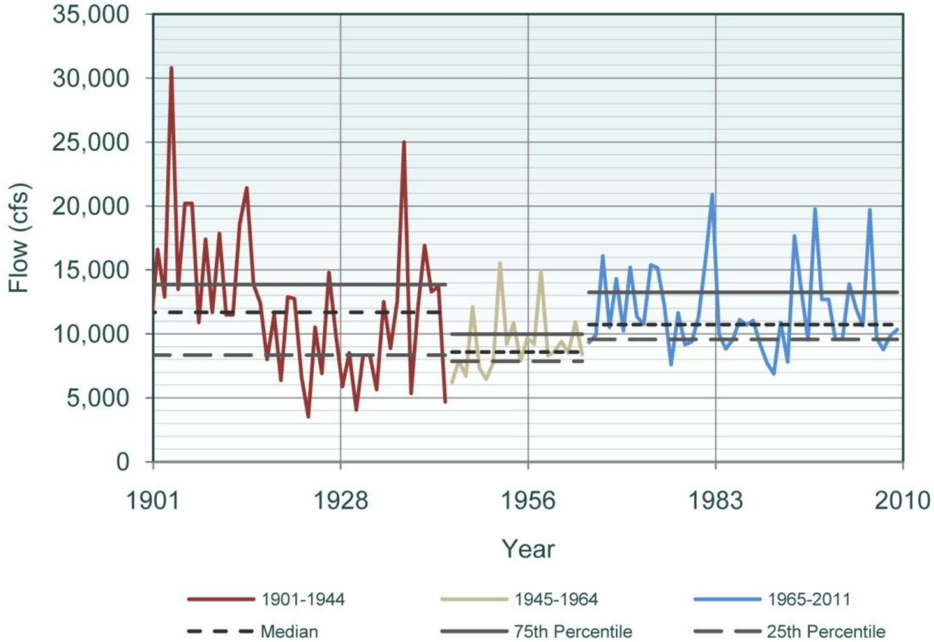
Recently, Trinity River imports have changed as a result of the Trinity River Mainstem Fishery Restoration Final EIS/EIR Record of Decision in 2000 (U.S. Department of Interior 2000).

Before completion of Friant Dam, monthly median flows in the San Joaquin River peaked in the May-to-June period (Figure 4-2). After Friant Dam was completed in 1941, flows in the San Joaquin River were much reduced because the vast majority of water is conveyed through the Friant-Kern and Madera canals (Figure 4-2).

The floodflows in spring are the most ecologically and geomorphologically relevant floodflows. Median spring flows for the Sacramento and San Joaquin rivers are shown on Figures 4-3 and 4-4. Sacramento River flows had much greater year-to-year variability before Shasta Dam was completed in 1944 than after completion of the dam. After flows from the Trinity River were added in 1965, annual variability increased, but not to the pre-Shasta level (Figure 4-3).

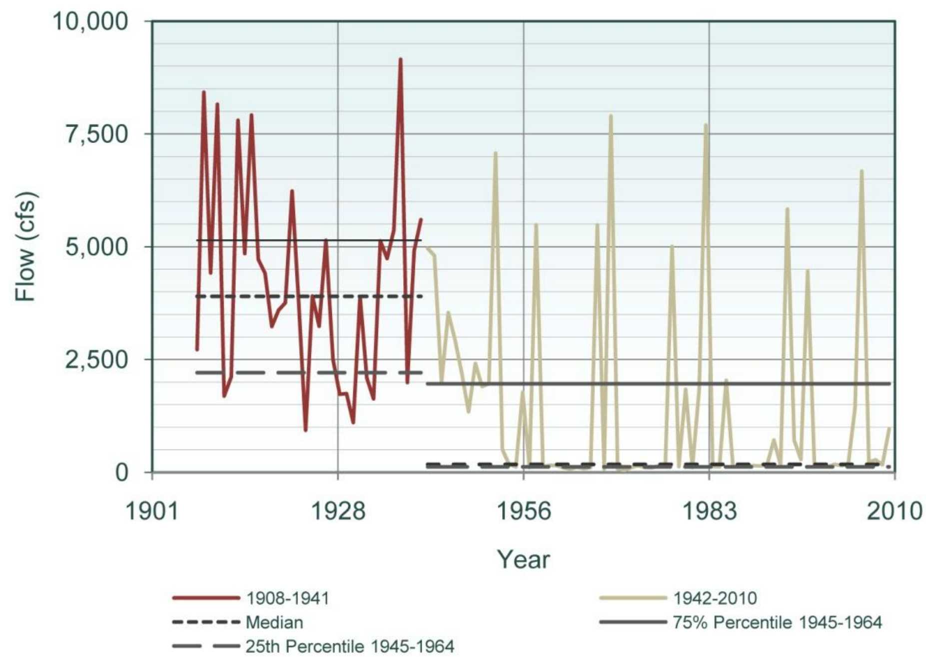
San Joaquin River flows decreased greatly below Friant Dam after the dam was completed, although large flood events (e.g., greater than 4,500 cfs) are not affected because they cannot be contained by the dam (Figure 4-4).

As discussed in Section 3, before the construction of major dams, the timing of flow events in the Sacramento and San Joaquin valleys had a consistent seasonal cycle, with maximum flows in spring and minimum flows in summer. In an environment with highly variable rainfall and streamflow regimes, these flows typically varied within years (from month to month) and between years, and species such as salmonids, various species of riparian trees and shrubs, and, by extension, wildlife that depend on riparian vegetation exhibited life histories that exploited these variable streamflow patterns. Natural communities were likely more diverse before the dams were built than after because the variability of streamflows and higher frequency of high, scouring flows created a diverse physical habitat.




*Source: Prepared by AECOM in 2011 based on USGS gage data*

**Figure 4-3. Median Spring Flow in the Sacramento River at Bend Bridge (USGS Gage 11377100)**




*Source: Prepared by AECOM in 2011 based on USGS gage data*

**Figure 4-4. Median Spring Flow in the San Joaquin River at Friant (USGS Gage 11251000)**

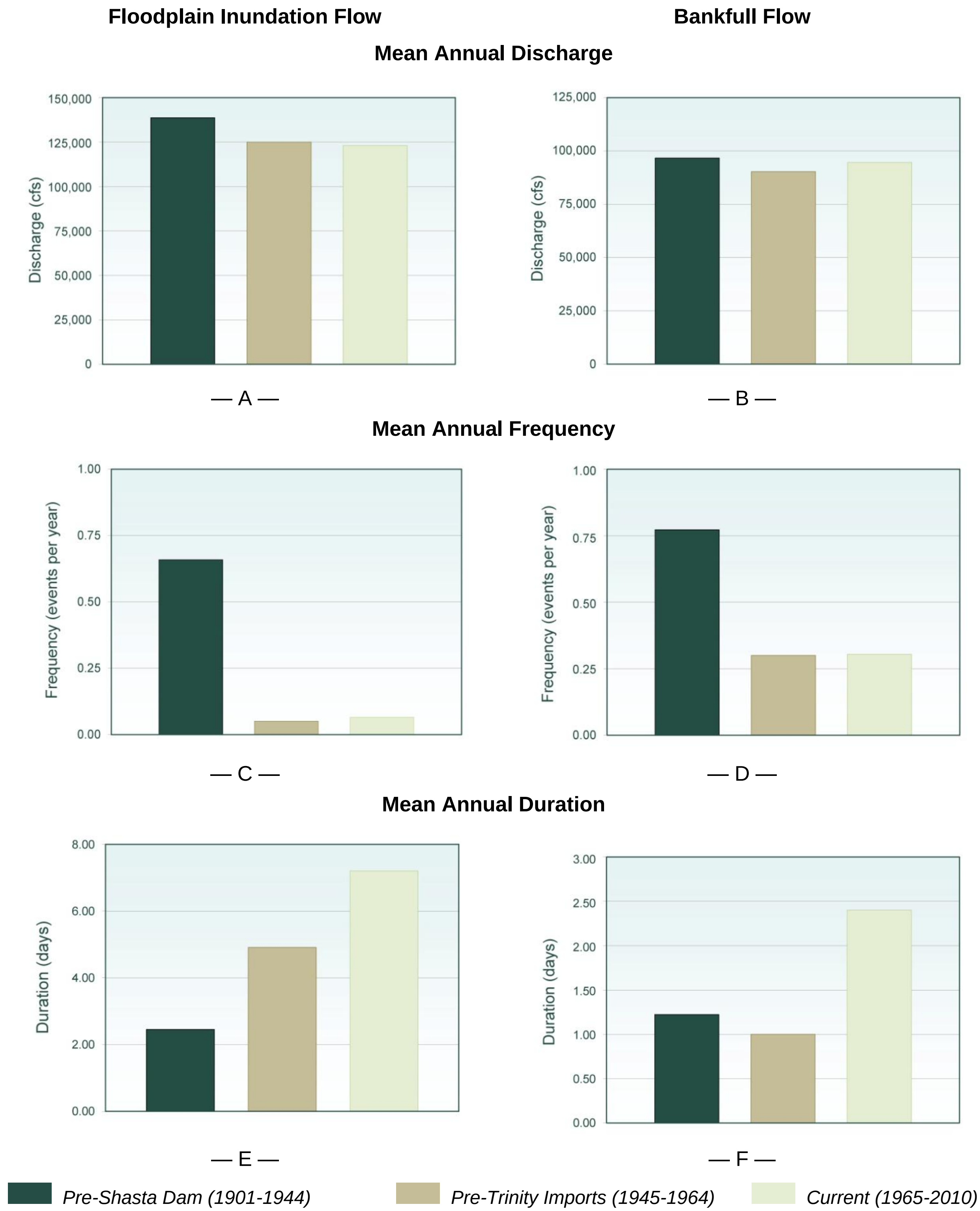
#### *Floodplain Inundation Flow Discharge, Frequency, and Duration*

Floodplain inundation flows provide native fish species access to floodplain habitat, where rates of predation by nonnative fish are lower and food production are higher than in the channel (Sommer et al., 2001, 2003). Floodplain inundation particularly benefits outmigrating salmonids and spawning Sacramento splittail (*Pogonichthys macrolepidotus*). Floodplain inundation also provides nutrients and seeds of riparian species to the floodplain and provides water to floodplain habitats. The discharge, frequency, and duration of floodplain inundation flows were assessed because a reduction in these parameters resulting from a change in reservoir operations would represent a reduction in benefits to native species and habitats.

**Methodology and Rationale** IHA was used to compute the average annual peak discharge, frequency, and duration of small floods before and after reservoir construction at the two long-term flow gages identified above. In IHA, a small flood is defined as a flow event with a peak flow greater than a pre-dam 2-year return interval flow rate and less than or equal to the pre-dam 10-year return interval flow rate. These small flood ranges were selected because these flows represent a range of floods (i.e., a 2- to 10-year recurrence interval) that inundated floodplains before the dams were constructed and that are thought to be positively related to a variety of ecosystem functions, such as the regeneration of riparian habitat and the provision of salmonid rearing habitat (see Section 3.4.2). Larger floods with a recurrence interval of greater than 10 years may also have ecosystem benefits, but they do not occur regularly enough to have the ecosystem benefit of more frequent floods.

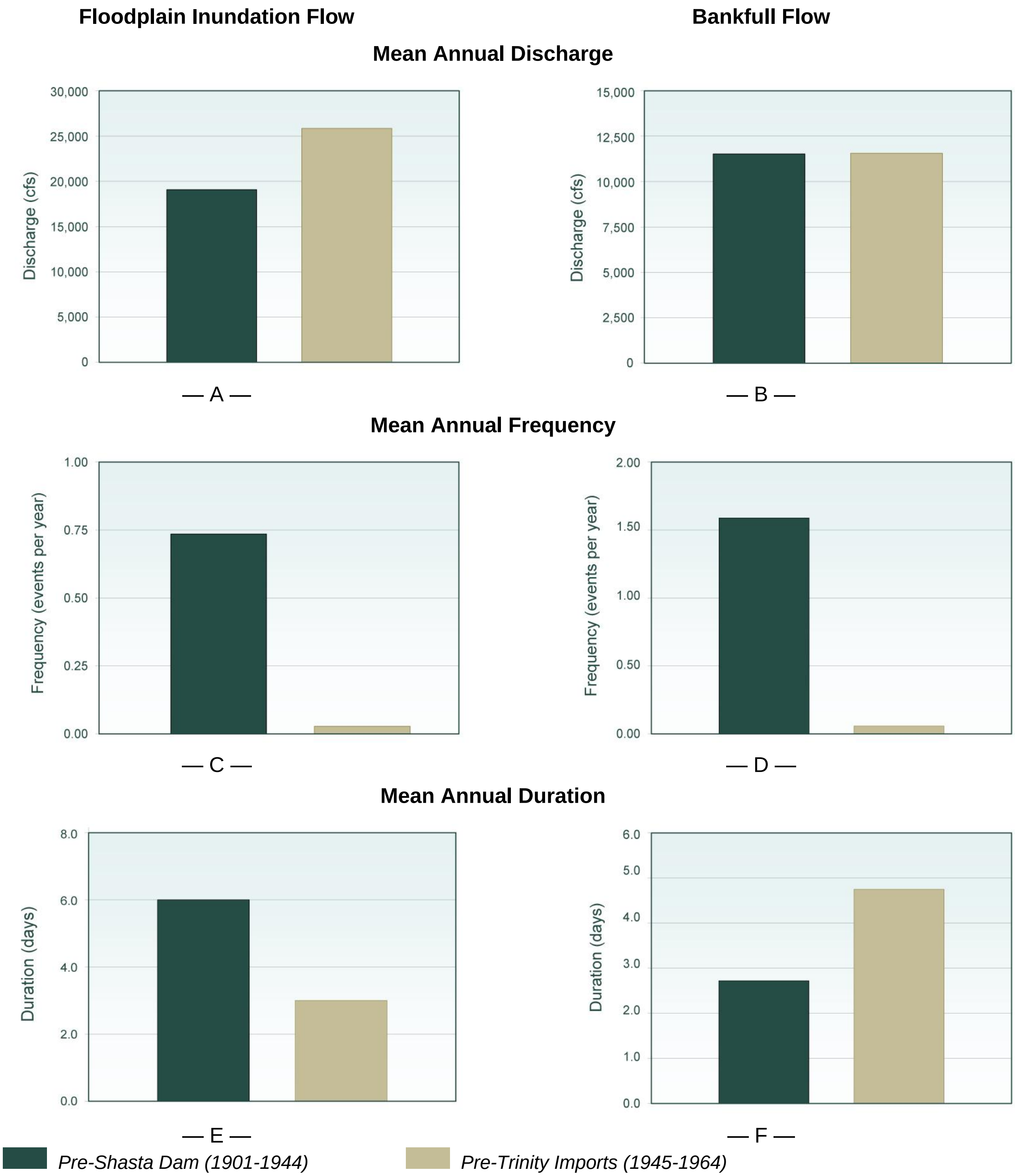
For each year in which a small flood event occurred, IHA computed the maximum event-peak discharge. The average of these maximum peaks was then computed and plotted in Microsoft Excel to convey the change, before and after dam construction, on small flood event peak discharges. In addition, IHA records the number and median duration of small flood events per year. The number and average duration of the events were then computed and plotted on an annual basis in Microsoft Excel. These plots are shown on Figures 4-5 and 4-6.

**Metric Summary** The average annual peak discharge of small floods on the Sacramento River downstream from Shasta Dam declined by 10 percent for the period from construction of Shasta Dam to before the Trinity imports began in 1965. Since the Trinity imports began, the average annual peak discharge remains similar (Figure 4-5A). Although peak discharges have not changed significantly, the average annual frequency has been reduced from 0.66 event per year to 0.07 event per year (Figure 4-5C). This suggests that although Shasta Dam has reduced the frequency of small floods on the Sacramento River, the dam does not have the capacity (or is not operated) to significantly reduce the peak of small flood events when they do occur. The average duration of these events increased by 100 percent during the pre-Trinity imports period (from 2.5 to 5 days) and again by 47 percent following the Trinity imports (from 5 days to 7.3 days), for a total increase of 193 percent since before Shasta Dam was constructed (Figure 4-5E). This increase in duration reflects typical flood control operations, where flood event peaks are stored and subsequently released at lower flow rates following the event peak.




Source: Prepared by AECOM in 2011 based on USGS gage data

**Figure 4-5. Mean Annual Discharge, Frequency, and Duration of Floodplain Inundation Flows and Bankfull Flows in the Sacramento River at Bend Bridge (USGS Gage 11377100)**




*Source: Prepared by AECOM in 2011 based on USGS gage data*

**Figure 4-6. Mean Annual Discharge, Frequency, and Duration of Floodplain Inundation Flows and Bankfull Flows in the San Joaquin River at Friant (USGS Gage 11251000)**

The average annual peak discharge for small floods on the San Joaquin River downstream from Friant Dam increased by 36 percent after Friant Dam was built in 1942 (Figure 4-6A). However, only two small flood events are recorded at the Friant gage since 1942. Peaks of 14,900 cfs and 36,800 cfs were recorded for these two events, where the 36,800 cfs peak is greater than any small flood event recorded during either period. This suggests that Friant Dam was likely at or near capacity before the second event peak and that the dam may be optimized for small flood events as opposed to large flood events, allowing for upper end (i.e., with a 10-year return interval) peak discharges to be released. Given that the frequency of small flood events has been reduced from 0.74 event per year to 0.03 event per year (Figure 4-6D), it is clear that Friant Dam is operated to capture and is successful at capturing small flood events. The duration of small floods has also been reduced, from 6 days to 3 days (Figure 4-6E), suggesting that the dam is operated not only to capture all small flood events but to release those events at extreme low-flow rates. This is confirmed by the increase in average yearly duration of extreme low-flow events from 29.4 days to a very long 352.3 days.

Small flood events (i.e., with a 2- to 10-year return interval) are both geomorphologically and ecologically important because of the overbank flooding that occurs during these events. Shasta and Friant dams have significantly reduced overbank flooding, as is evident from 90 percent and 96 percent reductions in small flood frequency on the Sacramento and San Joaquin rivers, respectively, and have reduced the frequency of inundation of floodplain habitats and species.

#### *Bankfull Flow Discharge, Frequency, and Duration*

Bankfull flows drive meandering and other related geomorphic processes (e.g., erosion and deposition of sediment) in the major rivers. LWM, which provides important habitat for native fish and invertebrate species, is generated by the erosive processes caused by these flows because they cause trees to fall into the channel. The discharge, frequency, and duration of bankfull flow were assessed because a reduction in these hydrologic parameters resulting from a change in reservoir operations would represent a reduction in the geomorphic process that generates LWM and maintains habitat diversity.

**Methodology and Rationale** IHA also was used to compute the discharge, frequency, and duration of high pulse flows. In IHA, a high pulse flow is defined as a flow event greater than a pre-dam 1.5-year return interval flow rate and less than or equal to the pre-dam 2-year return interval flow rate. A 1.5- to 2-year recurrence interval flow is roughly equivalent to the hypothetical bankfull flow, and although dynamic channel processes have been observed on the Sacramento River at discharges much less than the presumed bankfull discharge, the bankfull discharge, because of its regularity and force, is assumed to be responsible for most of the force in the bed and channel. Thus, the bankfull discharge is strongly linked to sediment mobilization and transport and with the creation and maintenance of meandering streams, eroded banks, and point bar deposition. These physical changes to the stream can be positively associated with a variety of ecosystem functions (see Section 3.4.1).

As for small flood metrics, high pulse-flow metrics were computed and plotted using IHA and Microsoft Excel, as described in the following section.

**Metric Summary** The high pulse flow (or bankfull flow) was defined as a particular range of discharges observed before dam construction, and the pre-dam and post-dam median peak flows were selected to be the same and, therefore, do not differ (Figures 4-5B and 4-6B). The high pulse flow in the San Joaquin River was about 12 percent of the high pulse flow in the Sacramento River.

The frequency of these pre-dam bankfull flows is much reduced by the dams (Figures 4-5D and 4-6D), especially by Friant Dam. These flows are responsible for most of the channel migration, so the extent of channel migration was severely reduced with construction of the dams, especially on the San Joaquin River (Jones & Stokes Associates 1998b, 2002). However, on the Sacramento River, the effects of an increase in land conversion to agricultural land uses and an increase in bank revetment that have also occurred since Shasta Dam was built have confounded the effect of the hydrologic changes on geomorphology and plant community diversity.

The duration of the high pulse flows increased after the construction of dams on the Sacramento and San Joaquin rivers (Figures 4-5F and 4-6F). The reason is that the dams are operated to keep flows at the bankfull level and to keep them from spilling onto the floodplain.

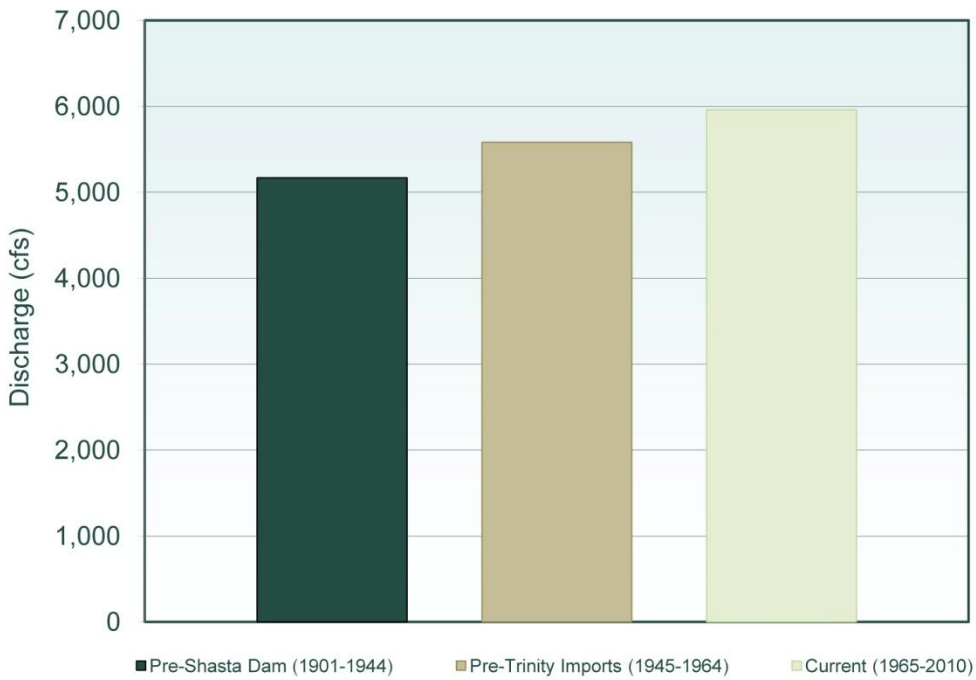
#### *Extreme Low-Flow Discharge*

Low flows maintain riparian vegetation through summer by preventing desiccation. However, if summer low flows are too high, they may cause the drowning of seedlings of riparian trees and shrubs. The discharge of low flows was assessed to determine whether changes in summer low flows resulting from a change in reservoir operations could result in the desiccation or drowning of riparian vegetation.

**Methodology and Rationale** Extreme low-flow events were defined as events with a peak discharge less than or equal to the maximum of the minimum 90-day running-average flows of each water year. The flow record for each gage was queried using IHA for the minimum 90-day flow for each year, and Microsoft Excel was used to determine the maximum of these 90-day-duration minimums. IHA and Microsoft Excel were then used to compute the average annual discharge of extreme low-flow events.

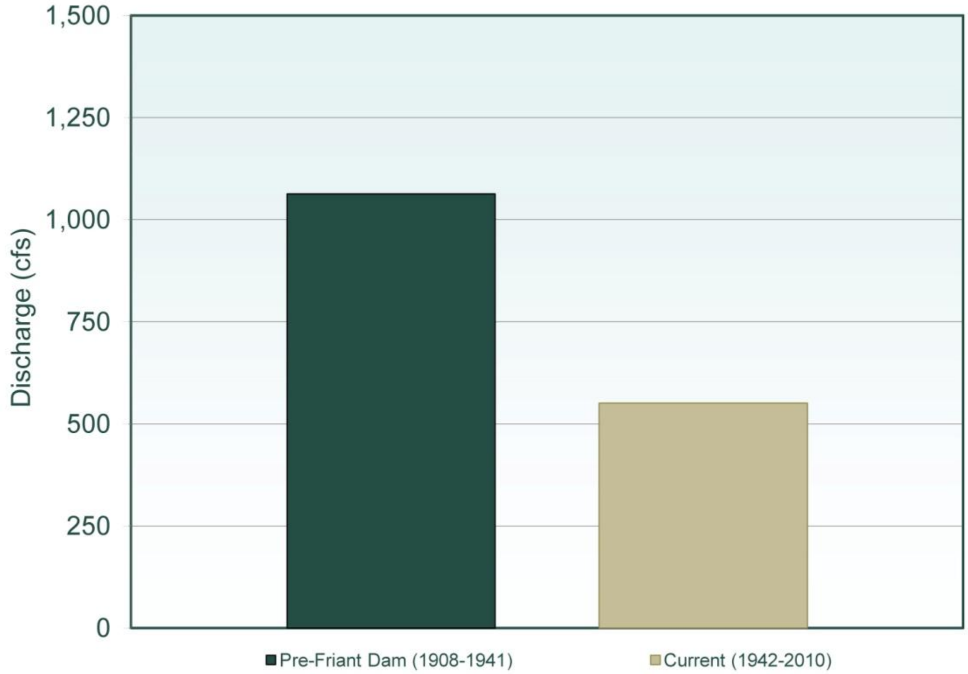
A 90-day minimum flow was chosen to represent low flows because a flow of this duration is most likely to represent the average annual base flow. As described in Section 3.2.3, base flows are positively linked to the sustainability of riparian vegetation and riparian wetlands and the suitability of salmonid spawning habitat. Modified base flows may also be a primary factor limiting the recruitment of early successional riparian vegetation in the Sacramento River (see Section 3.5.3).

**Metric Summary** The low flow of the Sacramento River was increased after Shasta Dam was completed to provide irrigation water during summer (Figure 4-7, see also Figure 4-1). These flows are high enough to “drown” seedlings of riparian tree and shrub species. In the San Joaquin River, low flows after Friant Dam was completed were much lower than the flows before dam construction (Figure 4-8, see also Figure 4-2). Low flows in the San Joaquin River are so low that riparian seedlings cannot survive the summer in the reach between Gravelly Ford and Mendota Dam.




Source: Prepared by AECOM in 2011 based on USGS gage data

**Figure 4-7. Base-Flow Discharge in the Sacramento River at Bend Bridge (USGS Gage 11377100)**




Source: Prepared by AECOM in 2011 based on USGS gage data

**Figure 4-8. Base-Flow Discharge in the San Joaquin River at Friant (USGS Gage 11251000)**

### 4.1.2 Channel and Floodplain Dynamics

***Description of Metrics***

The metrics chosen to represent the status and trends of channel and floodplain dynamics are total river length, floodplain reworked (i.e., area that the channel moved through), and floodplain age. These metrics were computed previously for the middle reach of the Sacramento River (from RM 143 to 244) (Larsen, 2010). Because of time constraints associated with preparing this information for inclusion in the 2012 CVFPP, these metrics were included from this previous report but were not calculated for other reaches of the Sacramento River, tributaries to the Sacramento River, or the San Joaquin River system. It is anticipated that these metrics will be calculated for other rivers in the Sacramento and San Joaquin valleys as part of the 2017 CVFPP.

***Total River Length***

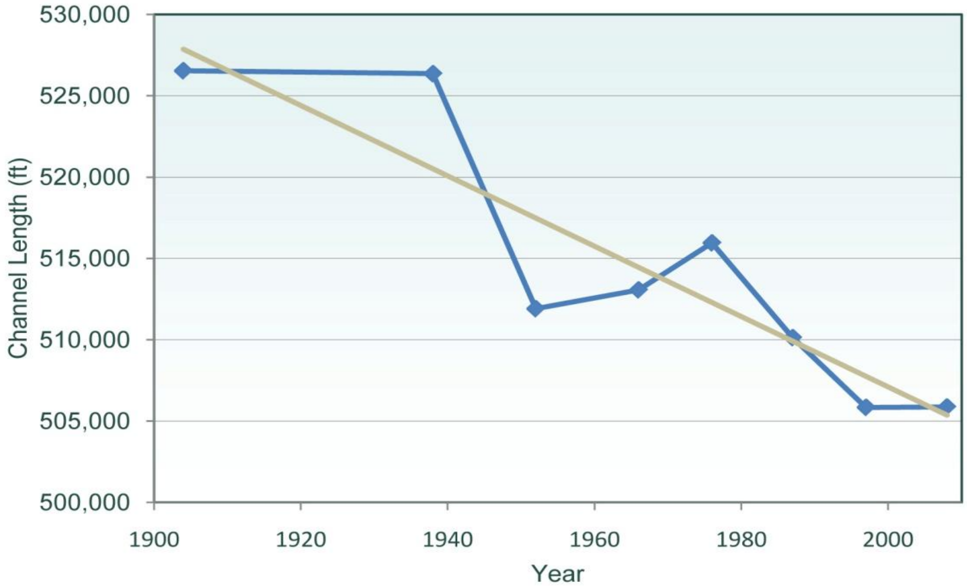
Total river length represents the amount of riverine and channel margin habitat available to native species. Changes in total river length were assessed to determine whether habitat for native species had changed as a result of a change in river planform.

**Methodology and Rationale** Total river length was calculated as the distance along the Sacramento River channel centerline from the Red Bluff Diversion Dam (RM 244) to the Colusa Bridge (RM 143). The total river length was calculated in GIS by measuring the centerline length of the river channel for eight periods between 1904 and 2007. Historic river centerlines were created by GIS analyses of aerial photographs and historic centerlines. Because the river tended to be located in different locations through time, a common start and end point was chosen for analysis. Channel segments that extended past these points were trimmed, resulting in a measure of river length reflective of sinuosity between a common starting and ending point.

The total length of river between a starting location and an ending location is a clear and obvious measure of the size of the river. For ecosystem processes related to the areal extent of a river channel, such as salmonid rearing habitat or floodplain interaction, and area of riparian habitat, a greater total length of river (given fixed end locations) will provide more area and therefore more ecosystem functions and processes. Total river length is by definition a large-scale metric that assesses the overall health of the river. This indicator was previously used as a metric of river health on the Willamette River in Oregon (IMST, 2002).

A longer, and therefore more sinuous, river provides an ecosystem with greater habitat values (e.g., Brookes, 1987; James and Henderson, 2005). In alluvial river settings, a sinuous river has more cut banks and point bars than a straight river. It is also likely to be a more active river in terms of riverine processes of meander migration and erosion and sediment deposition, although such processes may be constrained by the presence of riprap on the riverbank. Because sinuous rivers have a greater complexity of habitats and ecological processes associated with them (e.g., Boano et al., 2006), they are more supportive of native species (e.g., bank swallows, salmon) and communities (e.g., cottonwood forests) (e.g., Jungwirth et al., 1993; Brunke and Gonser, 1997).

**Metric Summary** From 1904 through 2007, the geometric complexity and meander migration dynamics of the middle Sacramento River have decreased (Figure 4-9), which has implications for the riparian ecosystem. The river channel length has tended to decrease, suggesting that the river length lost to cutoff and other processes has not been replaced by an increase in length related to channel migration over that period. In addition, other metrics representing the channel complexity and dynamics have also decreased in a manner similar to the channel length (Larsen, 2010; Micheli and Larsen, 2011). For example, the formation of high-sinuosity bends susceptible to future cutoff has declined; the river sinuosity, the average entrance and exit angle magnitudes, and the average migration rate have all tended to decrease with time. The entrance angle represents the upstream curvature of a bend and can be correlated with a tendency to cut off the bend (Micheli and Larsen, 2011). Cutoffs can produce oxbow lakes on the Sacramento River, which are important habitats (Morken and Kondolf,




*Source: Larsen, 2010*

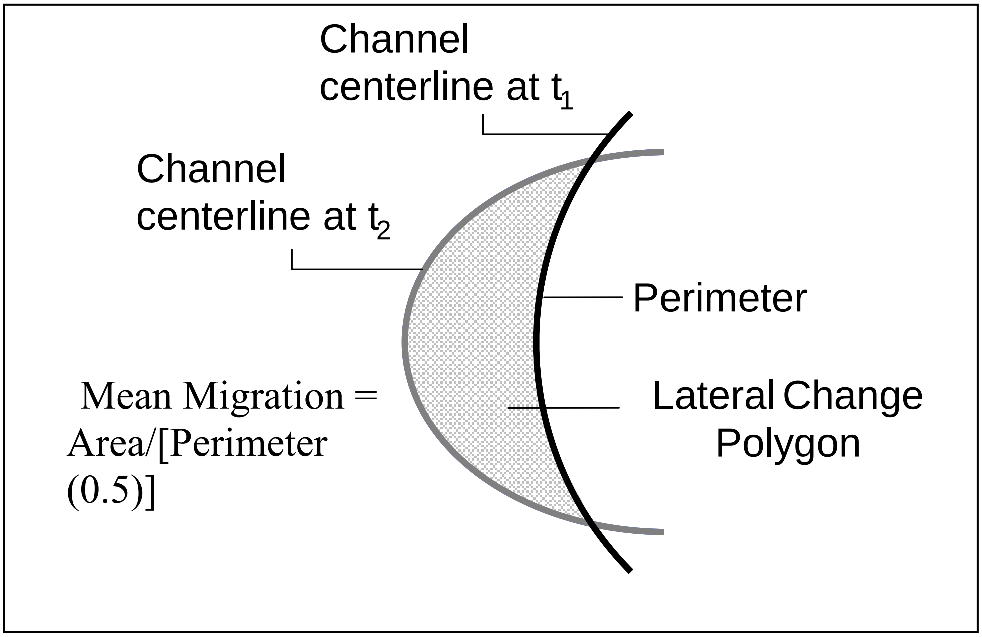
**Figure 4-9. Change in Total River Length over Time for the Middle Sacramento River (RM 143 to RM 244)**

2003). The exit angle is similar but is measured at the downstream inflection point.

***Floodplain Reworked***

**Methodology and Rationale** The area of floodplain reworked per year was calculated in GIS by measuring the area of the "lateral change polygon" that is formed when two channel centerlines from two different periods are intersected. A time series of river centerlines was created as described above under "Total River Length." The resultant area between two river centerlines was divided by the number of years in the time interval between the two periods (Figure 4-10). The area of floodplain reworked measured in this way is an estimate of "new floodplain created" (Larsen et al., 2006b). A related metric is floodplain age (Fremier, 2003), which is described in more detail below.

For ecosystem functions and processes related to the areal extent of river channel or of riparian habitat area, the reworking of land and creation of new floodplain are critical (Malanson, 1993; Naiman et al., 2005; Greco et al., 2007). For example, Fremont cottonwood development depends on point bars that are created. As cottonwoods mature, they depend on the time-sequence of land reworked or floodplain creation. Other riparian species also require heterogeneity of floodplain age, which is produced by land being reworked (van Coller et al., 2000; Dixon et al., 2002; Steiger et al., 2005). The “per year” measurement of land reworked is a metric of the rate that such land is being produced.




*Source: Prepared by Dr. Eric Larsen in 2011*

**Figure 4-10. Calculation Method of Area of Floodplain Reworked**

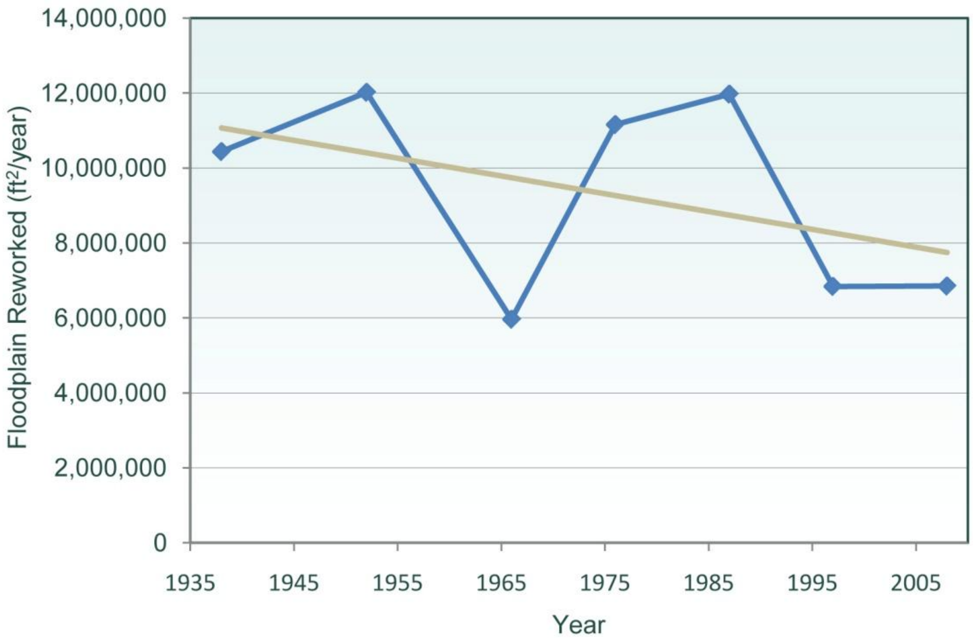
**Metric Summary** The floodplain area reworked generally shows a decreasing trend over time, although there are large fluctuations (Figure 4-11). As described below, the reasons for these fluctuations are complex.

Some of the reasons can be better understood by separating the area of floodplain reworked into separate components, such as progressive migration, partial cutoff, and chute cutoff (Micheli and Larsen, 2011).

Changes in the indicator values indicate that some of the changes in the river have causes and conditions that conflict with each other. An example of these complicated relationships is the rate of floodplain area reworked. The changes in area reworked on the middle Sacramento River are the result of multiple (sometimes conflicting) causes. For example, the rate of area reworked has decreased with the use of bank protection, but it also has increased with replacement of native riparian vegetation with agriculture (Micheli et al., 2004).

***Floodplain Age***

**Methodology and Rationale** Floodplain age is defined as the time elapsed since a specific area changed from aquatic to terrestrial (e.g., river channel to point bar). This metric was measured using the same digitized time series of channel centerlines used to compute total river length and floodplain reworked. Algorithms were developed in GIS to interpolate channel positions between years because the source aerial photographs used to derive channel centerlines were taken, on average, 10 years to 15 years apart. The resultant geospatial data depict the estimated age of the

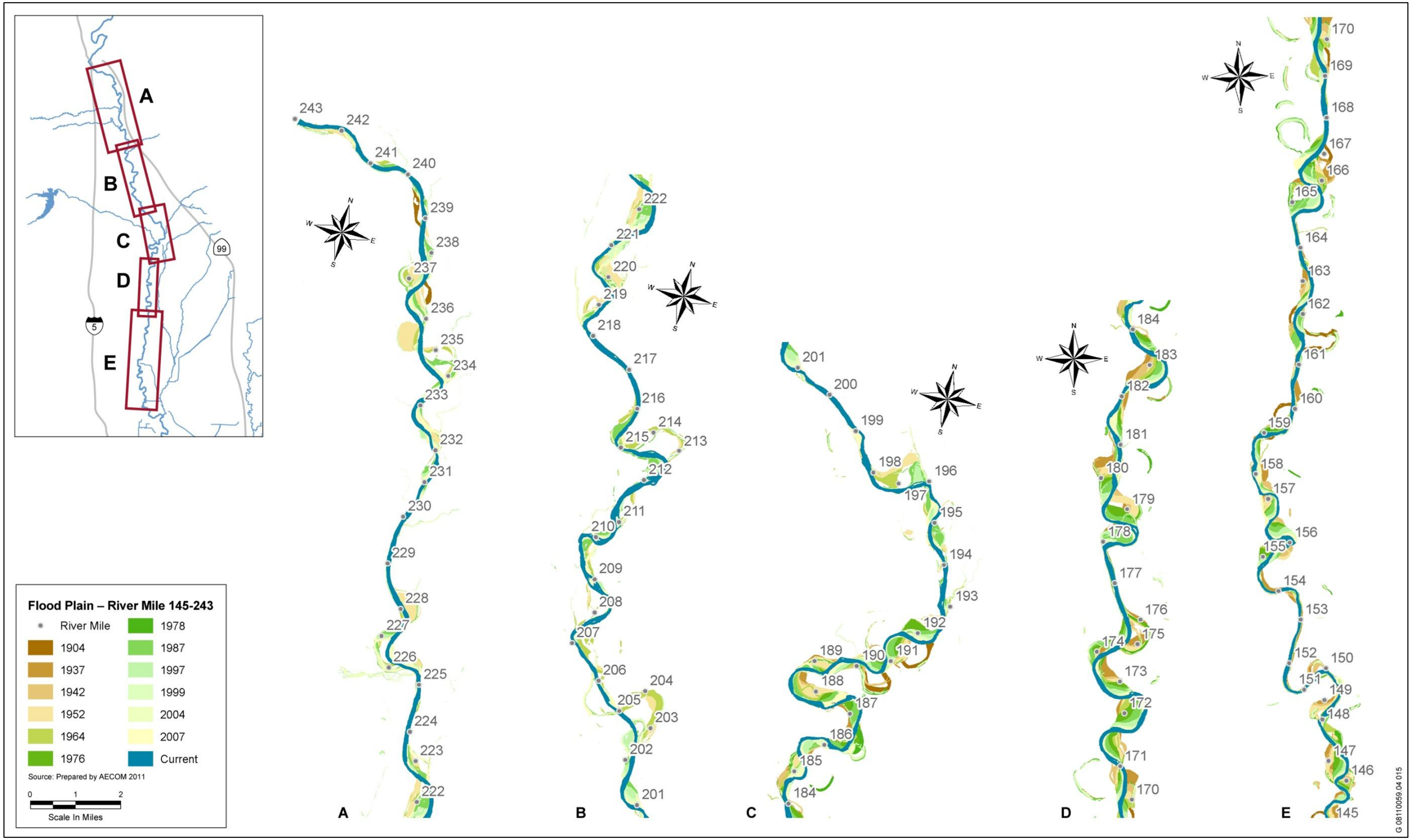



*Source: Larsen, 2010*

**Figure 4-11. Area of Floodplain Reworked over Time for the Middle Sacramento River (RM 143 to RM 244)**

floodplain surface and the mechanism by which new floodplain was created (i.e., floodplain created by progressive channel migration rather than channel abandonment). A full description of the methodology used to calculate floodplain age is provided elsewhere (Fremier and Girvetz, in prep.; Figure 1).

**Metric Summary** An example of the floodplain age analysis is shown on Figure 4-12 (different colors represent different floodplain ages). Like the floodplain reworked metric, the floodplain age metric provides a useful measure by which riparian habitat ecosystem functions can be assessed (Fremier et al., 2009). Figure 4-13 shows the acreages of floodplain patches of different ages in a reach of the Sacramento River. Because riparian ecosystems undergo relatively predictable patterns of vegetation succession following disturbance, it can be assumed that river reaches with a wide diversity of floodplain ages will have a diversity of vegetation communities. This diversity would include early successional species on younger floodplains, a mixture of early and late successional species on middle-aged floodplains, and late successional species on older floodplains (Greco and Plant, 2003; Fremier et al., 2009). An assumed positive relationship exists between floodplain age diversity and species diversity, as described in Section 3.4.1.




Source: Prepared by Dr. Eric Larsen in 2011

**Figure 4-12. Floodplain Age Mapped Along the Middle Sacramento River (RM 145 to RM 243)**

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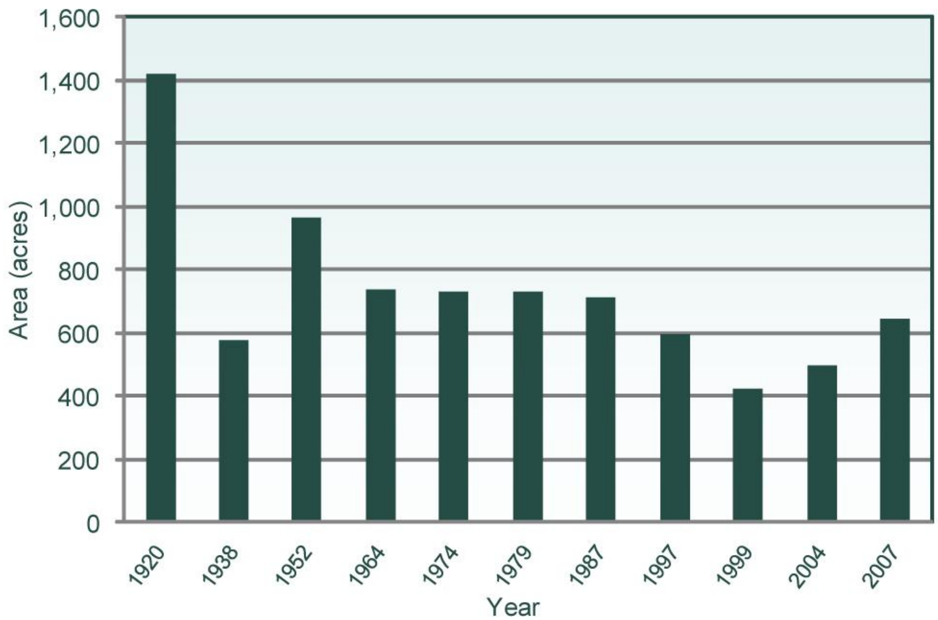



*Source: Prepared by Dr. Eric Larsen in 2011*

**Figure 4-13. Area of Newly Created Floodplain by Year Along the Middle Sacramento River (RM 217 to RM 243)**

### 4.1.3 Riparian and Riverine Habitats

A diversity of floodplain ages reflects ecosystem processes that lead to a diversity in habitats. Newly formed land undergoes primary succession and is colonized through this process by early successional woody species, such as willows and cottonwoods. These species provide habitat for important conservation target species. Conservation of primary and secondary successional processes is an important management goal (Greco et al., 2007).

Meander migration and channel cutoff processes are necessary to create and support the landscape heterogeneity of different riparian wildlife habitats. For example, Greco et al. (2002) showed that the yellow-billed cuckoo's habitat consists of cottonwood forest that is maintained by periodic disturbance.

***Description of Metrics***

The metrics chosen to represent the status and trends of riparian and riverine habitat are (1) SRA cover length, (2) habitat distribution and extent, and (3) species distribution and abundance. SRA cover length is presented in tabular format (i.e., summarized by reach). Habitat and species distributions are presented spatially. Species abundance ideally would be presented as counts of representative species, but those data are not available.

### *Shaded Riverine Aquatic Cover*

**Methodology and Rationale** SRA cover is defined as "the unique near-shore aquatic area occurring at the interface between a river (or stream) and adjacent woody riparian habitat. Key attributes of this aquatic area include (a) the adjacent bank being composed of natural, eroding substrates supporting riparian vegetation that either overhangs or protrudes into the water, and (b) the water containing variable amounts of woody debris, such as leaves, logs, branches and roots, often substantial detritus, and variable velocities, depths, and flows" (USFWS, 1992).

Three attributes of SRA cover make it an important component of fish and wildlife species habitat (USFWS, 1992):

- Overhanging vegetation and (sometimes) riverbanks provide at least six types of habitat values to fish and wildlife species:
  - Shade and cover reducing visibility to predators
  - Moderation of water temperatures important to salmonids
  - Input of plant material which provides instream cover for fish
  - Habitat of terrestrial and aquatic invertebrates which provide food to birds and aquatic species
  - Perches, nesting, and resting areas for bird species
- In-water cover, including (1) overhanging or fallen trees or branches, (2) aquatic vegetation, (3) diversity of substrate sizes, and (4) irregular banks, provides habitat complexity to fish and wildlife species, which supports a high diversity and abundance of invertebrate and fish species.
- Natural, eroding banks, often have cavities, depressions, and vertical faces that support bank-dwelling species, including bank swallow, belted kingfisher (*Megaceryle alcyon*), mink (*Neovison vison*), river otter (*Lontra canadensis*); and that provide cover and shelter for fish. The bank dwelling species may use these banks and their cavities as access points for the water or for nesting. Erosion of natural bank substrates provides instream spawning substrate for aquatic species, including salmonids.

SRA cover data are available for three reaches of the Sacramento River: Red Bluff to Chico Landing, Chico Landing to Colusa, and Colusa to Verona. Data for the reaches from the latter two (downstream) reaches were collected by the USFWS and USACE in spring and summer 2002. Data for the reach from Red Bluff to Chico Landing were collected by DWR in 2007. The methods were developed jointly by DWR, USFWS, and USACE, and followed the protocol of the *Standard Assessment Method for the Sacramento River Bank Protection Project* (USACE, 2004).

The following data were mapped along the three reaches:

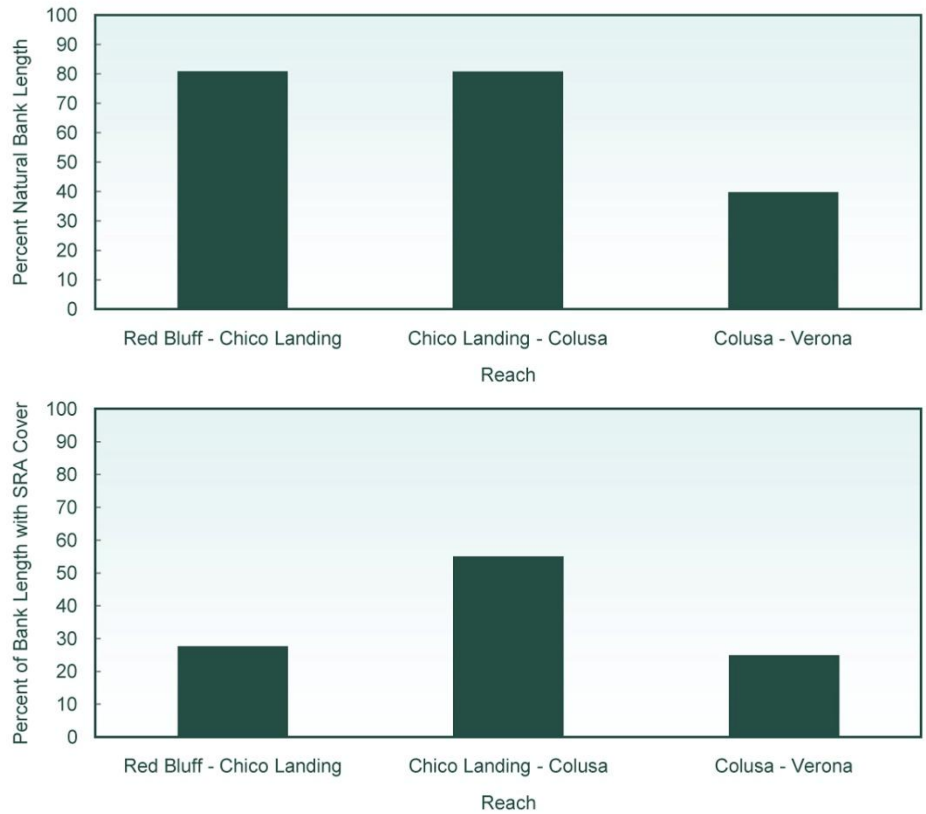
- Bank type: mostly erosional or mostly stable (which are SRA cover types), or mostly depositional or revetment (which are non-SRA cover types)
- Vegetative cover: more than 75 percent cover of woody vegetation (an SRA cover type), less than 75 percent woody vegetation (a non-SRA cover type)
- Woody vegetation type: riparian forest (taller than 20 feet), riparian scrub (shorter than 20 feet)
- LWM cover: percentage bank length with large woody material
- Overhead cover: percentage of riverbank line shaded at noon (not analyzed in this report)

Overhead cover height: cover mostly less than 10 feet high, cover mostly more than 10 feet high (not analyzed in this report). Sites were only considered to have SRA cover when they had mostly erosional or mostly stable bank types, more than 75 percent woody vegetative cover, with shaded bank line, and LWM present.

**Metric Summary** Approximately 81 percent of the banks between Red Bluff and Colusa are natural (i.e., without revetment) (Figure 4-14). Between Colusa and Verona the amount of revetment is much greater and the natural bank portion is about 40 percent. The percentage of banks with SRA cover is greatest between Chico Landing and Colusa (55 percent), and considerably less upstream and downstream (approximately 28 and 25 percent, respectively) (Figure 4-14).

For natural banks, the type of SRA cover (riparian forest versus scrub, and LWM cover) differs substantially among the three reaches. The majority of the SRA cover in the reach from Red Bluff to Chico Landing consists of riparian scrub (62.2 percent), while from Chico Landing to Colusa the percentage of scrub is much less (22.8 percent), and from Colusa to Verona the scrub percentage is very much less (1.8 percent) (Figure 4-15). Almost all SRA cover between Colusa and Verona consists of riparian forest.

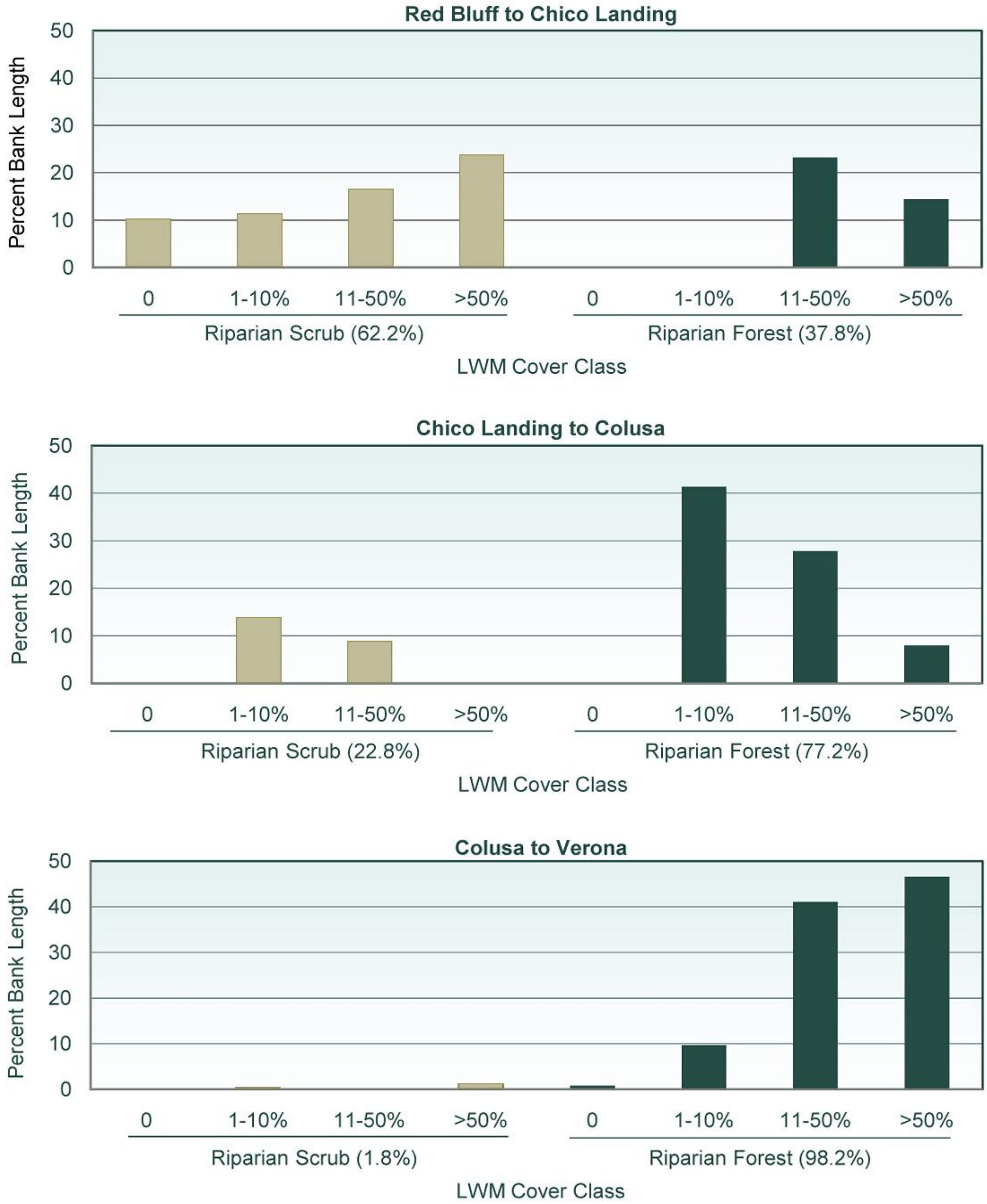
Approximately 38 percent of the natural banks between Red Bluff and Chico Landing are in the highest LWM cover class (Figure 4-15). Most of this LWM is contributed by riparian scrub, and presumably consists of relatively small material. Only 8 percent of the natural banks in the reach between Chico Landing and Colusa are in the largest LWM class, and all this material is associated with riparian forest, presumably including logs and large tree branches (Figure 4-15).




*Source: Prepared by Dr. Eric Larsen in 2011*

**Figure 4-14. Percent Natural Bank Length and SRA Cover by Reach**

Overall bank length with more than 50 percent LWM cover can be calculated by multiplying the overall natural bank percentage (Figure 4-14A) with the percentage of bank length in a particular LWM cover class (Figure 4-15). For the reaches from Red Bluff to Chico Landing, Chico Landing to Colusa, and Colusa to Verona, bank lengths with more than 50 percent LWM cover represent 31 percent, 6 percent, and 19 percent of the total bank lengths, respectively. Overall bank lengths with LWM cover between 1 percent and 50 percent for the reaches from Red Bluff to Chico Landing, Chico Landing to Colusa, and Colusa to Verona are 42 percent, 74 percent, and 20 percent, respectively.




*Source: Prepared by Dr. Eric Larsen in 2011*

**Figure 4-15. LWM Cover Class Distribution of Riparian Scrub and Forest by Reach**

### *Habitat Distribution and Extent*

**Methodology and Rationale** Habitat distribution and extent were analyzed using the Central Valley Riparian Mapping Project GIS database prepared by California State University, Chico, and DFG. The data were developed for the CVFPP SPA to inventory riparian vegetation, wetlands, and other natural communities in the SPA. Land-use types were mapped to the broadest categories (i.e., agriculture and urban). The data were heads-up digitized at a scale of 1:2,000 using National Agricultural Inventory Program 2009 aerial imagery (USDA, 2009). The minimum mapping unit (MMU) for natural vegetation is 1 acre with an average width equal or greater to 33 feet for polygons mapped to the National Vegetation Classification System (NVCS) Group Level; provisional NVCS groups are as presented by Sawyer et. al. (2009) and temporary provisional groups are as presented by Todd Keeler-Wolf (pers. comm., 2009).

For the production of the large-scale maps in this report, natural vegetation types were combined into the following broad wetland and riparian habitat type categories: riparian forest, riparian scrub, freshwater permanent wetland, seasonal wetland, vernal pool complex, and alkali seasonal wetland complex. Acreages were calculated for each of these broad habitat types, and maps showing the distribution of these habitat types were created. To indicate the extent of change from historical conditions, the extent of riparian and perennial wetland vegetation from The Bay Institute’s (1998) map of historical riparian and wetland vegetation of the Central Valley is also displayed on the maps.

**Metric Summary** Figures 4-16 through 4-22 display the known distribution of riparian and wetland habitat in the Sacramento and San Joaquin valleys. As described in Section 2, riparian and wetland habitats are greatly restricted relative to their likely historical distribution. Although the historical trend has been a widespread decline in wetland and riparian habitats, recent restoration efforts have likely reversed this trend in parts of the Sacramento and San Joaquin valleys. It should be noted that most habitat restoration efforts to date have involved planting riparian vegetation and, occasionally, creating wetlands rather than restoring fluvial and geomorphic processes that would promote “natural” habitat regeneration. The locations and acreages of riparian and wetland habitat restoration projects completed in the Sacramento and San Joaquin valleys were not tabulated for preparation of this report.

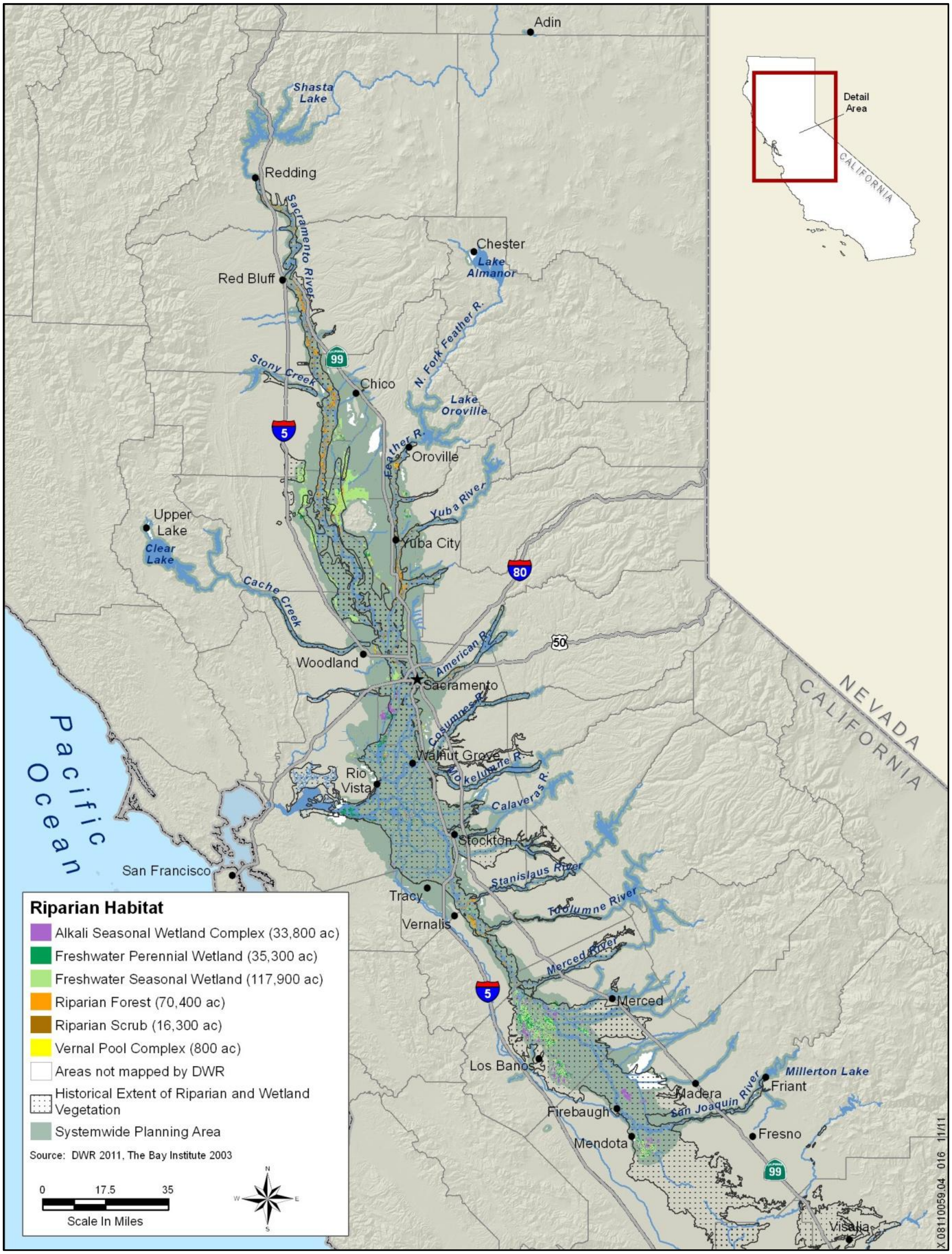



**Figure 4-16. Riparian and Wetland Habitat in the Central Valley**

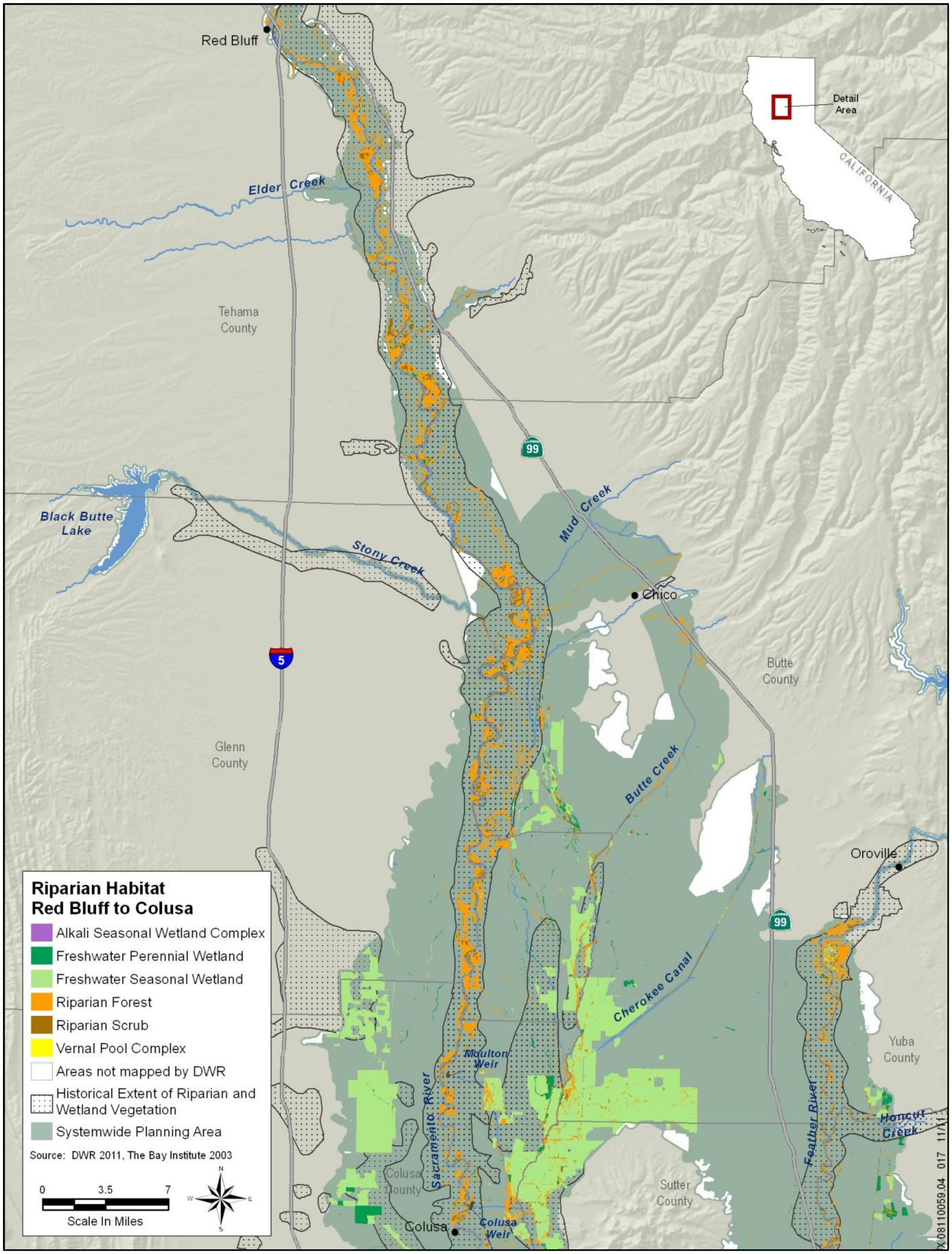



**Figure 4-17. Riparian and Wetland Habitat in the Central Valley: Red Bluff to Colusa**

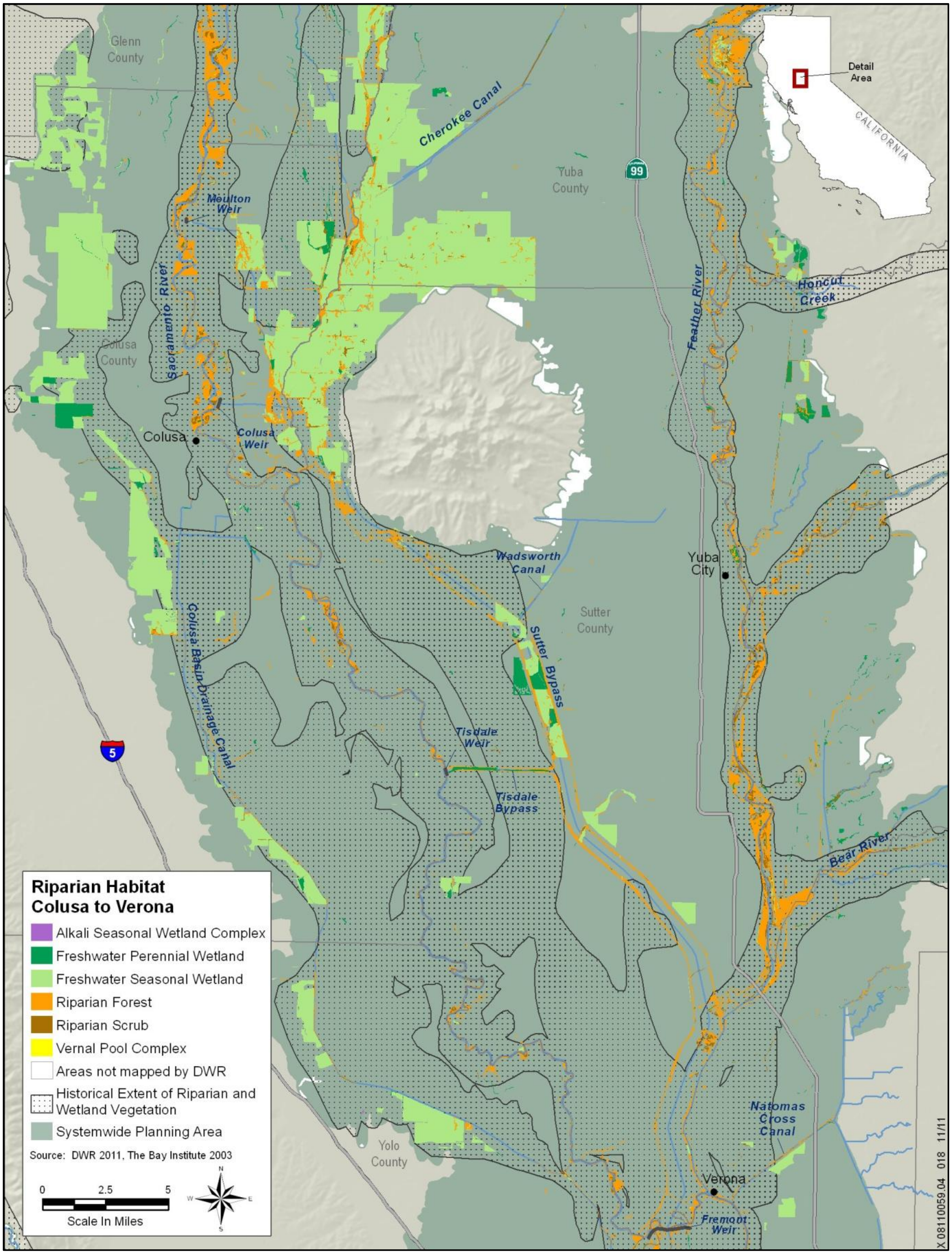



**Figure 4-18. Riparian and Wetland Habitat in the Central Valley: Colusa to Verona**

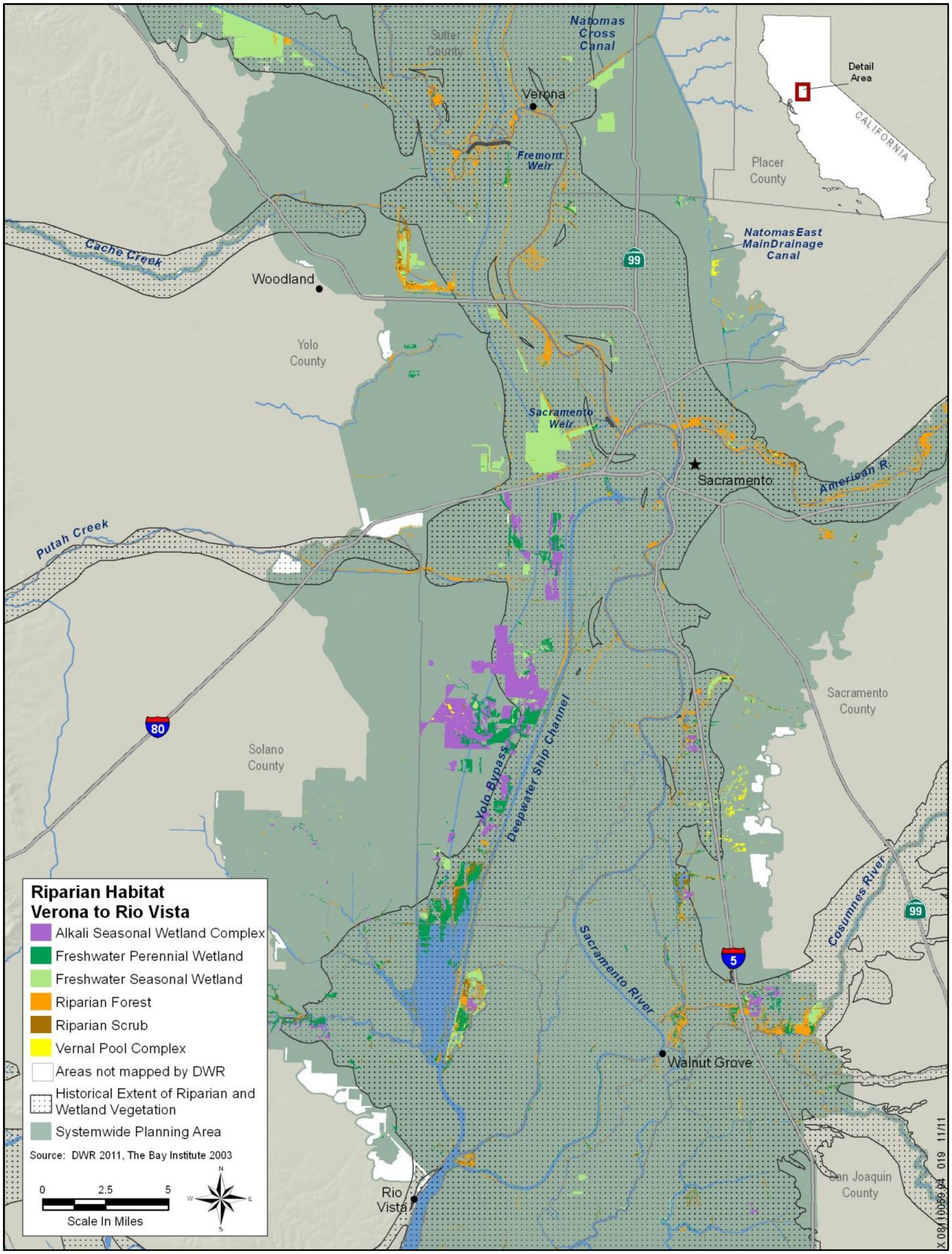



**Figure 4-19. Riparian and Wetland Habitat in the Central Valley: Verona to Rio Vista**

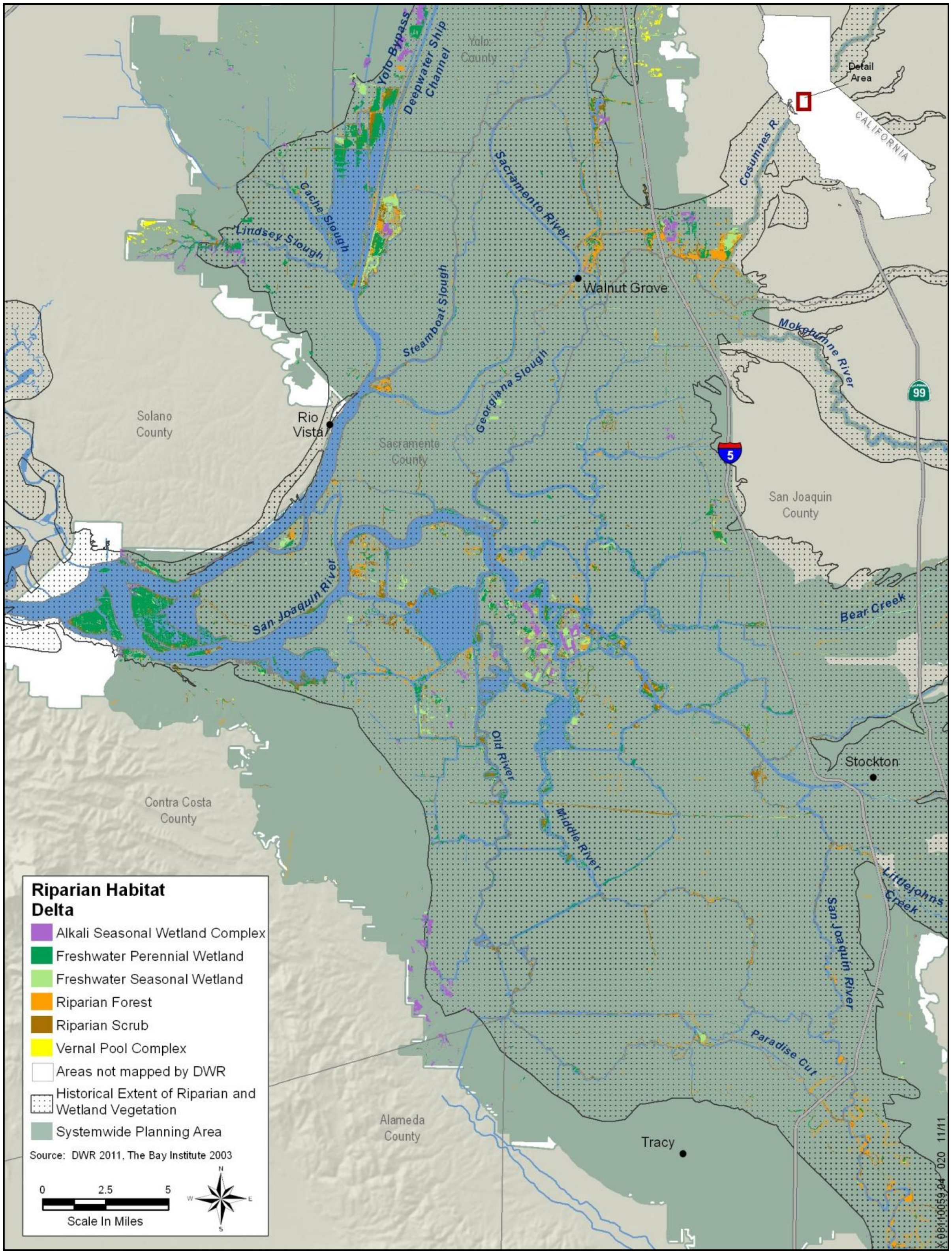



**Figure 4-20. Riparian and Wetland Habitat in the Central Valley: Delta**

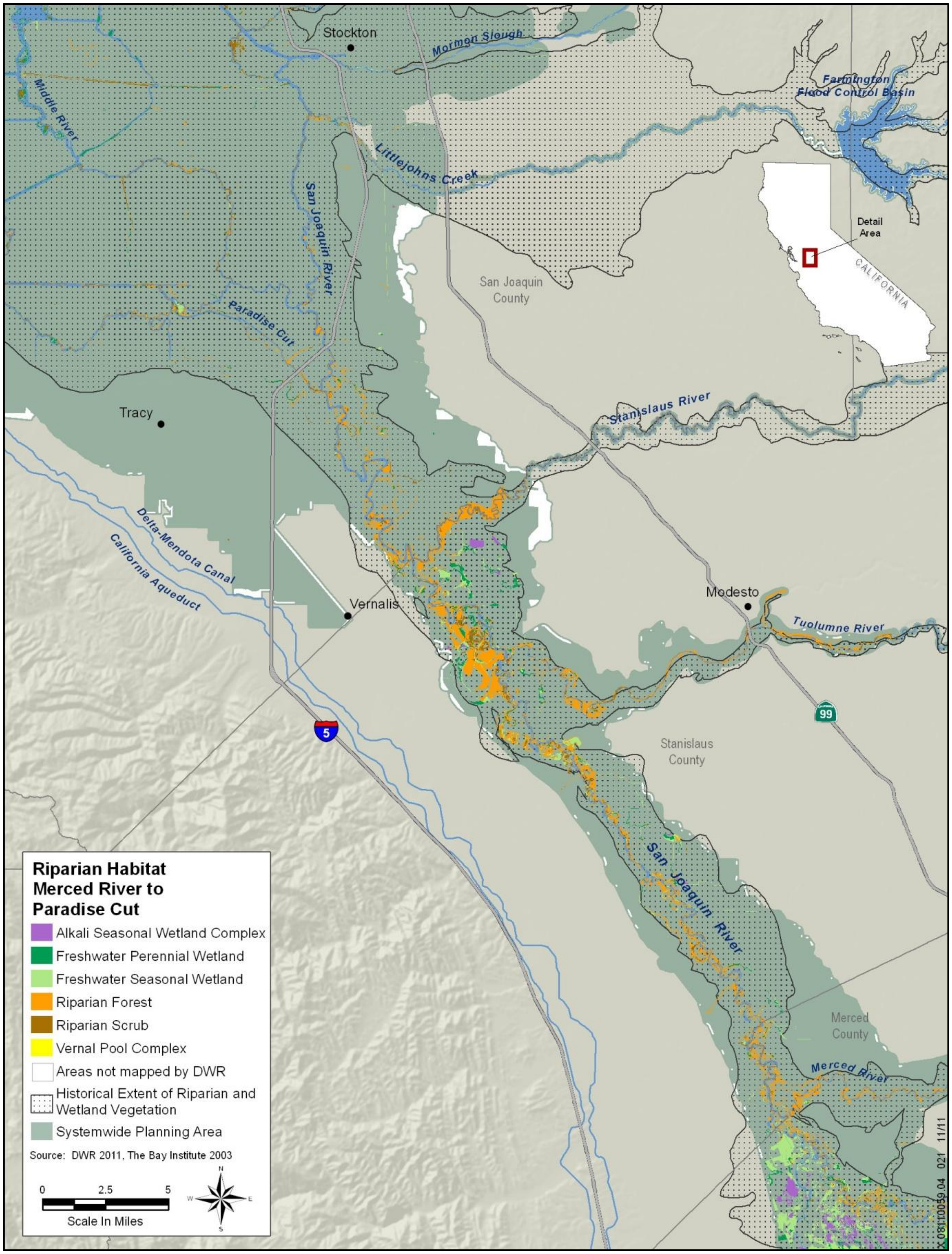



**Figure 4-21. Riparian and Wetland Habitat in the Central Valley: Paradise Cut to Merced River**

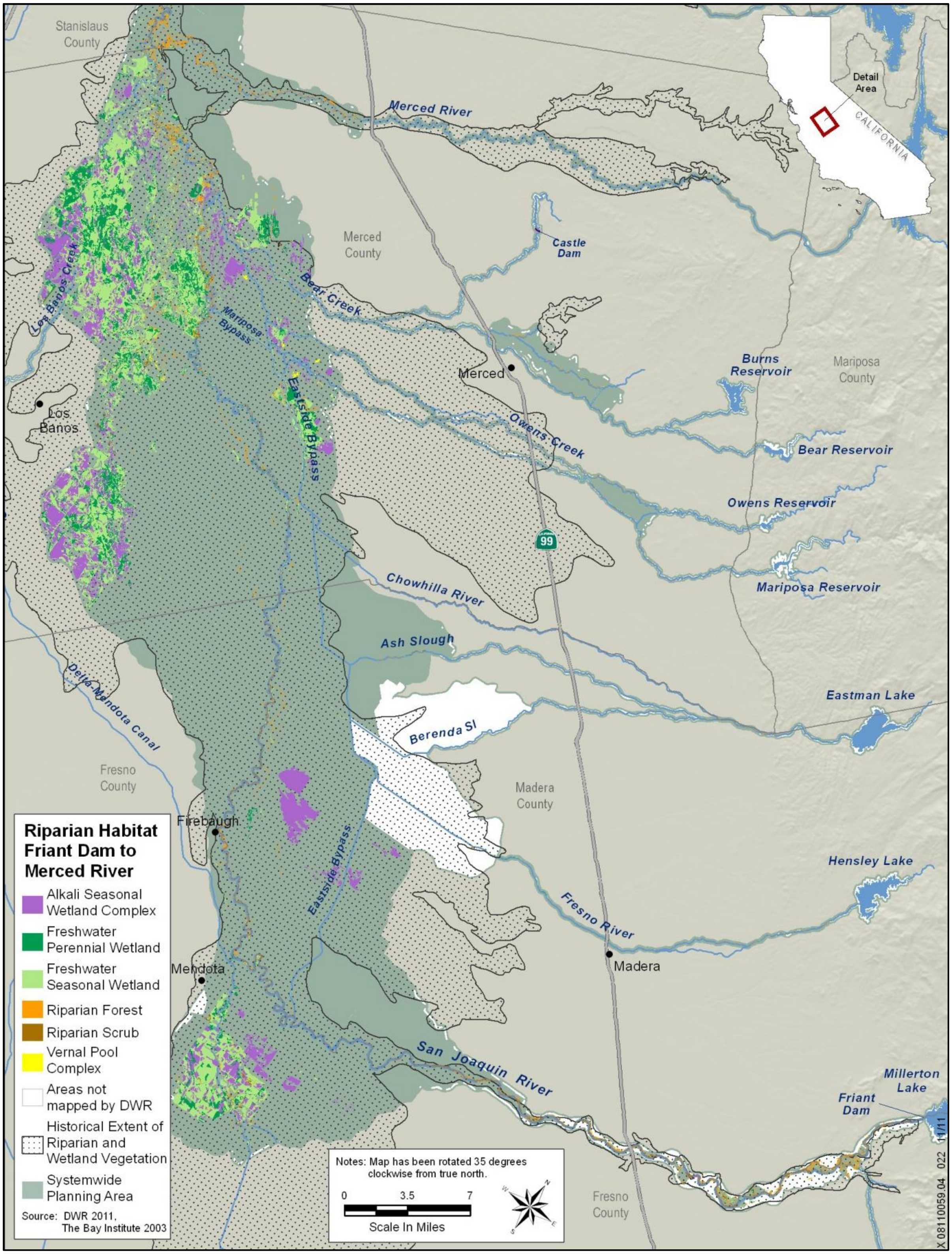



**Figure 4-22. Riparian and Wetland Habitat in the Central Valley: Merced River to Friant Dam**

Areas of riparian and wetland habitat that still exist, including areas of restored habitat, are primarily found between the levees or within historical flood basins that serve as flood bypasses or are protected as wildlife refuges by federal or state agencies. Although these areas still provide valuable wildlife habitat (e.g., San Luis National Wildlife Refuge Complex, Yolo Bypass Wildlife Area), much of the remnant habitat exists as linear strips adjacent to the Sacramento and San Joaquin rivers and their tributaries. Linear strips of habitat frequently lack the structural characteristics and landscape attributes (e.g., patch size, edge-to-interior-habitat ratios, connectivity) that are required for many species of riparian wildlife; therefore, the habitat values of these remnant patches are limited in many cases.

Although not shown in these data, various studies and anecdotal observations (see Sections 2 and 3) indicate that much of this remnant riparian habitat is characterized by late succession vegetation, such as valley oak woodland. Early succession vegetation preferred by some species of migratory songbirds, including sensitive species like yellow-billed cuckoo and yellow-breasted chat (i.e., cottonwood-willow scrub and woodland), is absent from much of the Sacramento and San Joaquin valleys because the disturbance and specific combination of flow events required to encourage germination and recruitment of early succession species is lacking.

#### *Species Distribution and Abundance*

**Methodology and Rationale** For terrestrial species, the California Natural Diversity Database (CNDDB) (Version 3.1.0) was used to depict species distribution. The CNDDB is maintained by the Habitat Conservation Division of DFG. The primary function of the CNDDB is to gather and disseminate data on the status and locations of rare and endangered plants, animals, and vegetation types (Bittman, 2001). The goal of the CNDDB is to provide the most current information available on the state’s most imperiled elements of natural diversity and to provide tools to analyze these data (DFG, 2011a). Although more detailed data are available for some species in some parts of the state, the CNDDB provides data that are consistently compiled for a large number of sensitive species throughout the Sacramento and San Joaquin valleys.

The CNDDB was queried for occurrence records for the following species: valley elderberry longhorn beetle (VELB) (*Desmocerus californicus dimorphus*), bank swallow, yellow-billed cuckoo, yellow-breasted chat, riparian brush rabbit (*Sylvilagus bachmani riparius*), riparian woodrat (*Neotoma fuscipes riparia*), and least Bell’s vireo. These species were selected because they are highly dependent on riparian habitats in the Sacramento and San Joaquin valleys for foraging, breeding, or other important life history requirements. They also were selected because each is considered by state or federal resource agencies to be rare, threatened, or endangered.

Although the number of individuals of each species observed at each CNDDB occurrence is usually recorded in CNDDB records, it is not always reliably reported, nor is it systematically collected at the same location over time. Therefore, it is difficult, if not impossible, to determine the number of individuals observed at each occurrence and how these population sizes have changed over time. Furthermore, CNDDB contains information only on areas that have been surveyed for species and therefore is an incomplete record of historical and current species' distributions.

For aquatic species, the current distribution of Chinook salmon and steelhead, as determined by the National Marine Fisheries Service (NMFS), was analyzed using the Chinook and Steelhead Distribution GIS (NOAA Fisheries, 2005). This dataset was compiled by the NMFS Southwest Regional Office in an effort to designate critical habitat for Chinook salmon and steelhead in the Sacramento and San Joaquin valleys. The data represent an approximation of Chinook salmon and steelhead occupancy in the region and are best suited for mapping at a regional scale. Historical occupancy was inferred from published reports (McEwan, 2001; Yoshiyama et al., 2001), and GIS maps depicting historical occupancy were prepared for Chinook salmon and steelhead using the information contained in these reports.

The GrandTab report from 2009 (DFG, 2009) was used to display the current status and historical trend of Chinook salmon abundance in the Sacramento and San Joaquin valleys. It contains annual population estimates (escapement) for the Sacramento and San Joaquin river systems compiled from various sources by the Fisheries Branch Anadromous Resources Assessment Unit of DFG. Estimates are based on counts of fish entering hatcheries and migrating past dams, carcass surveys, live fish counts, and ground and aerial redd (Chinook salmon or steelhead nest) counts. The 2009 report includes data from 1960 through 2008.

The current status and historical trend of steelhead abundance was determined from the CalFish database (CalFish, 2009a). Adult return estimates of the spawning population in the upper Sacramento River system (between Keswick Dam and the mouth of the Feather River) are available from 1953 through 1988. This dataset was used because it is the most complete record of steelhead abundance in the Sacramento and San Joaquin valleys (despite the fact that it lacks information on San Joaquin Valley steelhead entirely).

**Metric Summary** Figures 4-23 through 4-25 display the current known distribution of the seven key riparian species identified above. Bank swallow and VELB have a wide geographic range throughout the Sacramento and San Joaquin valleys (Figures 4-23 and 4-24) but are highly dependent on riverine and riparian habitat, which has been significantly reduced in the Sacramento and San Joaquin valleys. Bank swallow has been described as historically common throughout lowland California (Grinnell and Miller, 1944; DFG, 1995). No historical distribution or abundance information is available for VELB.

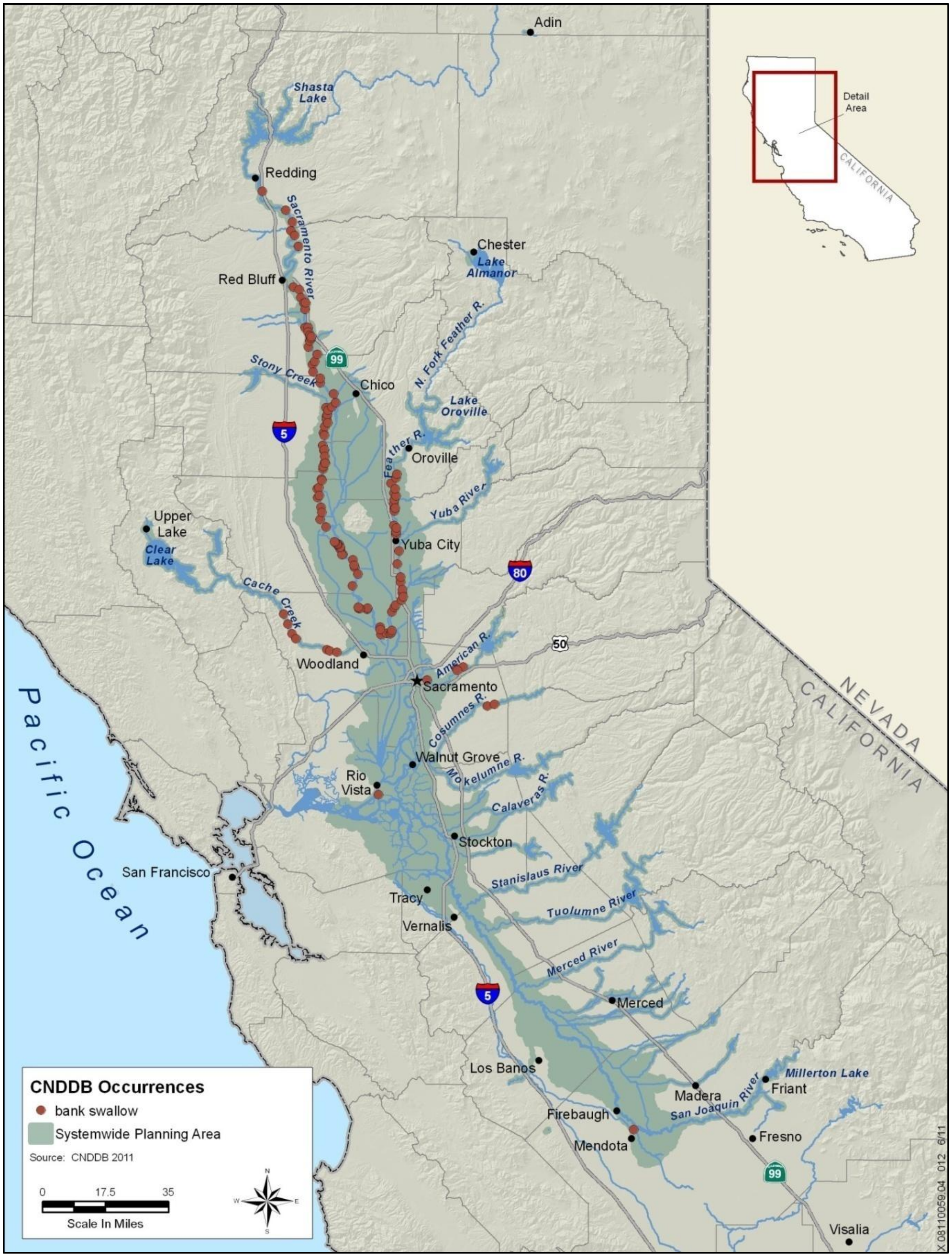



Figure 4-23. CNDDB Occurrences: Bank Swallow

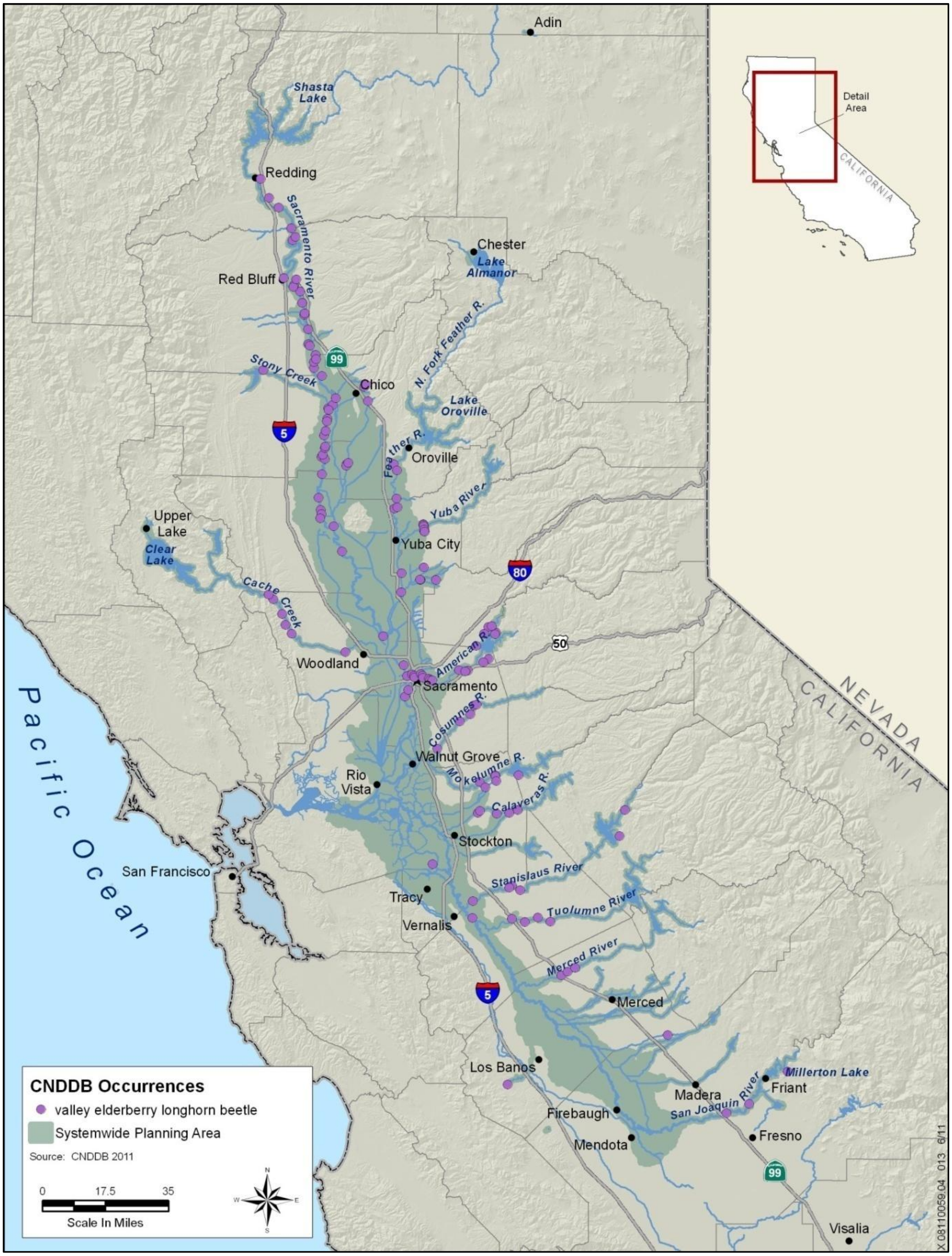



**Figure 4-24. CNDDB Occurrences: Valley Elderberry Longhorn Beetle**

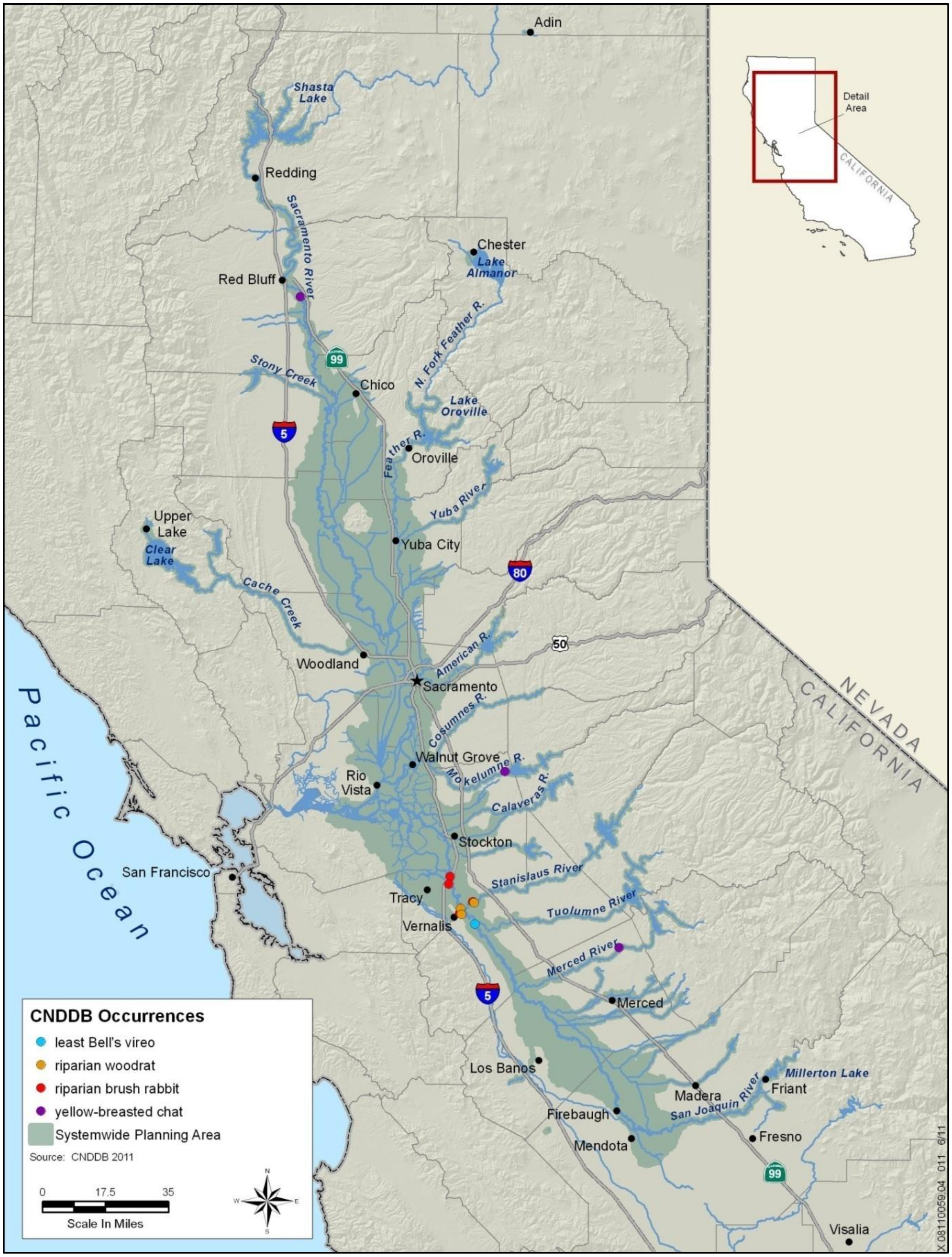



**Figure 4-25. CNDDB Occurrences: Least Bell's Vireo, Riparian Woodrat, Riparian Brush Rabbit, and Yellow-Breasted Chat**

Surveys conducted in 2009 by DFG, USFWS and DWR estimate the Sacramento River bank swallow population at 8,180 breeding pairs, down 38 percent from the 1986 estimate of 13,170 pairs (DFG, 2010). The Feather River population was estimated at 1,260 in 2009, less than half of the estimate for 1988 of 2,970 breeding pairs (DFG, 2010). Bank swallow population declines have been documented at least since the 1970s (Garcia et al., 2008).

Yellow-breasted chat has specific habitat requirements that do not restrict it to Sacramento Valley and San Joaquin Valley riparian habitat, but according to CNDDB records it is present in only one location in the Sacramento and San Joaquin valleys (Figure 4-25). Historically, yellow-breasted chats were found throughout California and more abundantly in the Sacramento and San Joaquin valleys (Grinnell and Miller, 1944). As late as 1973, singing males were common on the upper Sacramento River in northern Colusa County (Gaines, 1974, cited in Ricketts and Kus, 2004).

Riparian woodrat and riparian brush rabbit are restricted to the Sacramento and San Joaquin valleys and known from only a few locations. Both species probably historically occurred throughout the extensive riparian forests along major streams in the northern San Joaquin Valley (62 Federal Register 62277, November 21, 1997).

Historically, least Bell's vireo commonly bred throughout the Sacramento and San Joaquin valleys, but before 2005 no nesting pairs had been confirmed for more than 50 years (Howell et al., 2010). Since 2005, this bird has been breeding at a restoration site in the San Joaquin River National Wildlife Refuge in Stanislaus County (Howell et al., 2010). In 2010 and 2011, least Bell's vireos also have been observed in spring in the Yolo Bypass (E. Whistler, pers. comm. 2010 and 2011).

Historically, yellow-billed cuckoo was common to locally abundant in lowland riparian habitat, ranging from coastal Southern California through the Sacramento and San Joaquin valleys as far north as Red Bluff (Grinnell and Miller, 1944; Kus, 2004). There are no recorded occurrences of yellow-billed cuckoo in the CNDDB. It has been described as historically common throughout riparian habitat in lowland California, but it had been extirpated from many locations by 1944 (Grinnell and Miller, 1944). A survey conducted in 2010 estimated the Sacramento River population to be up to 38 breeding pairs (Dettling and Howell, 2011).

Although historical occurrence records or population estimates for these species are lacking, these species were likely relatively common in the Sacramento and San Joaquin valleys (see references in above paragraph and Table 4-2). Therefore, the current range of these species and number of observations in that range can be interpreted, and a probable trend can be inferred, relative to an assumed baseline condition for each species (Table 4-2).

**Table 4-2. Probable Historical Distribution of Key Riparian-Associated Species**

| Species | Historical Distribution | Historical Population Size | References | Inferred Trend |
|---|---|---|---|---|
| Valley elderberry longhorn beetle | No information available | No information available | NA | Unknown |
| Bank swallow | Throughout lowland California | Common | Grinnell and Miller, 1944; DFG, 1995 | Declining |
| Yellow-breasted chat | Throughout California | Common to abundant | Grinnell and Miller, 1944; Gaines, 1974, cited in Ricketts and Kus, 2004 | Declining |
| Yellow-billed cuckoo | Riparian habitat throughout lowland California | Common | Grinnell and Miller, 1944 | Declining |
| Least Bell's vireo | Lowland riparian habitat from coastal Southern California through the Sacramento and San Joaquin valleys | Common to locally abundant | Grinnell and Miller, 1944; Kus, 2004 | Declining |
| Riparian brush rabbit | Along major streams in the northern San Joaquin Valley | No information available | 62 Federal Register 62277, November 21, 1997 | Declining |
| Riparian woodrat | Along major streams in the northern San Joaquin Valley | No information available | 62 Federal Register 62277, November 21, 1997 | Declining |

*Source: AECOM, 2011*

Key:
NA = none available

Figures 4-26 and 4-27 display the historical and current distribution of Chinook salmon and steelhead in the Sacramento and San Joaquin valleys. Historically, salmon and steelhead travelled much farther upstream to spawn. The construction of dams and other passage barriers has greatly restricted available habitat for these species, as described in Section 3.5.5. As a result, Chinook salmon and steelhead have been extirpated from the upper reaches of their historical range, including the upper San Joaquin River system (upstream from the confluence with the Merced River). Overall estimates of salmonid habitat loss in the Sacramento and San Joaquin valleys range from 80 percent to 95 percent (Moyle et al., 2008).

Most of the historically available habitat is now behind impassable dams and other barriers (Lindley et al., 2006; McEwan, 2001; Yoshiyama et al., 2001), and the habitat that remains is at lower elevations that were historically used as migration corridors and, except for small reaches, are not ideal for spawning, rearing, or holding (Yoshiyama et al., 2001; McEwan, 2001).

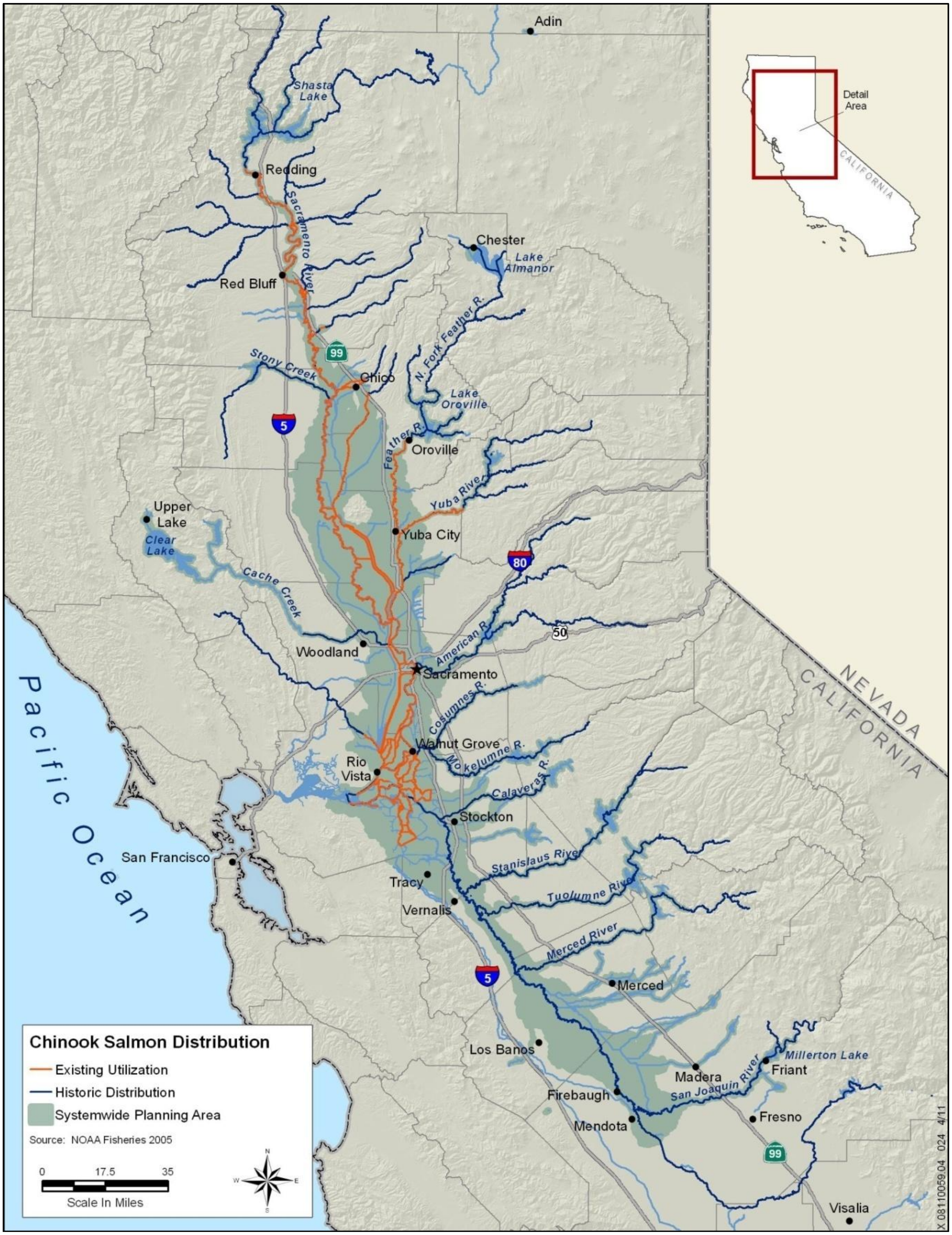



**Figure 4-26. Chinook Salmon Historic and Current Distribution in the Central Valley**

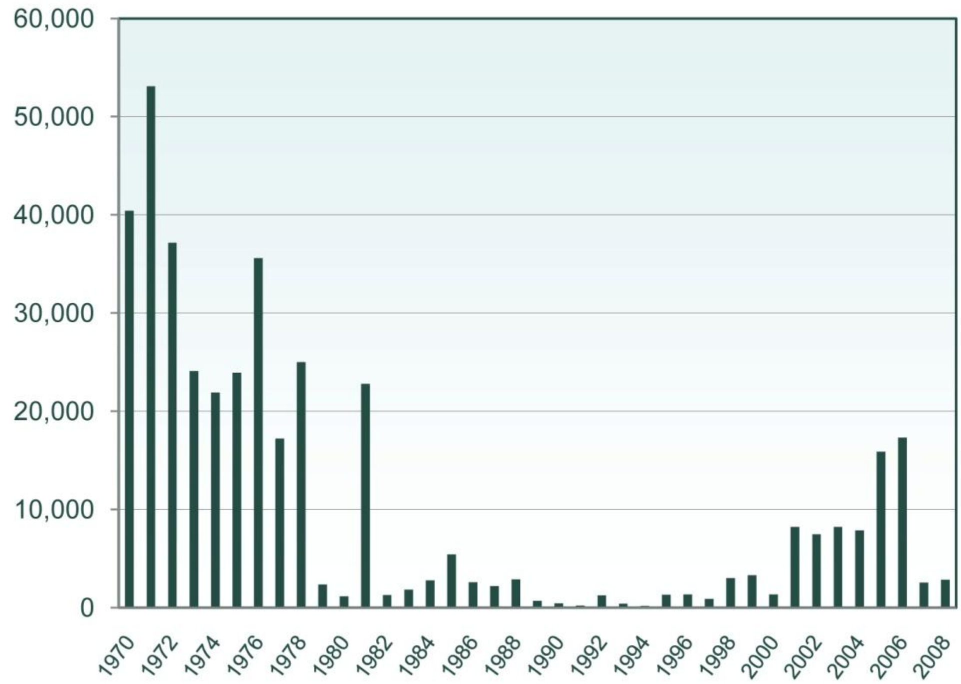

**Figure 4-27. Central Valley Steelhead Historic and Current Distribution in the Central Valley**

Figures 4-28 through 4-31 display the annual population estimates of fall, late fall, winter, and spring runs of Chinook salmon in the Sacramento and San Joaquin river systems. Figure 4-32 displays the adult return estimates of steelhead in the upper Sacramento River system.

Winter-run Chinook salmon have declined significantly since the 1970s (Figure 4-28). They historically spawned in spring-fed headwaters in the upper Sacramento River system (Yoshiyama et al., 2001), most of which are now behind impassable dams (Figure 4-26). Blocked access to historical spawning habitat, impaired passage at Red Bluff Diversion Dam, ocean harvest, elevated water temperatures, water quality effects of Iron Mountain Mine, and entrainment at large, unscreened diversions are all plausible mechanisms for low winter-run abundance (TNC, 2007). Abundance data on winter-run Chinook escapement before dam construction are rare, but there is some indication from gill net studies and other observations that winter-run abundance may have been in the hundreds of thousands before construction of Shasta Dam (TNC, 2007). This species persists today largely because of cold-water releases from Keswick Dam during the summer months, when winter-run fish are holding and spawning in the upper reaches of the lower Sacramento River.

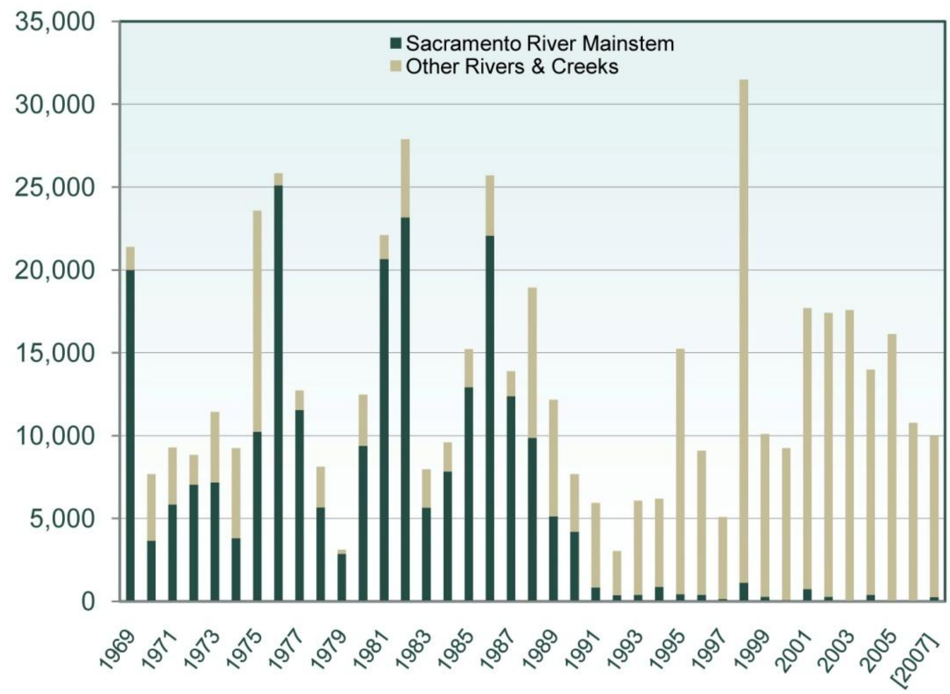
Although spring-run Chinook salmon abundance throughout the Sacramento River system has not changed significantly since 1969, numbers of the fish in the mainstem Sacramento River have decreased significantly (Figure 4-29). Spring-run Chinook salmon historically spawned in high-elevation streams (Yoshiyama et al., 2001), and dams have blocked access to much of this historical spawning habitat (Figure 4-26). Dams may also have reduced or eliminated spatial and temporal segregation between spawning spring- and fall-run Chinook salmon in some areas, particularly in the mainstem Sacramento River, leading to increased potential for hybridization on the spawning grounds (TNC, 2007). At one time, spring-run Chinook salmon may have been the most abundant race throughout the Central Valley, with escapement in the hundreds of thousands (Mills and Fisher, 1994, cited in TNC, 2007).

The fall run of Chinook salmon is the most abundant run in the Sacramento and San Joaquin valleys (Figure 4-30), in large measure because it has suffered relatively less displacement from historical habitats by dam construction (TNC, 2007). Fall-run Chinook salmon historically spawned on the valley floor and in lower foothill reaches below 500 feet to 1,000 feet in elevation, depending on location (Yoshiyama et al., 2001). The relatively high abundance of fall-run Chinook salmon is also a function of hatchery supplementation because they have been the primary target of hatchery production at Central Valley hatcheries for several decades (TNC, 2007).




*Source: DFG, 2009*

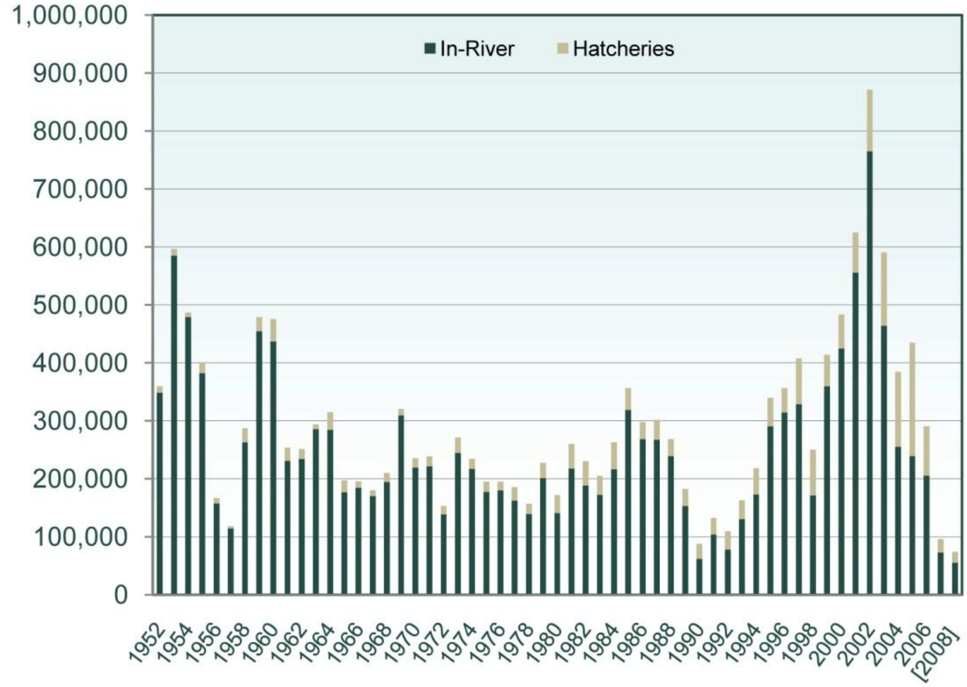
**Figure 4-28. Winter-Run Chinook Salmon Escapement in the Central Valley**




*Source: DFG, 2009*

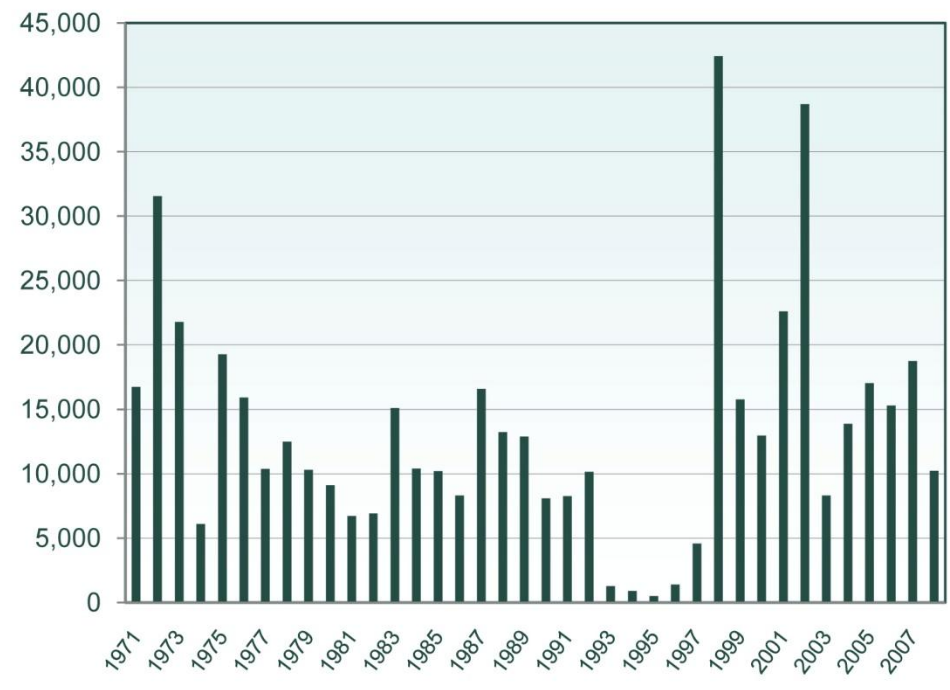
Note: Year is shown in brackets when numbers are preliminary.

**Figure 4-29. Spring-Run Chinook Salmon Escapement in the Central Valley**




*Source: DFG, 2009*
Note: Year is shown in brackets when numbers are preliminary.

**Figure 4-30. Fall-Run Chinook Salmon Escapement in the Central Valley**




*Source: DFG, 2009*

**Figure 4-31. Late Fall-Run Chinook Salmon Escapement in the Sacramento River System**

The lack of reliable escapement data for most of the past decades may hinder the identification of a clear trend in the abundance of late fall-run Chinook salmon (Figure 4-31). Escapement data on late fall-run Chinook salmon is available only for the Sacramento River system, and escapement estimates made after 1985 are unreliable for a variety of reasons (TNC, 2007). Little information is available to indicate the historical abundance of late fall-run salmon in the Sacramento River Basin; they were first recognized by fishery agencies as a distinct run only after the construction of Red Bluff Diversion Dam in 1966 (TNC, 2007).

Steelhead abundance in the upper Sacramento River system has declined since the 1960s (Figure 4-32). An accurate estimate of current steelhead abundance throughout the remainder of the Sacramento and San Joaquin valleys is unavailable. Historically, steelhead spawned and reared in high-gradient reaches of tributaries to the Sacramento and San Joaquin rivers (TNC, 2007), nearly all of which are now blocked by impassable dams (Figure 4-27). There may have been as many as 1 million to 2 million adult steelhead spawning in these reaches annually before 1850 (McEwan, 2001).

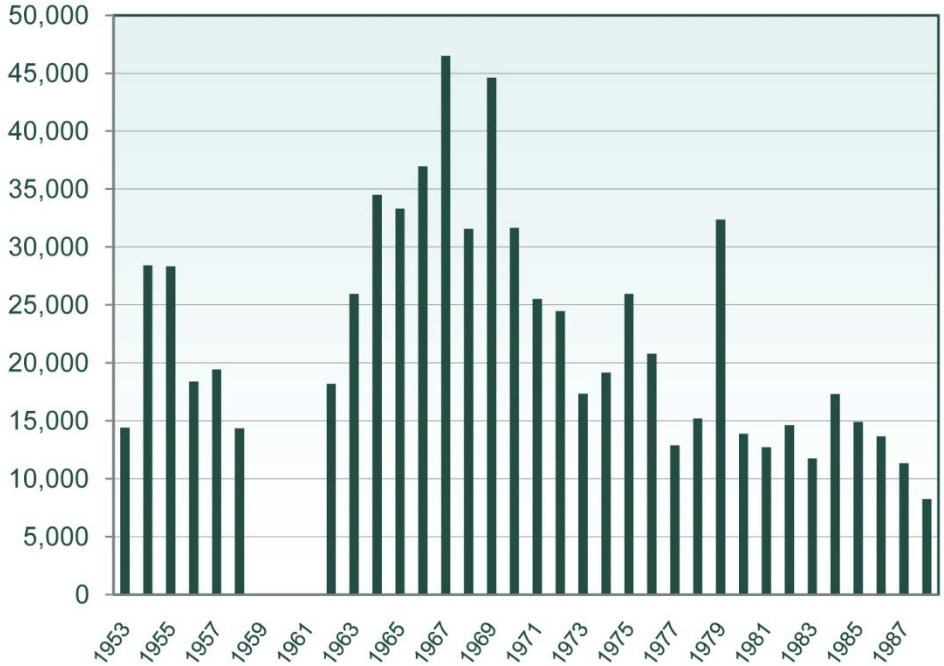
## 4.2 Stressor Metrics

### 4.2.1 Levees and Bank Revetment

***Description of Metrics***

Channel migration, meander cutoff, and other important ecosystem processes are severely limited by bank revetment and near-channel levees. Such constraints reduce the potential for these ecosystem processes to occur, which can be estimated by quantifying the degree of meander potential. Analyses performed for this report quantified the area available for future migration. In this report, an area where the channel could potentially migrate is called a “meander potential” area.

Two categories of meander potential were quantified: natural and existing. The difference between the two estimates is the difference between the natural channel dynamics and the dynamics limited by current bank restraints. The methods used to quantify these categories are described below.




*Source: CalFish, 2009a*

**Figure 4-32. Central Valley Steelhead Adult Return Estimates in the Upper Sacramento River System**

***Methodology and Rationale***

In a study of the meander migration patterns of RM 80 to RM 243 of the middle Sacramento River, it was shown that providing the full range of meander migration and cutoff dynamics required that channel constraints be set back approximately three channel widths (Larsen et al., 2006a).

This setback width was overstated. Not all levees need to be set back three channel widths because (1) geology is limiting in some cases, and (2) levees are already set back in some areas (i.e., in some areas they are not exactly on the banks). The total needed setback would be less in these cases.

To estimate the extent of meander potential, a zone was identified that was three bankfull channel widths from the centerline of the river. Then, areas under geologic constraints were removed from that zone, creating a *natural meander zone*. Areas within the natural meander zone that were restrained by levees, bank revetment, structures (e.g., wastewater facilities, docks, pump stations), and roads were removed, creating an *existing meander zone*. The difference between the natural and existing meander zones represents the *area of meander potential* that has been lost because of engineered, permanent features, such as levees, bank revetment, structures, and roads.

***Metric Summary***

Levees in the Sacramento and San Joaquin valleys are shown on Figure 4-33. Bank revetment along the Sacramento River is shown on Figure 4-34. Levees and bank revetment are major limitations to channel migration and meandering. Meander potential on the Sacramento River is shown in the maps of Figures 4-35A and 4-35B.

Note that although the metric as calculated gives a precise number, the metric is best used to identify overall trends. A number of assumptions and estimates were made to produce maps that illustrate the metric. For example, in many areas, the meander potential on the concave side (inside) of a meander bend is shown as a meander potential area. Most meander bends migrate outward, not inward. The area on the inside of a bend in most cases does not represent potential floodplain generation and therefore ecosystem benefit. If all bends were limited from moving by restraining their outside bank, but not the inside bank, essentially 100 percent of the migration would be limited; however, the current metric would show that 50 percent of the area is available for meander potential. Similarly, where levees are located on the inside of a bend (e.g., south of Colusa), the metric would show limitations of meander potential where the meander would in most cases not migrate. Regardless, the meander potential metric provides a reasonable quantitative estimate of the relative degree of ecosystem limitation and potential for restoration in the areas measured on the middle Sacramento River.

The meander potential as shown with the metric differs significantly upstream and downstream from Colusa (RM 145) because downstream from Colusa, the river is generally lined on both banks by levees. Upstream from Colusa, the relative potential migration ranges between about 50 percent and 75 percent; downstream from Colusa, the potential ranges between about 10 percent and 25 percent. These maps could potentially be used to identify site-specific areas where revetment removal and levee setback could be considered to restore ecosystem function or where existing habitat potential exists in areas of high meander potential.

### 4.2.2 Reservoirs

***Methodology and Rationale***

Reservoirs are major stressors on riparian and riverine ecosystems. The many effects of reservoirs on the ecosystem interact in multiple ways. Each of the metrics used in Section 4.1 to characterize the status and trends of the riparian and riverine ecosystems is affected by reservoirs. The effects of reservoirs on hydrologic processes are described in Section 4.1, where the effects of Shasta Dam on downstream flows in the Sacramento River and the effects of Friant Dam on downstream flows in the San Joaquin River were discussed in detail.

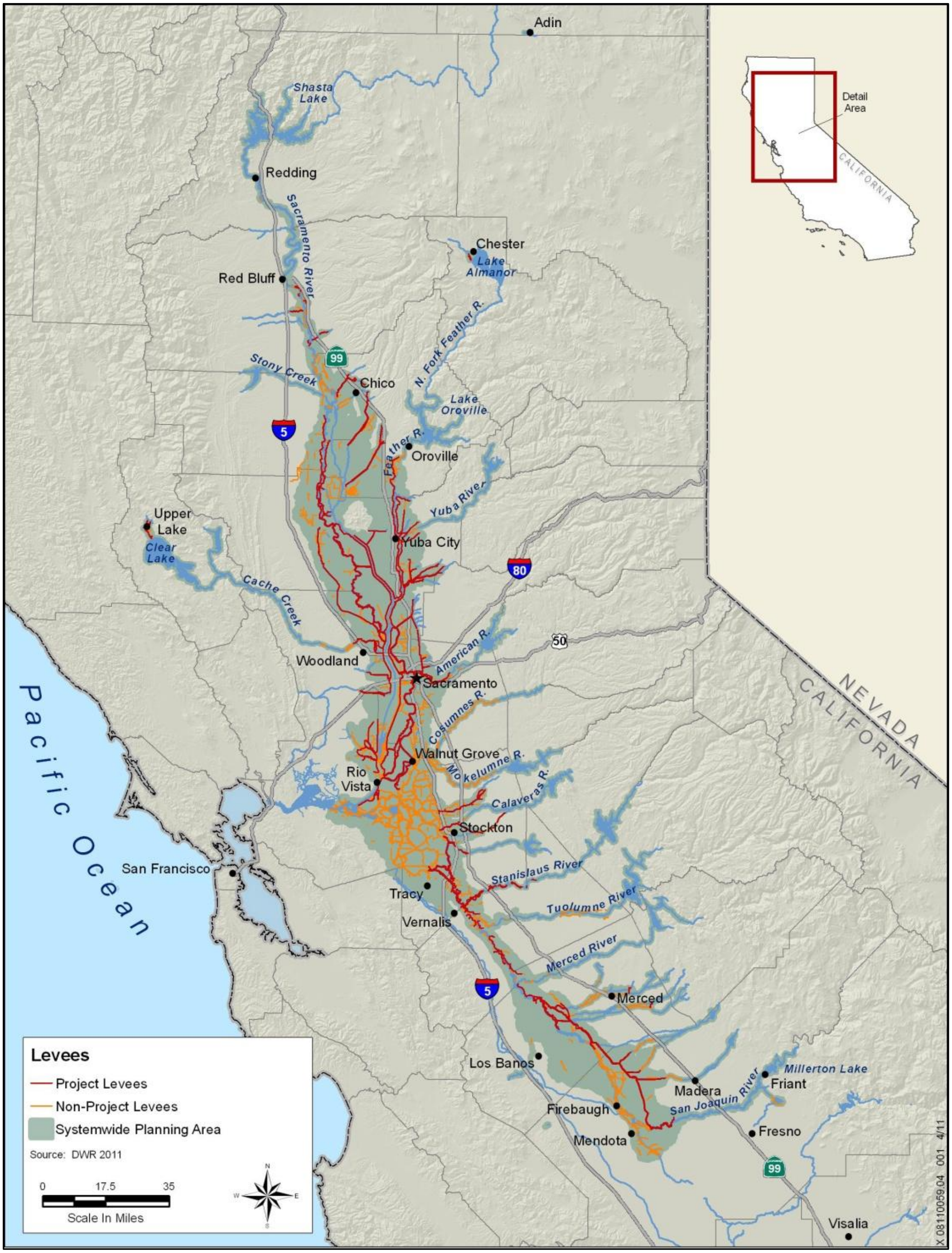



**Figure 4-33. Levees in the Central Valley**

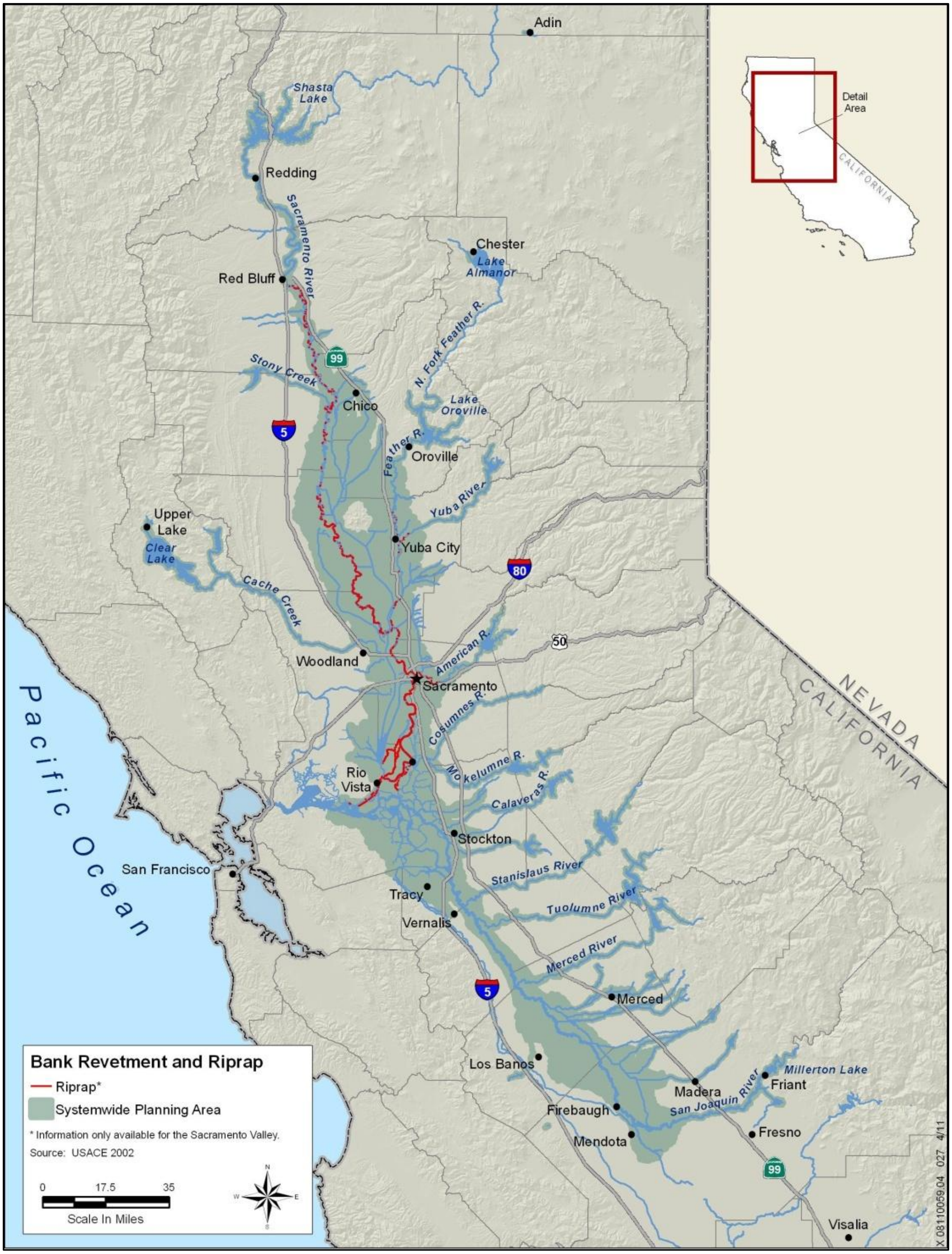



Figure 4-34. Bank Revetment in the Sacramento Valley

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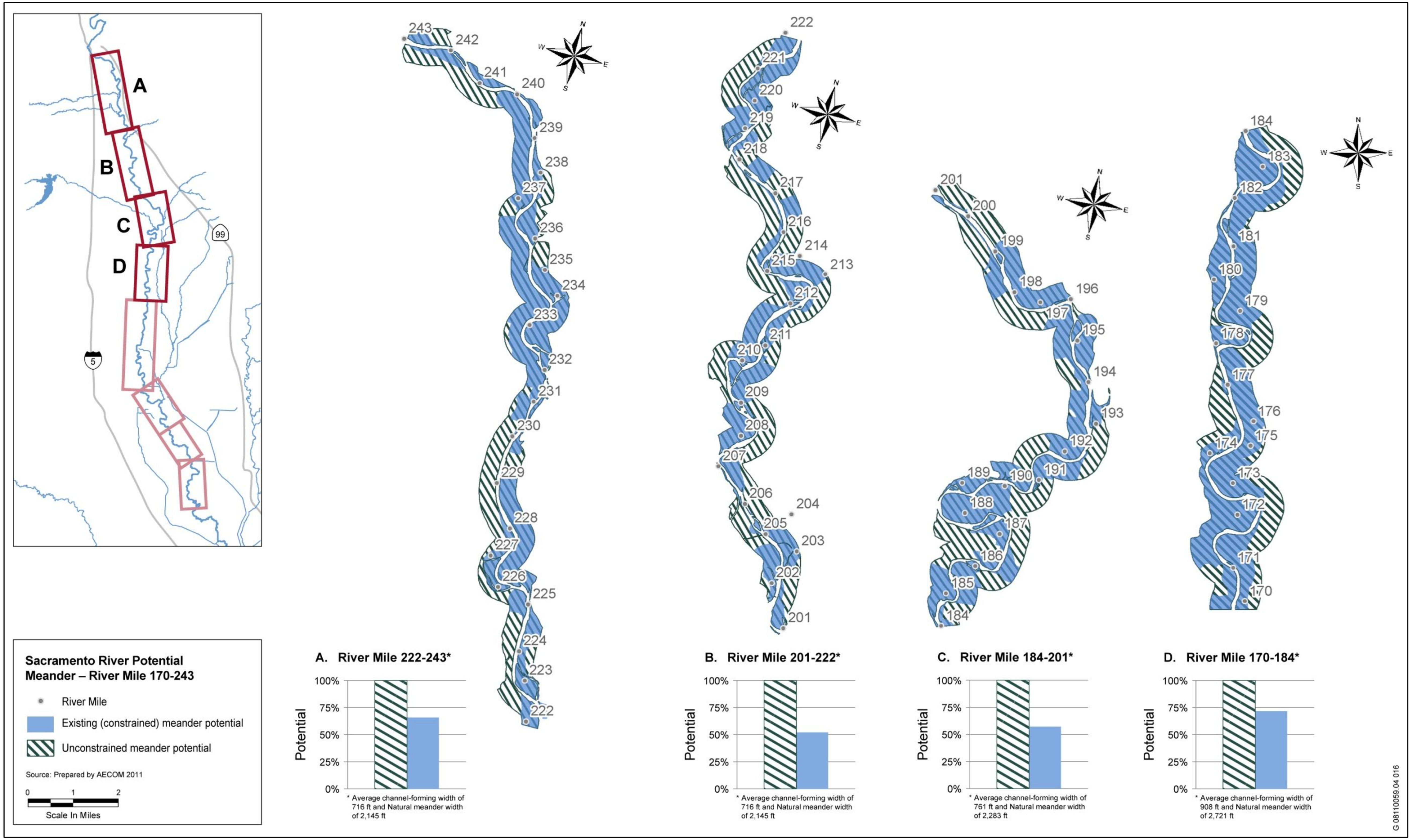


*Sources: USACE, 2004; DWR, 2002 , 2010; Dr. Eric Larsen, 2011; MWH, 2011 ; AECOM, 2011*

Note: Sixty-six percent of natural river meander potential is available.

**Figure 4-35A. Meander Potential Along the Sacramento River (RM 170 to RM 243)**

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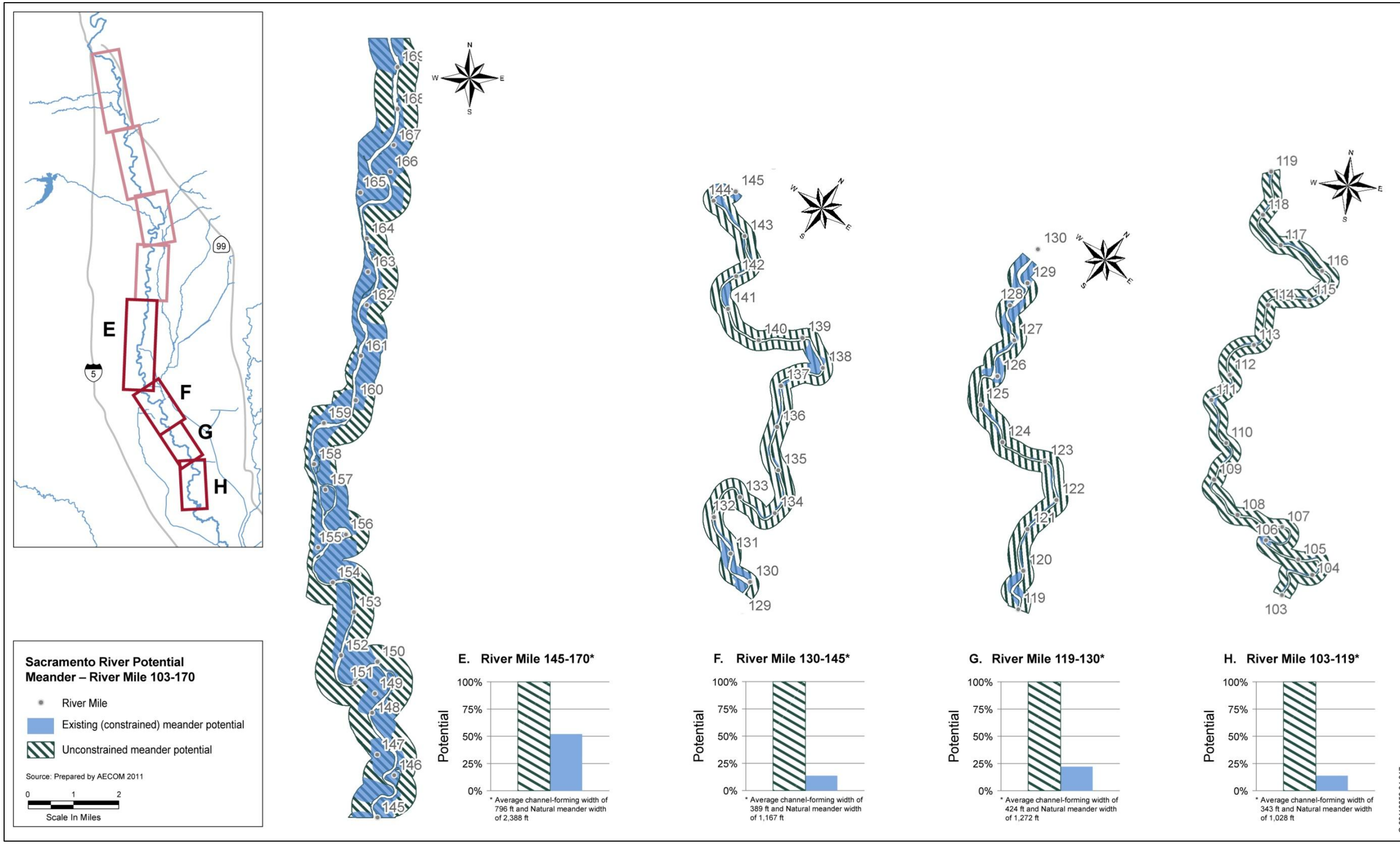


*Sources: USACE, 2004; DWR, 2002 , 2010; Dr. Eric Larsen, 2011; MWH, 2011 ; AECOM, 2011*

Note: Fifty-three percent of natural river meander potential is available.

**Figure 4-35B. Meander Potential Along the Sacramento River (RM 103 to RM 170)**

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The geomorphic effects of dams include the effects of hydrologic modifications, as well as interruption of sediment transport. Because the hydrology-related effects of dams on geomorphology are confounded with the effects of land-use changes and revetment on fluvial geomorphology, no analysis was done to assess the effect of reservoirs on geomorphology.

A promising analysis method was presented by Singer (2007), who identified the IRI, which is the ratio of reservoir capacity to median annual flood runoff volume. Singer calculated the IRI for the major reservoirs in the Sacramento River watershed. An analysis for the San Joaquin River watershed reservoirs was beyond the scope of that preliminary report.

#### *Metric Summary*

The effects of dams on hydrology were discussed in detail in Section 4.1.1; therefore, no separate discussion of those effects is provided here.

### 4.2.1 Diversions

#### *Description of Metrics*

Two related metrics, the number and distribution of known diversions, were selected to depict the current status of water diversions as a stressor. As described in Sections 3.5.3. and 3.5.5, water diversions are not a stressor in terms of the total volume of water diverted (in the Sacramento River system); however, they are likely significant stressors both on salmonid populations, because of juvenile fish entrainment at diversion points, and on cottonwood and willow recruitment, because of modifications to historical flow patterns that are required to facilitate water diversions. In the San Joaquin River, water diversions are a major stressor because water that would otherwise be carried downriver is diverted directly into canals for agricultural use. The reduced flows in the San Joaquin River negatively affect salmonids, riparian vegetation, and riparian wildlife.

#### *Methodology and Rationale*

The Passage Assessment Database (PAD) (CalFish, 2009b) was queried for screened and unscreened water diversions. The PAD is an ongoing, map-based inventory of known and potential migration barriers to anadromous fish in California. The PAD is compiled and maintained through a cooperative interagency agreement that gathers available fish passage information from many different sources and stores this information in a central standardized database. The PAD was used for this report because it is the most current, readily available geo-spatial database of water diversions throughout the Sacramento and San Joaquin valleys.

***Metric Summary***

Figure 4-36 displays the known distribution of screened and unscreened diversions in the Sacramento and San Joaquin valleys. The total amount of water diverted from the river system through these structures is unknown, although, as previously indicated, the volume of water diverted from the San Joaquin River is likely significant and results in significant ecological impacts. The volume of water diverted from the Sacramento River is not likely significant, but the correlated effects of fish entrainment and modified flows related to facilitating diversions during the summer months likely have significant adverse ecological effects.

### 4.2.2 Invasive Species

***Description of Metrics***

Metrics selected to depict the status of invasive species as a stressor are the number of invasive plant species and the distribution of two important invasive plants: red sesbania and giant reed. The following discussion of invasive species focuses on terrestrial and aquatic plants documented in the Sacramento and San Joaquin valleys. Other invasive species, such as invasive aquatic animal species, are also potential stressors in the region; however, the effects of these species are more apparent in the San Francisco Bay-Delta (Cohen and Carlton, 1998) than in the Sacramento and San Joaquin valleys.

***Number of Invasive Species***

**Methodology and Rationale** The California Invasive Plant Inventory was searched for invasive plant species found in riverine, riparian, and wetland habitat in the Sacramento and San Joaquin valleys (Cal-IPC, 2007). The inventory is maintained by the California Invasive Plant Council (Cal-IPC) to catalog and rank nonnative invasive plants in California. Threats described in the inventory include competition with and displacement of native species, hybridization with native species, other types of alteration of biological communities, and alterations of ecosystem processes (e.g., wildfire return intervals). The inventory categorizes plants as high, moderate, or limited, reflecting the potential for each species (based on its life history characteristics, growth form, reproductive output, current distribution, and other factors) to negatively affect native species and habitats in California.

Although the number of invasive species is a simple metric, it provides a baseline condition against which future enumerations of invasive species can be compared as a means of tracking the number of invasive species over time. The listing of invasive species also ranks each species by its potential to cause ecological and economic harm, providing an additional baseline condition against which future, similar tabulations of invasive species can be compared (e.g., to see if a species' threat status is elevated over time or to track the relative proportion of high-threat species to low-threat species over time).

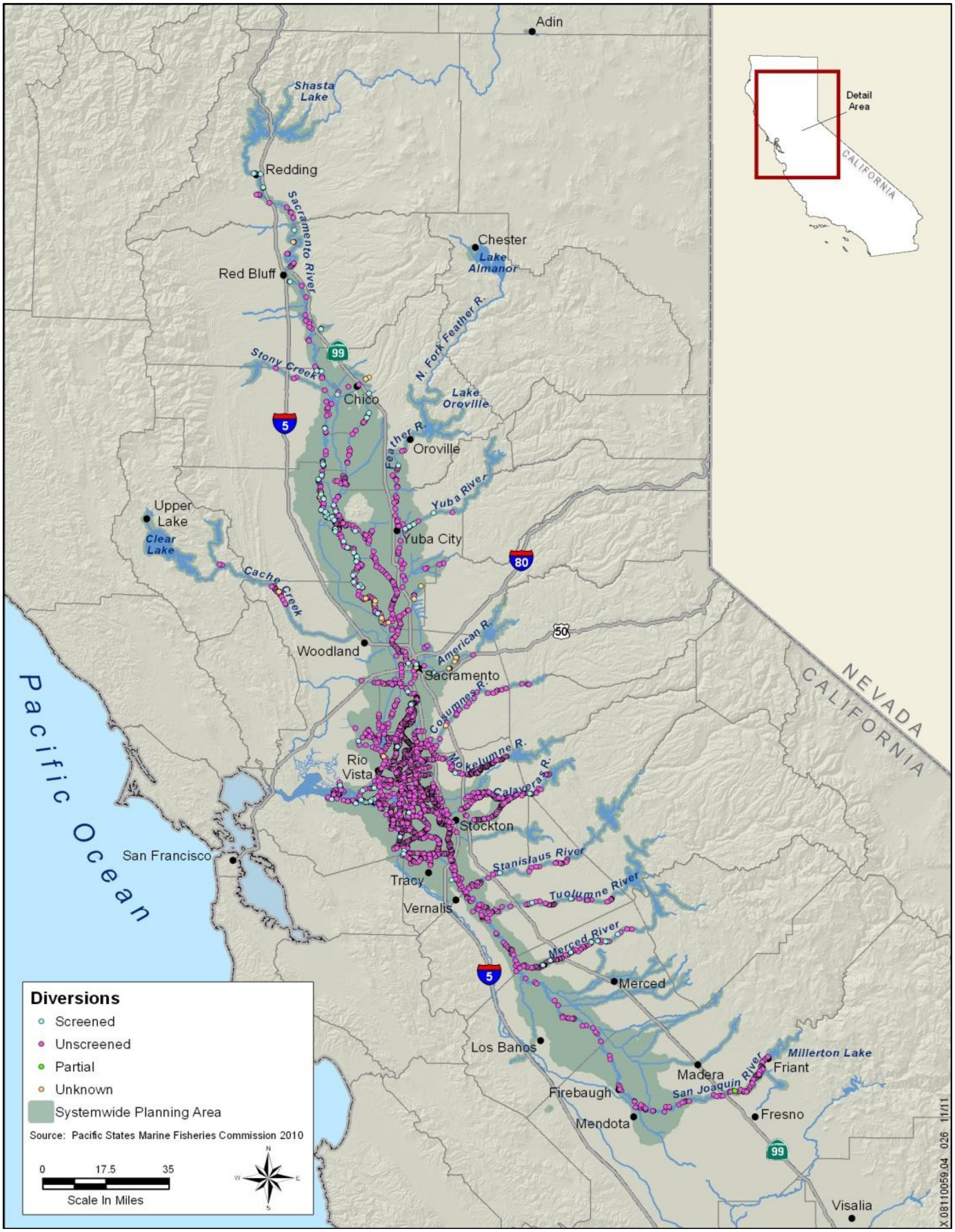
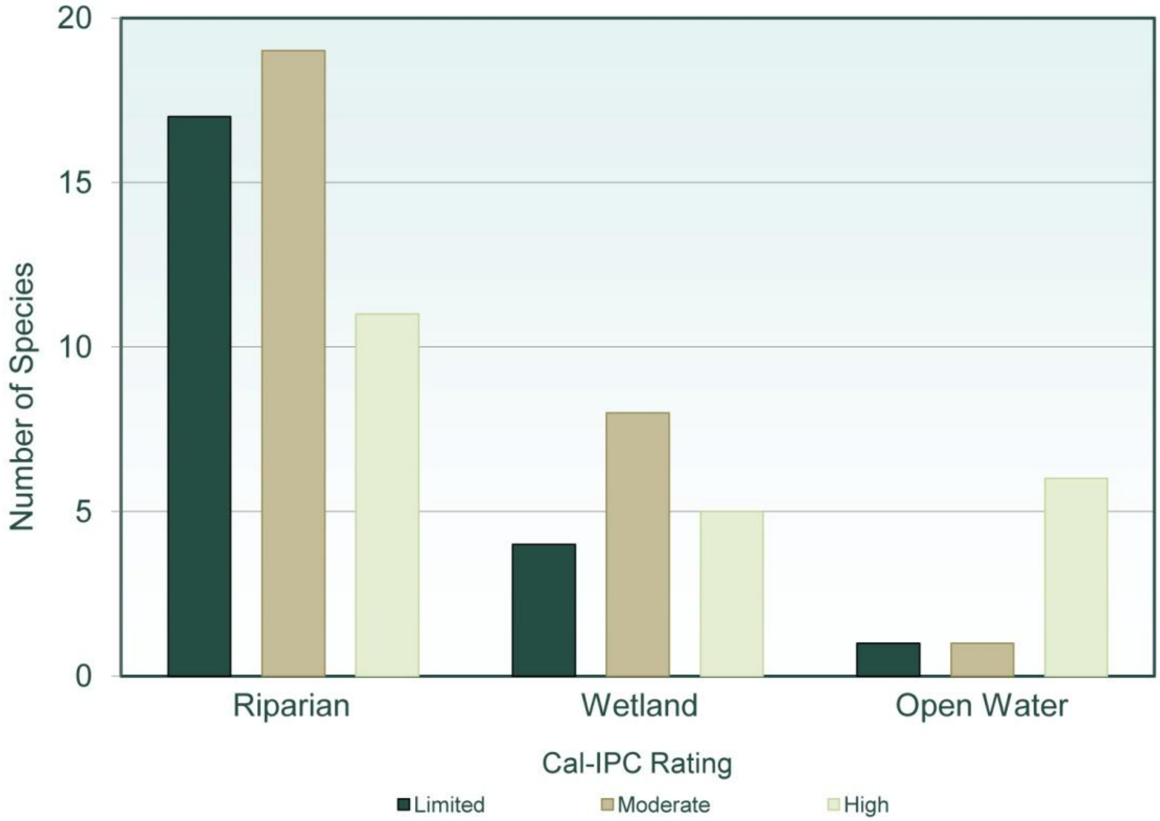



**Figure 4-36. Diversions in the Central Valley**

**Metric Summary** For each species, the inventory lists the regions where the species is found and the habitat of concern for that species. The numbers of species found in riparian, wetland, and aquatic habitats in the Great Central Valley floristic province (defined as the Central Valley floor and foothill regions where oak and pine woodlands become the dominant vegetation communities) are shown on Figure 4-37. A total of 61 invasive plant species is presumed extant in riparian, wetland, and open water habitat in the Sacramento and San Joaquin valleys. Riparian habitat is the most heavily invaded habitat; three-quarters of the invasive plant species are located in riparian habitat, and two-thirds of these species are rated high or moderate by Cal-IPC.




*Source: Cal-IPC, 2007*

**Figure 4-37. Invasive Plant Species in Riparian and Riverine Habitat in the Central Valley**

### *Distribution of Invasive Species*

**Methodology and Rationale** Although the California Invasive Plant Inventory documents which invasive plant species are found in a region, it does not identify the exact locations or extent of invasive plant populations. Information on the location and extent of these populations is compiled by DFG in the Biogeographic Information and Observation System (BIOS). BIOS is designed to enable the management, visualization, and analysis of biogeographic data collected by DFG and its partner organizations. BIOS is the best available source for data on the mapped extent of invasive plant species in the Sacramento and San Joaquin valleys. Other sources are available but are either more coarsely mapped or mapped over more limited areas. The BIOS data were used to map the extent of two species of concern in the Sacramento and San Joaquin valleys: giant reed and red sesbania.

Giant reed is a tall perennial grass that typically forms dense stands in riparian areas and wetlands (Cal-IPC, 2011c). It threatens riparian ecosystems by outcompeting native species for water, reducing habitat quality and food supply for special-status species, interfering with levee maintenance and wildlife management, altering hydrological regimes and reducing groundwater availability, altering channel morphology by retaining sediments and restricting flows, and promoting bank erosion (Dudley, 2000).

Red sesbania is a deciduous shrub or small tree that forms dense thickets in riparian areas. It displaces native plants used by wildlife, contributes to bank erosion, and reduces water flow and flood conveyance in rivers (Cal-IPC, 2011b).

Giant reed and red sesbania are emphasized because mapped locations for these species are found in BIOS and because these species are widespread, characteristic invasive species of riparian areas. They also have a high potential to cause negative ecological effects. Many other invasive plants occur and have important effects on the ecosystem, including salt cedar and water primrose (*Ludwigia* sp.).

**Metric Summary** The known extent of giant reed and red sesbania in the Sacramento and San Joaquin valleys is presented on Figures 4-38 and 4-39. Giant reed is widely distributed throughout the Sacramento and San Joaquin valleys (Figure 4-38), and red sesbania in found in several riparian systems in the Sacramento and San Joaquin valleys (Figure 4-39).

Giant reed was brought to North America quite early and was abundant by 1820 in the Los Angeles River (Dudley, 2000). Horticultural propagation of the species is widely conducted, and invasive populations almost certainly resulted from escapes and displacement of plants from managed habitats (Dudley, 2000).

Red sesbania is a relatively recent invader in the Sacramento and San Joaquin valleys. Although introduced to California as an ornamental before 1930, it was not documented in riparian vegetation until 1987, and it was not acknowledged as a potential threat to riparian ecosystems until 2000 (Hunter and Platenkamp, 2003).

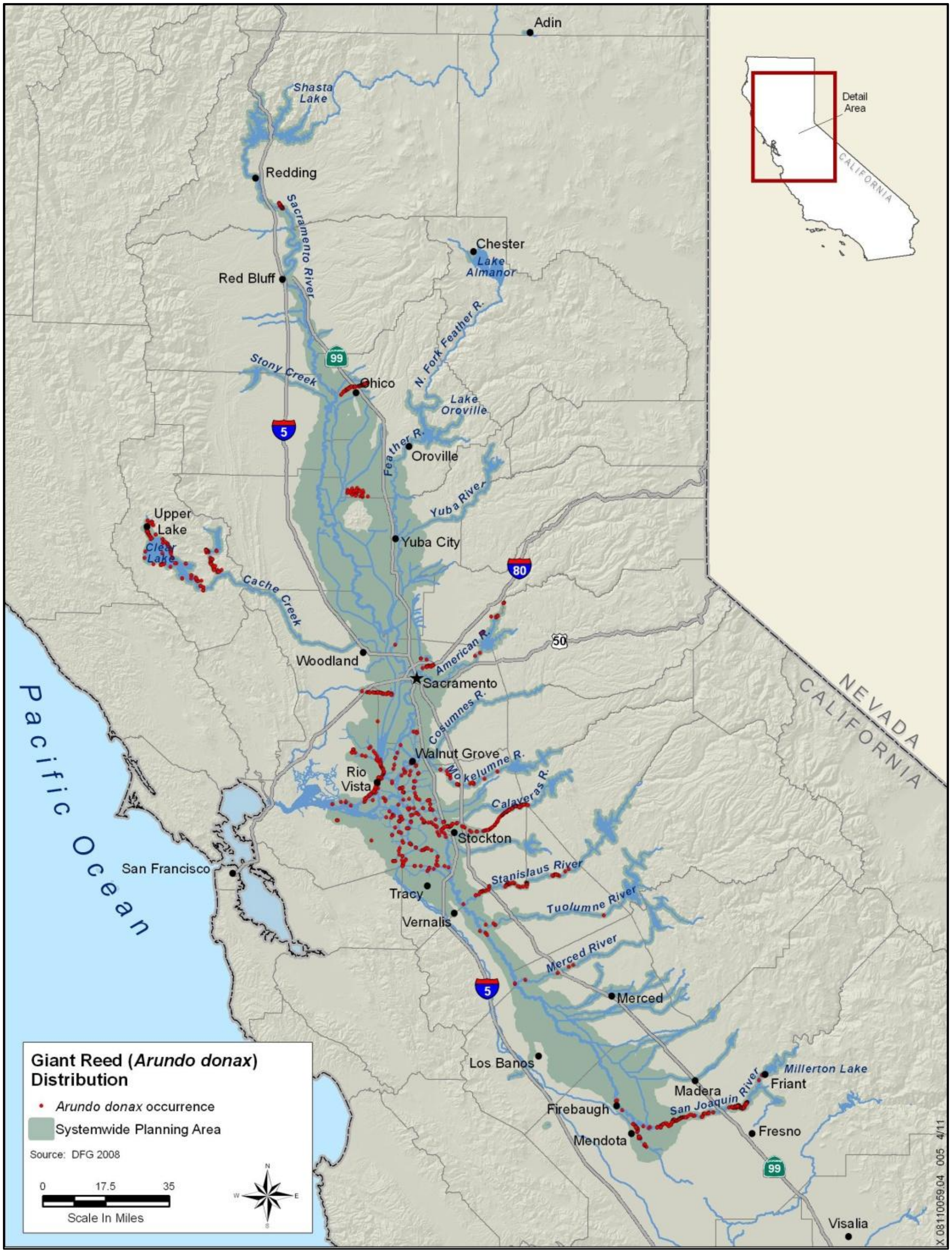



**Figure 4-38. Giant Reed Distribution in the Central Valley**

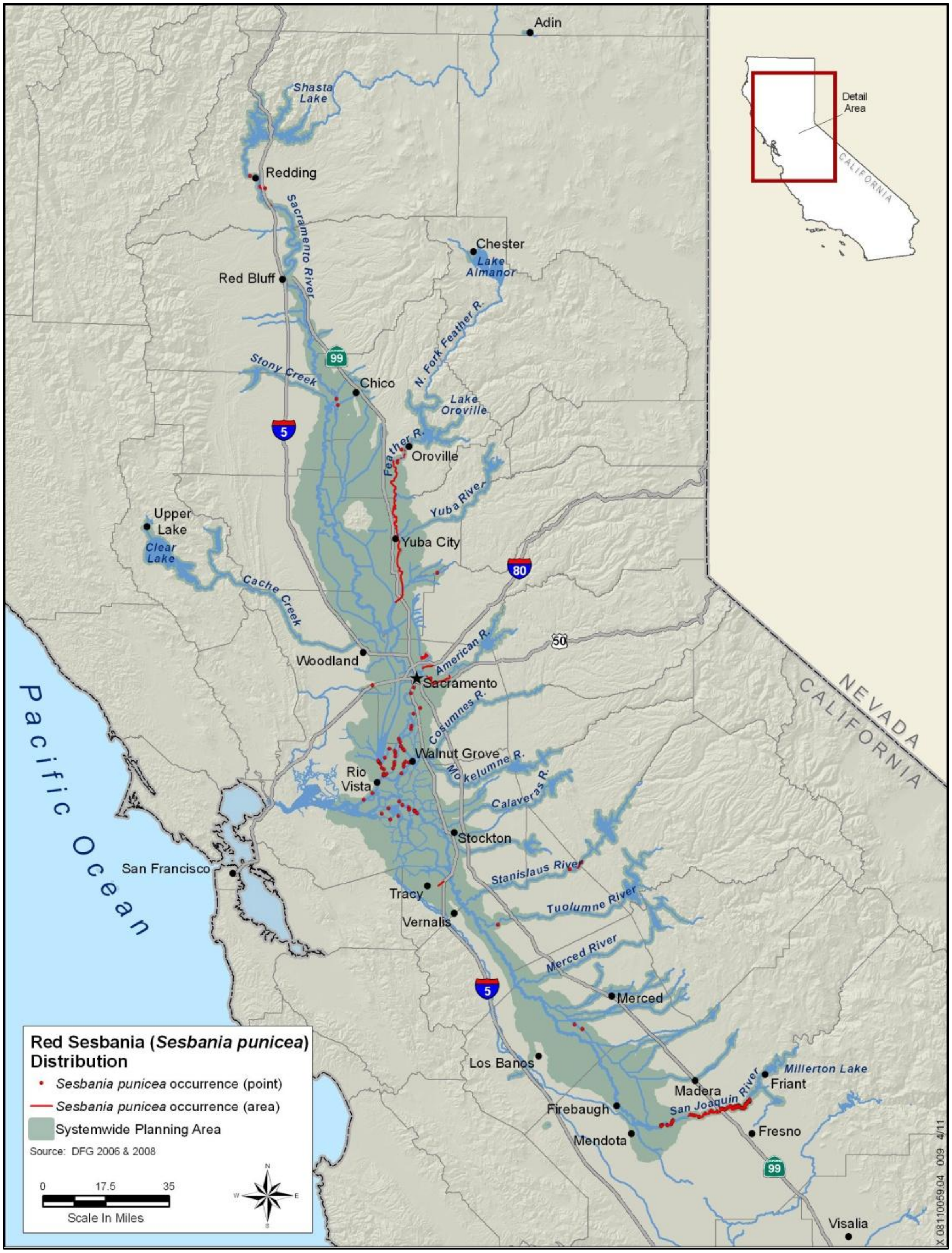



Figure 4-39. Red Sesbania Distribution in the Central Valley

### 4.2.3 Fish Passage Barriers

***Description of Metrics***

The metrics chosen to represent the status of fish passage barriers are the location and number of human-made barriers documented in the PAD (CalFish, 2009b). These data are further refined as described below to include all barriers in the SPFC that may not be reflected in the PAD.

***Methodology and Rationale***

The PAD was queried for human-made barriers, not including water diversions (see Section 4.2.3 for information on water diversions in the Sacramento and San Joaquin valleys). It was used for this report because it is the most up-to-date database of fish passage barriers in the Sacramento and San Joaquin valleys.

This data set was further refined by identifying only those barriers in the PAD on anadromous streams in the SPA. A buffer of approximately 1,000 feet was used to account for positional accuracy between data layers. PAD entries that were not relevant (e.g., nonstructural barriers and barriers that are in the database but that have been removed) were excluded. Finally, any SPFC components that were known barriers but that were not included in the PAD were added to the dataset. Further details on these methods can be found in the technical memorandum prepared by DWR on fish and flood management as part of the CVFPP (DWR, 2011b).

***Metric Summary***

The refined metric was assembled using GIS analysis, expert knowledge, and available written information, and identified 180 barriers in the SPA (107 dams, 59 road crossings, 11 gravel pits, 2 flood control channels, and 1 flow measurement weir) (Figure 4-40). These include total and partial barriers, as well as barriers of unknown passage status. Approximately 26 of these barriers are total barriers. If these 26 barriers were removed, approximately 940 miles of salmonid habitat would become at least partially available (some upstream partial barriers may exist).

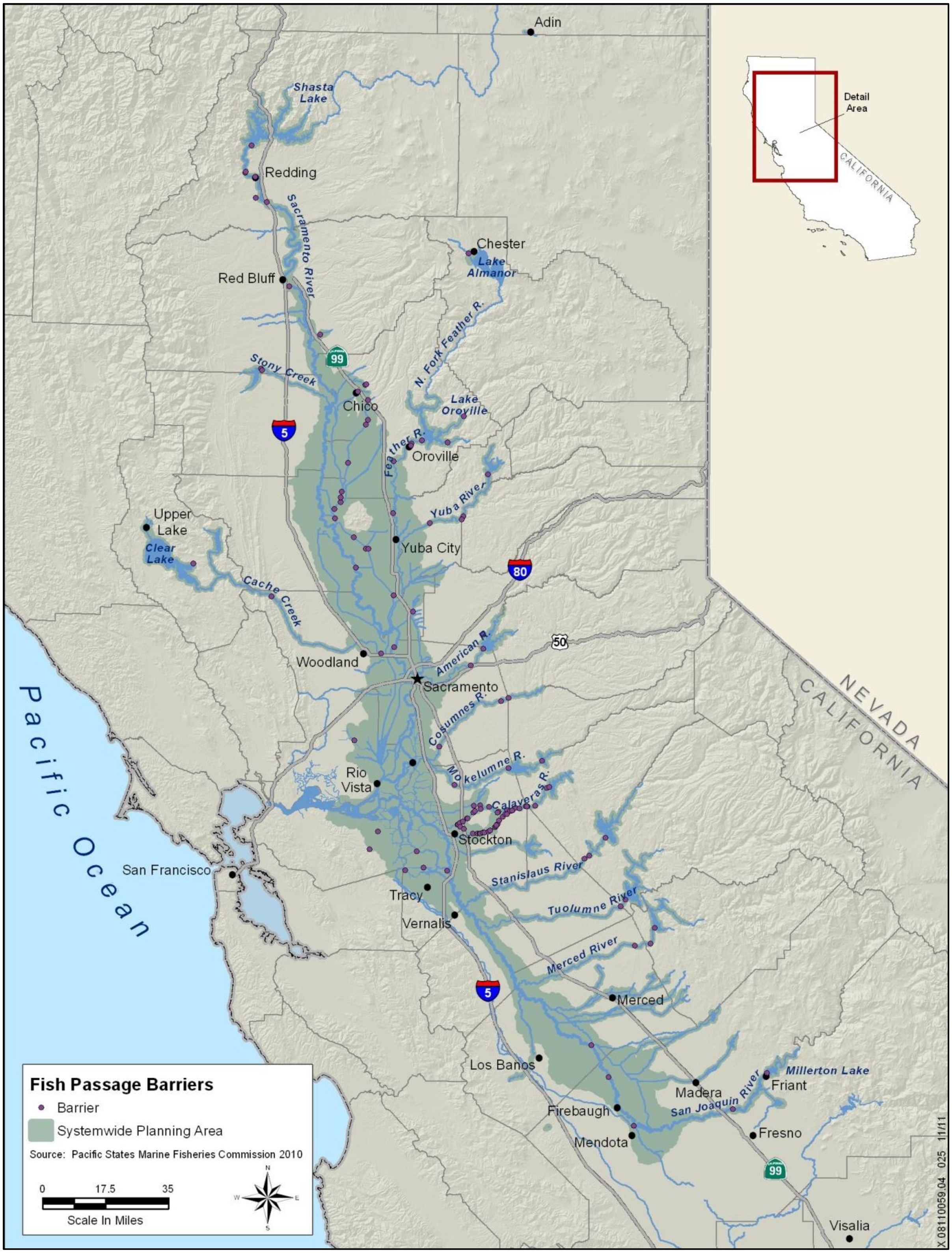



**Figure 4-40. Fish Passage Barriers in the Central Valley**

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# 5.0 Recommendations and Conclusions

This section identifies data gaps and areas where additional analysis would benefit the development of the 2017 CVFPP. The section also provides specific recommendations to fill the data gaps and conduct needed analysis. In addition, it addresses the development of conceptual models.

## 5.1 Data Gaps and Analysis Needs

This report assesses the status and trends of hydrologic and geomorphic variables, habitats, and stressors of riparian and riverine ecosystems in the SPA. It also describes the effects of the flood control system on riparian and riverine ecosystems because elements of the system are stressors on these ecosystems. However, our understanding of riparian and riverine status and trends, and of the effect of flood control systems on them, is limited by gaps in our knowledge of historical and current conditions and by the limited extent of analyses conducted to date. This section recommends additional data collection and analyses to increase the availability and analysis of data related to the hydrologic and geomorphic variables, habitats, and stressors assessed in this report and therefore increase our understanding of the riparian and riverine ecosystems in the SPA.

### 5.1.1 Hydrologic Processes

**Recommendation 1: Analyze hydrologic data from gages in addition to the Friant and Bend Bridge gages. A more complete understanding of the hydrologic processes of the Sacramento and San Joaquin rivers and their tributaries should be developed to help guide riparian and riverine ecosystem conservation and restoration throughout the Sacramento and San Joaquin valleys.**

Gage data were analyzed for only two gages. Additional analyses of data for the other dozen or so gages with a long-term record in the SPA could be conducted. Information on other gages would aid interpretation of the effects of reservoir operation on tributaries, import of water from the Delta to the San Joaquin River through the Delta-Mendota Canal, and diversions along the Sacramento and San Joaquin rivers. A more complete understanding of the hydrologic processes along the Sacramento and San

Joaquin rivers and their tributaries should be developed to help guide riparian and riverine conservation efforts. A more thorough understanding of hydrology would assist with identifying those areas where restoration would likely be most successful. Additional tools for assessing relationships between flow and ecological properties could be assessed, for example the Sacramento River Ecological Flows Tool (SacEFT) (ESSA Technologies, 2005).

**Recommendation 2: Analyze the effect of groundwater decline on riparian plant species, especially as it relates to channel incision. The effect of groundwater tables on riparian habitat restoration potential should be assessed.**

This report analyzes surface water hydrology. However, groundwater hydrology may also be important for riparian systems in the Sacramento and San Joaquin valleys. Especially in reaches where rivers have incised, the groundwater table may have dropped substantially compared to historical conditions. Groundwater overdraft may also cause a decline in groundwater that affects riparian plant species. In areas where groundwater has declined, riparian habitat restoration may face more challenges than in areas with shallower water tables.

### 5.1.2 Channel and Floodplain Dynamics

**Recommendation 3: Analyze the geomorphology of the Sacramento and San Joaquin valleys, and analyze the channel and floodplain dynamics of reaches in addition to the middle Sacramento River. A better understanding of geomorphology could identify fluvial processes that can be restored and thereby guide riparian habitat restoration.**

The geomorphology of the middle Sacramento River is fairly well understood, and channel and floodplain dynamics of this reach have been analyzed in detail. The geomorphology of other parts of the Sacramento and San Joaquin valleys is less understood. A better understanding of geomorphic processes operating throughout the Sacramento and San Joaquin valleys would help to guide riparian habitat restoration. Restoring fluvial processes is fundamental to restoring habitats.

Total river length, floodplain reworked, and floodplain age are metrics that represent the status and trends of channel and floodplain dynamics. These metrics are presented in Section 4.1.2 of this report for the middle reach of the Sacramento River (RM 143 to RM 244). These metrics were not calculated for other reaches of the Sacramento River, tributaries to the Sacramento River, or the San Joaquin River and tributaries. They could be calculated for other rivers in the Sacramento and San Joaquin valleys and foothills as part of the 2017 CVFPP.

### 5.1.3 Riverine and Riparian Habitats

***Shaded Riverine Aquatic Cover***

**Recommendation 4: Develop consistent SRA cover data for the Sacramento and San Joaquin rivers and their major tributaries.**

SRA cover data were available for analysis for three reaches of the Sacramento River; however, no data were available for the San Joaquin River, or for the tributaries of these rivers. Sacramento River SRA cover data from different reaches were collected at two different points in time (2002 and 2007), which made them not entirely comparable, because bank revetment was likely added in that 5-year period.

SRA cover is an important habitat component for native fish, bird, and mammal species. However, at this time a consistent baseline for this habitat is not available for the SPA. A consistent GIS database of SRA cover would help in identifying riparian habitat restoration and conservation opportunities and would provide a baseline against which the effects of future bank protection projects could be measured. Although estimates are currently available about the historical loss of SRA cover (e.g., USFWS, 1992) these estimates are not based on sufficient baseline data.

***Species Distribution and Abundance***

**Recommendation 5: Conduct systematic surveys for specific rare wildlife species that are good indicators for specific habitat conditions.**

The CNDDB is the only comprehensive data source on occurrence for all special-status species in the SPA. Other sources are available, but they do not provide coverage for all groups of species. Unfortunately, the CNDDB is not an exhaustive and complete inventory of all rare species and natural communities statewide (DFG, 2011a). It contains records of where species have been observed in a specific location, usually in conjunction with a focused survey effort; it does not contain records where species have been surveyed for but not found. It is biased toward areas where survey efforts are greater and toward species that receive more survey effort. In addition, data are reported to the CNDDB with varied precision. Some occurrences are well documented with explicit locations (e.g., Global Positioning System coordinates), whereas others are reported with more general location information (e.g., the boundary of a park where an occurrence is documented). Although the number of individuals and general notes about the condition of the habitat at the occurrence location are usually recorded, the data cannot be used to draw conclusions about the health or viability of the population. These data are not always reliably reported, nor are they systematically collected at the same location over time. It is therefore difficult to evaluate any population trends from CNDDB records. Finally, the vast majority of CNDDB records are not independently verified, either by additional field visits or by photographs, and observer error is a concern. No readily available data source is available to describe the abundance of representative species in the Central Valley. A better understanding of the distribution of rare species would assist with identifying those areas where habitat restoration would aid in the recovery of these species. Additional surveys should focus on species that are indicators for habitat quality (e.g., western yellow-billed cuckoo, yellow-breasted chat).

**Recommendation 6: Assess status of selected common species that use relevant habitats.**

DFG's Wildlife Habitat Relationships database could be used to identify common wildlife species that use riparian habitat, riverine habitat and potentially other habitats of interest. The status (e.g., abundance or density) of these species could be monitored over time. Because of their greater abundance, common species may show responses to habitat area and quality changes over time more clearly than rare special-status species.

**Recommendation 7: Collect population counts of Central Valley salmonids throughout the SPA.**

The best data for Central Valley salmonid abundance is available from GrandTab and CalFish. Each of these sources compiles data from various sources that use several different estimation methods. The reliability of each of these data sources varies, and comparison across years may be problematic, especially for late fall-run Chinook salmon. Additionally, accurate estimates of late fall-run Chinook salmon and Central Valley steelhead are unavailable for the entire Central Valley. Their current status throughout the SPA is therefore unknown.

### 5.1.4 Levees and Bank Revetment

**Recommendation 8: Periodically update GIS databases of bank revetment for the Sacramento and San Joaquin rivers and major tributaries to help identify restoration opportunities.**

Bank revetment (e.g., riprap) often strongly interferes with channel dynamics and other geomorphic processes. GIS databases for bank revetment along the Sacramento and San Joaquin rivers are available. Similar GIS databases should be developed for the major tributaries and these databases should be periodically updated to document changes in revetment conditions and to update restoration opportunities.

### 5.1.5 Reservoirs

**Recommendation 9: Calculate the IRI for reservoirs in the San Joaquin River watershed, and analyze the combined operations of reservoirs to develop a better understanding of the effects of reservoir operations on the riverine and riparian ecosystems.**

The IRI is a useful index of the effect of dams on downstream hydrology. It is the ratio of reservoir capacity to median annual flood runoff volume (Singer, 2007). This index was calculated by Singer (2007) for major reservoirs in the Sacramento River watershed. Calculation of the IRI for reservoirs in the San Joaquin River watershed may provide a better understanding of the effects of reservoirs on the hydrology of the watershed and help improve operations to benefit ecosystem restoration.

### 5.1.6 Diversions

**Recommendation 10: Inventory the permitted flow capacity of each water diversion in the SPA.**

Although the current number and distribution of water diversions in the SPA is available through the PAD, the total amount of water diverted from the river system through these structures is unknown. Knowledge of the capacity and diverted amount of water would be useful in identifying the potential effects of diversions on the riverine ecosystem and native fishes.

### 5.1.7 Invasive Species

**Recommendation 11: Map the extent of invasive species with significant ecological effects on the riverine and riparian habitat in the SPA. This effort may be included in the fine-scale vegetation mapping (see Recommendation 4).**

The California Invasive Plant Inventory provides limited information on the status of invasive species in riparian and riverine habitat in the Central Valley. Because the data are presented at a coarse scale (i.e., floristic province), they cannot be used to determine whether and where a species has been documented in the SPA or the extent of the invasion. The Cal-IPC rating represents cumulative impacts statewide, but the impact of each species varies regionally. BIOS and data collected by other entities, such as The Nature Conservancy, California Department of Parks and Recreation and USDA, contain detailed information on some invasive plant species in the state but is not a comprehensive inventory of the location and extent of invasive species in the SPA. Invasive species to be mapped should be selected based on their habitat (e.g., riparian or floodplain), and their impact (e.g., species rated by the California Invasive Plant Council (CalIPC, 2007) as having a “High” and “Moderate” impact).

### 5.1.8 Fish Passage Barriers

**Recommendation 12: Complete the prioritization of fish passage barriers in the fish and flood management technical memorandum consistent with the Fish Passage Forum.**

A fish passage technical memorandum prepared by DWR (2011) identifies the known and potential barriers in the SPA that are within the control of DWR. The barriers were prioritized for removal or modification based on an initial analysis that includes the following criteria: (1) barriers in the SPFC, and (2) prioritization of recovery actions in the NMFS (2009) "Fisheries Public Draft Recovery Plan for ESUs of the Sacramento River Winter-Run Chinook, Spring-Run Chinook and DPS of Central Valley Steelhead." This initial analysis will be refined based on statewide prioritization conducted by the Fish Passage Forum[1] so that the barriers in the SPFC are addressed in a manner that is consistent throughout the state.

**Recommendation 13: For those fish passage barriers with an unknown status, complete a field assessment to determine status and finalize the ranking.**

In some instances, the barrier status is unknown. The DWR (2011) fish and flood management technical memorandum identifies and ranks these barriers for assessment. Assessments of these barriers should be completed to ensure proper ranking in the prioritization for removal or modification.

## 5.2 Development of Conceptual Models

**Recommendation 14: Develop conceptual models of the relationships between flood management and riparian and riverine ecosystem attributes in the SPA.**

Our understanding and management of riparian and riverine ecosystems of the SPA is limited not only by gaps in the availability and analysis of relevant data, but also by the extent to which available data and analyses have been synthesized and communicated. Riparian and riverine ecosystems are complex, and the processes that sustain them are influenced by many variables. Thus, identifying and communicating what is known about these relationships – and their relative importance – is challenging.

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[1] The Fish Passage Forum is an association of public, private, and governmental organizations that promote collaboration among private landowners, community groups, and public agencies on fish passage restoration programs and activities that contribute to the protection and recovery of listed anadromous salmonid species throughout California. DWR is a member of the forum.

Furthermore, to increase the conservation benefits of flood management, it is necessary to synthesize and communicate our understanding of relationships between components of the flood management system and riverine and riparian ecosystems.

Conceptual models provide a framework for organizing information that can be useful in synthesizing and communicating the current understanding of ecosystems. These models, which can consist of diagrams, text, and tables, provide a formal description of relationships among factors affecting ecosystem processes, habitats, and species; they also serve to define the components of the ecosystem that are of interest.

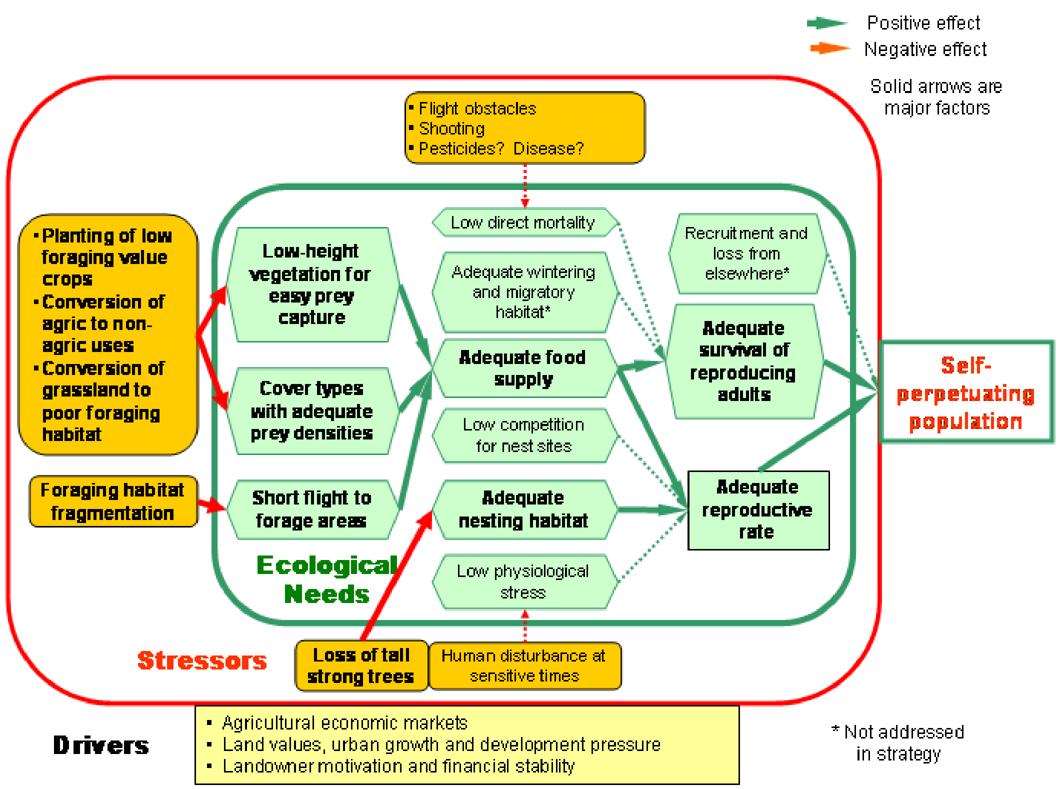
An essential part of a conceptual model is usually one or more diagrams that depict the (assumed or postulated) relationships among variables. The diagram usually identifies different types of variables that are linked by relationships with different attributes. The model diagram is an important communication tool for depicting our understanding of the modeled system.

Figure 5-1, for example, shows a diagram for a conceptual model of the major ecological attributes, stressors, and broader drivers related to a self-sustaining population of Swainson's hawks in the Central Valley (DFG, 2011b). This diagram follows conventions by Ogden et al. (2005). It presents external driving forces that have large-scale influences on the natural system as rectangles; it also presents internal stressors (ovals) and important ecological attributes (hexagons). The relationships can be either positive (green) or negative (red) and be either major (solid arrow) or minor (dotted arrow). Other attributes that could be assigned to relationships are the level of understanding of the relationship (high, medium, or low) and the level of predictability (high, medium, or low) (Fremier et al., 2008).

To be most useful, conceptual models for the effect of flood management on ecosystems should be developed specifically for that purpose. Conceptual models developed for a different purpose will have only limited or no usefulness. For example, Fremier et al. (2008) developed a conceptual model for the riparian vegetation in the Delta. The model is not specifically focused on the relationships between flood management actions and the riparian ecosystem and is therefore not suitable for the CVFPP, although some relationships in the model may be useful components of a conceptual ecosystem model for the CVFPP.

The usefulness of a conceptual model for the CVFPP depends on how specific it is to the problem at hand (i.e., the relationship between flood management and ecosystem functioning) and whether it includes and adequately characterizes the most essential relationships. For example, a conceptual model of the effect of flood management on riverine and riparian species may include the following relationships (among many others):

- Reservoir operations–bankfull flow frequency
- Bankfull flow frequency–channel migration rate
- Bank revetment–channel migration rate
- Channel migration rate–floodplain age
- Floodplain age–successional stage of riparian vegetation




*Source: DFG, 2011b*

**Figure 5-1. Conceptual Model Diagram Example for Central Valley Swainson's Hawk Conservation**

For several reasons, conceptual models help to guide management actions related to improving ecosystem conditions. First, conceptual models are particularly effective for developing a shared understanding of an ecosystem, and as a communication tool among scientists, decision makers, and system managers. Second, the organization of information in a conceptual model may assist with identifying areas where our understanding and knowledge needs to be improved to better understand the interactions between management and ecosystems. Third, in addition to summarizing the current (conceptual) understanding of the system, a conceptual model can be a tool for integrating new knowledge into our understanding of the system as a whole, which may force the modification of relationships in the model. Development of conceptual models is therefore recommended for the 2017 CVFPP.

## 5.3 Conclusions

The riparian and riverine ecosystems of the SPA have been greatly modified since 1850 by flood management activities and other human activities, such as agricultural, industrial, and urban development. An analysis of the status and trends of hydrologic and geomorphic processes, habitats, and key wildlife and fish species shows that the modification of these physical processes has reduced their ability to support important ecosystem functions.

Analysis of hydrologic data at one gage downstream from Shasta Dam and one gage downstream from Friant Dam shows that the presence of the dams has substantially changed the annual median flows, floodplain inundation flows, bankfull flows, and summer low flows.

In the Sacramento River, monthly median flows in winter and spring have been reduced, summer and fall flows have been increased, and the variability in median spring flows has been greatly reduced. The frequency of small floods (i.e., flow events with 2- to 10-year return interval, or approximately floodplain inundation flows) and the duration of small floods have increased. The frequency of small pulse flows (i.e., flow events with a 1.5- to 2-year return interval, which approximate bankfull flows) has been greatly reduced, and the duration of these flows has been increased. Geomorphic processes have been affected by these changes, especially by reduction in the frequency of bankfull flows, which are responsible for most of the channel migration work performed by the river.

Shasta Dam also has interrupted and strongly affected sediment transport. The geomorphic processes along the Sacramento River between Red Bluff and Colusa, a reach where the river still actively meanders, have been affected by these changes in hydrology and sediment transport, and they have been affected by land-use changes (loss of riparian forest), increased bank revetment, and construction of levees. The result has been a reduction in total river length, reduction in area of floodplain reworked by the river, and reduction in the variability of floodplain age.

These changes in the physical processes of the Sacramento River have resulted in a loss of riparian forest, scrub, and wetland area; habitat and species diversity; and the ability to support wildlife species. The processes that maintain the diversity of habitats and species supported by them have been greatly affected. In addition, the spread of invasive plant species has deteriorated riparian habitat quality.

Riverine habitats for salmonids and other native fishes have also been greatly affected by the change in physical processes and the response of the riparian plant species. Two important habitat components – area of SRA cover and the quantity of LWM – have been reduced. In addition, dams, diversions, and other obstacles have strongly affected salmonid migration. Many miles of spawning habitat are no longer accessible to Chinook salmon and steelhead, and diversions and the water management needed to maintain them have greatly affected fish habitat. Salmonids and other native fish species have been greatly affected by the isolation of floodplains from channels, because floodplains provide important rearing habitat that is no longer accessible when floodplains and habitats are disconnected. Bypasses in the Sacramento Valley still partially perform a floodplain function for native species.

In the San Joaquin River, Friant Dam has had an even greater effect on physical fluvial processes. Median annual flows have been greatly reduced year-round because flows are diverted at the dam into two major irrigation canals. The frequency of floodplain inundation flows and bankfull flows has been greatly reduced. The average duration of floodplain inundation floods has been reduced, but the duration of bankfull floods has been increased. Large reaches of the San Joaquin River below Friant Dam have been dry during part of the year or for several years in a row. Increased flows have been released to the San Joaquin River since 2009 because of Reclamation's San Joaquin River Restoration Program.

The geomorphology of the San Joaquin River has been much less studied than that of the Sacramento River. However, it still apparent that hydrologic changes and land-use changes have greatly reduced riparian habitat area, habitat and species diversity, and the ability to support wildlife species along the San Joaquin River. Levees have disconnected floodplains from river channels in the San Joaquin River and its tributaries. Dams and other obstacles have greatly reduced salmonid migration and access to historical spawning grounds. Diversions have also deteriorated the habitat of native fish species. In-channel mining pits have created habitat for nonnative predatory fish, increased water temperatures, and opportunities for invasive plant species, such as red sesbania and giant reed, in the San Joaquin River and its tributaries, which have further deteriorated the quality of riverine and riparian habitat.

Our knowledge of the relationships between physical processes and habitats and between habitats and species is limited by data gaps and lack of conceptual models that organize our understanding of the crucial relationships between management actions and ecosystem responses. The recommendations described above address the data gaps and the lack of a conceptual model.

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# 7.0 Abbreviations and Acronyms

BIOS .......................... Biogeographic Information and Observation System
Board .......................... Central Valley Flood Protection Board
BOD .......................... biological oxygen demand
Cal-IPC .......................... California Invasive Plant Council
cfs .......................... cubic feet per second
CNDDB .......................... California Natural Diversity Database
CVFPP .......................... Central Valley Flood Protection Plan
CVFSCS .......................... Central Valley Flood System Conservation Strategy
Delta .......................... Sacramento-San Joaquin Delta
DFG .......................... California Department of Fish and Game
DO .......................... dissolved oxygen
DWR .......................... California Department of Water Resources
GIS .......................... geographic information system
IHA .......................... Indicators of Hydrologic Alteration
IRI .......................... impoundment runoff index
LWM .......................... large woody material
MMU .......................... minimum mapping unit
NMFS .......................... National Marine Fisheries Service
NVCS .......................... National Vegetation Classification System
PAD .......................... Passage Assessment Database
Reclamation .......................... U.S. Department of Interior, Bureau of Reclamation
RM .......................... river mile
SPA .......................... Systemwide Planning Area
SPFC .......................... State Plan of Flood Control
SRA .......................... shaded riverine aquatic
USFWS .......................... U.S. Fish and Wildlife Service
VELB .......................... valley elderberry longhorn beetle

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STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES