CHAPTER 8. VEGETATION

8.1. INTRODUCTION

Species composition and distribution of plant communities are determined by local environmental factors: soils, surface water hydrology, fluvial geomorphology, groundwater hydrology, climate, slope, aspect, herbivores, pests, and others. Hydrology and fluvial geomorphology are environmental factors that heavily influence wetland and riparian vegetation along the San Joaquin River. Hydrology and fluvial geomorphology influence not only the species composition in the corridor, but also the location and extent of each species. Compared to other major river systems draining into the Central Valley, the San Joaquin River upstream from its confluence with the Merced River is unusual in several respects. Under natural conditions, it had a later and more moderate peak flow (dominated by snowmelt rather than rainfall). Other lowland Central Valley river systems, such as the Sacramento River, formed extensive natural levees or berms where their sediment-laden waters overflowed the banks in the valley and these berms supported extensive riparian and oak communities. The lower reaches of the San Joaquin River carried less sediment than other Central Valley rivers, and consequently the natural levees characteristic of these other Central Valley rivers were not as tall and wide. Historically, extensive flood basins and low sediment loads in downstream reaches between Mendota and the Merced confluence resulted in vast tule marshes with a narrow band of woody riparian vegetation along the margins of the San Joaquin River. Vast riparian forests historically did not appear to occur in these reaches because of the low sediment supply and prolonged inundation during the snowmelt runoff period.

Further upstream, denser riparian forests did occur along the San Joaquin River floodway in reaches with greater sediment supply (Reach 2), although the width was still not extensive (usually less than 2,000 ft. In the gravel-bedded Reach 1, the channel morphology encouraged riparian vegetation along the channel margins, high flow scour channels, and side channels. The lateral extent of riparian vegetation was confined by bluffs, making the forested zone less extensive than on other large rivers draining into the San Joaquin Valley. Rivers entering the valley on broad alluvial fans, such as the Kings River and Kaweah River, were flanked by extensive oak woodlands, in addition to having broad riparian zones along the major channels.

This chapter will focus on the riparian zone, a corridor flanking the river in which potential natural vegetation is influenced by the river-related factors such as elevated soil moisture or periodic flooding, and as a result, is distinct from the vegetation of adjacent zones that are not influenced by the river. Along the study reach of the San Joaquin River, the most characteristic riparian zone vegetation is typically dominated by trees such as willows and cottonwoods. However, the riparian zone also includes areas dominated by non-woody hydrophytic vegetation, and these areas may also be referred to as tule marshes or wetlands. In the discussions that follow, there is no attempt to discriminate between riparian communities that may or may not meet state or federal regulatory definitions of wetland.

Riparian and wetland vegetation strongly influenced the biota that used the San Joaquin River corridor on a permanent and/or seasonal basis. Sediment and nutrients were exchanged and cycled during frequent overbank flows (e.g., distributing salmon carcasses, recruiting terrestrial insects into the flowing water). The overbank flows also recharged shallow groundwater tables and deposited nutrients and fine sediments, resulting in floodplains being some of the most productive areas in the Central Valley. Deposition of conifers from the upper watershed, combined with contribution of large riparian trees into the San Joaquin River by channel migration and/or avulsion, provided large wood structure to the river, contributing to the complex aquatic habitat framework typically provided by a dynamic channel morphology. The importance of overbank flows, sediment loads, and large woody riparian vegetation again highlight the interconnectedness of the river ecosystem components in the San Joaquin River (See Figure 2-1).

Historical vegetation in the San Joaquin River corridor can be broadly categorized by the larger scaled geomorphic differences between the reaches. In upper sand bedded (Reach 2A) and lower gravel bedded reaches (Reach 1), the canopy species within the riparian corridor consisted of a patchy band of cottonwoods, willows, and valley oaks on floodplain and terrace surfaces between the confining bluffs. In downstream reaches (downstream of Mendota), river morphology was quite different. Floodplains (higher geomorphic surfaces inundated every 1-2 years [Leopold et al, 1964]), gave way to large flood basins (low lying areas adjacent to the river channel) dominated by tule marsh on both sides of the river, often many miles wide. Riparian canopy species (cottonwood, willow, valley oak) were limited to relatively narrow bands (typically less than 1,000 feet wide based on 1914 maps) of mineral soil berms deposited along channels that dissected the vast tule marsh.

The value of these expansive tule marshes to waterfowl is obvious; flocks numbering in the millions lived in or migrated through the San Joaquin Valley. The riparian forests were important to many bird species, including herons, egrets, ospreys, yellow-billed cuckoo, and many other species. Land management--beginning with grazing and agricultural clearing, followed by dramatic changes to fluvial geomorphic processes, surface water hydrology, and shallow groundwater hydrology--directly reduced the amount of vegetation along the San Joaquin River corridor. Reduction in riparian vegetation cascades down to the biota supported by the riparian vegetation, extirpating many animal species, and greatly reducing populations of other species.

This chapter describes historic vegetation along the San Joaquin River corridor, describes the evolution of riparian vegetation characteristics from historic to current conditions, discusses land use changes that caused the evolution in vegetation, and presents conceptual models linking riparian vegetation regeneration to surface water hydrology and fluvial geomorphology.

8.2. OBJECTIVES

The objectives of the Vegetation Communities chapter are to:

- Describe and evaluate stream dependent (riparian and wetland) vegetation conditions, life history, and distribution.
- Compare changes in riparian vegetation species and distribution over time as a result of human influences.
- Analyze and summarize changes in physical conditions and their effect on the recruitment, maintenance, and succession of riparian vegetation.
- Analyze life history and distribution of key riparian vegetation species and develop conceptual models that relate these species to pre- and post-Friant Dam annual hydrographs, and pre- and post-Friant Dam geomorphic processes.

It was originally intended for the Background Report to also evaluate whether certain sequences of water years facilitate recruitment classes of riparian vegetation by analyzing cores taken from established riparian trees; however, this task was not conducted, and therefore should be considered in future riparian evaluations.

8.3. STUDY AREA

The study area for the Vegetation Communities chapter encompasses the San Joaquin River from Friant Dam downstream to the confluence with the Merced River. For characterization of the historic pre-Gold Rush conditions, the study area's lateral limits encompass the floodplains and flood basins of unimpaired river conditions. This broad study area is defined to describe the historical vegetation conditions, and for planning and analyzing future restoration activities.

This chapter also includes a historical riparian vegetation coverage analysis using historical aerial photographs; this analysis defined a narrower study area width. While the narrower study area width significantly underestimates historic and existing riparian and wetland vegetation, the analysis provides a useful illustration of recent changes in riparian and wetland vegetation along the present river corridor. Aerial photographs from 1938 were used as the oldest mapping base. By 1938, much of the riparian vegetation had been cleared and wetlands drained, which was one reason why a narrower study area was used. A set of rules was devised by JSA (1998) to ensure that riparian habitat associated with the mainstem and adjacent land uses was included despite the complexity of conditions in the study area. The rules devised are as follows:

- When no levee, escarpment, or clear and discrete outer boundary of riparian vegetation was present, but riparian vegetation extended more or less continuously from the mainstem to adjacent sloughs or side channels, the boundary was set at 2,000 feet from the center line of the main channel of the San Joaquin River (e.g., portions of Reach 5). When a clear escarpment or levee that confined the river was present, the boundary was set at 1,000 feet beyond the escarpment or levee (e.g., the upper portion of Reach 1 and most of Reaches 3 and 4).
- When no levee or escarpment was present, but the outer boundary of riparian vegetation associated with the mainstem was clear, the boundary was set at 1,000 feet beyond the outer limit of the riparian vegetation (e.g., portions of Reaches 1 and 2).
- When no levee, escarpment, or clear, discrete outer boundary of riparian vegetation was present, but riparian vegetation extended more or less continuously from the mainstem to adjacent sloughs or side channels, the boundary was set at 2,000 feet from the center line of the main channel of the San Joaquin River (e.g., portions of Reach 5).

Figure 8-1 and 8-2 illustrate the application of the above four guidelines.

8.4. INFORMATION SOURCES

Qualitative and quantitative information sources were used in this chapter. Historical anecdotal information (explorer journals, hand-drawn maps, etc.) was used to describe historical conditions in a qualitative way. Aerial photographs, detailed maps, and ground surveys provided quantitative information for comparing changes in vegetation coverage.

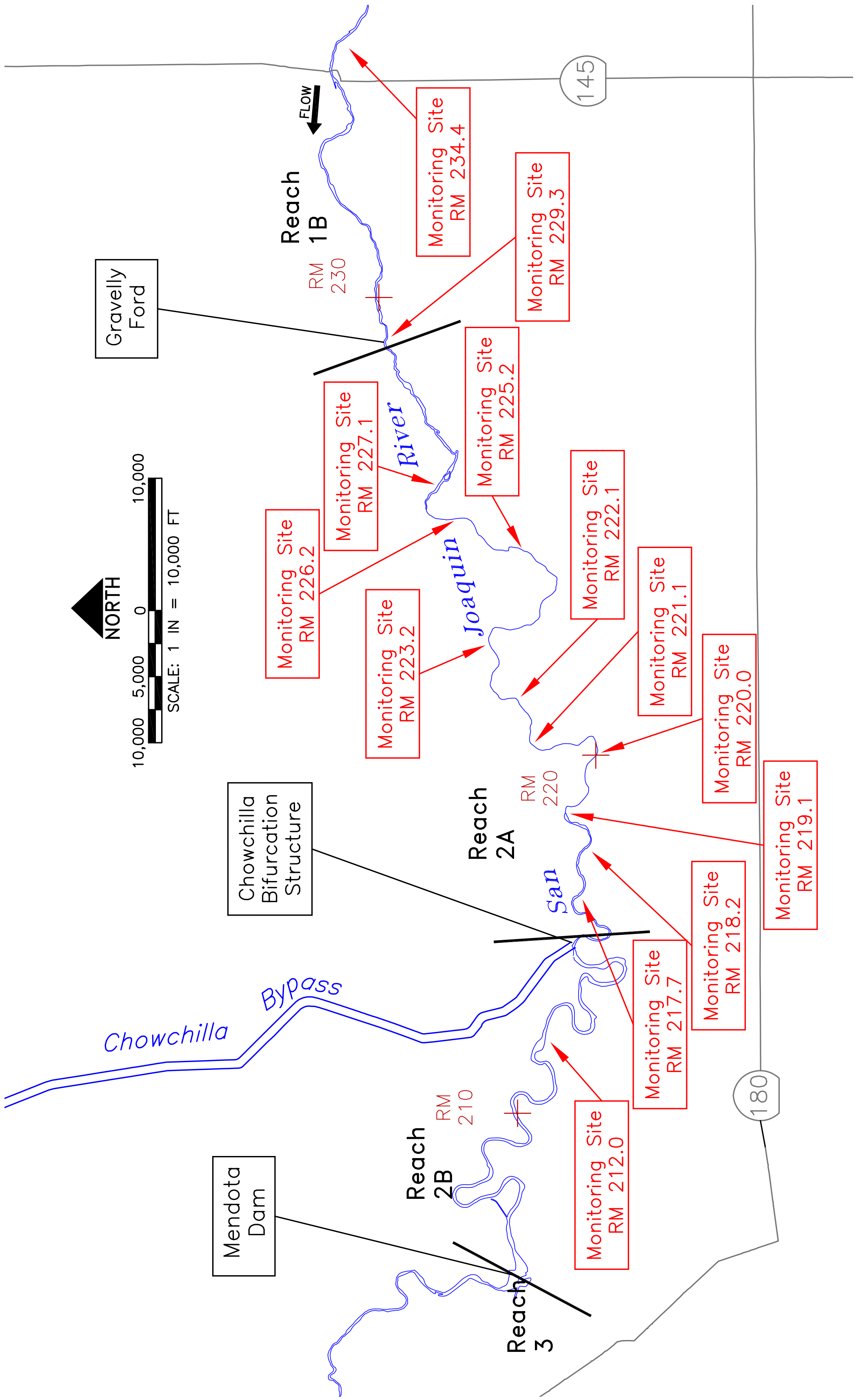


Figure 8-1. Location of 1999-2001 San Joaquin River Riparian Habitat Restoration Program Pilot Project study sites.

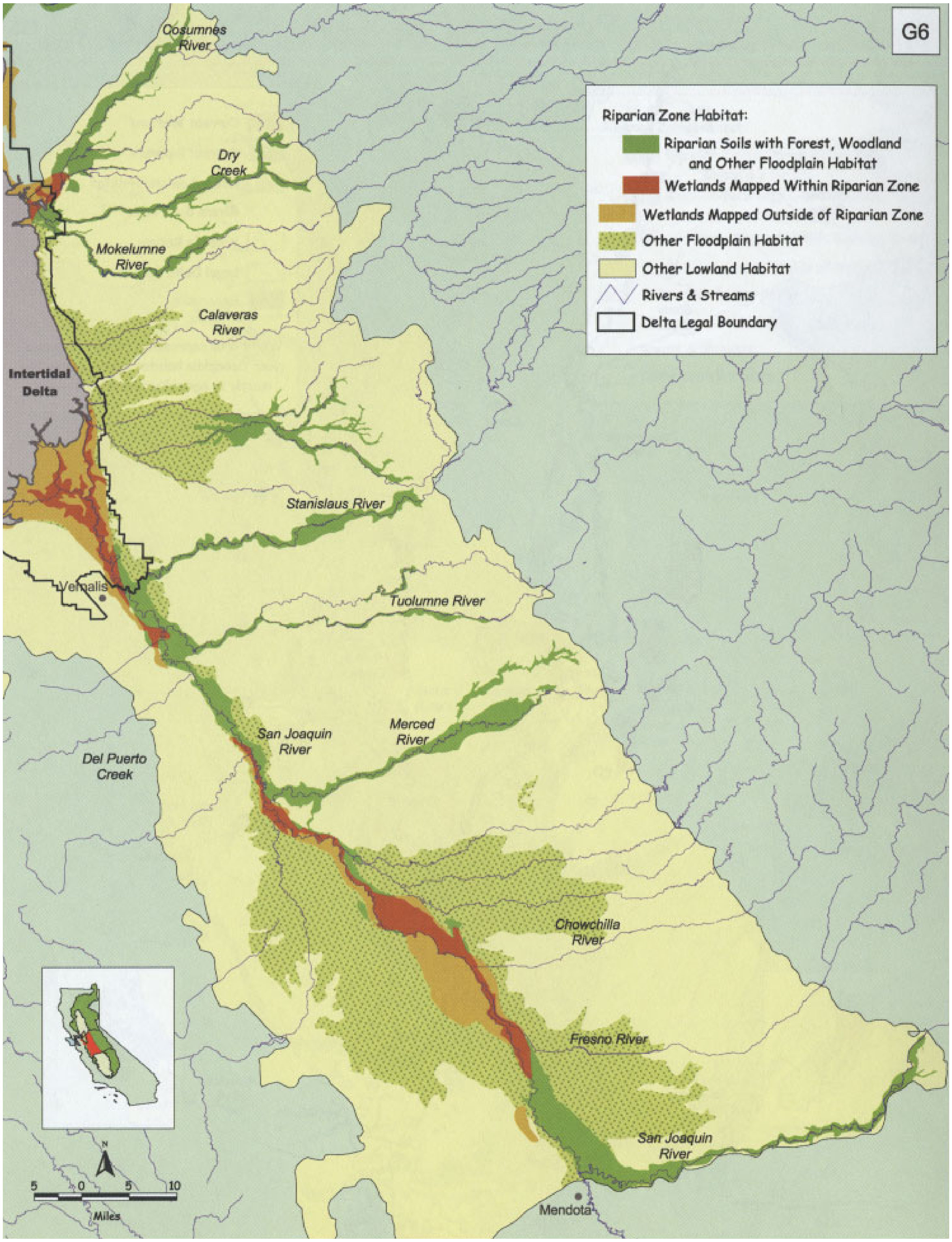


Figure 8-2. San Joaquin Valley historical river floodplain ecosystem (from The Bay Institute, 1998).

8.4.1. Historical and Existing Vegetation Conditions' Sources

Historical descriptions from early explorers were used to develop a general description of Central Valley vegetation prior to European settlement. Recent book compilations of historical sources and descriptions of the San Joaquin Valley were also used. The primary sources are listed below; complete references are cited at the end of this chapter:

- Edwin Katibah (1984): A brief history of riparian forests in the Central Valley of California.
- John Thompson (1957): The settlement geography of the Sacramento-San Joaquin Delta.
- Hubert Bancroft (1884): The history of California.
- William Brewer (1949): Up and down California.
- Phyllis Fox (1987a and 1987b): Excerpts of early explorer descriptions of the San Joaquin Valley.
- George Derby (1852): Map of Tulare Lake and San Joaquin River.
- John Nugen (1953): Topographic sketch of the Tulare Valley.
- William Hall (1886): Topographical and irrigation map of the San Joaquin Valley.
- US Government Land Office (1855): Plat maps along the San Joaquin River.
- Jones and Stokes Associates, Inc. (1998). Analysis of historical riparian habitat conditions along the San Joaquin River.
- Jones and Stokes (2000) and SAIC (2002): 2000 and 2001 results of San Joaquin Riparian Restoration Program Pilot Project.
- Moise and Hendrickson (2002): 1998 riparian habitat mapping and 2000 vegetation transects on the San Joaquin River.

These sources--coupled with the descriptions of later investigators who used soil survey data, remnant vegetation, and additional historical accounts as tools to reconstruct earlier vegetation-- form the basis for discussing pre-1937 vegetation conditions in Section 8.6.1. There are historical ground photos available that would help illustrate historical vegetation along the San Joaquin River; however, due to time constraints, the Background Report relied more on gathering historical maps and aerial photographs rather than ground photos. Another source that was not used, but would provide some additional information on historical riparian vegetation, is the field books of William Hammond Hall (e.g., Hall, 1880 for the Kings River). The 1913–1914 California Debris Commission (CDC) survey maps (ACOE 1917), which encompass the area from Herndon downstream to the confluence with the Merced River, are another useful source; however, these maps clearly reflect that effects on the riparian environment from relatively extensive land use changes had already occurred.

8.4.2. Vegetation Mapping Sources

Post-1937 vegetation was mapped using air photos taken in 1937, 1957, 1978, 1993 and 1998; and using topographic maps or orthophotoquads created at various dates. These maps and photos are described more fully under methods (Sections 8.5.1 and 8.5.2). Two studies published in 1998 formed the basis for much of this analysis. They are the historical air photo analyses of the study region performed by JSA (1998) and the evaluation of physical processes and riparian habitat potential of the San Joaquin River prepared by JSA and MEI (1998).

Present day vegetation is described in Moise and Hendrickson (2002), which is based on interpretation of detailed rectified air photos taken in 1998 and on extensive field transects conducted in by the California Department of Water Resources (DWR) in 2000. Monitoring data from two sets of transects, which were designed to document the vegetation responses to the 1999 pilot project flows (JSA and MEI 2000, JSA and MEI 2002), provide additional recent background information.

8.5. VEGETATION MAPPING METHODS

8.5.1. Photographic Materials

Historical aerial photographs were used to identify land cover signatures. The aerial photographs used were taken at approximately 20-year intervals starting at 1937. Photographs were taken within 1 to 4 years of 1937, 1957, 1978, 1993, and 1998.

Extensive research was conducted to locate historical aerial photographs at government agencies, libraries, and universities. Although many sources for aerial photographs of the San Joaquin River Basin were found, in most cases, complete coverage of the entire study area was unavailable for a particular year (Table 8-1). Differences in photograph scale and quality affected the data's quality. False-color infrared photographs are ideal for identifying vegetation types, but photographs using this technology were not available. In some instances (1937, Fresno County; 1957, Merced County) institutions were unable to lend photographs, and high-quality photocopies of the photographs were used. Although considered adequate for this project, the 1978 aerial photographs were the least suitable because of their scale; differences between riparian forest types are somewhat unreliable and should be interpreted with caution. When sufficient overlap existed between photographs, stereo pairs were examined using a Lietz MS-27 3X-magnifying stereoscope. A 6X-magnifying hand lens was also used to identify vegetation signatures.

For 1937, 1957, and 1978, aerial photographs for the entire study area could not be obtained. Missing portions were "filled in" using photographs taken no more than 4 years before or after the pertinent year. The 1957 photographs were supplemented with 1961 photographs for the reach from Mendota Dam to State Route (SR) 152 (RM 175-RM 205; Table 8-1). The 1978 photographs were supplemented with 1980 photographs for the reach from Biola to Friant Dam (RM 237-RM 267; Table 8-1). Throughout this report, the year that provided most of the photographs is used to indicate the time in the analysis. For example, although photographs from both 1978 and 1980 were used to represent the third period, this period is designated 1978.

In some cases, aerial photographs did not cover the entire study area width. Photographs always included the riparian corridor but did not always include adjacent areas. These areas, which were almost exclusively agricultural or grassland, were assigned a "no data" label on the maps.

Table 8-1. Aerial photographs used for historical vegetation mapping.

Period	Date	Scale	B/W or Color	Flown for	Contact for Originals	Prints/ Photocopies/ digital	River Miles	Description
1937	9/9/1938	1:10,000 (1”=833’)	B/W	ACOE	ACOE, Sacramento, CA	prints	267–243	Friant Dam to Herndon (Hwy 99)
	10/6/1937	1:7,920 (1”=660’)	B/W	USDA	California State University, Fresno, Map Library, Fresno, CA	photocopies	243–175	Herndon (Hwy 99) to Merced/Fresno county line (near Hwy 152)
	7-10/1937	1:7,920 (1”=660’)	B/W	USDA	Central California Irrigation District, Los Banos, CA	prints	205–136	Mendota Dam to upstream of confluence with Bear Creek
	7-8/1938	1:7,920 (1”=660’)	B/W	USDA	National Archives, Washington, D.C.	prints	175–118	Merced/Fresno county line (near Hwy 152) to confluence with Merced River
1957	8/31/1957	1:12,000 (1”=1000’)	B/W	USDA	Department of Water Resources, Fresno, CA	prints	267–205	Friant Dam to upstream of Mendota Dam
	7/1961	1:7,920 (1”=660’)	B/W	USDA	California State University, Fresno, Map Library, Fresno, CA	photocopies	205–175	Mendota Dam to Merced/Fresno county line (Hwy 152)
	4&5/1957	1:7,920 (1”=660’)	B/W	USDA	Merced Community College, Merced, CA	photocopies	175–118 (89% of area)	Merced/Fresno county line (Hwy 152) to confluence with Merced River
	8/31/1957	1:63,360 (1”=1 mile)	B/W	USDA	USBR, Fresno, CA	prints	175–118 (11% of area)	Merced/Fresno county line (Hwy 152) to confluence with Merced River
1978	3/8/1980	1:12,000 (1”=1000’)	B/W	USDA	Department of Water Resources, Sacramento, CA	prints	267–237	Friant Dam to Biola
	12/6/1978	1:24,000 (1”=2000’)	B/W	ACOE	ACOE, Sacramento, CA	prints	237–118	Biola to confluence with Merced River
1993	5/23/1993	1:6000 (1”=500’)	Color	USBR	USBR, Sacramento, CA	prints	267–118	Friant Dam to confluence with Merced River
2000	9/2/1998	1:4,000 (1”= 333’)	Color	USBR	USBR, Fresno, CA	digital	267-229	Friant Dam to Gravelly Ford
2000	7/30/1998	1:4,000 (1”= 333’)	B/W	ACOE	ACOE, Sacramento, CA	digital	229-118	Gravelly Ford to confluence with Merced River

8.5.2. Topographic Base Maps

Riparian vegetation and land use types were transferred by hand to rectified base maps. Four types of rectified base maps were used: black-and-white photocopies of 1920s USGS topographic maps (scale = 1:31,680; surveyed: 1915–1922); current USGS 7.5-minute topographic quadrangle maps (scale = 1:24,000; surveyed: 1956–1965, updated 1964–1987); 1976–1978 USGS "orthophoto quads" (rectified composites of aerial photographs; scale = 1:24,000); and rectified 1998 aerial photographs (scale = 1:4,000). The four types of maps offer different advantages. The 1920s topographic maps clearly show that the channel planform more closely resembles 1937 conditions than do the current topographic maps; the orthophoto quads clearly represent vegetation from 1976 to 1978; and the current topographic maps show elevation and, in some cases, urban and industrial development through the 1980s.

The 1920s maps were used for mapping the 1937 habitat and land use types. The orthophoto quads were used for mapping the 1978 habitat and land use types from the Mendota Dam quadrangle (RM 218.5) to the Merced River. USGS does not have orthophoto quads for the area east of the Mendota Dam quadrangle, so that area was mapped on current topographic maps. With the exception of the orthophoto mapping of the Gustine and Stevenson quadrangle areas (downstream from RM 140) for 1993, the 1957 and 1993 habitat types were mapped on current topographic maps. The lower reach of the study area for 1993 was mapped on orthophoto quads for 2 reasons: l) to increase consistency with the 1978 maps, and 2) because an accurate representation of streams is more important than elevation.

8.5.3. Methods for Historical Aerial Photograph Interpretation

Historical vegetation communities were mapped onto rectified base maps using historical aerial photographs taken from 1937 to 1993. The historical conditions were also compared to existing conditions, mapped in 2000 by DWR onto 1998 digital aerial photographs (Moise and Hendrickson 2002). The methods used for mapping existing conditions are described in the "Existing Conditions" section below. The maps were digitized and "built" into ARC/INFO polygon coverages. ARC/INFO (Version 8) software was used to analyze the spatial data, and Arcview 3.2 software was used to create maps.

8.5.3.1. Mapping Precision

Riparian vegetation types were mapped using a minimum mapping unit of 5 acres, and adjacent land uses were mapped using a minimum mapping unit of 20 acres. Linear features were mapped with a minimum width of 75 feet on the 1920s topographic maps, and with a minimum width of 50 feet on the current topographic maps. When widths on the 1920s maps were from 75 to 250 feet and many adjacent features were also narrow and linear, the features were mapped as a line with the width indicated; this line was later expanded to a polygon with the appropriate width. On the current topographic maps, this mapping method was sometimes used for narrow linear features (50 to 150 feet wide). The locations of vegetation polygons were generally more precisely mapped on the orthophoto quads than on the topographic maps because vegetation boundaries were visible on the orthophoto quads but were generally invisible on the topographic maps. Polygon location was more accurately mapped on the current topographic maps than on the 1920s maps because the 1920s maps were at a larger scale.

8.5.3.2. Mapping Accuracy

When identifying the appropriate category for a riparian vegetation polygon, the level of accuracy depended on the aerial photographs' scale, resolution, and type (color or black and white). The accuracy was highest for the 1993 color aerial photographs (scale = 1:6,000) and lowest for the 1980 black-and-white photographs (scale = 1:12,000). For 1957, two small areas (6.5 river miles, or 4% of the study area) were mapped from index composite photographic sheets at a scale of 1:63,360 (1" = 1 mile) because no coverage for these areas could be located. Acreage estimates were not seriously affected by this lower accuracy because the areas were small. On October 29, 1997, some "ground truth" data were collected for the 1993 vegetation-type identification. The ground truth effort consisted of visiting mapped areas between Mendota and Firebaugh to verify aerial photograph signatures using the 1993 aerial photographs.

Because mapping precision and accuracy depended on a number of unknown and variable relationships between the created maps and aerial photographs of varying quality and scale, and because ground truth data of historical vegetation could not be collected, confidence intervals could not be quantified for acreages obtained from the vegetation maps. Therefore, for changes in acreages between years, approximate statistical significance levels could not be calculated.

8.5.3.3. Digital Data Management and Quality-Control Procedure

Hand-drawn maps were digitized using AutoCAD Version 12 software. The root mean square digitizing error was less than 14.7 feet. The digitized lines and vegetation attributes were exported to ARC/INFO Version 7.1 software and built into separate polygon coverages for each map. A uniform study area boundary was drawn (see Section 8.3) on a set of 7.5-minute quadrangle maps and digitized, and all riparian habitat and land use data were clipped at this boundary.

8.5.3.4. Data Analysis and Interpretation

Habitat and land use maps were intersected with the study reaches in ARC/INFO, and acreages of habitat and land use were calculated by subreach. For each subreach, an interpretation was developed of how riparian habitat types changed over time, as a function of known changes in land use and hydrology. As in most historical analyses, exact and unambiguous causes of observed historical changes could not always be assigned. However, factors that are likely to change historical vegetation patterns could be identified.

8.5.4. Development of Historical and Present-day Toposequences

Toposequences for five reaches along the San Joaquin River were developed using a combination of data sources. The toposequences are conceptual cross-sections of the riparian corridor, which illustrate the relationships of different riparian plant assemblages with river channel/valley floor topography, and which show the relationships' changes over time (pre-1770, 1937 and 1998). A vertically exaggerated cross section was drawn using the 1914 CDC maps to illustrate the main channel, side channels, and overflow basins. These 1914 CDC cross-sections provided the base on which the pre-1770 vegetation toposequences were drawn. The vertical axis is exaggerated to better illustrate the relationship of the plant assemblages to topography. Land use changes were already evident on the 1914 maps and these may have had localized effects on the river morphology. Pre-1770 conditions are assumed to be unimpaired, as this was the approximate date when European influence began in the San Joaquin Valley. An idealized riparian vegetation assemblage was depicted for the pre-1770 cross sections; however, for the 1937 and 1998 cross sections, we used air photos and contemporary topographic maps to develop the toposequences and to update the topography, which reflected changes such as leveled fields, gravel mine pits, and other changes in the active channel. Within the different assemblages, the plant species are selected representative dominant species known from the area, based on historical documents and present day distribution. Although a considerable amount of data supports these toposequences, some of the information is recognized as speculative, especially data on herbaceous cover of upland and riparian habitats that were affected by widespread livestock grazing in the late 18th and early 19th centuries. In addition, climatic changes from the pre-1770 period to present, as well as long series of wet or dry years, have also possibly induced changes to the riparian vegetation. However, the dramatic change in flow regime, sediment regime, and land use and the associated effect on riparian vegetation is assumed to overwhelm any climatically induced changes to riparian vegetation.

8.5.5. Classification Used to Map Historical Vegetation

Riparian vegetation and land use types were mapped as a part of this project; two vegetation mapping classification systems have been used in this document (Table 8-2). The first was used in mapping the historical vegetation from air photos (JSA 1998). The second, more detailed classification system is used in defining existing vegetation conditions (Moise and Hendrickson 2002). The more detailed classification was allowed through greater resolution in the air photos and the extensive on-the-ground vegetation sampling that accompanied the mapping. A one-to-one correspondence between the classification systems does not exist (Table 8-2) but considerable overlap does occur. Vegetation types are adapted from Holland's (1986) *Preliminary Descriptions of the Terrestrial Vegetation of California.* JSA's classification system is hierarchical (Table 8-2), and can be correlated to the classification used by Moise and Hendrickson (2002). For riparian scrub and forest, a low-density modifier was used when the shrub or tree cover was below 30% for the polygon. Characteristics of the vegetation/land cover types used in the air photo interpretation and historical vegetation analysis (JSA 1998) are described below. Section 8.5.6 describes the system used by DWR to map and classify present-day vegetation (Moise and Hendrickson 2002).

8.5.5.1. Open Water

"Open water" is characterized by unvegetated permanent, or semi permanent ponded or flowing, water. Open water may be the result of constructed impoundments or naturally occurring water bodies. The open water mapping category also may include small areas of riparian scrub or herbaceous riparian vegetation that were too small to map as separate polygons.

8.5.5.2. Riverwash

"Riverwash" consists of alluvial sands and gravel associated with the active channel of the San Joaquin River. Generally, riverwash areas exist as sand and gravel point bars within the floodplain of the river. The acreage of riverwash should not be interpreted as a precise estimate because riverwash acreage is partially a function of the flow at the time that the aerial photograph was taken.

8.5.5.3. Great Valley Cottonwood Riparian Forest

"Great Valley cottonwood riparian forest" is a multilayered riparian forest found on the active low floodplain of the San Joaquin River. Older and decadent stands of Great Valley cottonwood riparian forest also exist in areas that were formerly active floodplains, but are now on functional terraces because of the reduction in high flow regime following completion of Friant Dam and associated diversion canals.

Pristine Great Valley cottonwood riparian forests have three somewhat distinct vertical layers: overstory, midstory, and understory. Winter deciduous trees that are adapted to frequent flooding dominate the overstory. Common dominant trees in the overstory include Fremont cottonwood (*Populus fremontii*) and Goodding's black willow (*Salix gooddingii*). California wild grape (*Vitis californica*) is a conspicuous vine found growing within the canopy of this forest. The midstory is often dominated by shade-tolerant shrubs and trees, such as Oregon ash (*Fraxinus latifolia*) or California box elder (*Acer negundo* ssp. *californica*). Other shrubby species of willow (*Salix* spp.) may also be present within the midstory. The understory typically is dominated by native grasses and forbs, such as creeping wildrye (*Leymus triticoides*), nettle (*Urtica* sp.), and Barbara sedge (*Carex barbarae*). Great Valley cottonwood riparian forest intergrades with Great Valley willow scrub at lower elevations near the active channel, and with mixed riparian forest on higher floodplain positions.

Table 8-2. Comparison of classification systems for historical and existing vegetation and land use.

Historical Vegetation Classification (JSA 1998)			**Existing Vegetation Classification (Moise and Hendrickson 2002)**
Category[1]	**Subcategory**	**Vegetation type**	**Category**
Open water			Open water
Riverwash			Riverwash
Riparian vegetation	Riparian forest	Great Valley cottonwood riparian forest	Cottonwood riparian forest
			Willow riparian forest
		Great valley mixed riparian forest	Mixed riparian forest
			Exotic trees
		Great Valley valley oak riparian forest	Valley oak riparian forest
	Riparian scrub		Willow scrub
			Riparian scrub (nonwillow)
			Elderberry savanna
			Giant reed
	Herbaceous riparian and marsh		Wetland
			Alkali sink
			Grassland and herbaceous riparian [2]
Open space	Grassland and pasture		Grassland and herbaceous riparian [2]
	Agricultural field		Agricultural field
	Orchard and vineyard		
Disturbed land	Disturbed land-other		Disturbed
	Former aggregate mining		
Urban and industrial	Aggregate mining		
	Other industrial		
	Urban/residential		Urban

Notes:

[1] Corresponding mapping categories are shown in the same horizontal box

[2] Herbaceous riparian in JSA (1998) is included in Grassland and herbaceous riparian in Moise and Hendrickson (2002).

8.5.5.4. Great Valley Mixed Riparian Forest

"Great Valley mixed riparian forest" is a multilayered winter-deciduous forest generally found on the intermediate terrace of the floodplain of the San Joaquin River. Under pristine conditions, this vegetation type experiences less physical disturbance from flood flows than does the cottonwood riparian forest. However, following the construction of Friant Dam and the resulting attenuation of flood flows, sites that typically would support cottonwood riparian forest now exhibit structure and species composition of the mixed riparian forest.

Species dominance in mixed riparian forest depends on site conditions, such as availability of groundwater and frequency of flooding. Typical dominant trees in the overstory include Fremont cottonwood, box elder, Goodding's black willow, Oregon ash, and western sycamore (*Platanus racemosa*). Immediately along the water's edge, white alder (*Alnus rhombifolia*) occurs in the upper portion of the study area. Common shrubs include red willow (*Salix laevigata*), arroyo willow (*Salix lasiolepis*), and buttonbush (*Cephalanthus occidentalis*). The understory of mixed riparian forest is similar to that of Great Valley cottonwood riparian forest.

Great Valley mixed riparian forest intergrades with Great Valley valley oak riparian forest at sites higher on the floodplain, and with Great Valley cottonwood riparian forest and Great Valley willow scrub on sites closer to the active channel.

8.5.5.5. Great Valley Valley Oak Riparian Forest

"Great Valley valley oak riparian forest" is a tree-dominated habitat with an open-to-closed canopy. This forest type is found on the higher portions of the floodplain and is therefore exposed to less flood-related disturbance than other riparian vegetation types in the study area. Dense stands of this vegetation type were not observed in aerial photographs of the study area; however, woodland-like stands of this type were observed upstream of Herndon.

Valley oak is the dominant tree in this vegetation type; California sycamore, Oregon ash, and Fremont cottonwood are present in small numbers. Common understory species in this vegetation type include creeping wild rye, California wild rose (*Rosa californica*), Himalaya blackberry (*Rubus procerus*), and California blackberry (*R. ursinus*).

Great Valley valley oak riparian forest intergrades with mixed riparian forest closer to the active channel, and with grassland habitats on higher terraces of the San Joaquin River.

8.5.5.6. Great Valley Willow Scrub

"Great Valley willow scrub" is a dense assemblage of willow shrubs often found within the active floodplain of the river. Sites with willow scrub are subject to more frequent scouring flows than are sites supporting riparian forests. Willow scrub often occupies stable sand and gravel point bars immediately above the active channel. Often, riparian scrubs are successional to riparian forest and persist only in the presence of frequent disturbance.

Dominant shrubs in Great Valley willow scrub include sandbar willow (*Salix exigua*), arroyo willow, and red willow. Occasional emergent Fremont cottonwood may also be present in Great Valley willow riparian scrub.

Initially, mapping was intended to include buttonbush scrub, elderberry savanna, and exotic vegetation (giant reed and tamarisk); however, following a review of the project's aerial photographs, mapping of these vegetation types was determined infeasible. Buttonbush scrub is present in the study area; however, patches of this vegetation type occur primarily as small, linear features along the water's edge or as small areas of scrub within back-swamps and could not be identified on available aerial photographs. Without false-color infrared aerial photographs, separation of the signatures of buttonbush scrub and Great Valley willow scrub was extremely difficult. Buttonbush scrub in the study area could not be mapped without extensive on-the-ground mapping.

Elderberry savanna has not been reported along the San Joaquin River within the study area (Natural Diversity Data Base 1997) and was not discernible, even on the oldest aerial photographs (1937 and 1938). However, recent field work by DWR and the San Joaquin River Riparian Pilot Project did find small patches of the elderberry savanna type in the study area. Based on site conditions where this vegetation type does occur (i.e., silty, sandy soils on high floodplains along the American and Sacramento Rivers and along the San Joaquin River at Caswell State Park), extensive areas of this vegetation type would have likely occurred historically along the San Joaquin River study area, particularly in Reach 1B and Reach 2 where silty, sandy, well-drained floodplain and terrace soils would have occurred.

Exotic vegetation (giant reed and tamarisk) is present along the San Joaquin River in the study area; however, patches were too small (i.e., less than 5 acres) to be accurately mapped using the historical aerial photographs.

8.5.5.7. Herbaceous Riparian Vegetation and Marsh

"Herbaceous riparian vegetation and marsh" cover types includes two distinct components: a terrestrial component composed of annual and perennial herbaceous vegetation found on mesic sites within the floodplain of the river; and an aquatic component (tule and cattail marsh) dominated by emergent wetland vegetation. Characteristic herbaceous riparian species in the study area include Bermuda grass (*Cynodon dactylon*), sunflower (*Helianthus* spp.), cocklebur (*Xanthium strumarium*), goosefoot (*Chenopodium* spp.), and beggar's tick (*Bidens frondosa*). Characteristic marsh species include bulrushes (*Scirpus* spp.) and cattails (*Typha* spp.).

8.5.5.8. Grassland and Pasture

"Grassland and pasture" is an herb- and grass- dominated vegetation type that is typically dominated by annual species. Generally, sites with grassland or pasture are well drained and flood only occasionally under present-day hydrologic conditions. Most areas of grassland or pasture are above the frequently flooded zone of the San Joaquin River. The grassland and pasture vegetation type is composed of an assemblage of nonnative annual and perennial grasses, and occasional nonnative and native forbs.

8.5.5.9. Orchard and Vineyard

"Orchards and vineyards" are agricultural areas planted in vines or trees and used for the production of stone fruits, nuts, raisins, and table grapes.

8.5.5.10. Disturbed Land—Other

Land in the "disturbed land–other" cover type is land that has experienced some level of disturbance unrelated to agricultural cultivation or aggregate extraction. Common examples of the "disturbed land–other" category include areas used by off-highway vehicles and sites where rubble or fill has been deposited.

8.5.5.11. Disturbed Land–Former Aggregate Mining (Inactive)

The "disturbed land–former aggregate mine" cover type was mapped in areas that were formerly aggregate mines but now exist as dry or unvegetated open pits. Where former aggregate mines were vegetated or had standing open water, other cover types took precedence in the mapping; the category of formerly mined areas is, therefore, underestimated.

8.5.5.12. Aggregate Mining—Active

"Active aggregate mines" were mapped in areas of active aggregate extraction. Open water areas within active aggregate mining operations were mapped as open water, which is described above.

8.5.5.13. Other Industrial

The "other industrial" cover type was used for farm compounds and outbuildings not associated with aggregate mining.

8.5.5.14. Urban/Residential

The "urban/residential" cover type indicates areas developed for urban and residential land uses.

8.5.6. Classification Used to Map Present-Day Vegetation

DWR staff mapped existing riparian vegetation in the study area onto rectified 1998 aerial photographs and field verified these maps in the summer and fall of 2000. Detailed mapping methods are described in Moise and Hendrickson (2002). The aerial photographs for Reach 1 were in color and taken on September 2, 1998. The photographs for the remainder of the study area were taken on July 30, 1998, and were black and white. The summer of 1998 was relatively wet, which may have resulted in higher cover of wetlands than in a typical year. In addition, the 1998 aerial photographs were taken following the largest flood in the study area since the completion of Friant Dam. This flood, which occurred in January 1997, caused some minor shifts in the planform of the river.

Vegetation was mapped onto photo prints at a scale of 1:4,000 (1" = 333') with a minimum mapping unit of 0.3 acres or smaller. Woody vegetation units bordering herbaceous areas were extended to include a "zone of influence" of one-half canopy width. Woody vegetation was mapped as low density or moderate to high density. Low-density vegetation had an absolute canopy cover of less than 50%. Individual plants outside a stand were ignored if their distance to the stand exceeded two canopy widths.

Woody vegetation types were given a structural classification according to Hink and Ohmart (1984) (Table 8-3).

Table 8-3. Hink and Ohmart (1984) structural classification system for describing canopy height and understory.

Class	Description
1	Canopy height 40 feet or greater, dense understory
2	Canopy height 40 feet or greater, sparse understory
3	Canopy height 15–40 feet, dense understory
4	Canopy height 15–40 feet high, sparse understory
5	Canopy height less than 15 feet, dense understory
6	Canopy height less than 15 feet, sparse understory

Several important, invasive, exotic plants was mapped and generated as a separate GIS theme. The exotic plant species included in the GIS layer are scarlet wisteria (*Sesbania punicea*), giant reed (*Arundo donax*), eucalyptus (*Eucalyptus* sp.), tree-of-heaven (*Ailanthus altissima*), pampas grass (*Cortaderia* sp.), and edible fig (*Ficus carica*). A number of other invasive exotic species occur in the study area, but their occurrence was not systematically mapped. These species include Himalayan blackberry (*Rubus discolor*), white mulberry (*Morus alba*), castor bean (*Ricinus communis*), Lombardy poplar (*Populus nigra* var. *italiana*), and tamarisk (*Tamarix pentandra*) (Moise and Hendrickson 2002).

8.5.7. Present-day Vegetation Transect Methods

Section 8.6.3 (Existing Vegetation Composition) describes species composition, structure, and to the extent possible, the dynamics of vegetation under existing conditions along the San Joaquin River. Three recent data sets provided information for this description: a survey of riparian vegetation along the San Joaquin River by the DWR (Moise and Hendrickson 2002), and monitoring data from two sets of transects designed to document the response of vegetation to 1999 pilot project flows (JSA 2000, JSA and MEI 2002). These data sets and their use in this report are described below.

8.5.7.1. DWR vegetation transects

During July through October 2000, DWR staff collected data on the species composition and structure of vegetation along 125 transects located in 41 different mile-long segments of the river from Reach 1 to Reach 5 (Moise and Hendrickson 2002). These transects were subjectively located to represent the range of vegetation structure and species composition. They ranged in length from 11 to 428 meters, and passed through one or more of the vegetation polygons mapped in the GIS layer. The number of transects passing through each vegetation type and their combined lengths are summarized by reach (Table 8-4).

Three sets of data were collected along each transect: (1) herbaceous plant cover, (2) tree and shrub cover, and (3) tree diameter at breast height (DBH). The cover of each herbaceous species was recorded in 0.25 m^2 plots (0.71 m by 0.355 m) located every 5 m along the transect. Cover was visually estimated and recorded in the following cover classes, expressed as proportion of plot area: << 1%; <1 %; 1–5 %; 5–25 %; 25–50 %; 50–75 %; and 75–100%. Tree and shrub cover was recorded along the transect tape by measuring the length of tape covered by the vertical projection of the tree and shrub crowns of each species. DBH and species name were recorded for all stems >5 cm DBH, within 3 m of the transect tape. Thus, the tape served as the centerline for a 6-m-wide plot, in which tree diameters were recorded.

Descriptions of vegetation types were based on this DWR transect data. From the complete set of transect data in Appendix 1 of Moise and Hendrickson (2002), the absolute and relative cover were calculated for woody (trees and shrubs) and herbaceous plants, within each sampled vegetation type. Absolute cover is the percentage of woody and herbaceous plants relative to plot area or transect length; relative cover is the percentage of woody and herbaceous plants relative to the total cover of all plant species combined. For each tree-dominated vegetation type, the distribution of stem diameters was tabulated based on data in Appendices 1, 3, and 4 of Moise and Hendrickson (2002). Gradients along the river (from Reaches 1–2 to Reaches 4–5) are described where the data are adequate and indicate a gradient in the species composition or structure of a vegetation type. Because transect location was subjective, and the number of transects in a vegetation type varied among reaches and was often small, this data set did not provide a consistent basis for describing differences among reaches in the structure and composition of vegetation types. Therefore, transect data generally were not summarized by reach.

Table 8-4. Distribution of Moise and Hendrickson (2002) transects by vegetation type and river reach. "Total length" is the length of all transects that pass through a certain vegetation type, and "# of transects" is the total number of transects that pass through a certain vegetation type.

Vegetation Type	Reach 1		Reach 2		Reach 3		Reach 4		Reach 5		Total	
	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects	Total length (m)	# of transects
Agriculture	-	-	-	-	-	-	-	-	-	-	-	-
Cottonwood riparian forest	1,209	17	488	11	854	20	73	2	239	4	2,864	54
Disturbed	257	4	-	-	-	-	-	-	-	-	257	4
Elderberry	-	-	10	1	-	-	-	-	-	-	-	-
Exotic Tree	-	-	-	-	-	-	-	-	-	-	-	-
Giant Reed	61	2	-	-	-	-	-	-	-	-	61	2
Herbaceous	108	5	408	5	144	3	939	12	608	13	2,207	38
Mixed riparian forest	956	17	-	-	-	-	160	1	-	-	1,115	18
Riparian Scrub	36	2	248	6	-	-	226	4	11	1	521	13
Riverwash[a]	260	7	117	3	-	-	-	-	-	-	377	10
Valley Oak riparian forest	187	3					125	2	103	2	415	7
Wetland	47	2	23	1	45	3	123	3	158	5	396	14
Willow riparian forest	772	15	411	16	69	3	1,022	18	923	14	3,197	66
Willow Scrub	631	18	377	5	105	4	38	1	130	4	1,281	32

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

8.5.7.2. 1999-2001 Pilot Project

Additional sets of transects were established for monitoring the vegetation response in Reaches 1B, 2A, and 2B to pilot flow releases from Friant Dam in the 1999, 2000, and 2001 pilot project. In the 1999 pilot project, the goal of the flow releases from Friant Dam were to establish riparian vegetation on upper sand bar surfaces, primarily in Reach 2. Monitoring focused on evaluating whether managed flow releases promoted riparian tree growth along those subreaches that had very limited riparian vegetation due to long periods of dewatered conditions in the river, and at what locations vegetation established. In 2000, the goal of the pilot project flow release was primarily to maintain vegetation that had initiated during the previous years' pilot project release. In 2001, the goal of the pilot project flow releases was primarily vegetation maintenance and evaluation of hydrologic routing and shallow groundwater characteristics. The primary objectives of the monitoring was to evaluate vegetation at the beginning and end of the growing season, to determine the response of vegetation to augmented flows released into the San Joaquin River during the summer and fall of 1999-2001 (JSA and MEI, 2002a), and to evaluate and calibrate hydraulic and flow routing models. When widespread establishment of seedlings occurred in response to the flows, monitoring transects were installed to document their distribution, abundance, and subsequent growth and survival.

The first set of transects was established during September 1–5, 1999 (FWUA and NRDC 2002). These transects were resurveyed in November 1999 and April 2000. During 2000, additional permanently marked transects were established, for a total of 13 sites and 24 transects between River Miles 212 and 234.4 (Figure 8-1) (JSA and MEI 2002). Monitoring methods were also greatly revised in 2000 in order to better quantify vegetation changes. Transects were perpendicular to the channel and of varied length. They were monitored in 1999, 2000, and 2001 (JSA and MEI 2002, SAIC 2002). Transects were divided into 1-meter intervals, and data were recorded for all stems of woody species emerging from the ground surface within 1-meter of the transect line. Thus, each transect was treated as a series of 1-meter by 2-meter plots. At each study site, the following data was collected:

- Cross section geometry
- Water surface elevation in the channel
- Shallow groundwater surface elevation at one or more locations on each cross section
- Presence of riparian vegetation, plant numbers, plant size (size class), species, and cover class.

The presence of all species of vegetation was listed, and the cover of all species was documented at the cross sections; woody riparian vegetation was further quantified by documenting the numbers and species of all plants. Woody riparian plants were classified into three size classes: less than 1.5 meters tall; greater than or equal to 1.5 meters tall, but with stem less than 10 centimeters; and stem greater than 10 centimeters at breast height. Cover was characterized in six cover classes, ranging from zero to 100 percent cover, as well as an open water classification. At each site where permanently marked transects were located, the 2000 and 2001 densities of each woody riparian species were compared within the size classes, in order to evaluate establishment, growth, and mortality. This monitoring was conducted in the summers of 1999 (JSA, 2000), 2000 (JSA and MEI, 2002), and 2001 (SAIC, 2002).

Hydrology was monitored with a variety of techniques. Streamflow was estimated at the Gravelly Ford gaging station, discharge measurements were made at the Gravelly Ford gaging station, and spot discharge measurements were made at various locations in Reach 2 to evaluate gains and losses. Water surface elevations at cross sections were manually observed from staff gages, and shallow groundwater elevations were monitored by hand measurements in alluvial groundwater wells and instream and floodplain piezometers through 2002; pressure transducers and continuous water stage recorders monitored shallow groundwater elevations thereafter.

8.6. HISTORICAL AND EXISTING CONDITIONS

This section begins with a description of the likely conditions of the San Joaquin Valley from the early 1800s until the 1930s. Changes initiated by the Spanish/Mexican settlement began in Southern California in the late 1700s, and reached the San Joaquin River study reach during the early 1800s. Prior to the 1770s, Native American populations were sparse and their impact was comparatively modest. The tempo and magnitude of change increased dramatically in the years following 1848, when the Gold Rush began. Later subsections discuss the land use changes that can be measured after 1937, when the first known complete set of air photographs was flown. This analysis evaluates and compares habitat conditions in 1937, 1957, 1978, and 1993, and 2000, when relatively complete photographs of adequate resolution were available and quantitative estimates of habitat area could be made. This section concludes with a detailed description of present day conditions, including descriptions of plant communities present. Present-day conditions are based on air photo interpretation done using rectified air photos flown in 1998, supported by extensive vegetation field work conducted in 2000 by DWR and the restoration program.

8.6.1. Conditions Prior to 1937

Prior to the early 1800s, human impacts on the riparian systems in the San Joaquin Valley were limited to Native American activities (fishing, hunting, gathering, burning of grassland and marsh habitats to promote wildlife and desired food plant species). Early explorers and surveyors characterized the San Joaquin Valley outside of the riparian and marsh areas as a treeless plain, with extensive areas of grassland and alkaline soils, and very hot temperatures during summer. The historical written descriptions of pristine (pre-1800) vegetation along the San Joaquin River above the confluence with the Merced River are anecdotal, and refer mostly to extensive areas of tule marsh, especially along the axis of the San Joaquin Valley, with locally prevalent groves of riparian forest, the latter generally along stream and slough channel margins. The overall extent of riparian vegetation and wetlands was expansive (Figure 8-2). The general character of the historical riparian vegetation has been assumed to be similar to existing remnant patches of well-developed riparian vegetation, although the validity of this assumption has not received critical evaluation.

The impact of livestock grazing by the Spanish and Mexican ranchers began in the early 1800s following Lieutenant Gabriel Moraga's initial explorations of the San Joaquin River area, after the Mission San Juan Bautista was founded in 1797 (Rose 2000). Grazing by cattle, sheep, and other livestock introduced by the Spanish and then by Mexican ranchers is believed to have created profound changes in the landscape during the early 1800s. Grazing led to reductions in the dominance of palatable plant species, including native perennial and annual grasses; the introduction of livestock also led to the explosive spread and dominance of exotic annual grasses and forbs throughout the valley. Landscapes formerly dominated by native perennial and annual grasses and forbs were overrun with these exotic species, which were pre-adapted to the climate and had evolved with domestic livestock. The introduced livestock undoubtedly had effects on riparian vegetation through trampling, browsing, and spreading of exotic plant species, as well as causing bank erosion and water quality degradation during low flow periods.

By the 1830s, American and French Canadians entered the San Joaquin Valley and hunted beavers, mink, and river otter (Preston, 1981), leading to the near eradication of these species. Beavers had substantial effects on riparian zones. Their dams impound water and create shallow flooded areas, affecting vegetation, hydrology, and movement of fish and wildlife. Beavers' felling and removal of trees for food and construction led to profound changes in the local vegetation. The ecological effects of beaver eradication have not been specifically documented for the San Joaquin Valley, but are likely to have been significant.

After the Gold Rush began, human settlement in the San Joaquin Valley developed rapidly, and encouraged activities such as timber cutting (for steamship fuel and for construction), upstream gold mining, agriculture, water diversions, and water development. These activities initiated dramatic changes in the riparian corridor (Figure 8-3).

The general picture of the valley floor is riparian forest and scrub vegetation along the main river channels, especially on elevated surfaces of fine sediment deposited along the channel margins during flood overflow events (when water leaving the channel would drop sediment as it spread over the land). These localized zones of woody riparian vegetation were flanked by extensive tule marshes that formed where overflow waters spread over the nearly flat flood basin. The outer limit of the tule marshes was flanked by saltbush or grassland (prairie) communities; the tule marsh limits approximately coincided with the boundaries of the natural flood basin (Fox 1987a). These marshes would sometimes dry up in the late summer or fall, and extensive areas would sometimes burn under these conditions, according to accounts of early travelers. An 1850 reconnaissance map of Tulare Valley by Derby (1852) implies that the dominant vegetation was tule marsh in Reach 2 and 3 (Figure 8-4). Derby's map on the San Joaquin River does not include Reaches 4 and 5, and the mapping shown on the San Joaquin River should be treated with caution because of the large scale of the map, and that the map was prepared for the Tulare Lake basin rather than the San Joaquin River basin. This small-scale map does not illustrate woody riparian vegetation along the San Joaquin River (although it is shown on the Kings River and others draining into Tulare Lake), suggesting that under unimpaired conditions, the zone of woody riparian vegetation and associated oak woodland was narrow compared to that of other large rivers draining into the Central Valley. This is possibly because of the confining bluffs along most of Reach 1, extending from Friant Dam to the valley floor. These bluffs limit the potential area where riparian and oak woodland can grow. In contrast, the Kings River and Kaweah River enter the valley on extensive alluvial fans formed by flood deposits from migrating major and minor channels. These fans offer extensive areas with conditions suitable for extensive riparian forest and oak woodlands. An additional map by Nugen (1853) corroborates Derby's map with regard to the extensive tules in the Tulare Lake Basin and in Fresno Slough. Nugen's larger-scale map also shows a band of woody riparian vegetation along Reaches 1 and 2 (Figure 8-5), but does not show the lower reaches of the river. Nugen's map also shows extensive plains beyond the riparian and tule marsh boundaries. This map corroborates numerous descriptions by early explorers of the treeless nature of the plains away from the banks of the San Joaquin River. For example, Brewer (1949) describes the plains on the west side of the San Joaquin River:

> *"From a nearby hill yesterday we could look over an area of at least two hundred square miles and not see a tree as far as the river, where, ten miles off, there is a fringe of timber along the stream"*

Carson (1950) (as summarized in Fox 1987b) describes Reach 3 through 5 in the 1846-1852 era as follows:

> *The Mariposa, Chowchilla, and Fresno Rivers may be classed with the Calaveras, being running streams during the rainy season and spring only. These streams do not enter directly into the San Joaquin, but their united waters form the immense tule marsh between the bend of the San Joaquin [assumed to be at Mendota] and the mouth of the Merced; the water thus collected enters in the San Joaquin at many different points during high water"*

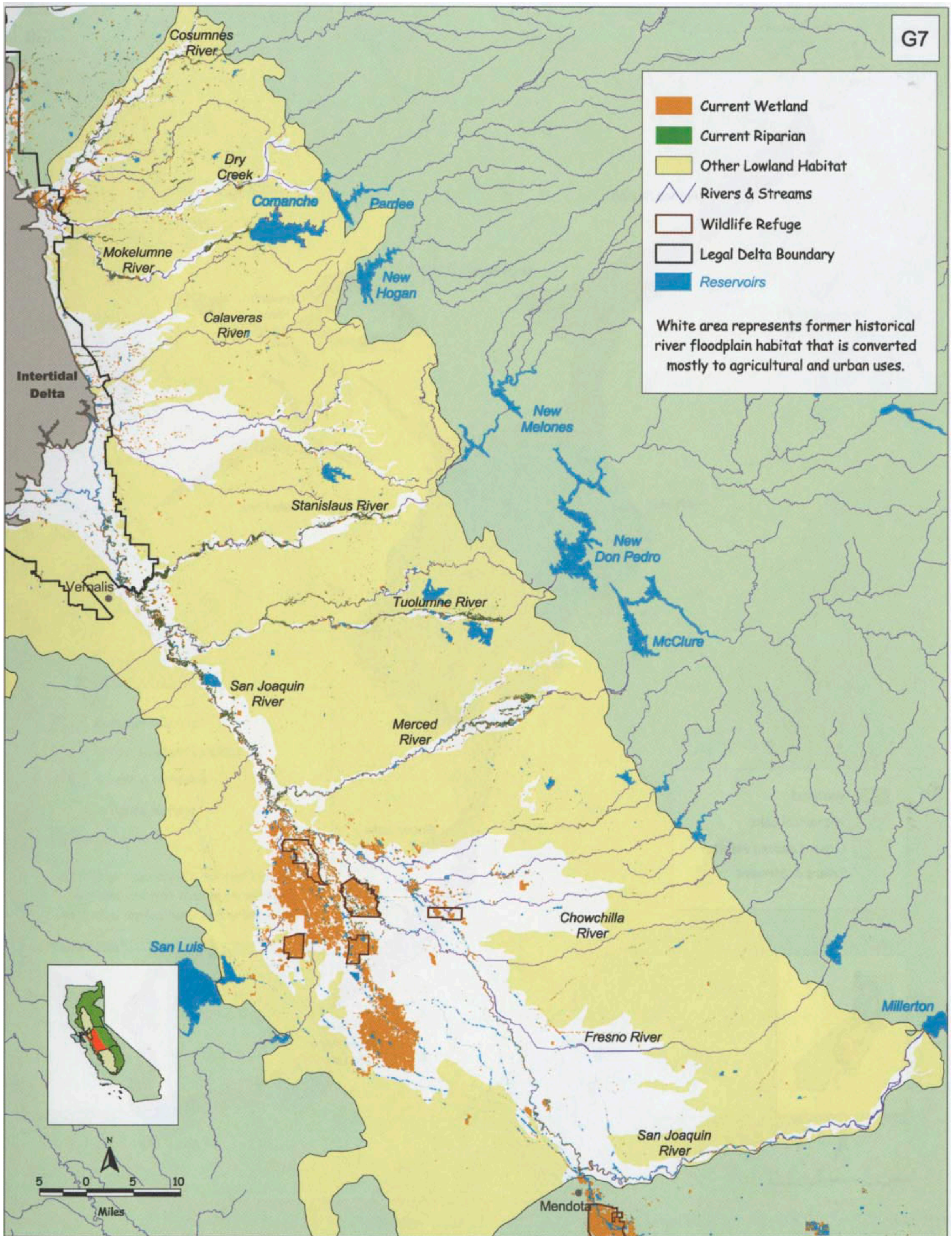


Figure 8-3. San Joaquin Valley current river floodplain ecosystem (from The Bay Institute, 1998).

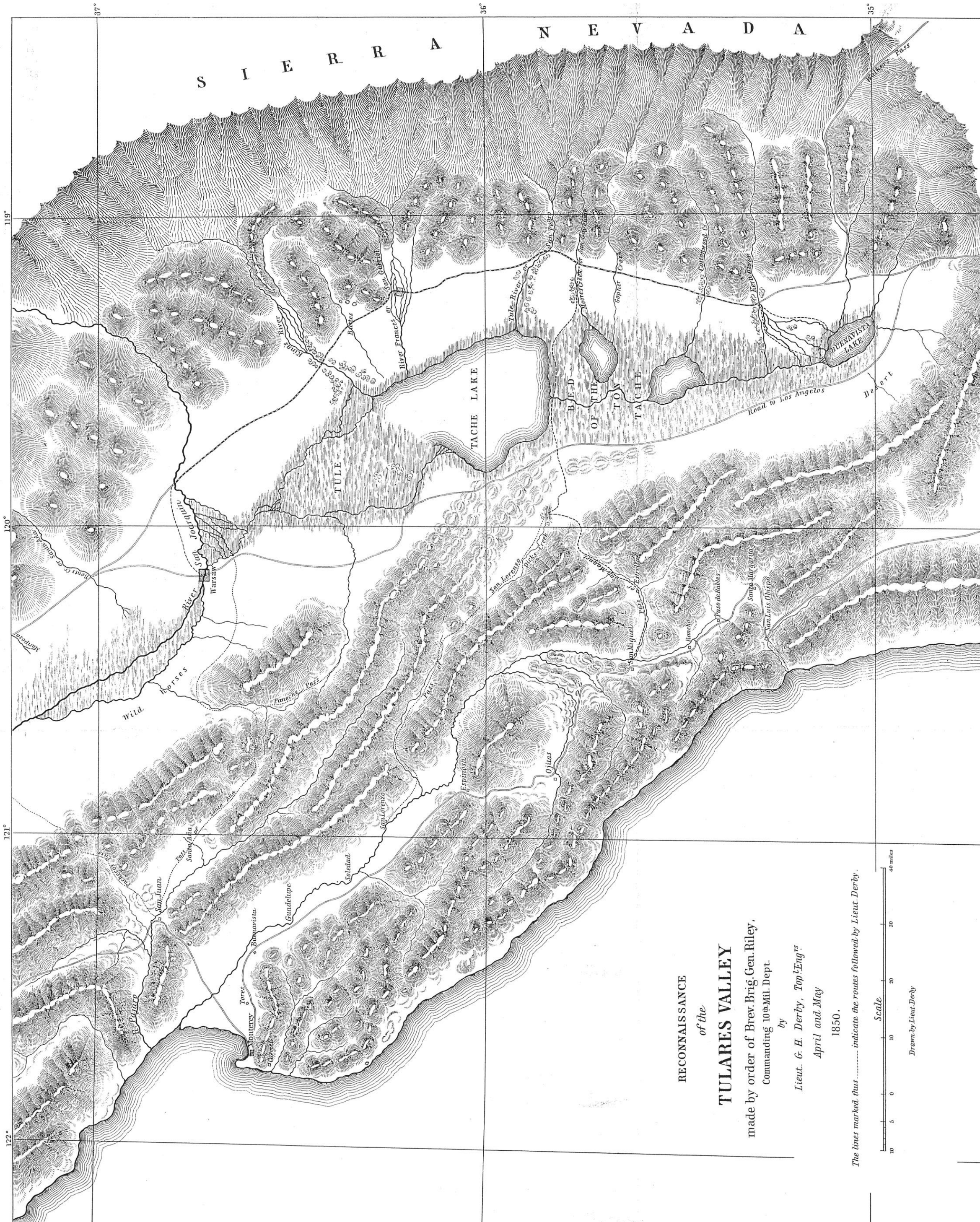


Figure 8-4. Reconnaissance map of the Tulare Valley, showing extensive tule marshes along the San Joaquin River, sloughs diverging from Reach 2 of the San Joaquin River into Fresno Slough, and no mapped woody riparian vegetation along the San Joaquin River (from Derby 1850).

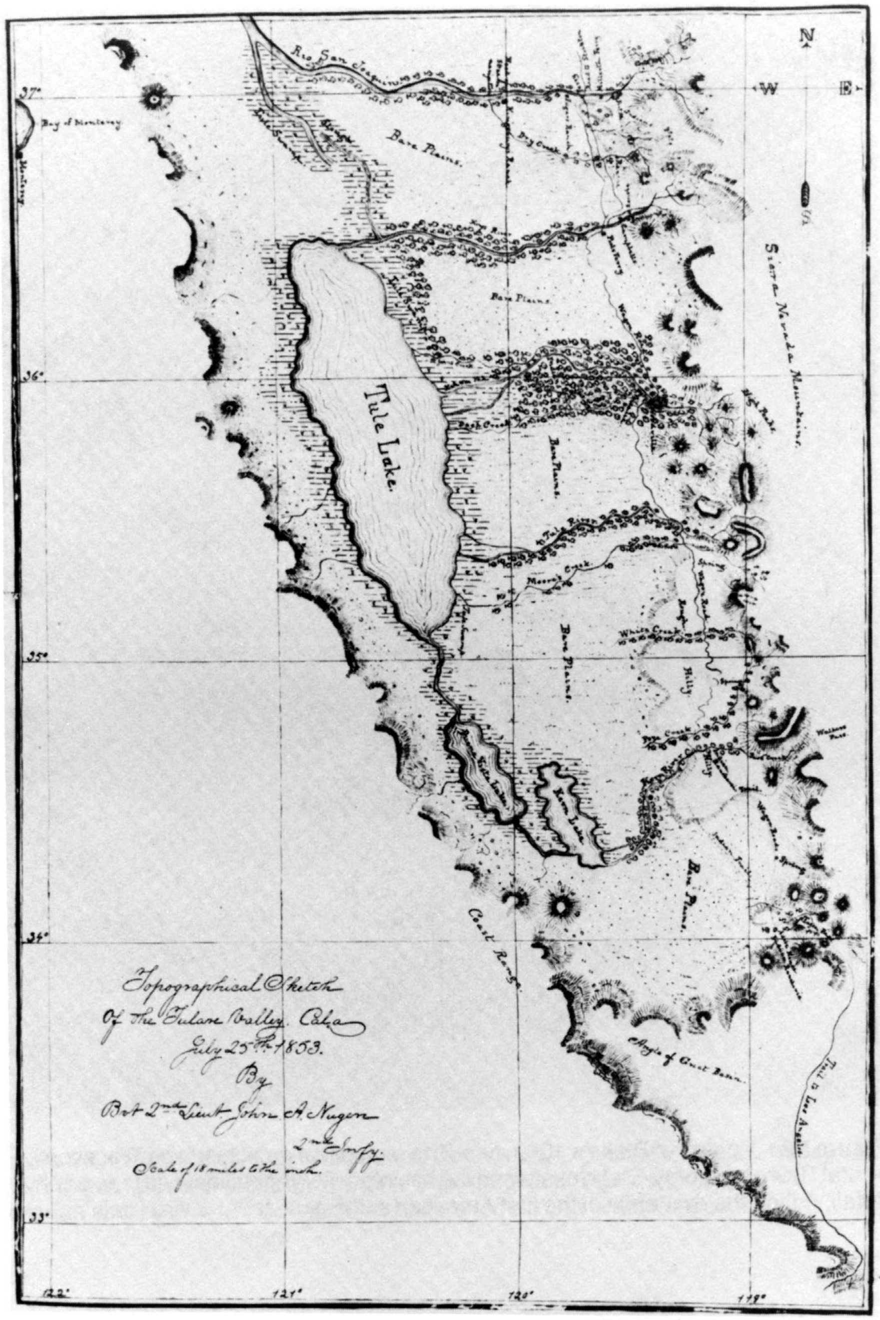


Figure 8-5. Topographical sketch of the Tulare Valley, showing tule marshes, sloughs diverging from Reach 2 of the San Joaquin River into Fresno Slough, and a thin band of woody riparian vegetation along Reach 1 and 2 of the San Joaquin River.

The Moraga expedition of 1806 (as summarized in Fox 1987b) describes the San Joaquin River near Santa Rita (Reach 4):

> *"There are also great tule swamps in all this region and much black willow along the stream. On all sides [of two stream beds] tremendous tule swamps present themselves, which can be very miry in wet years"*

Finally, the Fremont expedition in 1844 (as excerpted in Fox 1987b, and TBI 1998) describes the San Joaquin River in April moving upstream from the Merced River confluence (Reach 5):

> *"Here the country appears very flat; oak trees have entirely disappeared, and are replaced by a large willow nearly equal in size [probably black willow]… The river was deep, and nearly on a level with the surrounding country; its banks raised like a levee, and fringed with willows… After having traveled fifteen miles along the river we made an early halt under the shade of sycamore trees…Late in the afternoon we discovered timber, which was found to be in groves of oak-trees on a dry arroyo… Riding on through the timber… we found abundant water in small ponds… bordered with bog-rushes (Juncus effusus) and tall rush (Scirpus lacustris) twelve feet high, and surrounded near the margin with willow-trees in bloom; among them one which resembled Salix myricoides. The oak of the groves was the same already mentioned, with small leaves, in form like those of the white oak, and forming, with the evergreen oak, the characteristic trees of the valley:*

The large valley oak woodlands typical in the Sacramento Valley and terraces of rivers exiting the Sierra Nevada foothills did not appear to exist in the San Joaquin Valley plains in Reaches 2 through 5. Fremont's narrative suggests that the oaks occurred on tributaries and sloughs (e.g., Bear Creek, which joins the San Joaquin River about 15 miles upstream from the Merced confluence), but were not extensive along the San Joaquin River channel. It is also possible that the trees were on a high flow channel or slough between anastomosing channels of the San Joaquin River approaching the Merced confluence. Additionally, review of 1855 Government Land Office plat maps did not indicate that valley oaks were along the river. The U.S. Meander Lines surveyed by the Government Land Office typically use larger trees (valley oak and cottonwood) for "witness" trees; review of these maps in Reaches 2 through 5 show that all witness trees are willows, not valley oak or cottonwoods.

From several sources, Fox (1987a) postulated the extent of tule marsh and its relationship with saltbush and prairie communities on the valley floor (Figure 8-6). This map was compiled from sources that used varying lines of evidence (such as existing vegetation, soils, topography, patches of remnant vegetation, hydrology, climate, ecological requirements of the dominant plant species, and historical information). For the San Joaquin River drainage, this map closely resembles that of Kuchler (1977) that portrays potential natural vegetation not appreciably disturbed by humans.

The historical river floodplain ecosystem map (Figure 8-2) was based principally on mapped soils and geologic information (e.g., quaternary stream deposits) coupled with historical information. Figure 8-2 was a collaborative effort between TBI (1998) and Fox (personal communication 2002), thus supercedes Figure 8-2. Figure 8-2 identifies the area that could have been occupied by riparian woodland and forest sometime during the last 10,000 years (TBI 1998). This riparian vegetation estimate exceeds the amount that would likely have been present, at any one time, during that period.

Thompson (1961) described the major streams of the Sacramento Valley as bordered by well-developed riparian forests and woodlands, occurring on the coarse alluvium of natural levees and river terrace deposits. Sub-irrigation, fertile alluvial loam soils, and relative freedom from surface

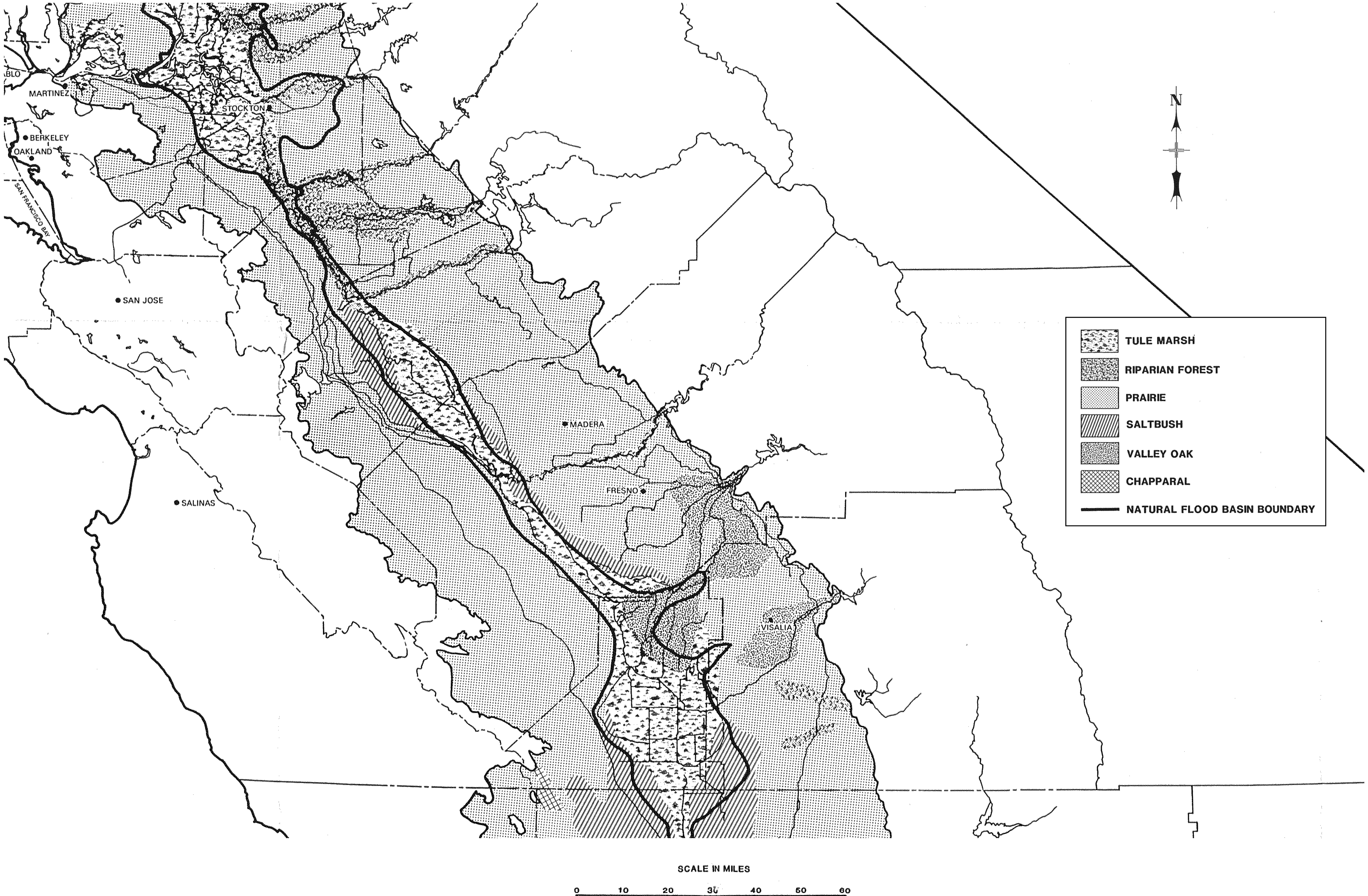


Figure 8-6. Natural vegetation and flood basins of the California Central Valley, based on compilations of maps by Kuchler (1977), Roberts et al. (1977), and DWP (1931).

waterlogging and fire were major factors contributing to their presence (Thompson 1961). Thompson correlated remnant riparian patches with historical evidence contained in diary accounts of early Central Valley explorers to conclude that the remnant patches did indeed reflect the historical conditions.

By applying Thompson's assumptions to the San Joaquin River, it can be deduced that the low and high floodplains in Reach 1 were probably vegetated by a winter deciduous broad-leafed riparian forest characterized by Fremont cottonwood, several species of willow, sycamore, box elder, Oregon ash, valley oak, buttonwillow, wild grape, California blackberry, and clematis. This assumption was validated by recent field observations and limited historical references. Photos from 1911, remnant vegetation, and accounts from old-timers suggest that sycamore and cottonwood were extensive along the lower portions of Reach 1 and the upper portions of Reach 2 (Cain 1997; Cain, personal communication, 2002). Nelson et al. (1918) described native vegetation occurring on Hanford series soils (the only recently deposited alluvial soil mapped along the San Joaquin River at that time) as including a moderate to heavy growth of willows, native vines, and cottonwoods that added considerable cost to land clearing for agricultural conversion.

The California Debris Commission Map of the San Joaquin River from Herndon to the Merced River (ACOE 1917) shows extensive areas of brush in the riparian zone, which likely represent willow vegetation associations; however, whether cottonwood was a significant component in this vegetation is unclear. Assuming the California Debris Commission maps represent unimpaired conditions needs to be done with caution, because extensive cattle grazing and fuel wood harvesting had been occurring for over 50 years prior to creation of the California Debris Commission maps, and agricultural manipulation of the river corridor was rapidly occurring (as suggested by numerous diversion canals shown on the maps).

While valley oak was not a dominant tree in the active floodplain, it probably was the dominant tree of young terraces and fans in Reach 1. Other less water-dependent riparian trees, shrubs, or vines, (including sycamore, Oregon ash, box elder, blue elderberry, blackberry, poison oak, grape, clematis, and wild rose) probably also were present. Remnants of dense rose and grape thickets are still evident today in Reaches 2, 3, and 4. Hall (1880) wrote a description of the vegetation along the Kings River (which contains similar recently deposited alluvial soils but is less arid than the San Joaquin River in Fresno County):

> *"thick growth of valuable timber composed principally of oak, with some cottonwood and willows, which latter are found immediately along the riverbanks, while the former extends out on the plains for several miles each side of the river. The soil within the timber belt is rich and productive upon compare. This extensive belt of woodland forms one of the most prominent and anomalous features upon the face of the country."*

In contrast to the broad and unconfined alluvial fan geomorphology along the Kings River, which supported wide expanses of oak woodland flanking the riparian forest where it flowed out of the mountains into the valley, the equivalent portion (Reach 1) of the San Joaquin River was limited to a much narrower zone of woodland and forest due to topography and soils. From Friant Dam downstream to near Gravelly Ford (Reach 1), the San Joaquin River is deeply incised below a Pleistocene-age terrace composed of paleo-alluvial fan sediments (Janda 1965). In this reach, the San Joaquin River floodplain is confined by bluffs to a relatively narrow-steep-sided valley, typically less than one mile in width (from data in Cain, 1997). Outside of the valley bottom, the arid habitat is unsuitable for woodland growth and probably supported grassland vegetation. The early explorer maps are consistent with this description (Figure 8-5).

In the reach below Firebaugh (Reach 3), the floodplain contained a narrow band of coarser riparian soils that form a complex association with finer riparian soils associated with the historical tule marshes. The mapping of riparian soils was limited mostly to the recently deposited alluvial soils occurring next to the river, even though the same soils may also occur away from the river but are separated by basin clays or clay loams. Minor areas of clay loam, however, were included in the riparian soil category if they occurred between a major slough (e.g., Pick Anderson Slough) and the San Joaquin River. The vegetation in the river reach below Firebaugh probably was a complex of cottonwood, willows, buttonwillow, and tules, with the taller woody species being localized and limited to the coarse-textured soils of higher ground, natural levees, or around the margins of oxbow lakes. Hall's *Topographic and Irrigation Map of the San Joaquin Valley* (1886) mapped swamp and overflowed lands up to 6 miles wide in this area (see Figure 4-6). Government Land Office plat surveys (circa 1855) map the areas as "overflowed willow swamp or tule swamp." A local newspaper, the *San Joaquin Democrat*, reported tules as far as the eye could see in an article from the 1860s (McKown, personal communication). The picture emerging from these different accounts is one of bands of woody riparian vegetation in a sea of tules.

Katibah (1984) emphasizes the relative scarcity of natural levees along the San Joaquin River after it reaches the valley floor (Reaches 4-5), a result of low natural sediment loads, compared with the extensive natural levees of other systems such as the Sacramento. The modest development of natural levees along portions of the San Joaquin River traversing the Valley bottom would have limited the habitat that could have been occupied by woody riparian vegetation. Prolonged inundation by floodwaters would have precluded growth of riparian forest in the flood basins. Fremont's accounts (described above) describing "levee-like banks fringed with willows" are not inconsistent with Katibah's because the scale of the levee-like banks are small compared to other lowland Central Valley rivers. Other systems such as the Sacramento River are characterized by well-developed natural levees created by flood deposited sediments. These natural levees, which ranged from 5-20 feet above the elevation of the surrounding flood basins and averaged 3 miles in breadth along the Sacramento River (Thompson 1961, in Katibah 1984) tended to contain the seasonal floodwaters during drier years and provided habitat for riparian and oak forest. The naturally low sediment loads along the San Joaquin River are attributed to relatively low-energy peak flows (Katibah 1984) and to significant inputs of essentially sediment free water (groundwater, overflow water from the Kings River, and San Joaquin River water that has deposited most of its sediment load by the end of Reach 2 and 3). With regard to the portion of the river between Fresno Slough (Mendota) and the confluence with the Merced River, Katibah (1984) states:

> *With no natural levees to contain its waters, the San Joaquin River spread out over the flat valley floor*

Quantitative studies of the historical riparian habitat in the San Joaquin River Basin have generally been based on anecdotal accounts of early travelers, historical maps, or historical and contemporary soil maps. Dawdy (1989) quotes several travelers' logs from the 18th and 19th centuries in which the lower San Joaquin River Basin is described as having extensive fields of tules with scattered willows in the river bed and "some nice groves of willows" at the confluence of the Merced and San Joaquin Rivers. Dawdy (1989) also points out that estimates of the extent of pristine riparian vegetation in the San Joaquin River Basin vary widely, from as little as a conservatively estimated 187,500 acres (Katibah 1984) to as much as 298,000 acres (Fox 1987b, in Dawdy 1989). More recent estimates in TBI (1998) based on soil surveys of the San Joaquin River Basin from Friant to the Delta resulted in an estimate of approximately 286,000 acres of potential riparian vegetation (329,000 acres of riparian soils minus 43,000 acres of wetlands within riparian zone). No quantitative estimates of potential riparian habitat were made for the study area (Friant to Merced River), but qualitative review of Figure 8-2 suggests that slightly greater than ½ of the 286,000 acres was within the study area. Fox (personal communication 2002), collaborated on this effort, which supersedes her 1987 estimates of the extent of riparian and wetland vegetation. Kuchler (1977) published a map of "potential natural" vegetation in California at a scale of 1:1,000,000. Kuchler's mapping of the study area conforms to an 1886 map by Hall that shows "swamp and overflowed" lands (mainly tule marsh) along the river north (downstream) of Mendota and "bottom lands" (woody riparian habitat) between Friant and Gravelly Ford (see Figure 4-6).

During and after the Gold Rush, the intensity of human disturbances along the San Joaquin River and other Central Valley systems increased dramatically. Placer gold mining, dredge mining, flood control activities and diversions, and agricultural encroachment all had substantial effects on the river systems (Fox 1987a; Roberts et al. 1977; Warner 1985). Logging for fencing, construction lumber, and steamship fuel, also affected riparian zones, which were the only source of wood on the floor of the valley. Early steamships periodically traveled up river from Stockton to points within the study reaches, including near the Merced River confluence, Firebaugh, Salt Slough, Fresno Slough, Herndon; and occasionally a steamship made it as far upstream as the present day location of Rank Island (RM 260, approximately seven miles downstream of Friant Dam). Although some steamboats were designed to use coal as fuel, they were periodically forced to use trees such as ash or willow from the riverbanks, leading to the deforestation of streamside vegetation. Early accounts cited in Rose (2000) relate the difficulty and time-consuming nature of obtaining wood to fire the boilers while traveling upriver.

Agricultural colonies were established in the San Joaquin Valley in the 1860s, with settlers pooling resources to establish irrigation projects. The hydrology of the San Joaquin River began to be affected by a system of canals and diversions to supply irrigation water and by high water bypasses that reduced the flood potential along the mainstem river (JSA and MEI 1998). In the 1870s, Mendota Dam was established and a major canal was constructed to irrigate the west side of the valley. Artesian wells were constructed throughout the valley in the 1880s and the use of electric and natural gas pumps spread during the 1890s as water tables declined. By the 1870s, railroad service had reached Modesto and Bakersfield (north and south of the study area, respectively, and by 1892, it had reached Fresno, greatly facilitating commerce and export of agricultural products and demise of riverboats.

By 1913 to 1914, the California Debris Commission (ACOE 1917) prepared a series of survey maps that encompassed the area from Herndon (RM 243) downstream to the confluence with the Merced River. The maps document extensive development of canals and other land use changes in the immediate vicinity of the river, affecting the riparian zone. During this time, dams, diversions and canals continued to be developed or improved, and the number of wells in the valley increased dramatically. Reclamation of wetland and riparian areas to agricultural lands became extensive. All of these factors directly or indirectly affected the vegetation and hydrology of the valley.

These historical references lead to the following conceptual model of historical conditions:

- Reach 1 and potentially portions of Reach 2 consisted of bands of woody riparian vegetation (alders, willows, cottonwoods, sycamore, and valley oak) along the floodway of the San Joaquin River corridor, typically in discontinuous patches along high flow scour channels and side channels closer to the groundwater table. Valley oak occurred on terraces primarily in Reach 1.
- Reaches 2 through 5 consisted of bands of woody riparian vegetation (in places perhaps exclusively black willow) along the margins of the San Joaquin River channels and sloughs,

with extensive tule marshes in the flood basins beyond the narrow (typically less than 2,000 feet wide) riparian bands. In these reaches, woody riparian vegetation probably also grew on higher ground along the margins of sloughs, oxbow lakes, and minor natural levees along abandoned channels.

This general conceptual model is discussed in more detail for the five reaches in the following section.

8.6.2. Historical Trends 1937–Present

In the mid-1940s, Friant Dam and associated diversion canals became operational and population growth and development continued in the region. The Delta-Mendota Canal became operational in the early 1950s, bringing water from the Delta back into the San Joaquin River at Mendota Dam. To provide estimates of the changes in riparian vegetation over this period, JSA (1998) mapped vegetation/land cover from 1937 aerial photographs (Figure 8-7); they also mapped vegetation/land cover for 1957, 1978, and 1993. A 1998 air photo was used by DWR to develop the most recent vegetation/land cover map (Figure 8-8) (Moise and Hendrickson, 2002). The 1937 and 1998 vegetation/land cover maps use different classifications; Table 8-2 illustrates these differences and attempts to correlate the classifications to make the two maps more comparable. To reduce differences in mapping methods and classification systems used by JSA (1998) for 1937–1993, and by DWR for 1998 (Moise and Hendrickson 2002), habitat types and land use categories were combined into broad categories for use in the following analysis.

Areas of riparian habitats and land use types within the study corridor width described in Section 8.3 dramatically changed between 1937 and 1998 (Tables 8-5 to 8-13; Figures 8-9 to 8-17). Changes in riparian features such as sloughs that extend further away from the main channel are not reflected in this analysis.

Acreage figures given in Moise and Hendrickson (2002) covered a larger study area than that covered by JSA (1998); reach boundaries were also slightly different. Even when broad habitat categories are compared for 1993 and 2000 over the same areas, differences in mapping methodology between JSA and DWR become apparent.

One difference in mapping methods was that DWR mapped riparian forest polygons including a "zone of influence" of one-half canopy width, while JSA used a "smoothed-out" canopy outline to determine the boundary of riparian forest. This may have resulted in a higher riparian forest area estimate from the DWR data than from the JSA data.

A second major difference in mapping methods was the minimum mapping units used in the two studies. JSA (1998) used a 5-acre minimum mapping unit for riparian habitats and wetlands, and a 20-acre minimum mapping unit for other cover types; this was appropriate for their unrectified low-resolution historical aerial photographs. DWR used a 0.3-acre minimum mapping unit, which was appropriate for their high-resolution rectified aerial photographs. In areas where many small polygons occur, such as riparian and wetland habitat in Reach 5, this minimum mapping unit difference would result in higher estimates from DWR data than from JSA data.

The distribution of habitat types in the 53,400-acre vegetation study area changed dramatically between 1937 and 1998 (Table 8-5, Figure 8-9), reflecting large changes in land use and physical and biological processes. The degree of change varied substantially between reaches due to differences in hydrology, geomorphology and land use. The 1937 habitat types in Table 8-5 do not imply pristine conditions; habitat types had already been drastically changed by 1937.

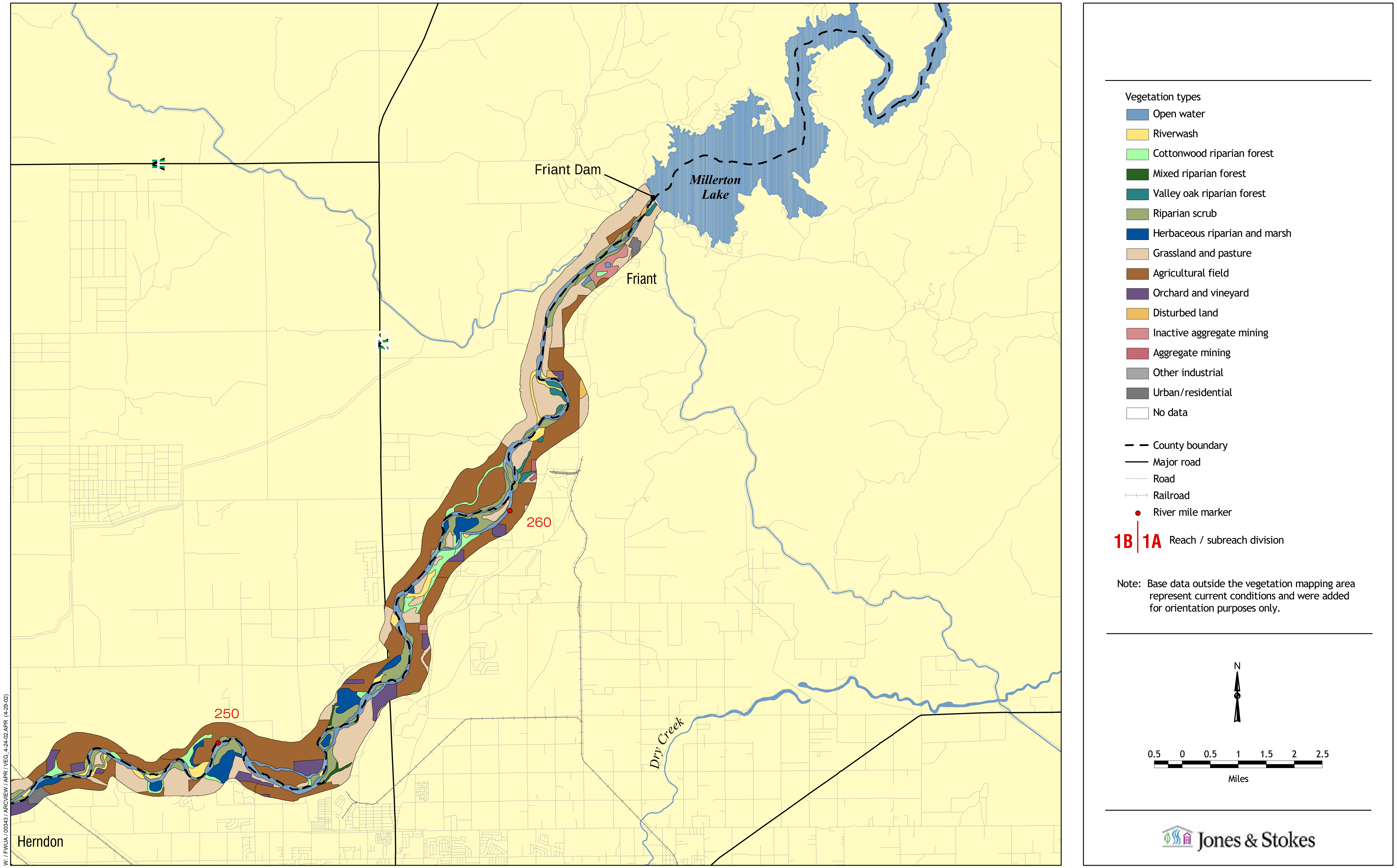


Figure 8-7. Vegetation types along the San Joaquin River in 1937 (JSA 1998a).

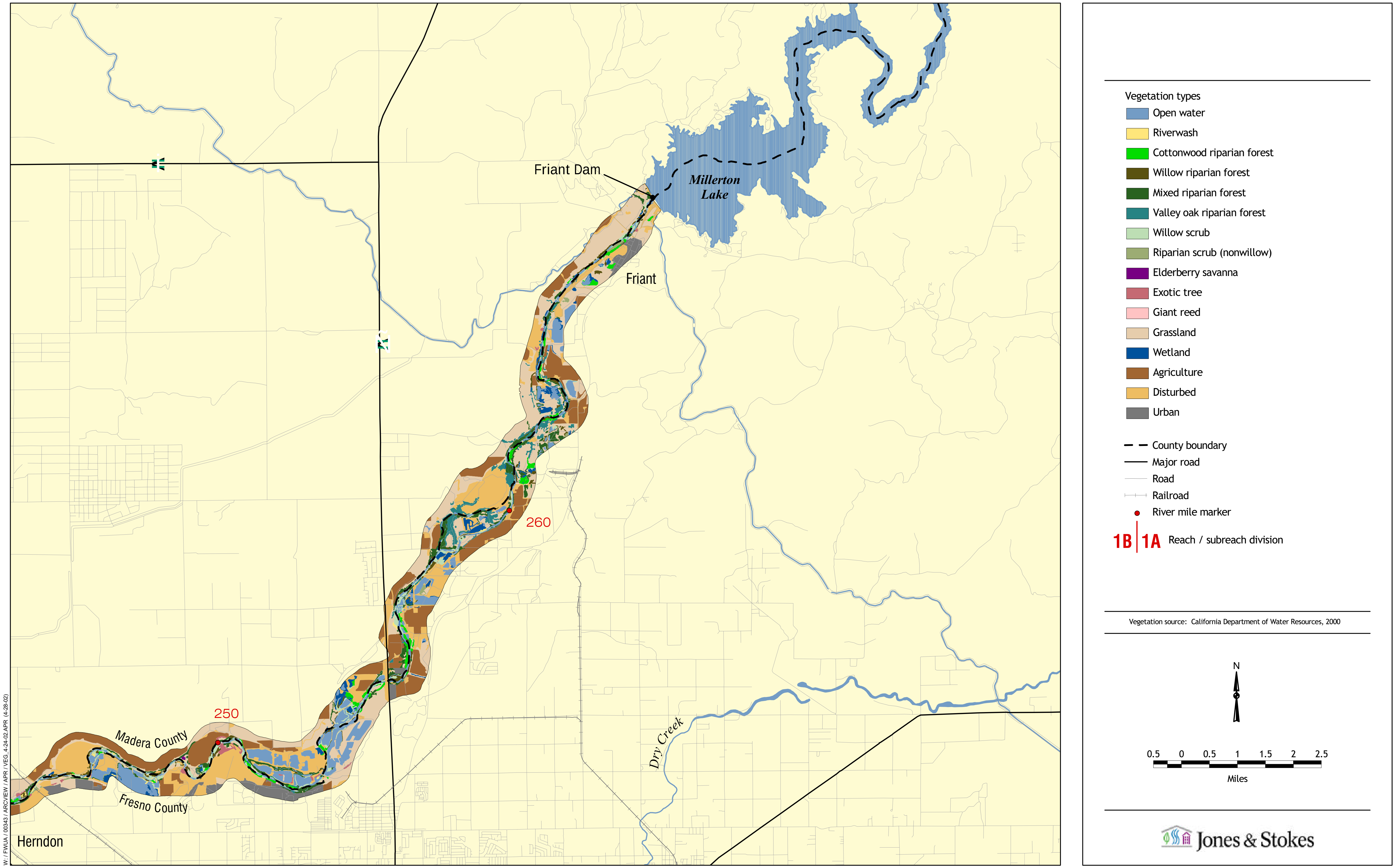


Figure 8-8. Vegetation types along the San Joaquin River in 1998 (Moise and Hendrickson 2002).

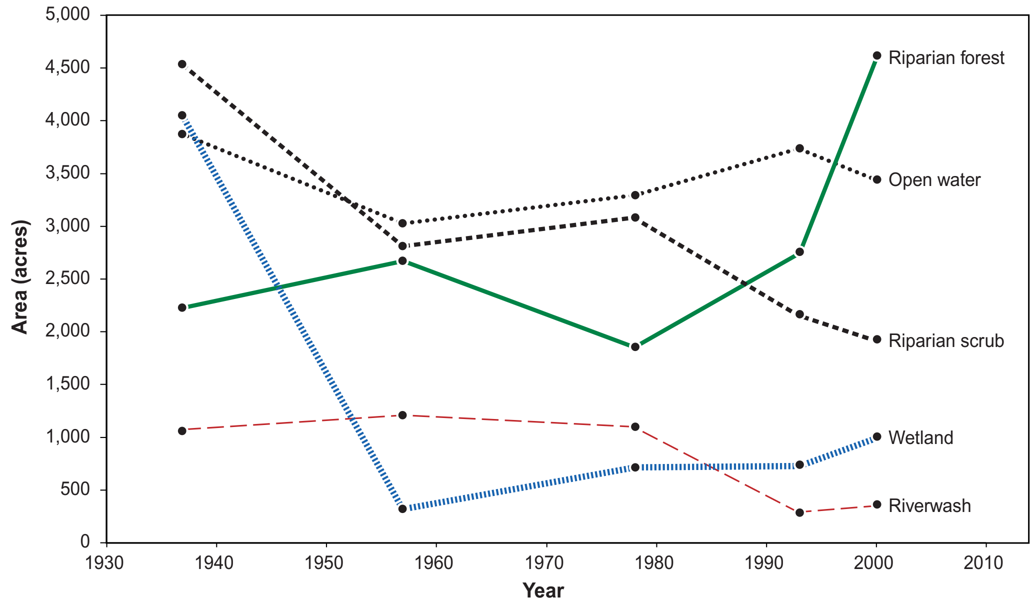


Figure 8-9. Change in vegetation area from 1937-1998 over entire study area (all reaches, Friant Dam to Merced River confluence). Data plotted as 2000 data were mapped on 1998 air photos.

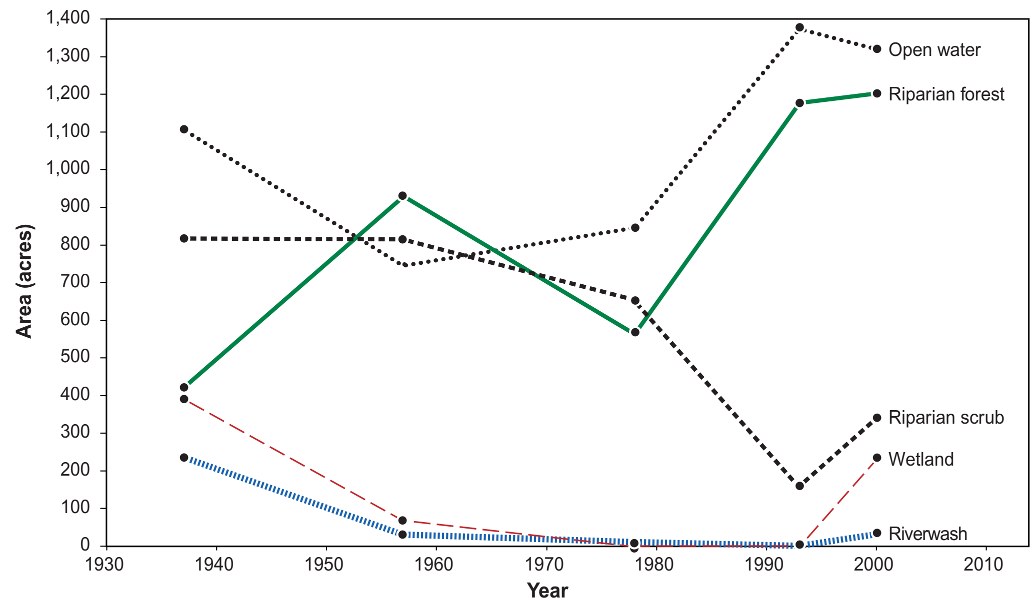


Figure 8-10. Change in vegetation area from 1937-1998 over Reach 1A (Friant Dam to Herndon). Data plotted as 2000 data were mapped on 1998 air photos.

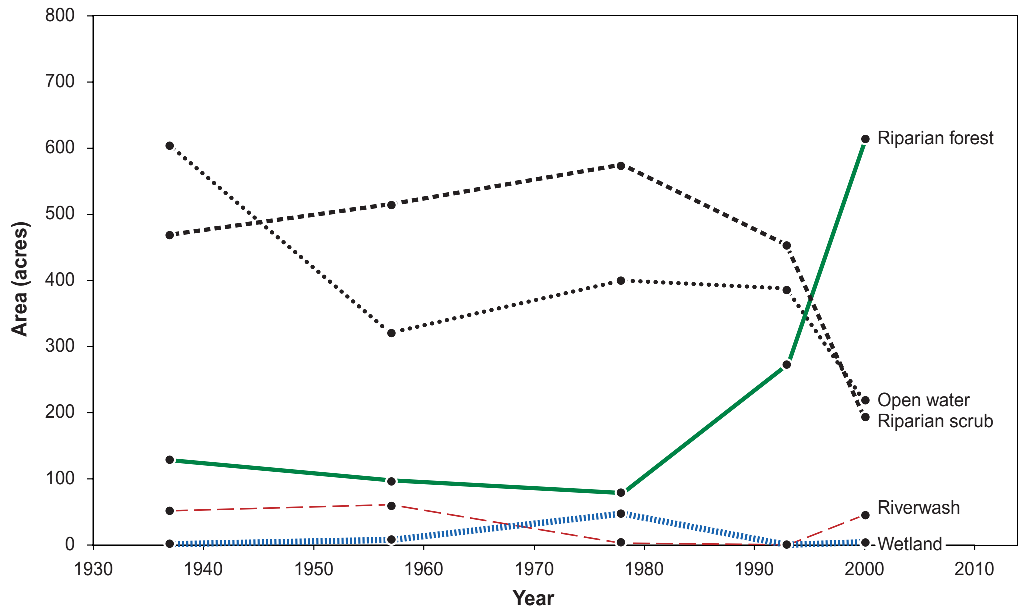


Figure 8-11. Change in vegetation area from 1937-1998 over Reach 1B (Herndon to Gravelly Ford). Data plotted as 2000 data were mapped on 1998 air photos.

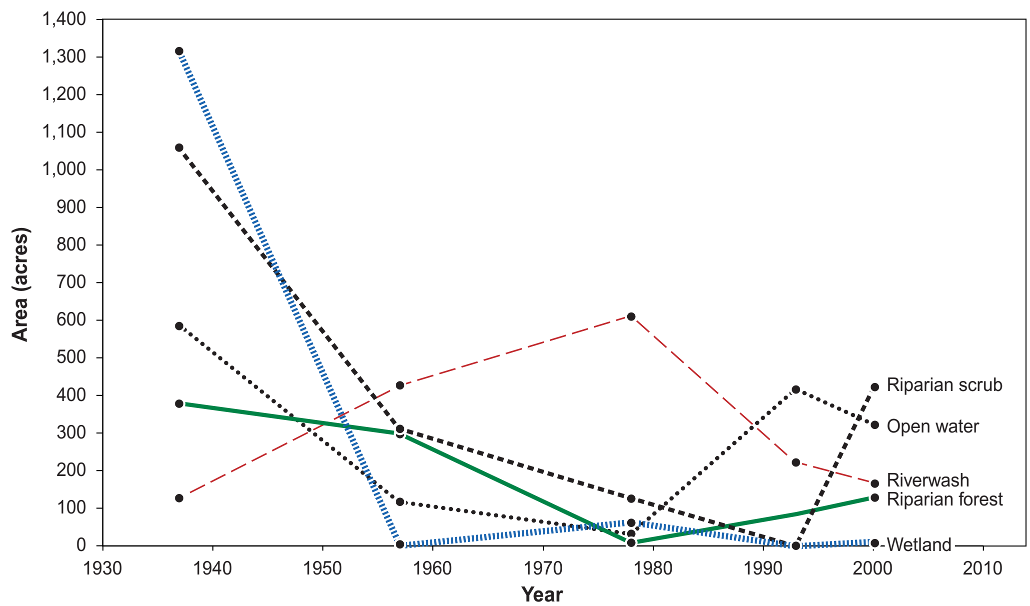


Figure 8-12. Change in vegetation area from 1937-1998 over Reach 2A (Gravelly Ford to Chowchilla Bifurcation Structure). Data plotted as 2000 data were mapped on 1998 air photos.

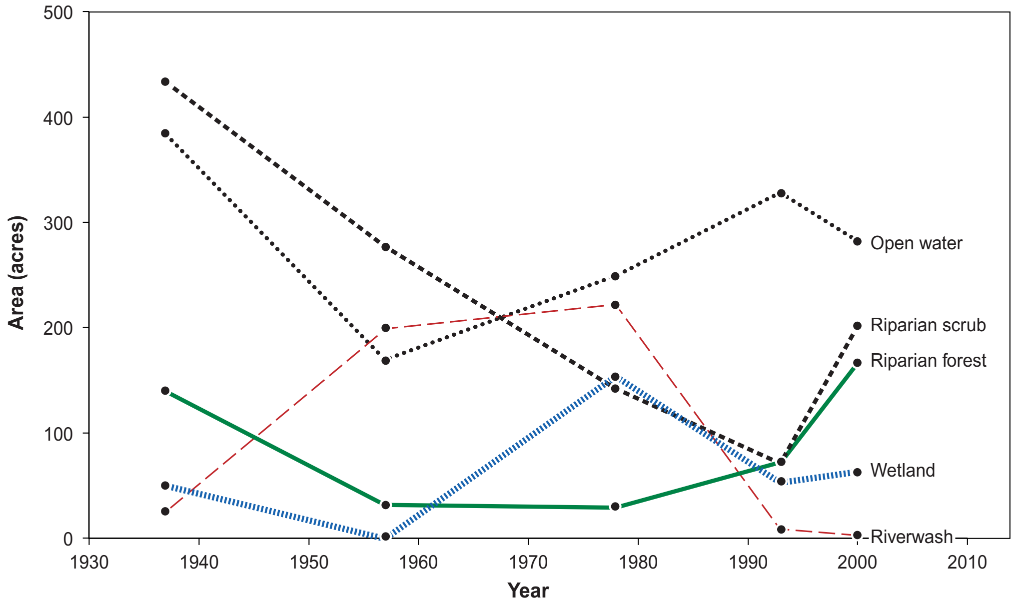


Figure 8-13. Change in vegetation area from 1937-1998 over Reach 2B (Chowchilla Bifurcation Structure to Mendota Dam). Data plotted as 2000 data were mapped on 1998 air photos.

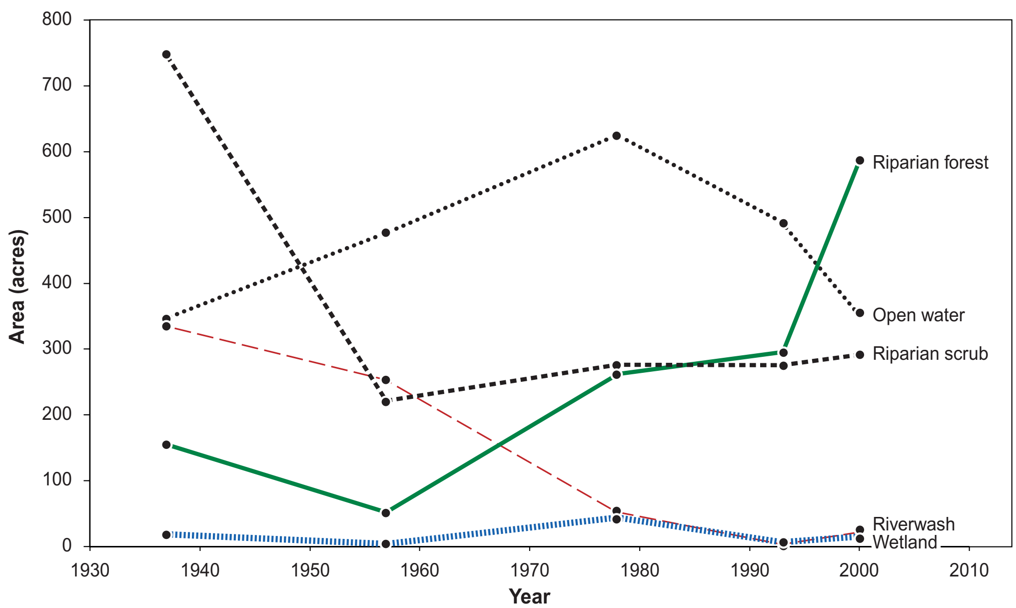


Figure 8-14. Change in vegetation area from 1937-1998 over Reach 3 (Mendota Dam to Sack Dam). Data plotted as 2000 data were mapped on 1998 air photos.

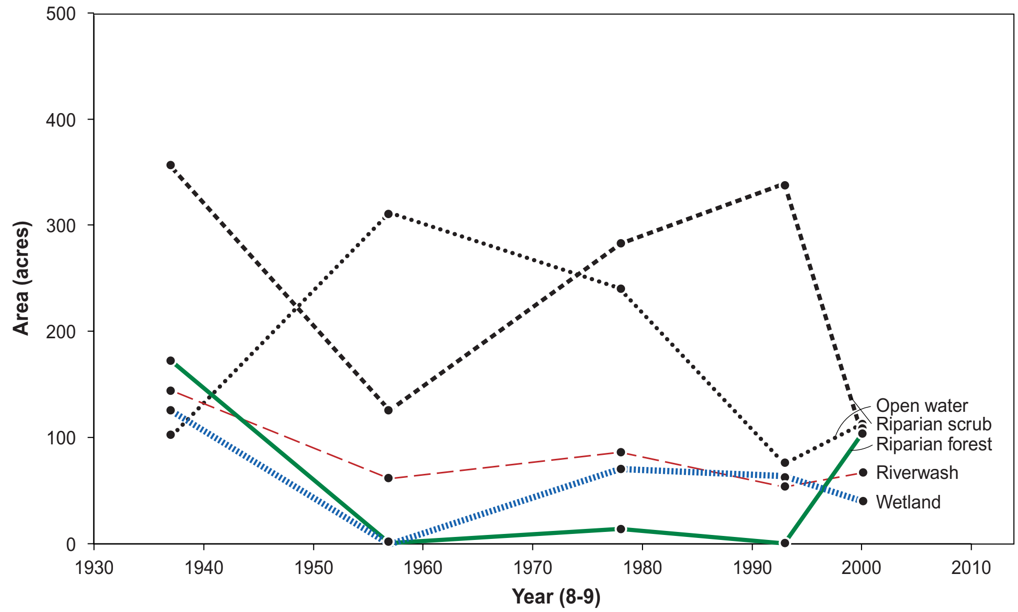


Figure 8-15. Change in vegetation area from 1937-1998 over Reach 4A (Sack Dam to Sand Slough Control Structure). Data plotted as 2000 data were mapped on 1998 air photos.

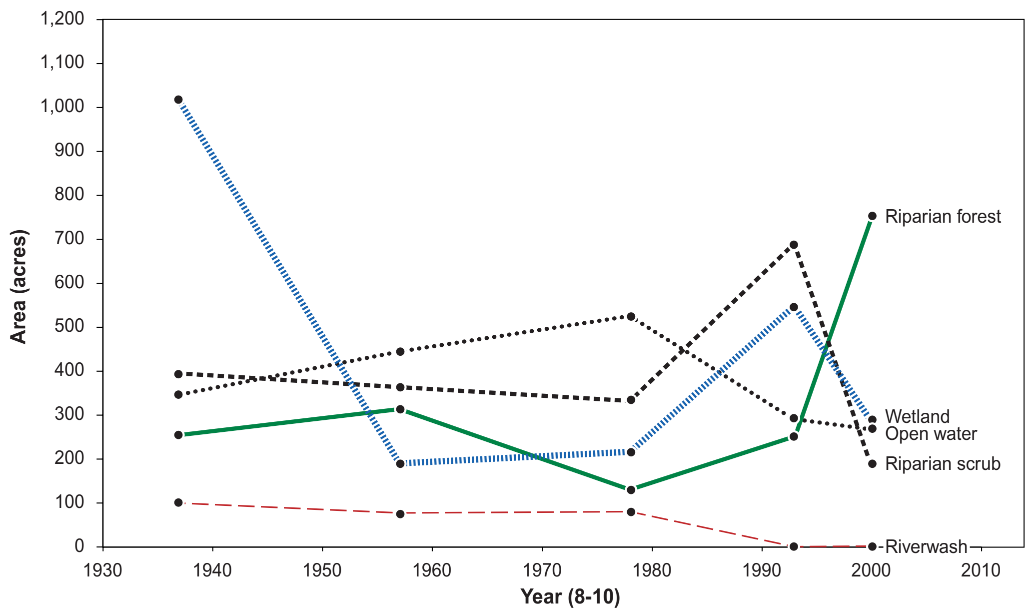


Figure 8-16. Change in vegetation area from 1937-1998 over Reach 4B (Sand Slough Control Structure to Bear Creek confluence). Data plotted as 2000 data were mapped on 1998 air photos.

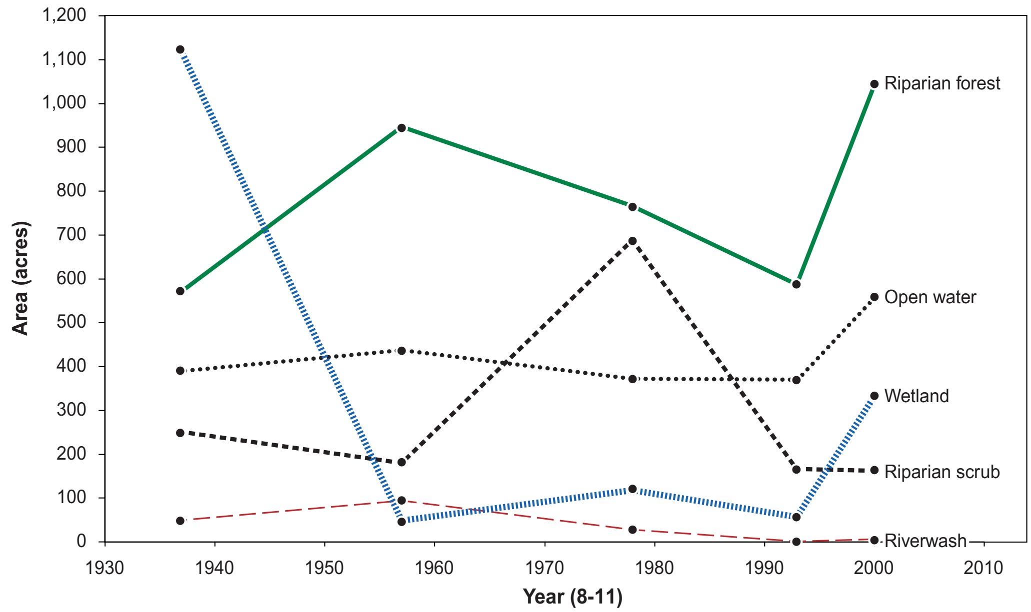


Figure 8-17. Change in vegetation area from 1937-1998 over Reach 5 (Bear Creek confluence to Merced River confluence). Data plotted as 2000 data were mapped on 1998 air photos.

Table 8-5. Area (acres) of habitat types in the study area over time (Friant Dam to Merced River).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	3,880	3,030	3,300	3,740	3,450
Riverwash[a]	1,080	1,210	1,100	300	350
Riparian forest	2,232	2,680	1,860	2,750	4,610
Riparian scrub	4,540	2,820	3,090	2,160	1,920
Wetland	4,055	320	720	730	1,000
Grassland	19,344	14,380	11,480	12,140	10,670
Agriculture	17,691	27,340	28,840	26,720	25,380
Urban and disturbed	562	1,630	2,840	2,990	6,030
No data	30	0	200	1,880	0
Total	53,413	53,410	53,410	53,410	53,410

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Between 1937 and 1957, wetland area decreased from 4,060 to 320 acres (a 92% reduction) over the entire study area (Table 8-5, Figure 8-9). Riparian scrub area also declined by 38% during this period, but riparian forest slightly increased. Large declines in riparian, and especially marsh habitat, were likely caused by 1) conversion of these lands to agricultural fields, and 2) changes in hydrology resulting from Friant Dam operations. Hydrologic changes likely affected vegetation maturation and succession processes; for example, reduced flood disturbance allowed mature vegetation to withstand scouring of sand and gravel bars. On riverwash areas, reduced flood disturbance and scouring allowed vegetation development, leading to riparian scrub, and maturation of vegetation from riparian scrub to riparian forest (JSA 1998).

Between 1957 and 1998, the area mapped as riverwash decreased, probably a result of encroachment by riparian vegetation. Wetland area increased, in part due to wetland management and restoration in the San Luis National Wildlife Refuge Complex and State Wildlife Management Areas. As vegetation matured, riparian scrub area decreased and riparian forest area increased.

However, between 1993 and 1998, the riparian forest area increased from 2,750 to 4,610 acres, which is more than can be accounted for by maturation of riparian scrub area (Figure 8-9). The apparent sharp increase in riparian forest area may be due to differences in mapping methods between DWR and JSA. Using a "zone of influence" rather than a "smoothed-out" canopy, plus using a minimum mapping unit of 0.3 acre instead of 5 acres, caused the riparian forest estimates mapped for 1998 to be higher than would be expected based on the methods used for 1993. In addition, the 1993 analysis followed a 6-year drought, whereas the 1998 analysis was based on 1998 air photos and data taken after 4 consecutive wet years (although it is not known what effect these antecedent dry and wet years had on the mapping results).

Another notable difference between 1993 and 1998 land cover is the increase in urban and disturbed lands. This category includes existing and former aggregate mines, other industrial lands, urban and residential areas, and waste places (unused, previously disturbed, barren or weedy land). Comparison of 1998 (upon which the 1998 mapping was performed) and 1993 photographs shows an increase in the area affected by aggregate mining and by urbanization. Since 1998, a further increase in the area affected by aggregate mining has occurred (Moise and Hendrickson 2002). Regardless of the differences in data from JSA and DWR, urban and mining areas increased, and agricultural and grassland area decreased.

Because of the hydrologic and geomorphic differences in the study reaches, an analysis of riparian habitat and land use changes by reach is more meaningful than an analysis of these changes for the study area as a whole. In each of the reaches below, the overall changes in riparian acreages between 1937 and 1998 are tabulated and discussed. In addition, a representative 2 to 4 mile-long section of the San Joaquin River was prepared for each of the five reaches, using the 1855 Government Land Office plat maps, the 1914 CDC maps (ACOE, 1917), the 1937 aerial photographs, and the 1998 aerial photographs. Unfortunately, the 1937 aerial photographs were unavailable in Reaches 4 and 5, and the 1914 CDC mapping effort did not extend into the upper portion of Reach 1. For each representative reach, we developed a conceptual cross section showing riparian and channel morphology evolution for each of the mapping/photo series. This cross section is based on the 1914 cross section surveys conducted by the ACOE, but the riparian vegetation and topography further from the channel is inferred from anecdotal sources rather than quantitative sources. Figure 8-18 shows the location of these example sites.

8.6.3. Historical and Present Conditions by Reach

8.6.3.1 Reach 1

8.6.3.1.1. Historical overview

Prior to 1770, broad, infrequently flooded terraces (>2 year flood recurrence) supported valley oak, interior live oak, walnut, elderberry and sycamore, with an understory of native grasses, herbs and shrubs. The active channels were flanked by a cottonwood-willow community that included white alder and Oregon ash. Point bars and channel margins were occupied by the willows and alders with the remaining species generally concentrated on slightly higher terraces. Abandoned channels, oxbows, and overflow channels supported a variety of communities depending upon the depth to

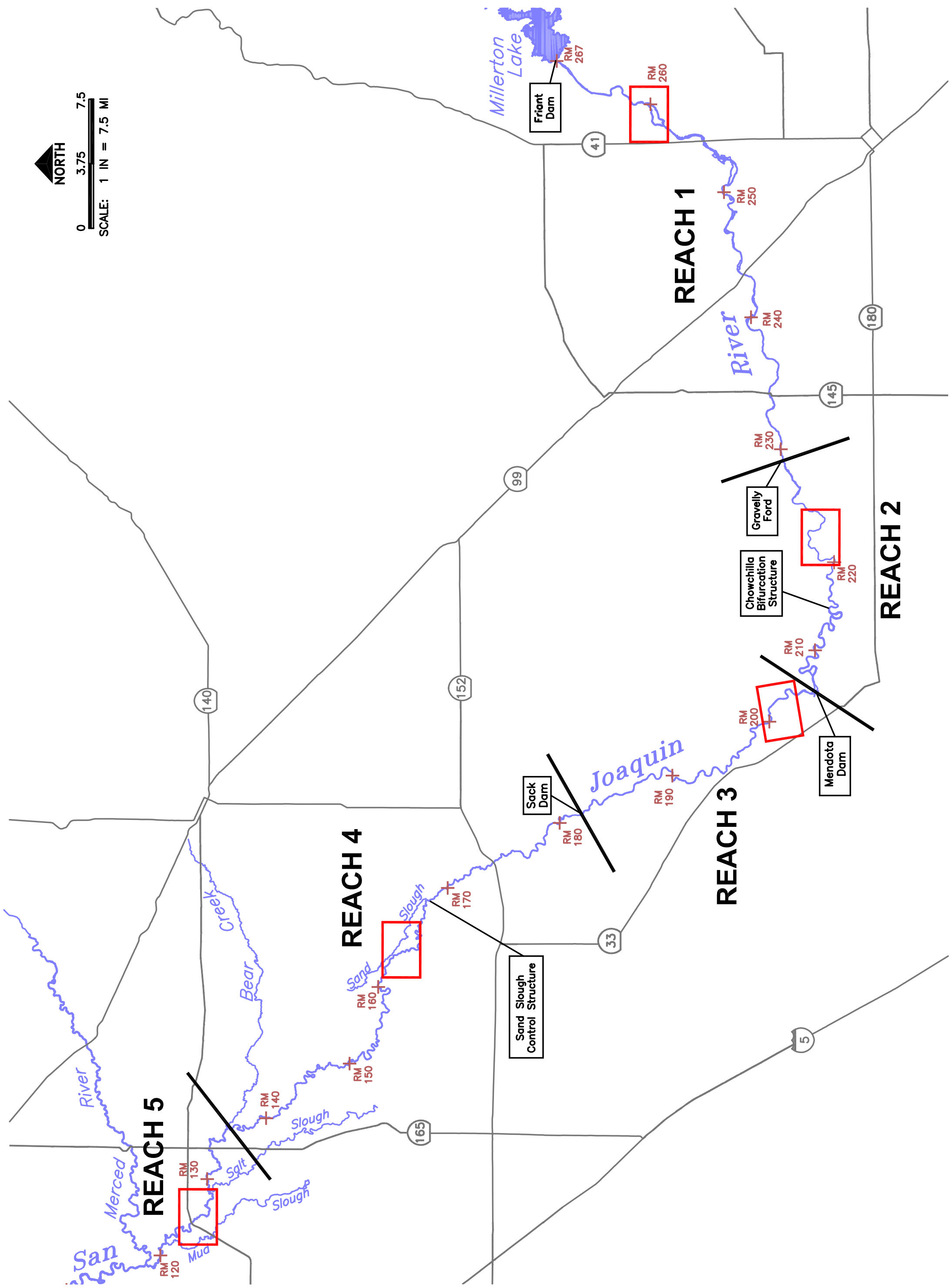


Figure 8-18. Location of historical planform evolution example reaches.

water, intervals between flooding and time since last flood. Backwaters provided permanently flooded or saturated (swampy) habitat with low flow and supported buttonwillow, tules, and cattails.

To illustrate some of the planform changes that have occurred, historical maps and air photos were compared for a portion of Reach 1A at River Mile 259, roughly 3 miles upstream from the Highway 41 crossing (Figure 8-19). Additionally, a conceptual cross section with topography and vegetation is provided based on historical maps and explorer accounts (Figure 8-20). The cross section shows hypothesized pristine conditions, in comparison to conditions apparent in 1937 and 1998, based on interpretations of aerial photographs and topographic maps (see Section 8.5.4 for a description of the methodology).

By 1937, clearing for agriculture or livestock grazing affected most of the accessible terraces that had previously supported valley oak woodland, resulting in a dramatic reduction in that habitat type. Some of this had been cut over much earlier. William Hammond Hall's early survey notes show that there were numerous oak stumps in Reach 1 providing evidence that Reach 1 once had significant oak woodlands that had been cut over by the time of his surveys in the 1870s. In 1998, the active channels are flanked by a declining cottonwood-willow community with an understory dominated by exotic upland species. White alder survives at the fringe of the cottonwood-willow community, where slope changes mark the former bankfull channel (1.5 to 2.2-year return interval under unregulated conditions).

Note the changes in shape and location of the active channels between 1937 and 1998. Following completion of Friant Dam, steady year-round flows and the lack of scouring flood flows have allowed narrow-leaf willow and white alder, which tend to form dense monotypic stands, to encroach on the active channels. This encroachment led to changes in the cross-sectional morphology of the channels by trapping sediment during infrequent higher flows, followed by cycles of additional plant growth and additional sediment deposition. The aggrading riparian berms, armored by the dense mats of willow stems and white alder roots, eventually create a more or less trapezoidal or rectangular cross section (Pelzman 1973; McBain and Trush 1997). This process, which has been documented on highly regulated streams throughout the western United States, "locks" the channel into place, reducing sinuosity, lateral channel migration, and habitat diversity. Compared to the sloping cross-section characteristic of unregulated conditions, the modified cross-section creates a simpler, more uniform aquatic habitat, which reduces salmonid spawning and rearing habitat. Additional discussion of riparian encroachment is in Section 8.7.6.

8.6.3.1.2. Current conditions.

Subreach Reach 1A presently supports nearly continuous riparian vegetation, except where the channel has been disrupted by instream aggregate removal or captured off-channel aggregate pits. The attenuation of peak inflows by the reservoir, and the reduction in the frequency and duration of channel-scouring flood flows below Friant Dam, have created more stable conditions in the active channel. Where the active channel was formerly dominated by riverwash deposits on large point bars and mid-channel islands, the reduced flow regime has promoted occupation of the bars and shoreline by alder, buttonwillow, willow, and ash (Figure 8-20). Continuous open water, created by a relatively uniform summer base flow and numerous instream mining ponds (Figure 8-19), appears to be the primary factor preventing greater encroachment of woody vegetation within the active channel (JSA and MEI 1998). These mining ponds are permanently flooded by the shallow groundwater table, and are bordered by narrow-leaf willow. Without mechanical filling, these pits will be long-term features because Friant Dam flow and sediment regimes would require centuries to naturally fill the pits.

Long-term removal of sand and gravel in the channel and floodplain, combined with loss of the

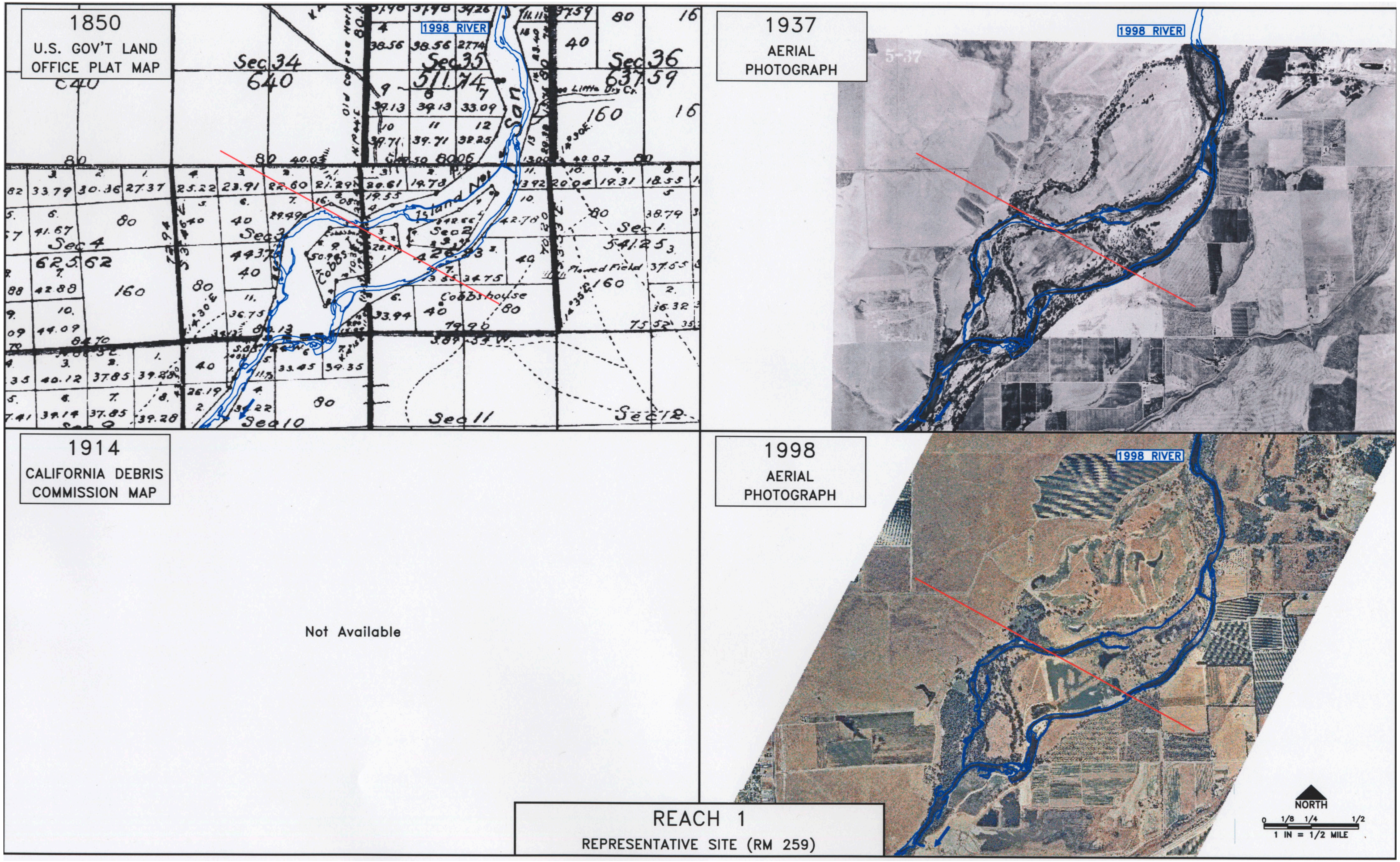


Figure 8-19. Example planform evolution in Reach 1 (RM 259), showing 1855 plat map, 1937 air photo, and 1998 air photo.

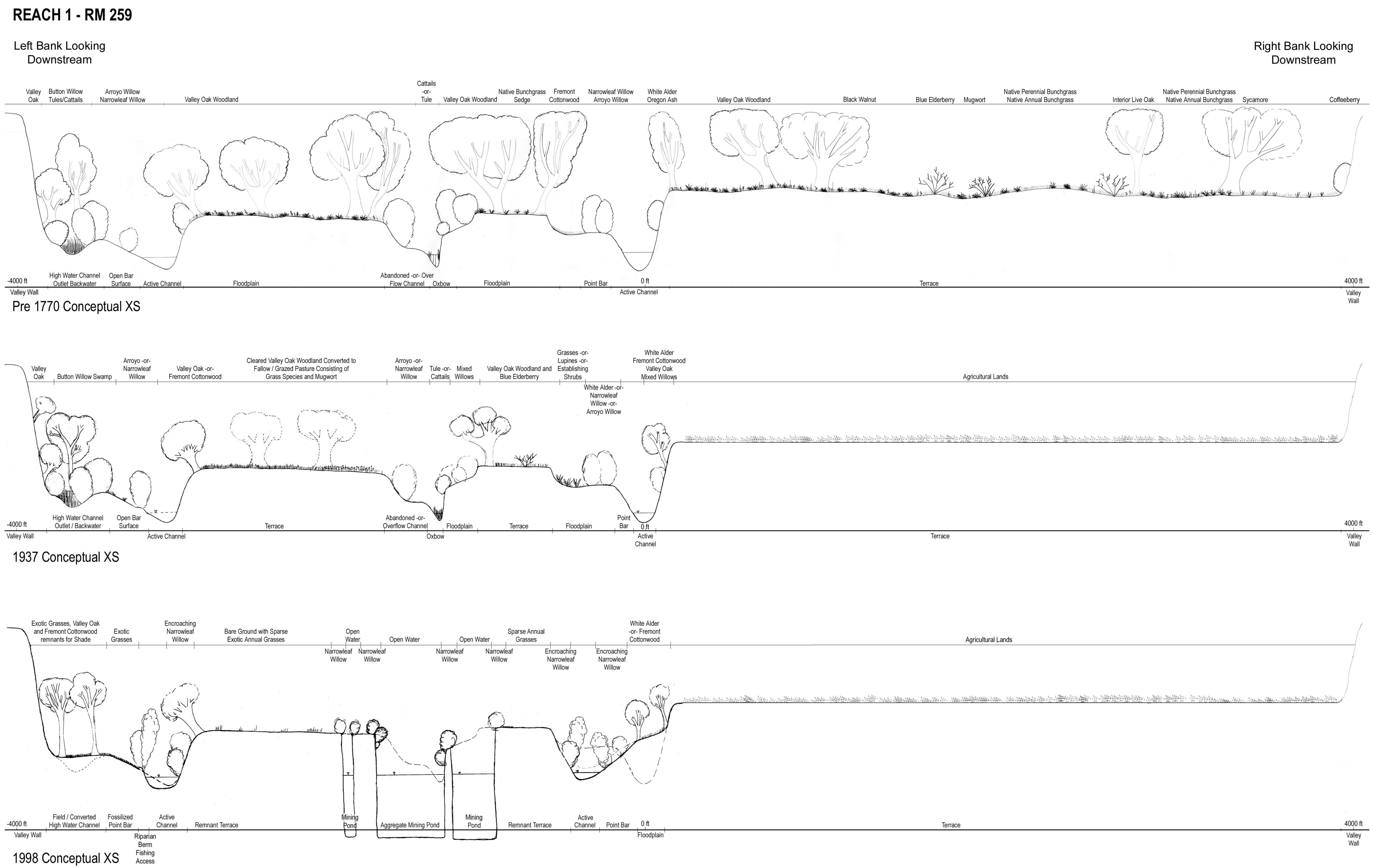


Figure 8-20. Conceptual cross section in Reach 1 (RM 259), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

upstream sediment supply, has caused local degradation of the channel thalweg in Reach 1. Channel incision and pit capture generally increase the cross sectional area of the channel; greater discharge is therefore needed to reach bankfull stage and inundate the adjacent floodplains where riparian vegetation is commonly found (JSA and MEI 1998).

In Reach 1B, mature vegetation on the backside of many point bars and on low floodplains is scarce; this may represent the lasting effect of the Corps' of Engineers extensive removal of riparian vegetation for floodway clearing, performed in 1968 through 1970 between Gravelly Ford and Highway 41 (JSA 1998). Remnant valley oaks are present on some of the higher terraces. Previously cleared terraces and the understory of the cottonwood and oak stands are dominated by exotic annual grasses. Riparian encroachment has occurred over most of Reach 1, with narrow-leaf willow and white alder dominating the canopy in the riparian berms.

8.6.3.1.3. Quantitative changes in vegetation documented between 1937 and 1998.

In Reach 1A, wetlands, riverwash, and riparian forest decreased in area from 1937 to 1957, as the result of development and an increase in upstream diversion (JSA 1998). Between 1957 and 1993, wetlands and riverwash further declined (Table 8-6 and Figure 8-10). In the 1960s and 1970s, riparian forest and riparian scrub declined in area, probably as a result of aggregate mining and urban development around Fresno (JSA 1998). In the following period, riparian scrub declined in area and riparian forest increased, probably as scrub habitat succeeded to forest habitat. Between 1993 and 1998, riparian scrub area increases, possibly the result of new habitat created by the January 1997 flood and subsequent high flows in 1998 (Moise and Hendrickson 2002). Wetland area also increased, possibly in response to the wet conditions in 1998 when the aerial photography for the 1998 mapping was taken (Moise and Hendrickson 2002).

Table 8-6. Area (in acres) of habitat types in Reach 1A (Friant Dam to Herndon).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	1,109	747	847	1,376	1,322
Riverwash[a]	239	32	12	2	33
Riparian forest	423	932	566	1,178	1,203
Riparian scrub	819	816	656	161	342
Wetland	394	69	0	0	233
Grassland	2,699	2,108	2,044	3,276	2,582
Agriculture	4,277	4,754	4,143	2,238	1,915
Urban and disturbed	300	803	1,929	2,029	2,629
No data	0	0	64	0	0
Total	10,261	10,261	10,261	10,261	10,261

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

In Reach 1B, after an initial decline in riparian forest and increase in riparian scrub, trends reverse after 1978 (Table 8-7, Figure 8-11). These trends may reflect the influence of encroachment first by scrub and then by forest on the low floodplain and channel. This process is also reflected in a decline in riverwash and open water area. A reduction in the incidence of clearing and snagging of vegetation from the floodway after the 1970s may also be reflected in the increase in the combined acreage of riparian scrub and forest (Table 8-7).

Table 8-7. Area (in acres) of habitat types in Reach 1B (Herndon to Gravelly Ford).

Class	Year				
	1937	1957	1978	1993	1998
Open water	606	322	401	389	220
Riverwash[a]	53	62	4	0	47
Riparian forest	129	98	79	274	614
Riparian scrub	470	516	576	455	196
Wetland	0	9	48	0	5
Grassland	481	290	218	396	300
Agriculture	3,146	3,467	3,466	3,347	3,167
Urban and disturbed	45	164	137	68	381
No data	0	0	0	0	0
Total	4,929	4,929	4,929	4,929	4,929

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1937 photo and 1998 photo to estimate changes in riparian width (Figure 8-19). There remains considerable remnant vegetation on the 1998 photo that is not reflective of being supported by the present flow/sediment regime, so width estimates from the 1998 photo are assumed to be the riparian width supported by the present flow/sediment regime (primarily the band of riparian encroachment. Because the 1937 riparian is a combination of valley oak patches, bands of cottonwood, and open bars, the 1937 to 1998 riparian widths in Reach 1 is not reasonably comparable. Given this caveat, the 1937 riparian widths range from 1,200 feet to 4,000 ft (includes approximately 250 feet width of river channel open water), and the 1998 riparian widths ranged from 80 feet to 300 feet (excludes the river channel width).

8.6.3.2. Reach 2

8.6.3.2.1. Historical overview

To illustrate some of the planform changes that have occurred, historical maps and air photos are compared for a portion of Reach 2 at River Mile 223, above the Mendota Pool between Gravelly Ford and the Chowchilla Bypass (Figure 8-21). A conceptual cross section with topography and vegetation is provided based on historical maps and explorer accounts (Figure 8-22). These maps, photos, and cross section document that the main channel is bounded by natural levees, known as rimlands, which were vegetated by a diverse forest likely dominated by Fremont cottonwood, black willow, and narrow-leaf willow. Broad, undulating floodplain deposits, abandoned oxbow channels, and high flow scour channels flanked the forested rimlands along the meandering channel. Wet channel features on the floodplain are vegetated by hydrophytes such as cattails and tules, with willows established along some of the channel margins. Except for these low channel features, the floodplain is shown as being dominated by native upland species (including perennial grasses and annual and perennial forbs). The reconstruction of the herbaceous upland vegetation in Figure 8-22 is somewhat speculative because vegetation changed rapidly with the introduction of livestock grazing and exotic plant species by the first Spanish and Mexican settlers; pristine conditions were not well-documented prior to land conversion.

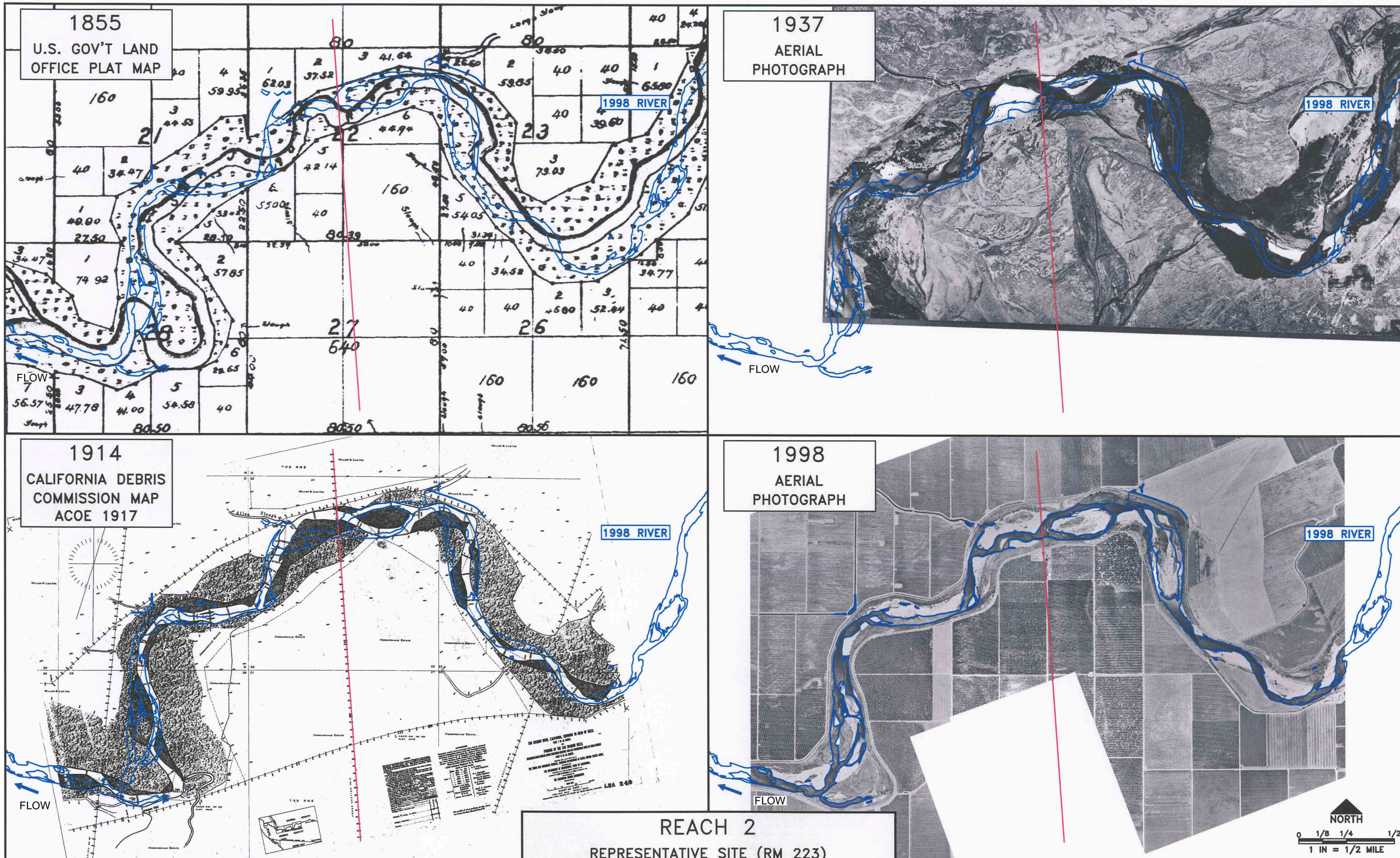


Figure 8-21. Example planform evolution in Reach 2 (RM 223), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

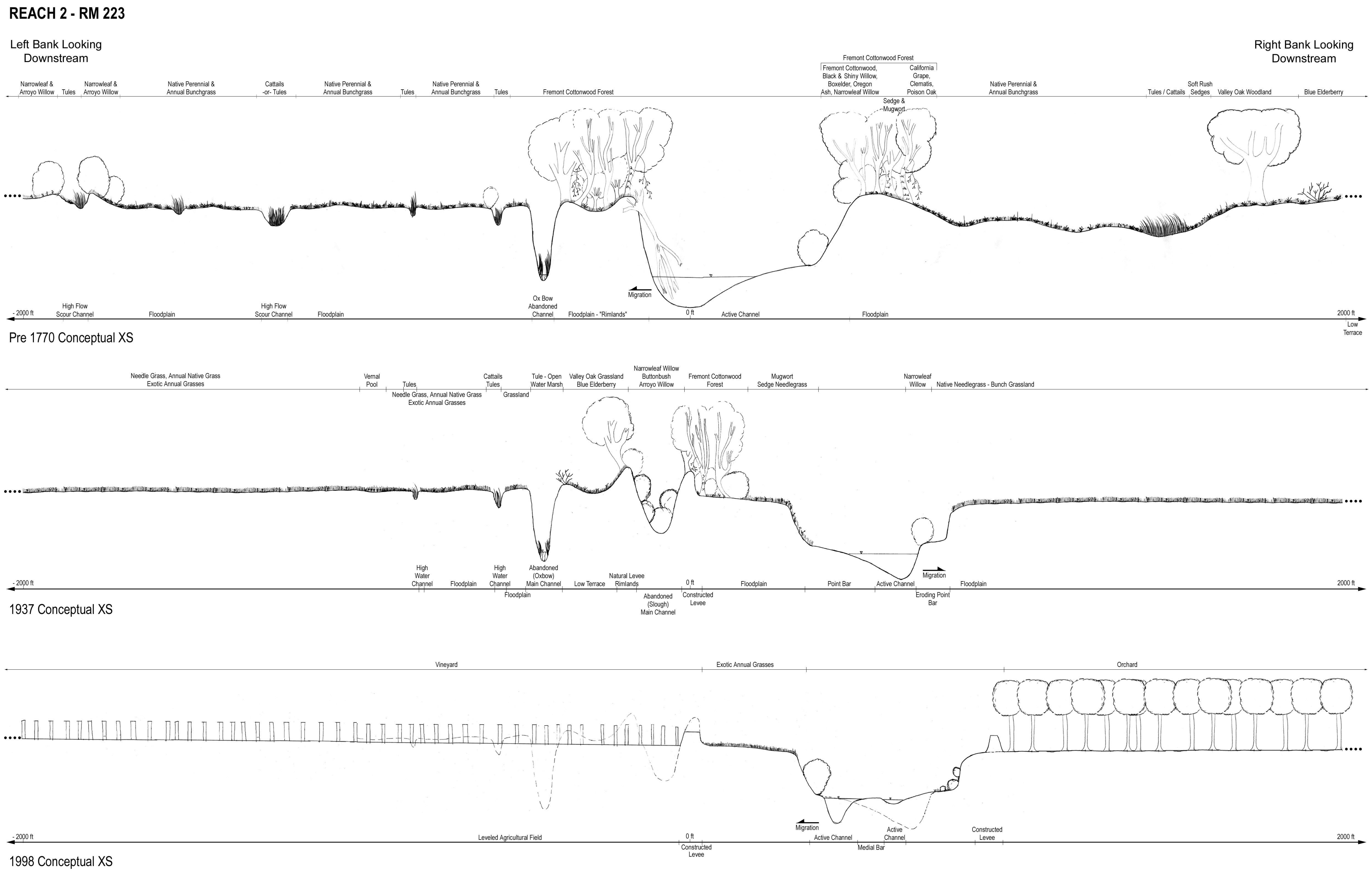


Figure 8-22. Conceptual cross section in Reach 2 (RM 223), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

Higher terraces remote from the main channel were likely primarily grasslands, with sporadic groups of valley oaks and blue elderberry savanna (Figure 8-22). Some of the upland area adjacent to the riparian zone may have supported alkali flat and mima mound habitat with saltbush scrub transitioning to grassland, as suggested by present-day habitat remnants. Early explorers (e.g., Brewer 1949) describe the highlands adjacent to the San Joaquin River as plains devoid of trees, so groups of trees were likely associated with some of the sloughs diverging from the San Joaquin River (e.g., Lone Willow Slough, sloughs connecting the San Joaquin River to Fresno Slough shown in Figure 8-5). By 1937, the floodplains had been heavily modified by previous agricultural grading and the aerial photograph shows grasslands dominated by native and exotic grasslands used for livestock grazing. The main channel has migrated to the right and the former channel has become a slough filled with willows and buttonbush. Remnants of the riparian forest shown on the 1914 CDC maps remain in the 1937 photographs, and channel migration has been minor over all sequences. By 1998, the main channel has not developed woody riparian vegetation except along its margins where narrow-leaf willow established. The lowered groundwater table, coupled with minimal or absent surface water flows, account for the general lack of riparian vegetation in the 1998 photograph.

8.6.3.2.2. Current conditions.

By 1998, agricultural grading has virtually eliminated the floodplain and former rimlands, and the remaining riparian zone is confined between levees and flanked by vineyards and orchards. Within the levees, the terraces are vegetated by exotic grasses and weeds, and the riparian forest is represented only by growth of narrow-leaf willows at the margins of the channel and on formerly active sandbars. Riparian vegetation in the upper 10 miles of this reach (Reach 2A) is sparse or absent because the river is usually dry and the shallow groundwater is overdrafted (see Chapter 4). However, there is an expanse of elderberry savanna on the left side near the Chowchilla Bifurcation Structure at the junction of Reaches 2A and 2B.

The lower few miles of Reach 2B support narrow, patchy, but nearly continuous vegetation where backwater forms upstream of Mendota Pool. The vegetation in Reach 2B may be supported by a shallower groundwater aquifer supplemented by Mendota Pool. In most years, the channel is essentially dry most of the year from Gravelly Ford to Mendota Pool, except under flood release conditions, when up to 2,000 cfs is passed downstream of the Chowchilla Canal bypass inlet (JSA and MEI 1998). USBR uses 5 cfs as a minimum flow to fulfill the requirement that there be at least 5 cfs flowing past every legal diversion point (State of California v. Rank). The last legal diversion is just upstream of the Gravelly Ford gaging station. When there are no flood releases and there is no localized rain runoff, the flow at Gravelly Ford is typically in the 0 to 20 cfs range. This flow does not extend far downstream from Gravelly Ford because of the porous bed substrate and high rate of percolation. Occasional higher flows at Gravelly Ford under these conditions result from upstream return flows or unused water right releases. The USBR compiles the mean daily flows each month in a spreadsheet that shows the Friant releases, Cottonwood and Dry Creek inflows, flows in lower Reach 1 at two gaging stations, and the flow at the Gravelly Ford gaging station.

8.6.3.2.3. Quantitative changes in vegetation documented between 1937 and 1998.

Reach 2A exhibited a large decline in wetland, riparian scrub, and riparian forest over most of the study area between 1937 and 1998 (Table 8-8 and Figure 8-12). These declines reflect the functional drought conditions prevalent in this reach after the completion of Friant Dam (JSA 1998). From 1978 to 1998, riparian forest area slightly increased, perhaps as the result of succession from riparian scrub to riparian forest. Riparian scrub was shown to increase dramatically from 1993 to 1998, perhaps in response to high flows in 1997 and 1998, and the 1999 and 2000 pilot flows. The open water acreages in 1993 and 1998 in Reach 2 were higher than typical since the photos were taken when there was a non-typical surplus water release occurring.

Table 8-8. Area (in acres) of habitat types in Reach 2A (Gravelly Ford to the Chowchilla Bifurcation Structure).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	590	119	32	418	327
Riverwash[a]	130	429	613	225	170
Riparian forest	380	300	10	86	130
Riparian scrub	1,061	313	128	0	424
Wetland	1,321	2	64	0	11
Grassland	2,380	1,931	344	800	491
Agriculture	430	3,199	4,970	3,427	4,554
Urban and disturbed	0	0	0	0	184
No data	0	0	132	1,336	0
Total	6,293	6,293	6,293	6,293	6,293

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

The pattern of Reach 2B is similar to that of Reach 2A, except that the riparian forest and scrub area are somewhat greater as a proportion of the total area (Table 8-9, Figure 8-13). Reach 2B also shows a higher and fluctuating area of wetland. These differences are attributable mainly to the influence of the backwater of the Mendota Pool, which causes the downstream portion of this reach to be wetter.

Table 8-9. Area (in acres) of habitat types in Reach 2B (Chowchilla Bifurcation Structure to Mendota Dam).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	385	170	250	329	284
Riverwash[a]	26	200	223	9	3
Riparian forest	140	32	29	73	167
Riparian scrub	434	278	143	71	203
Wetland	50	0	154	53	64
Grassland	1,112	554	1,403	342	226
Agriculture	1,104	2,019	1,048	2,373	2,047
Urban and disturbed	0	0	3	4	259
No data	0	0	0	0	0
Total	3,253	3,253	3,253	3,253	3,253

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 2 (Figure 8-21). In contrast to Reach 1, little remains of the vegetation observed on the 1914 maps and 1937 aerial photographs. The 1914 riparian widths range from 850 feet to 2,000 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranged from 0 feet to 250 feet (excluding exposed bars and wetted river channel).

8.6.3.3. Reach 3

8.6.3.3.1. Historical overview

Planform changes using historical maps and air photos are again provided for a portion of Reach 3 at River Mile 202, downstream of Mendota Pool (Figure 8-23). A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-24). These show hypothesized conditions prior to 1770, in comparison to conditions apparent in 1937 and 1998 based on interpretations of aerial photographs and topographic maps. The pre-1770 condition shows a narrow active channel bounded by an elevated floodplain, which is itself flanked by extensive lower-elevation floodplain and flood basin features. On the natural levees along the river margins, the dominant overstory woody riparian plant is uncertain. The cross section illustrates the dominant canopy species as Fremont cottonwood on the portions nearest to the river, with some valley oak woodland on terraces farther from the river (outside the tule marsh dominated flood basin). This is based on review of the 1914 CDC maps and 1937 aerial photographs. However, historical explorer accounts do not mention these species (while noting willows). Additionally, the US Government Land Office plat maps (1855) show willow witness trees, but no other species. Therefore, these conceptual cross sections may need further refinement.

The flood basins and overflow channels, subject to annual overflows and deposition of sand and silt, are vegetated by freshwater marsh with tules and cattails. Slightly elevated areas between overflow channels and basins support a cover of buttonbush, and shrubby willows. By 1937, the overflow channels and flood basins had been drained and filled and were used as pasture or for annual crops such as small grains (Figure 8-24). Levees, irrigation canals, and general thinning of riparian vegetation are evident on the rimlands, which were used for livestock grazing. A high water channel on the left side of the active channel assumes some of the function of the now- absent overflow channels and flood basins.

8.6.3.3.2. Current conditions.

By 1998, virtually all of the floodplain and rimlands have been agriculturally graded and leveled. Riparian vegetation is confined to the active channel, and is supported by delta water introduced to the river at Mendota Dam. Floodwaters are regulated by upstream structures, with most flows diverted out of the San Joaquin River into the Chowchilla Bypass.

Nearly continuous riparian vegetation of various widths and cover types occurs on at least one side of the channel within this reach. Continuous open water, created by a relatively uniform irrigation season base flow of imported Delta water, appears to be the primary factor preventing further encroachment of woody vegetation within the active channel (JSA and MEI 1998). Urban development at Firebaugh, local levees, agricultural encroachment, and irrigation canals that flank the river have further limited the natural vegetation that formerly grew there (JSA and MEI 1998).

8.6.3.3.3. Quantitative changes in vegetation documented between 1937 and 1998.

In Reach 3, riparian forest, riparian scrub, and grassland areas again decreased from 1937 to 1957 (Table 8-10, Figure 8-14). In that same period, the agriculture and urban areas greatly increased. After 1957, riparian scrub area remained relatively constant, while the riparian forest area increased. This increase coincides with a decrease in riverwash area, indicating encroachment of riparian vegetation on sand bars, at least up to 1993 (JSA 1998). The steep increase in riparian forest area between 1993 and 1998 coincides with a decrease in open water and may be attributable to increasing tree growth over the channel and/or a different mapping method.

Table 8-10. Area (in acres) of habitat types in Reach 3 (Mendota Dam to Sack Dam).

Class	Year				
	1937	1957	1978	1993	1998
Open water	349	478	626	495	355
Riverwash[a]	335	254	53	4	22
Riparian forest	156	53	263	296	588
Riparian scrub	750	222	277	276	292
Wetland	19	4	45	7	16
Grassland	1,597	112	150	186	174
Agriculture	4,763	6,409	6,057	5,978	5,361
Urban and disturbed	206	643	704	816	1,367
No data	0	0	0	118	0
Total	8,175	8,175	8,175	8,175	8,175

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 3 (Figure 8-23). The 1914 maps illustrate riparian vegetation between already constructed canals that confine the river corridor, so the riparian width estimates from the 1914 maps probably under predict unimpaired riparian widths. The 1937 aerial photographs show that clearing of the remaining riparian vegetation between the canals is underway. As in Reach 2, little remains of the vegetation observed on the 1914 maps and 1937 aerial photographs. The 1914 riparian widths range from 750 feet to 1,700 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranged from 20 feet to 250 feet (excluding exposed bars and wetted river channel).

8.6.3.4. Reach 4

8.6.3.4.1. Historical overview

Planform changes using historical maps and air photos were evaluated for a portion of Reach 4 at River Mile 163, downstream of Mendota Pool (Figure 8-25). This site is located in Reach 4B, downstream of the Sand Slough Control Structure. Unfortunately, a copy of the 1937 aerial photograph could not be obtained. A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-26).

The pre-1770 condition is likely a well-developed cottonwood-willow riparian forest which bounds the active channel on natural levees. Again, the conceptual model of cottonwood being a dominant canopy species along the river edge is subject to some additional discussion. The natural levees are produced by deposition of sediments by floodwaters as they overflow the main channel and deposit sediment along the rough channel edges caused by the vegetation. These natural levees likely decreased in size and height moving downstream between Reaches 3 and 5 as the sediment load decreased due to cumulative deposition on the levees. A variety of active and abandoned side channels and sloughs mark floodplains and flood basins away from the rimlands on the right hand

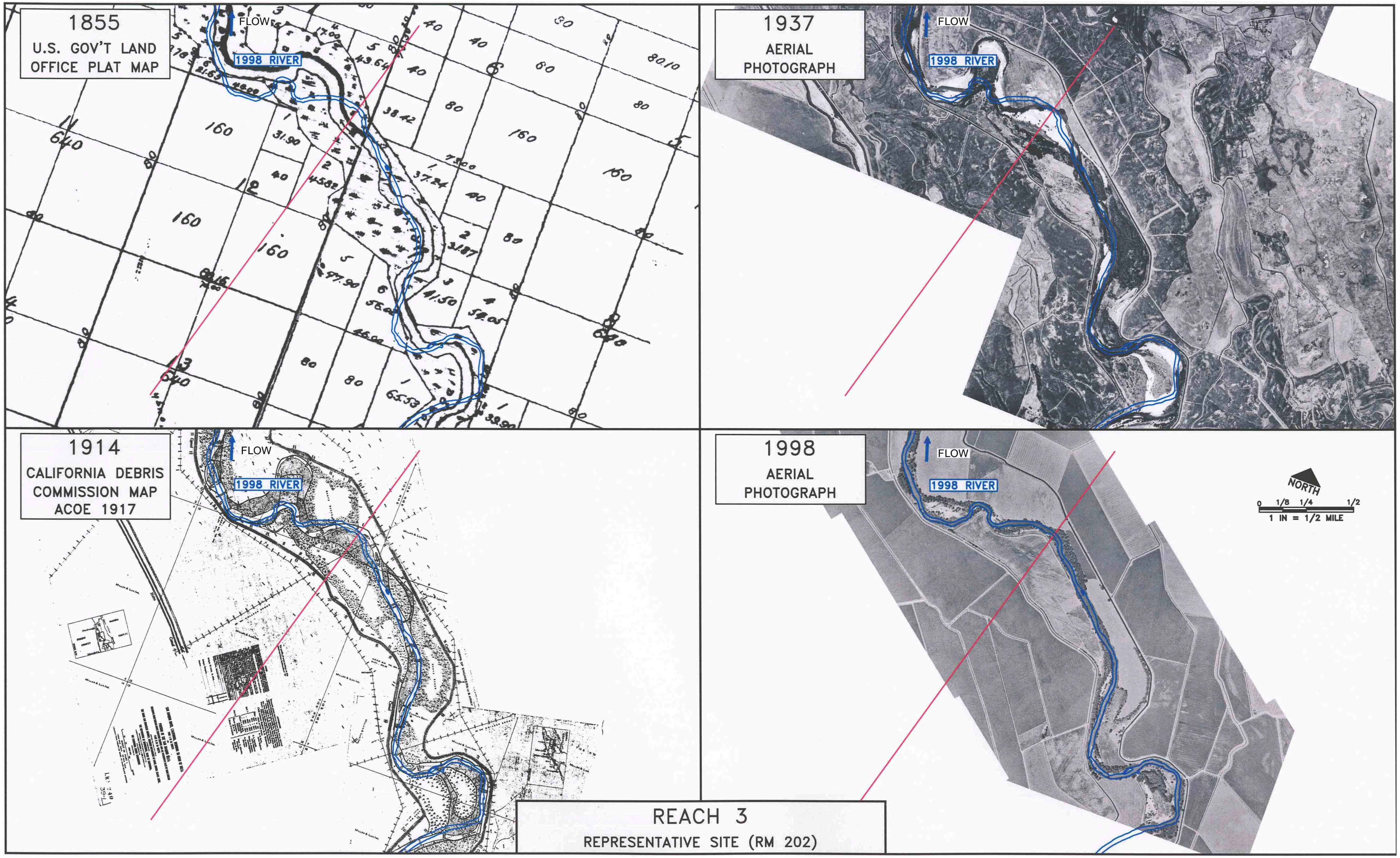


Figure 8-23. Example planform evolution in Reach 3 (RM 202), showing 1855 plat map, 1914 CDC map, 1937 air photo, and 1998 air photo.

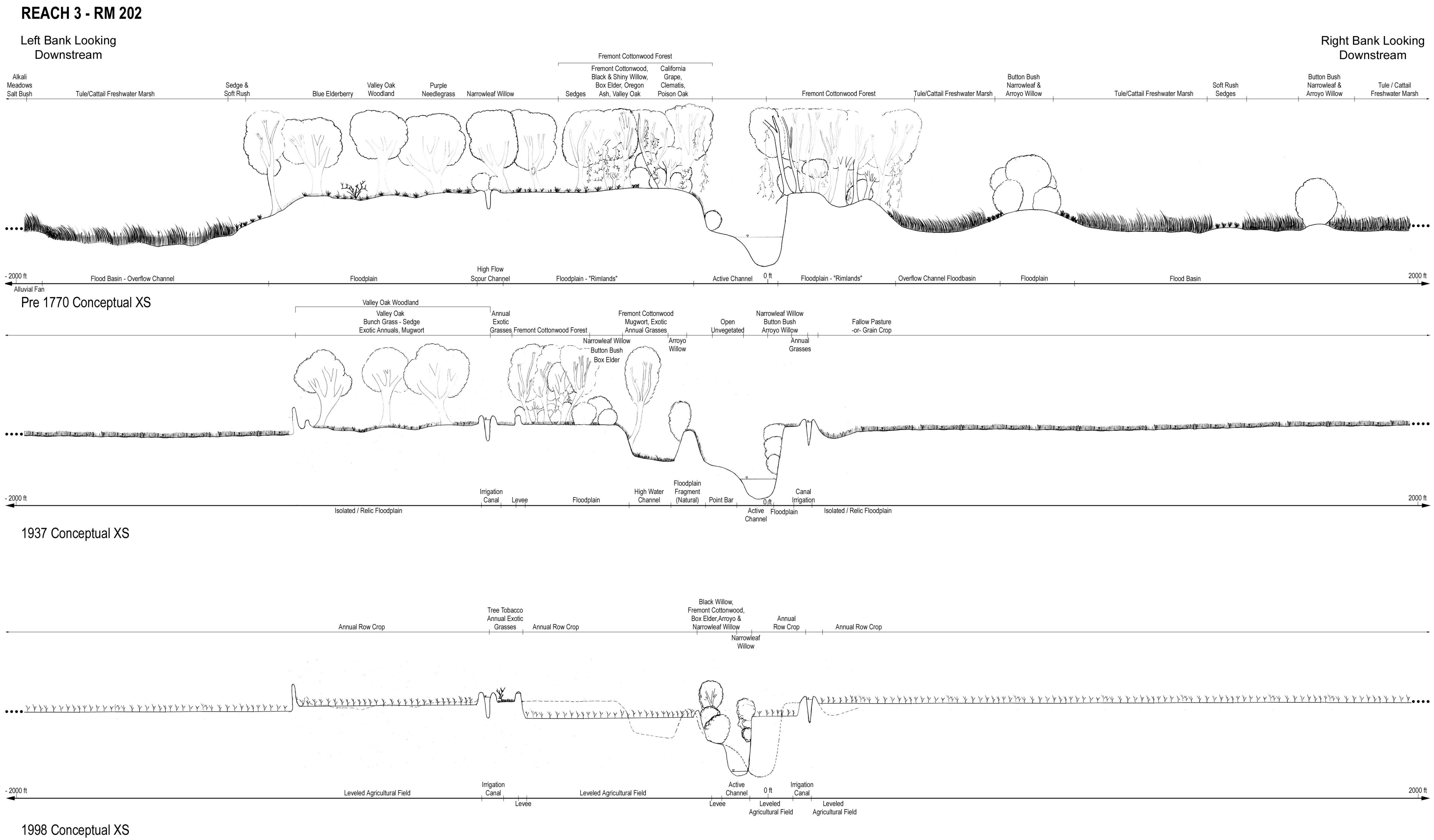


Figure 8-24. Conceptual cross section in Reach 3 (RM 202), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

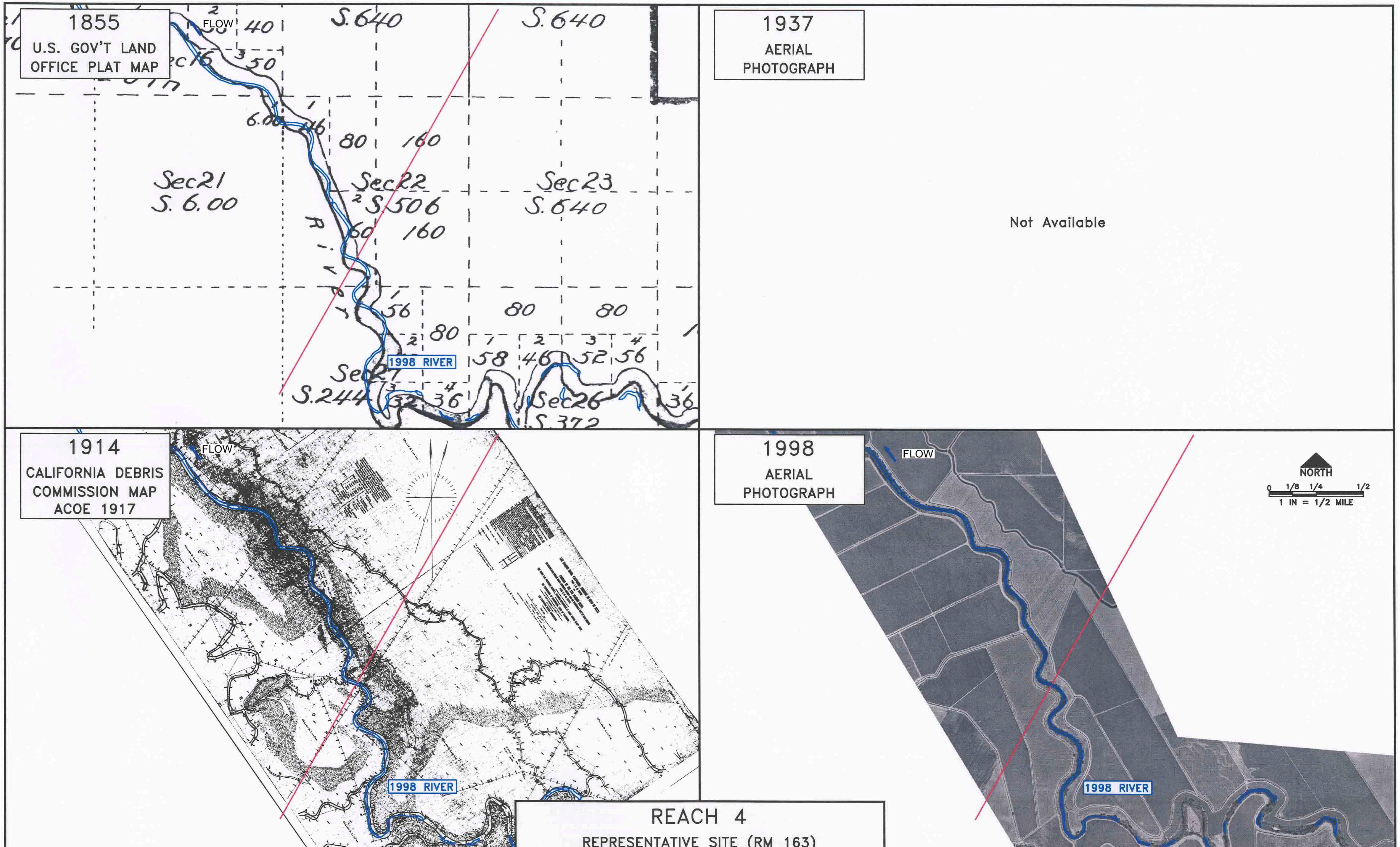


Figure 8-25. Example planform evolution in Reach 4 (RM 163), showing 1855 plat map, 1914 CDC map, and 1998 air photo.

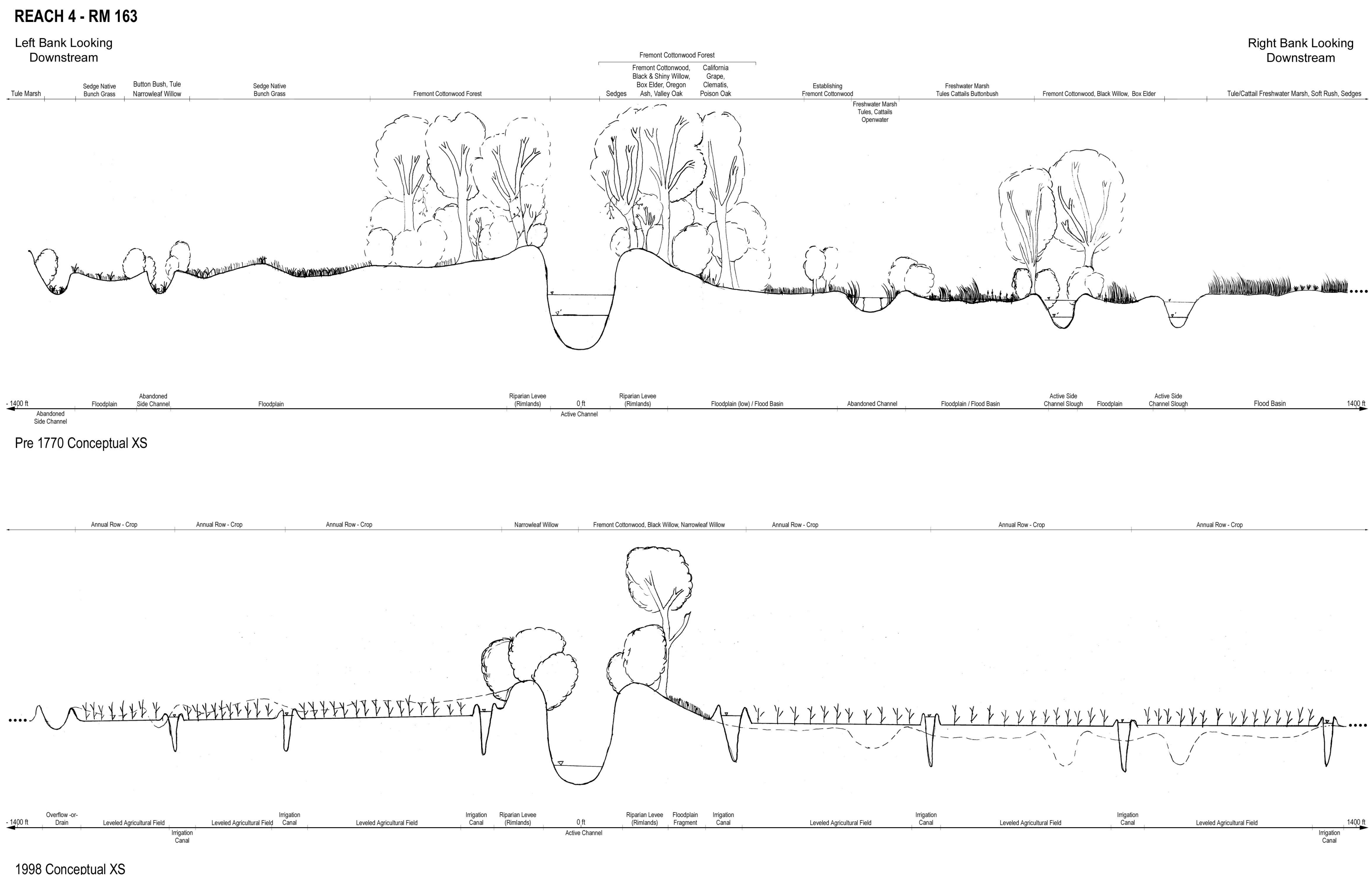


Figure 8-26. Conceptual cross section in Reach 4 (RM 163), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

side of the channel. These low areas were seasonally inundated and supported freshwater marsh, with riparian forest developing next to active side channels and sloughs. Low areas associated with active or abandoned side channels intersect the water table and allow wetland vegetation to develop.

By 1998, the floodplains on both sides of the river have been graded and converted into irrigated agriculture. The riparian forest is narrow and botanically simpler, and is confined to the remnant vegetation of the rimland on both sides of the river. The formerly extensive overflow habitat has been drained and converted to agriculture.

8.6.3.4.2. Current conditions.

Reach 4A (located upstream of the representative reach illustrated in Figure 8-25) is only sparsely vegetated, with a very thin band of vegetation along the channel margin (or none at all). Sporadic narrow strands or patches of mostly willow scrub occur, as do small “potholes” with marsh vegetation (JSA and MEI 1998). For most of the year, Reach 4A is dry. Survival of established (mature) riparian vegetation does not appear to be affected by the intermittent flow regime because groundwater is shallow along this reach. Full-canopied riparian scrub and forest occur in small to large stands, and ponds rimmed by small areas of marsh vegetation are present within the channel (JSA and MEI 1998).

In-channel vegetation is supported by flows and/or moisture from: 1) leakage or spillage at Sack Dam, 2) from shallow groundwater, 3) from field drain water, and possibly 4) from seepage from the canals that border the river. Field drain water is pooled in this section of the San Joaquin River with small berms and/or is run downstream to a small pool where it is recirculated by being pumped out for irrigation. These pools help maintain riparian vegetation, albeit, mostly within the channel outside of the wetted area. The in-channel vegetation increases the hydraulic roughness and increases sediment deposition, thereby affecting channel flow capacity. Historically, this subreach of the river had multiple channels in the overbank areas. Winter and spring high flows that were historically conveyed by the river and its sloughs are now conveyed in the Eastside Bypass system (JSA and MEI 1998).

Primary factors in the reduced acreage of riparian-associated habitats include reduced hydrology impacts (lower spring baseflow and lower bankfull discharge frequency and duration), levee and ditch construction that isolated backwater ponds and sloughs, and draining of large marsh areas. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to agricultural encroachment, infrequently inundated floodplains and secondary sloughs. Possibly higher concentrations of surface salinity could be contributed to an overall gradual loss of woody cover. Continuing land uses, primarily intensive agriculture and managed wetlands, also prevent reestablishment of riparian habitat on otherwise moist lowland surfaces, and in remnant basins and swales (JSA and MEI 1998).

Reach 4B also historically contained multiple channels, with the flows being divided between the meandering mainstem and multiple sloughs distributed throughout the expansive overbank area as illustrated above in the toposequence for this reach (Figure 8-25). Local levees and channel plugs now separate the sloughs from flow in the river. Under existing conditions, flows no longer are allowed to enter Reach 4B; therefore, inundation of the channel margins to encourage natural riparian regeneration no longer occurs (all flows are routed to the Eastside Bypass via the Sand Slough Control Structure).

Reach 4B upstream of the Mariposa Bypass supports a nearly unbroken, dense, but narrow corridor of willow scrub or young mixed riparian vegetation on most of the reach, with occasional large gaps in the canopy. Lack of surface flow in Reach 4B above the Mariposa Bypass outlet, coupled with agricultural return flows downstream of the Mariposa Bypass outlet; levee and ditch construction that isolated or filled backwater ponds and sloughs, and drainage of large marsh areas appear to be the primary factors causing reduced acreage of riparian-associated habitats. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to infrequent inundation of floodplains and secondary sloughs, clayey soils, and possible higher concentrations of surface water salinity, contribute to an overall gradual loss of woody cover.

8.6.3.4.3. Quantitative changes in vegetation documented between 1937 and 1998.

An initial decline in Reach 4B riparian scrub, riparian forest, and wetland area in the period from 1937 to 1957 was followed by an increase in these cover types after 1957 (Table 8-11, Figure 8-15). From 1993 to 1998, riparian forest increased in area, while riparian scrub declined, probably as the result of successional development from scrub to forest. However, the decline in riparian scrub is greater than the increase in riparian forest, suggesting additional loss of scrub. Grassland and open water were shown to increase in this period. These differences may be the result of clearing vegetation or flooding of scrub that encroached on the channel below Sack Dam.

Table 8-11. Area (in acres) of habitat types in Reach 4A (Sack Dam to Sand Slough Control Structure).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	102	312	241	76	113
Riverwash[a]	146	62	87	54	68
Riparian forest	174	1	15	0	104
Riparian scrub	357	126	283	340	109
Wetland	127	0	71	65	41
Grassland	1,447	199	5	50	201
Agriculture	1,358	3,010	3,009	3,126	2,702
Urban and disturbed	0	0	0	0	372
No data	0	0	0	0	0
Total	3,710	3,710	3,710	3,710	3,710

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Wetland area in Reach 4B declined in the period from 1937 to 1957, while the area in agriculture increased (Table 8-12, Figure 8-16). The area of riverwash, riparian forest, and scrub remained relatively constant from 1937 to 1978. From 1978 to 1993, wetland, riparian scrub, and riparian forest area increased, probably because of habitat restoration on the San Luis National Wildlife Refuge Complex. Subsequently, riparian scrub area declined while riparian forest area increased, probably at least in part as the result of succession.

Table 8-12. Area (in acres) of habitat types in Reach 4B (Sand Slough Control Structure to Bear Creek).

Class	Year				
	1937	1957	1978	1993	1998
Open water	348	446	526	292	269
Riverwash[a]	101	79	81	0	3
Riparian forest	256	314	132	253	756
Riparian scrub	396	364	334	692	190
Wetland	1,019	191	218	549	290
Grassland	5,592	4,368	3,287	2,342	2,730
Agriculture	1,361	3,303	4,484	4,840	4,189
Urban and disturbed	10	17	22	21	658
No data	0	0	0	95	0
Total	9,084	9,084	9,084	9,084	9,084

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 4 (Figure 8-25). The 1914 maps illustrate a narrow band of riparian vegetation along the river channel, with tule marsh beyond the band of riparian vegetation. Estimates of riparian width from the 1914 maps do not include the tule marsh width. Again, little remains of the vegetation observed on the 1914 maps. The 1914 riparian widths ranges from 50 feet to 1,000 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranges from 0 feet to 50 feet (excluding exposed bars and wetted river channel). The outer boundaries of the tule marsh on the 1914 are not clearly delineated, but the width of the tule marsh is at least 10,000 feet wide on Figure 8-25 (including the river channel, sloughs, and riparian bands).

8.6.3.5. Reach 5

8.6.3.5.1. Historical overview

Planform changes were evaluated using historical maps and air photos for a portion of Reach 5 at River Mile 126, near where Highway 140 crosses the river (Figure 8-27). Again, the 1937 aerial photograph for this sequence was unavailable. A conceptual cross section with topography and vegetation is again provided based on historical maps and explorer accounts (Figure 8-28).

Prior to the 1770s, environmental conditions were likely characterized by a dynamic system of well-developed and diverse willow-dominated riparian forest on natural levees, which bounded the main channel; riparian vegetation in different stages developed on secondary channels. Abandoned channels and lower portions of the floodplain were vegetated with freshwater marsh (primarily tules). Oxbow lakes formed on cutoff meanders, which supported freshwater marsh, bounded by buttonbush, black willow, and narrow-leaf willow. On the right bank of the river, the floodplain abruptly grades into higher ground based on the 1914 topography. This higher ground is likely a portion of the Merced River delta, where valley oaks would begin to occupy areas closer to the river. Native upland bunchgrasses would have also been on this surface. The floodplain was very broad on the left bank of the river.

By 1998, the flood basin on left bank of the river was modified for agriculture and the channel features were partially filled in. This historical flood basin now lacks native riparian vegetation or the wetland vegetation that historically existed there. A road has been developed on the river's left bank and no riparian vegetation is present on the side of the road opposite the river. Cottonwood trees still grow on the right side of the river, with occasional valley oaks and exotic annual grasses on the higher right bank surface. Narrow-leaf willow is present around the former oxbow lake.

8.6.3.5.2. Current conditions.

In Reach 5, the San Joaquin River is surrounded by large expanses of upland grassland with numerous inclusions of woody riparian vegetation within the floodplain. The floodplain and basin are generally disassociated from the mainstem river due to project levees, and remnant tree groves are concentrated on the margins of mostly dry secondary channels and depressions, or in old oxbows. Along the mainstem San Joaquin River, a relatively uniform pattern of patchy riparian canopy hugs the channel banks as large individual trees or clumps (primarily valley oaks or black willow) with a mostly grassland or brush understory. Visual examination of the 1938 aerial photographs by JSA (JSA and MEI 1998) showed a similar patchy pattern of vegetation, but total woody cover was greater, with a higher proportion of mixed riparian vegetation relative to scrub. Large expanses of herbaceous riparian vegetation and marsh clustered along the river and sloughs. None of these features are now present (JSA and MEI 1998).

The frequency of overland flow beyond the natural channel banks is likely greater in this reach than in those described previously, because Reach 5 is located downstream of the Mariposa Bypass, and collects flows from the Eastside Bypass and Bear Creek. However, inundation of the floodplain is still less frequent than occurred before construction of Friant Dam. Comparison of cross sections shows that the channel has both widened and deepened in the area where a significant portion of the flood flows from the Eastside Bypass are discharged back into the mainstem San Joaquin River (JSA and MEI 1998)

8.6.3.5.3. Quantitative changes in vegetation documented between 1937 and 1998.

Wetland area decreased from 1,124 to 50 acres (96%) in Reach 5 from 1937 to 1957 (Table 8-13, Figure 8-17). Most of this area was drained and converted to grassland and pasture, and a part of this area was converted to riparian forest. Lack of periodic floods encouraged establishment of riparian vegetation on the old natural levees that are abundant in this area. In 1978, riparian forest decreased over 1957 levels, perhaps as a result of temporarily lower flows caused by the drought in the 1970s. After 1978, the area of riparian scrub decreased, then increased by 1998 (perhaps as a result of the four wet years prior to 1998).

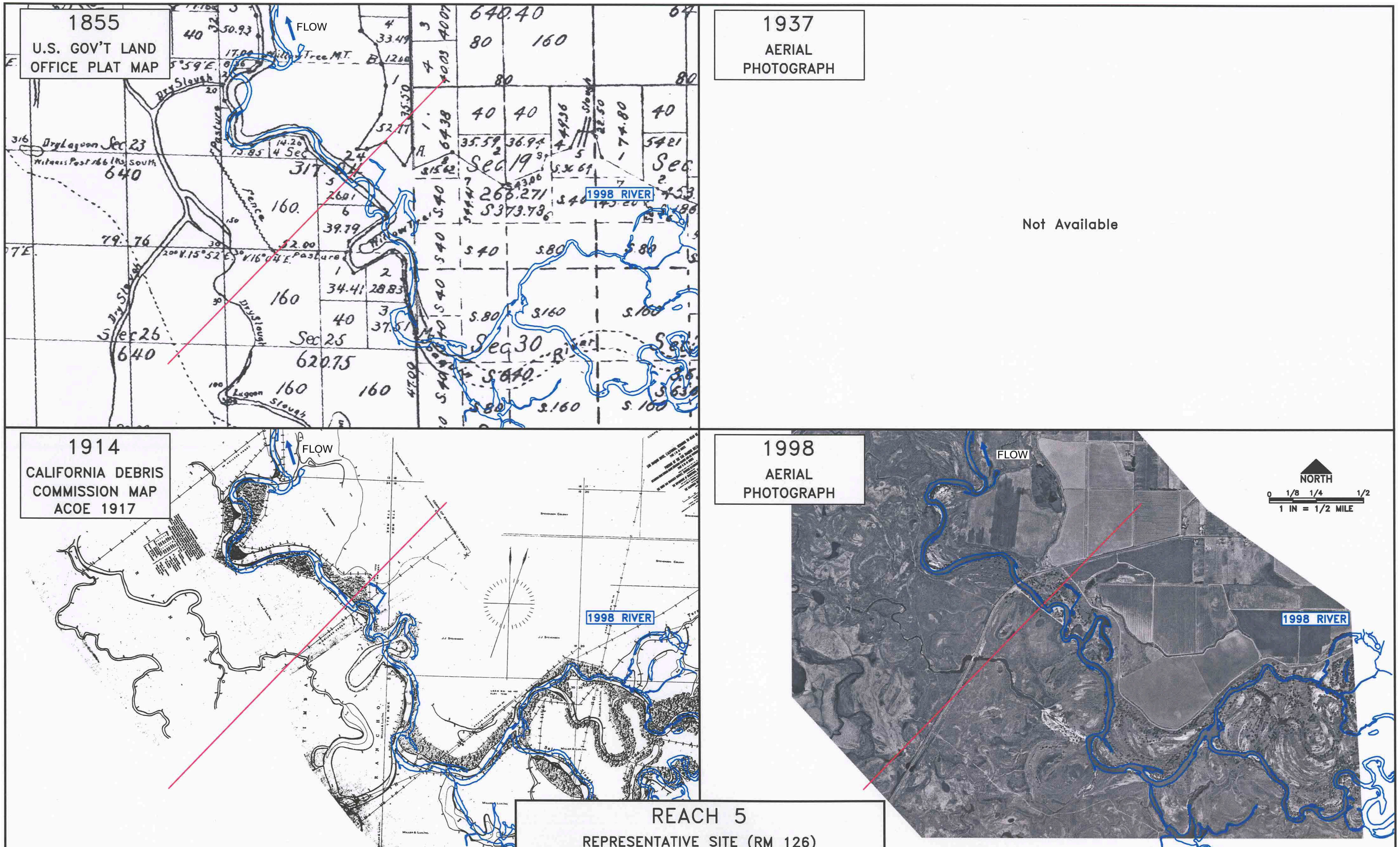


Figure 8-27. Example planform evolution in Reach 5 (RM 126), showing 1855 plat map, 1914 CDC map, and 1998 air photo.

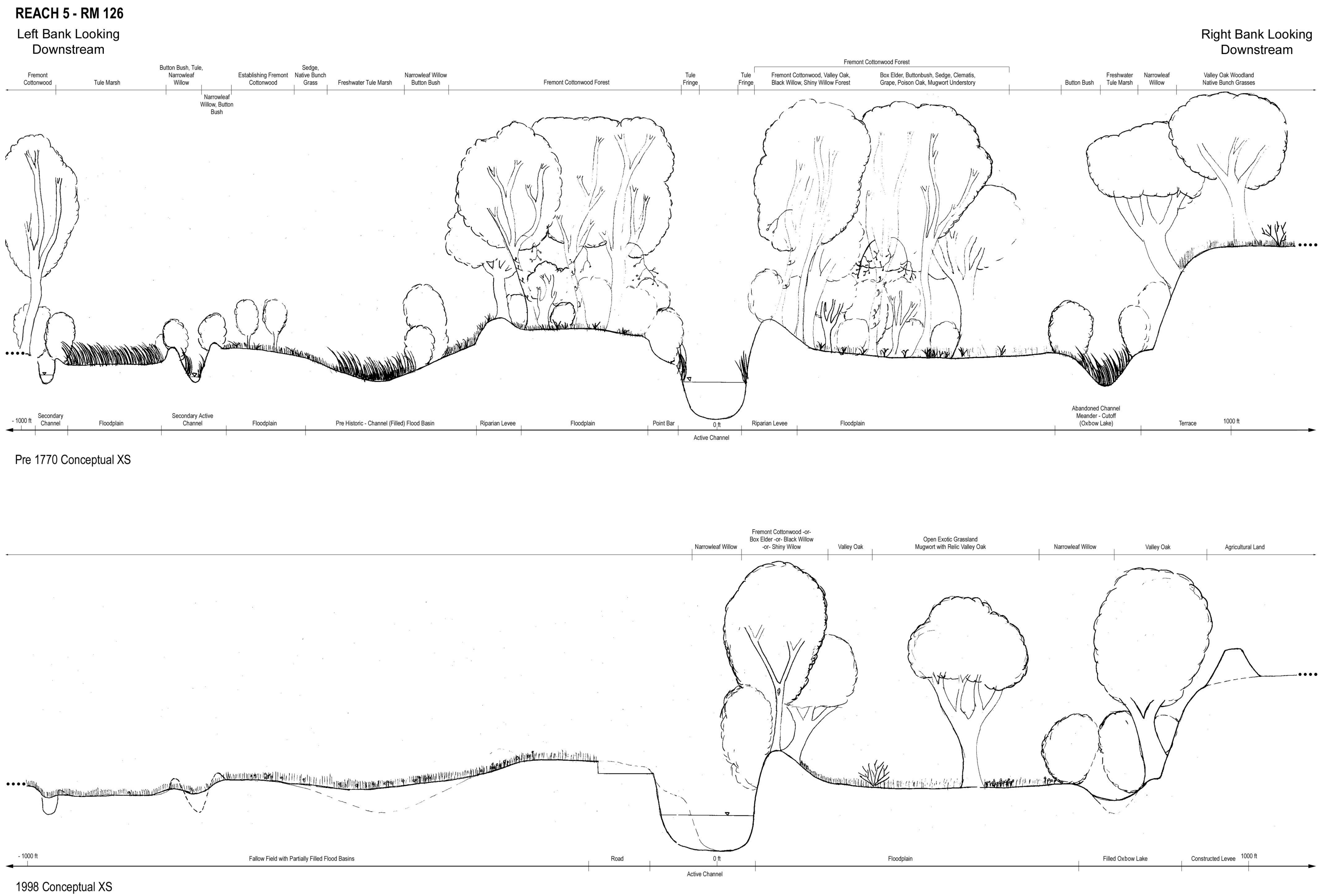


Figure 8-28. Conceptual cross section in Reach 5 (RM 126), showing hypothesized evolution in channel geometry and riparian vegetation coverage based on historic aerial photographs, maps, and explorer accounts.

Table 8-13. Area (in acres) of habitat types in Reach 5 (Bear Creek to Merced River).

Class	Year				
	1937	**1957**	**1978**	**1993**	**1998**
Open water	391	438	373	371	559
Riverwash[a]	51	95	29	2	7
Riparian forest	573	948	768	588	1,047
Riparian scrub	253	181	689	168	163
Wetland	1,124	50	118	57	336
Grassland	4,036	4,815	4,025	4,751	3,969
Agriculture	1,251	1,181	1,662	1,387	1,445
Urban and disturbed	0	0	43	55	182
No data	0	0	0	329	0
Total	7,709	7,709	7,709	7,709	7,709

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Wetland and riparian areas in Reach 5 apparently increased between 1993 and 1998. During that period, riparian forest area increased by 459 acres. However, much of this apparent increase is likely due to the different minimum mapping units used. Within Reach 5, wetlands are often seasonal swales and vernal pools, and riparian trees occur in many small and narrow patches. Most of these patches were not mapped for 1993 because JSA used a 5-acre minimum mapping unit (JSA 1998); instead, these patches were included in the surrounding grassland. DWR's 0.3 acre minimum mapping unit (Moise and Hendrickson 2002) allowed many of these small habitat patches to be included in the acreage totals. For example, in 1998, 110 acres of Reach 5's riparian habitat were in patches smaller than 1 acre, and thus would not have counted as riparian habitat in 1993.

Spot measurements of riparian width were made from the 1914 maps and 1998 photo to estimate changes in riparian width in Reach 5 (Figure 8-27). As with Reach 4, the 1914 maps illustrate a narrow band of riparian vegetation along the river channel, but the tule marsh beyond the band of riparian vegetation is not identified on the 1914 maps (although it most likely occurred there). Estimates of riparian width from the 1914 maps do not include this assumed tule marsh width. As opposed to Reaches 2, 3, and 4, it appears that some of the historic vegetation observed on the 1914 maps still remains as shown on the 1998 aerial photograph. The 1914 riparian widths ranges from 100 feet to 750 ft (excluding exposed bars and wetted river channel), and the 1998 riparian widths ranges from 50 feet to approximately 150 feet (excluding exposed bars and wetted river channel). If the 1998 riparian vegetation, wetland areas, sloughs, and river channels are included, the width is up to 5,300 feet.

8.6.4. Existing Vegetation Composition

This section describes the present-day vegetation in the study area. In contrast to the preceding descriptions, which are based primarily upon interpretation of historical to recent aerial photographs, the descriptions in this section are based upon a combination of on-the-ground vegetation sampling and interpretation of recent air photos. The area and distribution of vegetation by type are based on DWR studies during 2000 (Figure 8-8, Table 8-14) (Moise and Hendrickson 2002). Although extirpation of the area's native riparian plant species has not been documented, certain plant community types have been dramatically reduced, such as formerly extensive backwater sloughs or swamps dominated by buttonbush (see Table 8-16). This species apparently thrives and is sometimes dominant in backwaters where still, poorly oxygenated water stands throughout the year (Conard et al. 1977), but these habitats have been almost entirely destroyed by development making button bush swamp forest one of the rarest and most endangered vegetation types in the state (Holstein 1984). Comparing documented and hypothetical historical conditions, losses of higher terrace and floodplain riparian forests and valley oak woodlands have been severe; these areas, as well as the historic wetlands, have been extensively converted to agricultural land. Tule and buttonwillow swamps that occupied overflow channels, sloughs, and flood basins are other areas that experienced severe losses. In addition, the areal extent and diversity of cottonwood and willow forest have been greatly reduced, along with reductions in diversity of native understory species. Valley oak and sycamore, which tend to establish on the higher terraces and natural levees in the riparian zone after very infrequent major flood events, reproduce poorly under current conditions (under a modified flood regime and land use conversion).

Most of the woody plants are native; however, woody exotics such as blue gum (*Eucalyptus globulus*), giant reed, and Himalayan blackberry are widespread and abundant in the study reaches, and others are increasing in importance (see below in Section 8.6.4.11). In all transects, of the 25 woody species having one percent or more relative cover, 19 (76%) are native (Table 8-16). The proportion of native herbaceous (non-woody) species is considerably lower, however. Only 25 of the 48 herbaceous species (52%), comprising one percent cover of any of the vegetation transects, are native (Table 8-17).

Inspection of Table 8-14 leads to the following general observations:

- Almost half of the study area (25,400 acres) consists of agricultural lands (agricultural fields, orchards, and vineyards). The second largest category of cover type is grasslands (10,700 acres), which includes herbaceous riparian habitat.
- The study area supports approximately 4,200 acres of riparian forest.
- The largest area of valley oak riparian forest (265 acres) is in Reach 1A; it also has the greatest cover of invasive exotic species (58 acres). The relative proportion of willow riparian forest, dominated by black willow, becomes greater in downstream reaches.
- Riparian scrub is found on approximately 1,900 acres in the study area. In Reaches 1A, 1B, 3, and 4B willow scrub is the dominant riparian scrub type, but in Reaches 2A, 2B, and 4A the non-willow riparian scrub types dominate. In Reach 5 both scrub types are about equally abundant. Elderberry savanna, a scrub type that was not previously mapped along the San Joaquin River (Moise and Hendrickson 2002), was found on 63 acres in Reach 2B and was also mapped in small patches in Reaches 1A and 2A.
- Most of the 991 acres of wetland mapped in the study area was mapped in Reaches 1A, 4b, and 5. This includes 5 acres of alkali sink habitat, a rare vegetation community, mapped in Reach 5.

Below are descriptions of the species composition and canopy structure of most vegetation types along the San Joaquin River. These descriptions are based on data collected during the recent field surveys by DWR (Moise and Hendrickson 2002). Overall, they document forests with tree layers composed of small to medium-sized trees. The forests are dominated by relatively few species and have sparse covers of understory vegetation. In the sections that follow, descriptions of communities dominated by woody plants precede descriptions of communities dominated by herbaceous plants. In the descriptions that follow, the term “absolute cover” refers to the percentage of the ground surface that lies under the canopy of a species or vegetation type whereas “relative cover” refers to the proportion of the total vegetative cover contributed by a given species.

Table 8-14. Area of vegetation types (in acres) in 1998.

Category	Vegetation type	Reach								
		1A	**1B**	**2A**	**2B**	**3**	**4A**	**4B**	**5**	**Total**
Open water	Open water	1,322	220	327	284	355	113	269	559	3,447
Riverwash[a]	Riverwash	33	47	170	3	22	68	3	7	354
Riparian forest	Cottonwood riparian forest	167	79	31	48	441	16	32	41	855
	Cottonwood riparian forest, low density	27	114	41	1	23	4	4	0	213
	Willow riparian forest	205	119	43	112	116	65	508	590	1,759
	Willow riparian forest, low density	28	0	4	6	8	14	118	308	557
	Mixed riparian forest	400	260	0	0	0	6	0	32	697
	Mixed riparian forest, low density	56	19	2	0	0	0	0	17	94
	Valley oak riparian forest	265	0	0	0	0	0	23	46	335
Riparian scrub	Willow scrub	216	113	76	38	190	38	119	73	864
	Willow scrub, low density	74	32	124	15	41	10	13	10	318
	Riparian scrub (nonwillow)	47	48	216	87	61	61	58	81	658
	Elderberry savanna	2	0	3	63	0	0	0	0	68
Invasive Exotics	Exotic tree	55	22	9	0	0	0	0	12	99
	Giant reed	3	4	6	0	0	0	0	0	13
Wetland	Wetland	233	5	11	64	16	41	290	336	991
Other	Grassland	2,582	300	491	226	174	201	2,730	3,969	10,672
	Agriculture	1,915	3,167	4,554	2,047	5,361	2,702	4,189	1,445	25,380
	Disturbed	2,244	381	184	259	743	372	658	182	5,024
	Urban	385	0	0	0	623	0	0	0	1,008
Total		10,261	4,929	6,293	3,253	8,175	3,710	9,084	7,709	53,413

[a] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Table 8-15. Absolute cover of woody and herbaceous plants in vegetation along the San Joaquin River based on data in Appendix 1 of Moise and Hendrickson (2002).

Vegetation Type	Transect No.	Transect Length (m)[a]	Woody Cover (% of transect length covered)[b]	Herbaceous Cover (% of transect length covered)[c]
Cottonwood Riparian Forest	54	2,864	60	45
Disturbed	4	257	33	47
Grassland	38	2,207	1	67
Mixed Riparian Forest	18	1,115	72	40
Riparian Scrub	13	521	17	72
Riverwash[d]	10	377	26	26
Valley Oak Riparian Forest	7	415	61	65
Wetland	14	396	36	82
Willow Riparian Forest	66	3,197	50	50
Willow Scrub	32	1,281	41	43

Notes:

[a] Transect length is the combined length of transects within the vegetation type.

[b] Woody cover is the total cover of trees and shrubs.

[c] Herbaceous cover is the total cover of herbaceous plants.

[d] Riverwash is partially dependent on the flow at the time of the survey/photograph, and values should not be presumed to be precise.

Table 8-16. Relative cover of woody plants in vegetation along the San Joaquin River based on data in Appendix 1 of Moise and Hendrickson (2002).

	Vegetation Type: [a]	CORF	DIST	GRAS	MXRF	RPSC	RVWS	VORF	WETL	WLRF	WLSC
	Transect Number:	54	4	38	18	13	10	7	14	66	32
	Transect Length (m): [b]	2,864	257	2,207	1,115	521	377	415	396	3,197	1,281
Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Acer negundo	box elder										1
Alnus rhombifolia	alder	< 1			3						
Baccharis salicifolia	mule fat	< 1			1						< 1
Cephalanthus occidentalis	button bush	4			13		5		4	7	4
Eucalyptus globulus	blue gum	1	15			12					
Ficus carica	fig										
Fraxinus latifolia	Oregon ash	3			15	11	80			2	
Juglans californica **var. *hindsii***	N. California Black Walnut				1						
Morus alba	white mulberry				1					< 1	
Nicotiana glauca	tree tobacco				1	13					
Platanus racemosa	sycamore				11	15					3
Populus fremontii	Fremont cottonwood	33	41		4		7	< 1	4	4	< 1
Quercus lobata	valley oak	1	1		11			61		1	
Quercus wislizenii	interior live oak									2	
Rosa californica	California rose	2			1	12				3	
Rubus discolor	Himalayan blackberry				3					1	2
Rubus ursinus	California blackberry	4			7					1	
Salix exigua	sandbar willow	2	12		13	12	7	< 1	11	7	69
Salix Gooddingii	Goodding's black willow	42	30	100		17	2	38	81	68	12
Salix laevigata	red willow	1						1		1	

Table 8-16, Continued.

Scientific Name [c]	Common Name	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Salix lasiolepis	arroyo willow	4			1					< 1	
Salix lucida	shining willow									< 1	1
Sambucus mexicana	elderberry				1	7				1	< 1
Sesbania punicea	scarlet wisteria				1					1	2
Vitis californica	California wild grape				< 1						

Notes:

[a] Vegetation types are CORF = Cottonwood riparian forest, DIST = Disturbed vegetation, GRAS = grassland, MXRP = mixed riparian forest, RPSC = riparian scrub, RVWS = riverwash, VORF = valley oak riparian forest, WETL = wetland, WLRF = willow riparian forest, and WLSC = willow riparian scrub.

[b] Transect length is the combined length of transects within the vegetation type.

[c] Scientific names of native species are in bold

Table 8-17. Relative cover of herbaceous plants in vegetation along the San Joaquin River.

Scientific Name [c]	**Vegetation Type: 3**	CORF	DIST	GRAS	MXRF	RPSC	RVWS	VORF	WETL	WLRF	WLSC
	Transect Number:	54	4	38	18	13	10	7	14	66	32
	Transect Length (m): 4	2,864	257	2,207	1,115	521	377	415	396	3,197	1,281
	Common Name	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Ambrosia psilostachya	western ragweed	1		1		2	4				1
Anthemis cotula	dog- fennel			2				1			2
Anthriscus caucalis	bur-chevil		4		4						1
Artemisia douglasiana	Mugwort	10	6	1	10	24		5	9	11	14
Atriplex triangularis	spearscale	3				1					
Baccharis douglassii	coyote bush				2					1	
Brassica nigra	black mustard	1	3	3		9	3	1	2	2	5
Bromus diandrus	ripgut brome	18	54	7	26	2	4			4	6
Bromus hordeaceous	soft chess brome	1	4	1	2		4			2	
Bromus madritensis	fox-tail chess	1				1	4				12
Centaurea solstitialis	yellow star thistle		< 1	4	1	1		2	2	3	
Chenopodium berlandieri	pitseed goosefoot								9		
Conium maculatum	poison hemlock				4					2	
Conyza canadensis	horseweed	1	< 1	6				2		3	
Cynodon dactylon	Bermuda grass	16	1	1	30	2	12	14		11	3
Distichlis spicata	salt grass			4	2	9			1	5	2
Epilobium brachycarpum	willow herb	4	< 1	2	1	2	3	2	5		
Eremocarpus setigerus	doveweed		2				4				
Erodium botrys	broadleaf filaree		4	1			8				
Erodium cicutarium	red-stemmed filaree		< 1	9							
Euthamnia occidentalis	western goldenrod	3		1	2				25	4	4

Table 8-17., continued.

Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Frankenia salina	alkali heath			2	2						
Gnapthalium purpureum	purple cudweed						4				
Grindelia camporum	gum plant			4		4					
Hordeum marinum	Mediterranean barley			6							
Melilotus alba	white sweetclover							1	1	5	1
Helianthus annuus	sunflower	1		2		2		2	3	1	
Hemizonia pungens	spikeweed			2		4		1			
Heterotheca grandiflora	telegraph weed		1	2	< 1						3
Heterotheca oregona	Oregon goldenaster						2				
Juncus mexicanus	Mexican rush			1		5			4		2
Lactuca serriola	prickly lettuce	3	1	3		2		6		4	
Leerzia oryzoides	rice cutgrass	1			1		3				1
Lepidium dictyotum	alkali pepper grass						4				
Leymus triticoides	creeping wildrye	3		3	2	6		5	2	2	6
Lolium perenne	perennial ryegrass			1				7			
Lotus purshianus	Spanish clover	2	6	3		2	3			1	3
Malvella leprosa	alkali mallow	1			4				1		
Marsilia vestita	hairy pepperwort						3				
Polypogon monspeliensis	annual beard grass	1			1		1	3			
Polygonum lapathifolium	pale smartweed								13		
Silybum marinum	blessed milk thistle							2	1	2	
Solanum sp.	nightshade species					2					
Sorghum halpense	Johnson grass					2					
Stellaria media	common chickweed						8				
Urtica dioica	nettle				1	2				2	

Table 8-17., continued.

Scientific Name [c]	**Common Name**	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover	% cover
Vulpia myuros	rat-tail fescue	7	11	7	3		13			4	17
Xanthium strumarium	cocklebur					3		2	2	2	1

Notes:

[a] Vegetation types are CORF = Cottonwood riparian forest, DIST = Disturbed vegetation, GRAS = grassland, MXRP = mixed riparian forest, RPSC = riparian scrub, RVWS = riverwash, VORF = valley oak riparian forest, WETL = wetland, WLRF = willow riparian forest, and WLSC = willow riparian scrub.

[b] Transect length is the combined length of transects within the vegetation type.

[c] Scientific names of native species are in bold.

8.6.4.1. Cottonwood Riparian Forest

The cottonwood riparian forests occur along all reaches of the San Joaquin River (Table 8-14). Important characteristics of the cottonwood riparian forest include:

- The cottonwood riparian forest canopy of trees and shrubs covers 60% of the ground area, 44% with a single layer of trees or shrubs, and 16% with both a tree canopy and an understory of shrubs and suppressed saplings (Table 8-15)
- 42% of cottonwood riparian forests have canopies 15 to 40 feet high, and 57% have canopies more than 40 feet high (Figure 8-29). Trees are typically less than 40 cm (16 inches) dbh and only 5 per hectare (about 2 per acre) are greater than 60 cm (2 feet) dbh (Figure 8-30).
- The dominant tree species are Goodding's black willow and Fremont cottonwood.
- Shrub species have moderately low covers in cottonwood forests (Table 8-16), but the herbaceous layer covers 45% of the transect length (Table 8-15).

8.6.4.2. Mixed Riparian Forest

Mixed riparian forests occur along reaches 1, 4B, and 5 (Table 8-14) but more than 90% of the mixed riparian forest is along Reach 1, where it is the dominant forest type. Important characteristics of the mixed riparian forest include:

- The trees and shrubs canopy covers 72% of the area (Table 8-15), 45% with a single layer of trees or shrubs, and 27% with both a tree canopy and an understory of shrubs and suppressed saplings.
- More than half of the mixed riparian forests canopy is greater than 40 feet high, and the remainder canopies are 15 to 40 feet high (Figure 8-29).
- Trees are typically less than 20 cm (8 inches) dbh; only 8 per hectare (about 3 per acre) are larger than 40 cm (1.3 feet) dbh (Figure 8-30).
- The most abundant tree species are Oregon ash and Goodding's black willow (Table 8-16). Important shrub species include buttonbush, sandbar willow, and California blackberry.
- The herbaceous layer of the mixed riparian forest covers 40% (Table 8-15), with primary species being exotic grasses; Bermuda grass, and ripgut brome. Mugwort, with 10% relative cover, was the only native species with more than 2% relative cover in the herbaceous layer.

8.6.4.3. Valley Oak Riparian Forest

Valley oak riparian forests occur along reaches 1, 4B, and 5 (Table 8- 14) but 80% of this forest is along Reach 1. Important characteristics of the valley oak riparian forest include:

- The valley oak canopy and shrubs covers 61% of the area (Table 8-15), 53% with a single layer of trees or shrubs, and 8% with both a tree canopy and an understory of shrubs and suppressed saplings.
- More than 90% of valley oak riparian forests have canopies greater than 40 feet high, (Figure 8-29).
- Trees are typically 20 to 40 cm (8 to 16 inches) dbh, and only 4 per hectare (about 1½ per acre) are larger than 60 cm (2 feet) dbh (Figure 8-30).
- Valley oak and Goodding's black willow are the dominant tree species.

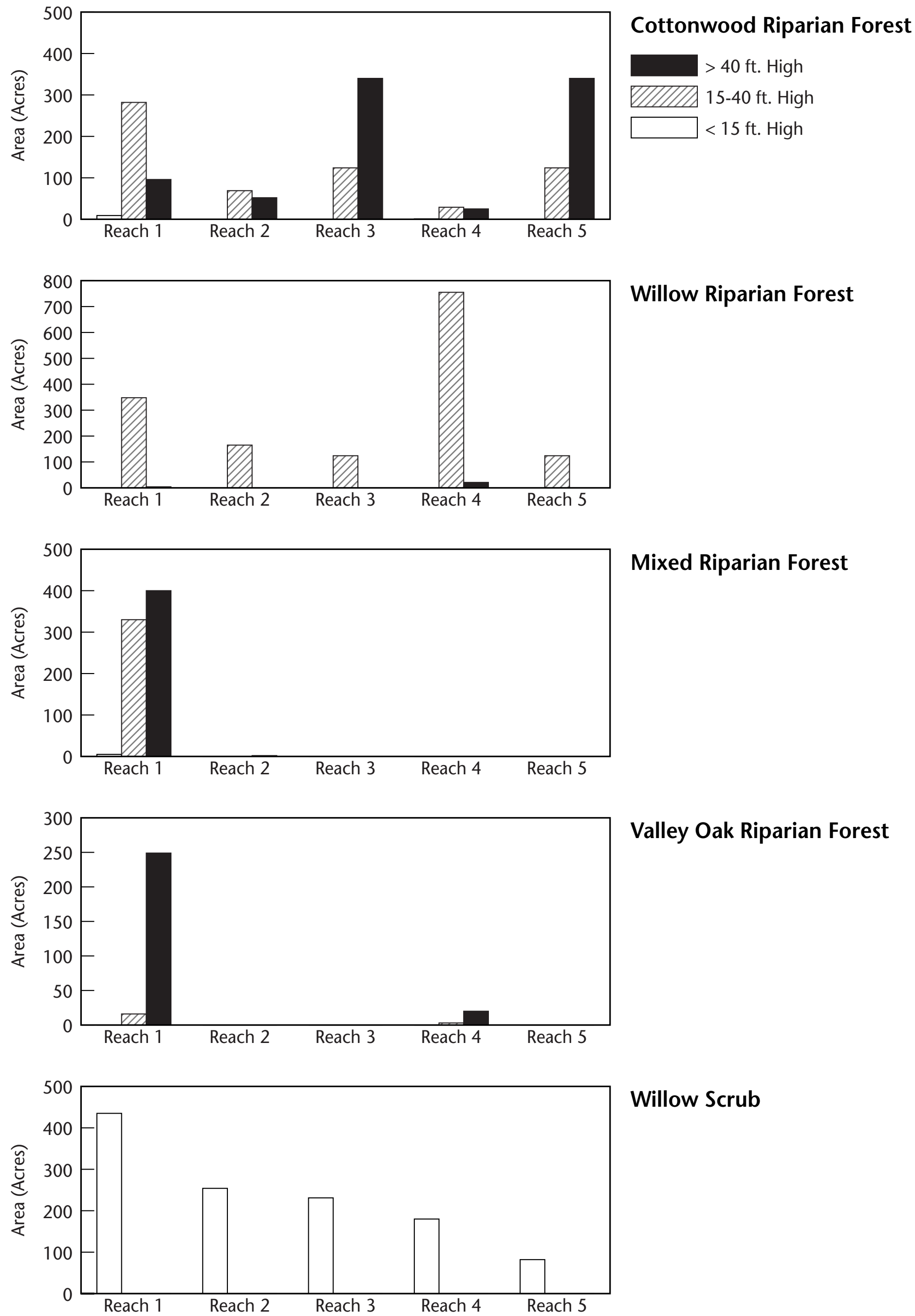


Figure 8-29. Histogram of canopy height and associated acreages of existing vegetation in Reaches 1-5.

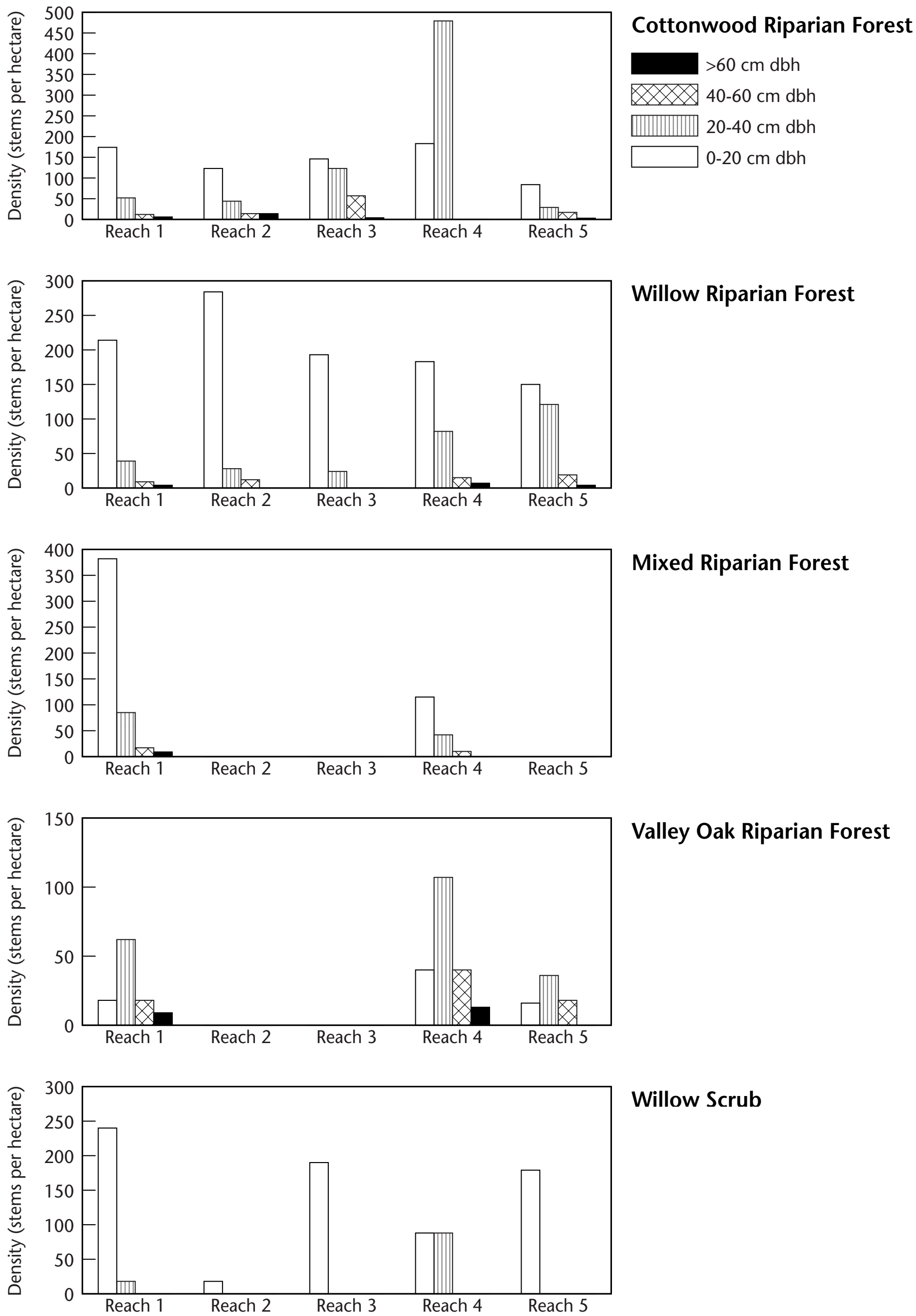


Figure 8-30. Histogram of stem diameters and associated plant densities of existing vegetation in Reaches 1-5.

- The herbaceous layer covers 65% of the transect length and is dominated by exotic species (Table 8-15 and Table 8-17). The most abundant exotic species are ripgut brome, Bermuda grass, perennial ryegrass, and prickly lettuce. Mugwort and creeping wildrye are the only abundant native species, with 5% relative cover each.

8.6.4.4. Willow Riparian Forest

Willow riparian forests occur along all reaches (Table 8-14). Important characteristics of the willow riparian forest include:

- Willow riparian forest tree and shrub canopy covers 50% of the area (Table 8-15).
- Most (98%) of willow riparian forests canopies are 15 to 40 feet high (Figure 8-29).
- Trees are typically less than 20 cm (8 inches) dbh, with only 14 per hectare (about 6 per acre) larger than 40 cm (1.3 feet) dbh (Figure 8-30). The dominant tree species is Goodding's black willow (Table 8-16). The herbaceous layer covers 50% of the transect length (Table 8-15).
- The dominant herbaceous species are Bermuda grass, and to a lesser degree, native species including mugwort and salt grass (Table 8-17).

8.6.4.5. Willow Scrub

Willow scrub occurs along all reaches (Table 8-14), and important characteristics of the willow riparian forest include:

- Trees and shrubs cover 41% of the willow scrub area (Table 8-15), 37% with a single layer of trees or shrubs, and 4% with both a tree canopy and an understory of shrubs and suppressed saplings.
- The canopy is less than 15 feet high, and stems are less than 20 cm (8 inches) dbh (Figures 8-29 and 8-30). The dominant species are sandbar willow and Goodding's black willow (Table 8-16).
- Several invasive exotics (giant reed, Himalayan blackberry, and scarlet wisteria) are more abundant in willow scrub than in other riparian forests, and have a combined relative cover of 10% (Table 8-16).
- Willow scrub area's herbaceous layer covers 43% of transect length (Table 8-15). Within it, the most abundant species are the exotic species rattail fescue and foxtail chess, and the most abundant native species being mugwort. Creeping wildrye, black mustard, and western goldenrod are also common, though less abundant (Table 8-17).

8.6.4.6. Disturbed Vegetation

Disturbed vegetation is associated with roads, canals, levees and aggregate pits. Although it exists along all five reaches, more than half the area of disturbed vegetation is along Reach 1 (Table 8-14). There it occupies more land than all types of riparian forest and scrub combined.

8.6.4.7. Grassland

Grassland vegetation occupies more area within the study area than any other native vegetation type (Table 8-14). The grassland category is internally variable and ranges from upland grasslands to herbaceous riparian vegetation, and grasslands that include or intergrade with the seasonal wetlands category. Overall, the five most abundant species are three exotic grasses (ripbut brome, foxtail fescue, and Mediterranean barley) and two herbs, the exotic red-stemmed filaree and the native horseweed (Table 8-17).

Grassland vegetation displays a shift in species composition from upstream to downstream reaches. Along Reaches 1 and 2, the dominant species are foxtail fescue, ripgut brome, and spike weed, all characteristic of upland grasslands. Along Reaches 4 and 5, the dominant species are creeping wildrye, salt grass, and alkali heath, which indicate wetter and more saline conditions.

8.6.4.8. Riparian Scrub

Riparian scrub is distributed throughout all reaches of the San Joaquin River (Table 8-14). On average, woody plants cover 21% of the area within riparian scrub; herbaceous plants cover 72% (Table 8-15). Several co-dominant woody species account for most of the tree and shrub cover (Table 8-16), and their abundance varies substantially among reaches. Similarly, of herbaceous species only mugwort and black mustard are abundant in all reaches.

Herbaceous species' abundance changes from upstream to downstream reaches. In Reaches 1 and 2, the most abundant species are mugwort, cocklebur, black mustard, spikeweed, and ripgut brome. In contrast, the most abundant species along Reaches 4 and 5 are mugwort, salt grass, black mustard, creeping wildrye, and Mexican rush. Except for black mustard, these are native perennial species. This change in species composition represents a change in growth form because mugwort, salt grass, creeping wildrye, and Mexican rush are all perennials with stems that spread along or below the ground. Greater soil moisture and changing soil types, including increased salinity and finer soil textures in the downstream areas, may be factors strongly influencing species composition.

8.6.4.9. Riverwash

Riverwash occurs along the length of the study reach (Table 8-14), but was sampled only along Reaches 1 and 2. As previously stated, The acreage of riverwash should not be interpreted as a precise estimate because riverwash acreage is partially a function of the flow at the time that the aerial photograph was taken. Woody and herbaceous plant cover is low (Table 8-15). Oregon ash is abundant in riverwash along Reach 1. Numerous herbaceous species occur within riverwash areas; however, most are relatively uncommon. The most abundant species are foxtail fescue, Bermuda grass, red-stemmed filaree, and willow herb (Table 8-17). Also abundant are lupines that grow on sandbar areas categorized as riverwash.

8.6.4.10. Wetland

Wetlands habitats range from seasonally saturated or inundated to persistently inundated; the type of vegetation reflects the duration of saturation or inundation. Wetland vegetation occurs along all reaches (Table 8-14). Wetland habitat has a low cover of woody plants, composed mostly of tree saplings, and a relatively high cover of herbaceous plants (Table 8-15). Goodding's black willow is the dominant woody plant (Table 8-16). The most abundant herbaceous species are western goldenrod and pale smartweed (Table 8-17). The species composition is indicative of seasonally saturated wetlands, rather than of persistently flooded wetlands or marshes that are typically dominated by bulrushes, cattails, and rushes. There are fringes of rush (*Juncus* sp.) along many areas of the river banks.

8.6.4.11. Invasive Exotic Plants

Exotic species are a major component of most, if not all, remaining natural habitats within the San Joaquin Valley, including habitats in the study reach. Some of these species are problematic invasive species that dominate areas to the exclusion of other plants, and expansion of their range and local abundance can cause substantial ecological change. In the understory, non-native species such as Himalayan blackberry are dominant components; however, the canopy vegetation is dominated by native trees and shrubs, except in localized areas where giant reed or eucalyptus dominate (Moise and Hendrickson 2002).

Invasive exotic species in California are well summarized in Randall and Hoshovsky (2000); thus not discussed in great detail here. Plant invasions alter ecosystem function and tend to reduce diversity of native species (Randall and Hoshovsky 2000). Invasive species may interfere with the regeneration of native dominants, reduce the cover and diversity of native species, form dense monotypic stands, alter resource availability, or change the disturbance regime. As a consequence, controlling invasive exotic plants is perhaps the most urgent task facing managers of natural habitats.

Controlling an invasive exotic plant before it becomes well-established is important. Once a species has become widespread and abundant, mechanical and/or chemical removal can be prohibitively expensive, and after an invasive species is removed, it frequently re-invades. Furthermore, removal of the invasive species is not guaranteed to remove the invasive impacts. Locally extirpated native species may require re-introduction to the site.

Several invasive exotics are already widespread and abundant in the study area. They cover 99 acres in nearly monospecific stands (Table 8-14) and are a minor component of most vegetation types. These species are particularly abundant and widely distributed along Reach 1. High levels of disturbance may have aided their spread in Reach 1, as suggested by their distribution relative to aggregate pits.

These species may interfere with the success of restoration actions, particularly when a restoration action (such as a dispersal flow or channel modification) creates an opportunity for the dispersal and establishment of the invasive species. Therefore, in developing restoration strategies, the biology of the individual species and the techniques available to control their spread must be considered (Table 8-18).

Table 8-18. Prevalent perennial invasive exotic species along the San Joaquin River.

Species	Description
Eucalyptus *(Eucalyptus globulus)* *CalEPPC List A-1*	Blue gum is a large, long-lived, Australian tree reaching more than 150 feet in height. It can form dense stands with little understory vegetation and a thick, flammable litter layer. When cut or damaged by fire, it sprouts new stems and blue gum seedlings establish readily on burned or otherwise disturbed sites (Boyd 2000). Because it is a valued landscape tree, biocontrol of blue gum is not an option, and burning is ineffective. However, repeated cutting of stems and application of herbicides are both successful techniques for eradicating blue gum (Boyd 2000). Blue gum and other naturalized eucalyptus species were widespread on the river in Reaches 1, 2, and 5. Nearly 85 acres were recorded in Reach 1A and 32 acres in Reach 1B ; Reaches 2 and 5 had 7 and 12.3 acres, respectively (Moise and Hendrickson 2002).
Giant Reed *(Arundo donax)* *CalEPPC List A-1*	Widespread in tropical regions, giant reed is a perennial grass whose stems (culms) are 10-30 feet in height, and whose below-ground stems reach depths of several feet. It forms dense stands that can expand to occupy much of the riparian zone. These stands have low value as wildlife habitat and provide little instream shade (Dudley 2000). Though rapidly growing and long-lived, giant reed does not appear to produce seed and establish seedlings in North America (Dudley 2000). Expansion of existing stands is entirely a result of vegetative reproduction. Successful extirpation of giant reed depends on herbicide application, as no biocontrol agents are available, burning is ineffective, and mechanical eradication is extremely difficult (Dudley 2000). This species is most prevalent along reaches 1A, 1B, and 2, where 16.4, 7.0, and 17.5 acres acres were mapped, respectively. Small amounts were present on all other reaches except Reach 4 (Moise and Hendrickson 2002).
Scarlet Wisteria *(Sesbania punicea)* *CalEPPC List Red Alert*	Scarlet wisteria is a South American shrub or small tree reaching 10 feet in height. It is grows rapidly, and its seeds are both readily dispersed and persistent. The pods containing the seeds may float for up to a week, and if not abraded the seed remain dormant, perhaps for years (Hunter, unpublished data). Scarlet wisteria can form dense stands excluding other species, and its populations are rapidly increasing. The species was not even included in the most recent flora for California (Hickman 1993) yet is now widespread and abundant in Reach 1A, along the lower American River, and elsewhere. Because it has become a problematic invasive plant only recently, the effectiveness of control strategies is still being evaluated. Scarlet wisteria was found mainly on Reach 1A extending downstream to river mile 242 in Reach 1B. It forms dense colonies on disturbed areas and on sand and gravel bars where it displaces the native willow scrub (Moise and Hendrickson 2002).
Tree-of-Heaven (*Ailanthus altissima*) *CalEPPC List A-2*	Tree-of-heaven is a clonal tree from China. Its individual stems are short-lived and seedling establishment may be relatively uncommon in California. However, it repeatedly produces new stems from it roots, forming persistent thickets of considerable area (Hunter 2000). Because of its production of root sprouts, cutting and burning are relatively ineffective in removing established tree-of- heaven thickets. Application of herbicide to frilled stems is probably the most effective means of removing tree-of-heaven (Hunter 2000). Tree of heaven was found on reaches 1 and 2, with almost 3 acres recorded in reach 1A (Moise and Hendrickson 2002).

Table 8-18., continued.

Species	Description
Himalayan blackberry (*Rubus discolor* = *R. procerus*) *CalEPPC List A-1*	Himalayan blackberry, native to western Europe, forms large impenetrable clumps and is widespread along the river, especially along channelized banks. It grows vigorously and according to Moise and Hendrickson (2002) "appears to have usurped the niche of its native relative, the California blackberry (*Rubus ursinus*)." It is a prolific seeder and the seeds are readily dispersed by mammals, birds, and water (Hoshovsky, 2000). It also reproduces vegetatively. Due to difficulty in distinguishing it from the native blackberry without relatively close examination, only one occurrence of this species was mapped (in Reach 1A) by Moise and Hendrickson (2002). However, they do state that most of the blackberry along the river appears to be Himalayan blackberry.
Parrot's Feather (*Myriophyllum aquaticum*) *CalEPPC List B*	Parrot's feather is a stout emergent aquatic perennial that forms dense mats of intertwined brownish stems (rhizomes) in water (Godfrey, 2000). Whorled feather-like leaves (four to six at a node) make the emergent stems resemble bright green bottlebrushes. These may extend as much as eight inches above the water surface. This aquatic weed was not documented in the DWR vegetation surveys, which focused on the wetland and upland vegetation, but was observed during recent field visits in Reach 1 (Orr, personal communication 2002).
Notes: CalEPPC = California Exotic Pest Plant Council. Exotic Pest Plant of Greatest Ecological Concern in California, October 1999. List A-1—Most Invasive Wildland Pest Plants—Widespread in California; List A-2-- Most Invasive Wildland Pest Plants—Regional distribution in California; List B—Wildland Plants of Lesser Invasiveness; Red Alert: Pest plants with the potential to spread explosively; infestations currently small and localized.	

8.6.5. Summary of results from San Joaquin River Riparian Habitat Restoration Program 1999-2001 Pilot Project

As discussed in Section 8.5.7.2, monitoring goals varied between the 1999-2001 pilot projects. In the 1999 pilot project, the goal of the flow releases from Friant Dam were to establish riparian vegetation on upper sand bar surfaces, primarily in Reach 2. Monitoring focused on evaluating whether managed flow releases promoted riparian tree growth along those subreaches that had very limited riparian vegetation due to long periods of dewatered conditions in the river, and at what locations vegetation established. In 2000, the goal of the pilot project flow release was primarily to maintain vegetation that had initiated during the previous years' pilot project release. In 2001, the goal of the pilot project flow releases was primarily vegetation maintenance and evaluation of hydrologic routing and shallow groundwater characteristics. Monitoring methods for the 1999-2001 pilot project are provided in Section 8.5.7.2. A brief summary of results is presented that focus on the 2001 monitoring season, as some of the more interesting observations were made during this monitoring season. Readers are directed to FWUA and NRDC (2002), SAIC (2002), and JSA and MEI (2002a and 2002b), for more details on monitoring methods and results of 1999, 2000, and 2001 pilot projects.

8.6.5.1. Hydrology Results

Flows were released from Friant Dam during the summers of 1999-2001 for the respective pilot projects (Table 8-19).

Table 8-19. Summary of hydrology during 1999-2001 releases for pilot projects.

Water Year	Dates of pilot project flows	Date of peak Friant Dam release	Peak release from Friant Dam (cfs)	Peak flow at Gravelly Ford (RM 227.5) (cfs)	Peak flow at Chowchilla Bifurcation Structure (RM 216.1) (cfs)
1999	July 3 – Oct 6	June 4-6	813[1]	550[1]	434[1]
2000	June 5-June 21	June 18	2,590	1,760	Not reported
2001	June 1-June 25	June 17-23	400[1]	181[1]	0[3]
2001	Aug 27-Sept 9	Sept 5-7	880[1]	640	0[4]

[1] Daily average flow, steady flow so roughly equal to instantaneous peak

[2] Daily average flow, short duration flow so less than instantaneous peak

[3] Flow extended downstream to at least RM 223.2 (SAIC 2002)

[4] Flow extended downstream to at least RM 217.7 (SAIC 2002)

Because the one of the primary objectives of the 2001 pilot projects was hydrologic routing and groundwater response, the following discussion focuses on results from the 2001 monitoring effort. In 2001, two pulse flows were released from Friant Dam (Figure 8-31): 1) a flow of 200 to 250 cfs between June 1 to June 24, with a short peak flow of approximately 400 cfs, 2) a shorter peak flow of 880 cfs between August 27 and September 9. The flow averaged approximately 40 cfs at Gravelly Ford between the two pulses, but flows approached zero during short periods of time (Figure 8-31). A two-day lag time occurred between Friant Dam and Gravelly Ford (approximately 39 river miles). Highlights from the hydrologic monitoring include:

- There was a strong relationship between the river flows and shallow groundwater table within the floodway and the transition between floodway and agricultural lands. Monitoring wells were not installed at any significant distance beyond the floodway margins, so the relationship between river flows and regional shallow groundwater elevations cannot be quantified. The severe depletion in the regional shallow groundwater aquifer (see Chapter 4) suggests that the groundwater flow gradient away from the river is strong, re-filling the depleted shallow groundwater aquifer. However, no data have been collected as part of the pilot project to confirm or reject this assumed gradient.
- Prior to the release, the river was dry downstream of Gravelly Ford (RM 227.5). The limit of flowing water in the river extended five miles downstream to RM 223.2 during the June pulse flow (peak release = 400 cfs). The September pulse flow (peak release = 880 cfs) extended farther downstream, with flowing water ending between the RM 217.7 and the RM 212.0 sites. Therefore, surface flows did not necessarily reach the downstream-most transects.
- In-river water surface elevations increased between 1 and 3 feet during the pulse releases.
- Corresponding shallow groundwater fluctuations depended on location. At sites upstream of Gravelly Ford, the June pulse increased shallow groundwater elevations by 1 to 2 feet, while the September pulse increased elevations by 2 to 3 feet (Figure 8-32). Shallow groundwater elevations naturally tapered off after the peak streamflow occurred, within one month after the pulse. This plateau occurred because flow is perennial upstream of Gravelly Ford (i.e., the river supports the local shallow groundwater table).

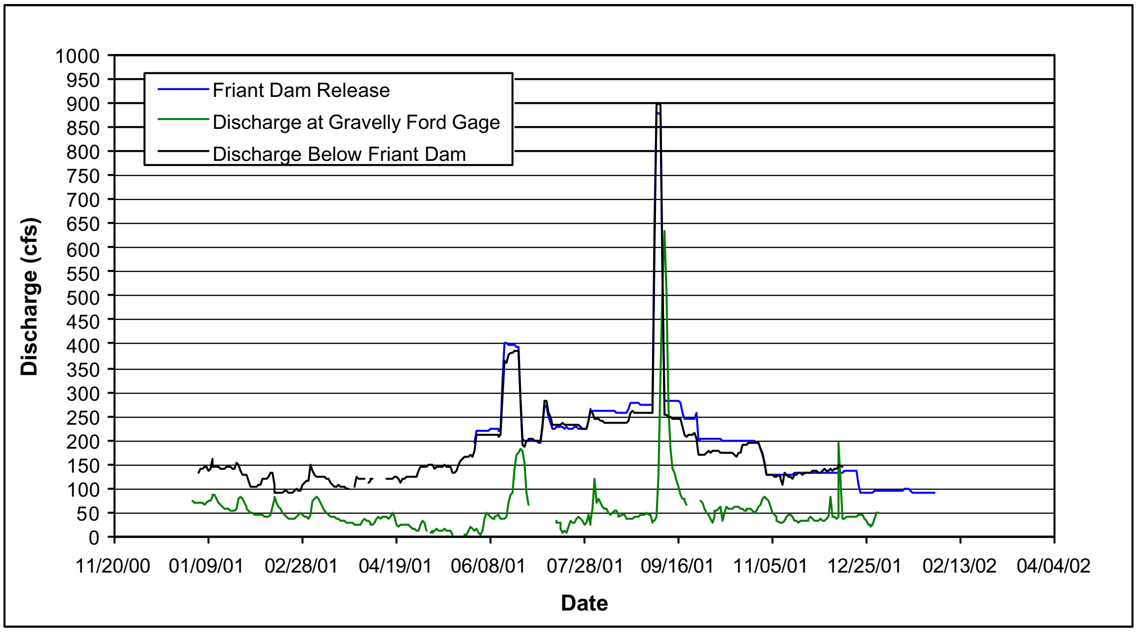


Figure 8-31. Friant Dam Release (May to September 2001) and San Joaquin River discharge below Friant Dam and at the Gravelly Ford Gage (January to December 2001).

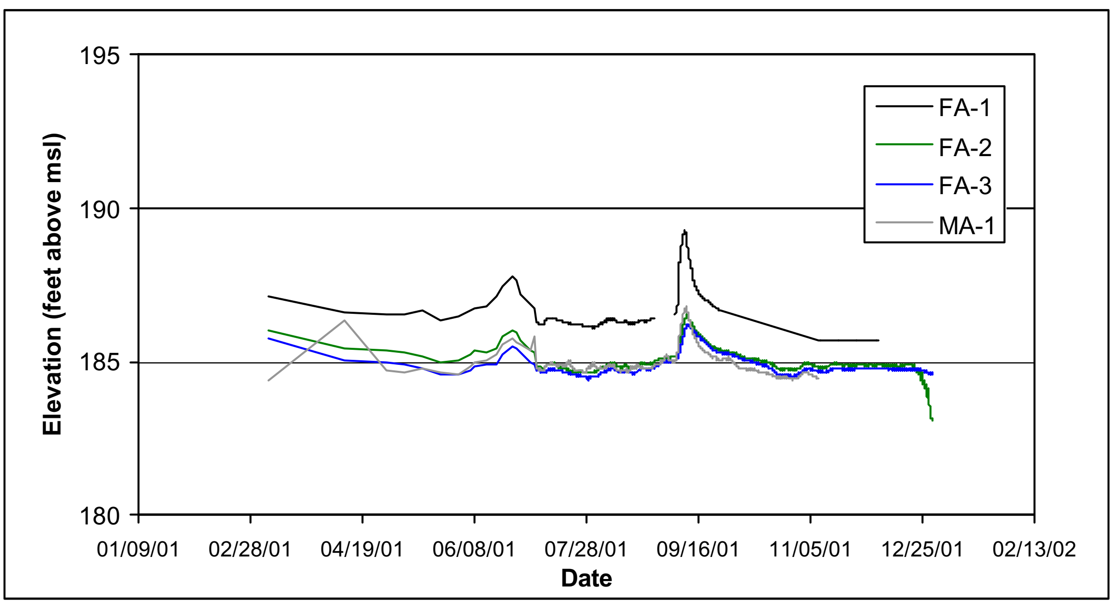


Figure 8-32. Summer 2001 Groundwater elevation trends from four alluvial wells at the RM 229.3 (Lake Avenue) study site (upstream of Gravelly Ford). Cross section thalweg elevation is 181.66 ft.

- Downstream of Gravelly Ford, sites do not normally have river flows except during Pilot Project pulse flows and flood control releases. The groundwater response to the Pilot Project flows was different compared to the upstream study site with its perennial flows. Due to groundwater overdraft (see Chapter 4), groundwater elevations are far below the thalweg of the San Joaquin River downstream of Gravelly Ford. Therefore, when streamflows are released, the shallow groundwater aquifer rapidly fills up (up to 15 feet) as it is recharged (Figure 8-33 and 8-34). This likely results in significant flow attenuation and flow loss until this shallow groundwater "hole" is filled. The peak flow at Gravelly Ford (RM 227.5) during the September pulse was approximately 630 cfs, but flow ended between RM 217.7 and 212.0, such that 630 cfs was "lost" to this hole in 11 to 16 river miles (Figure 8-31).
- The shallow groundwater response to the June 2001 pulse was strong downstream to the RM 222.1 site, but the response was very small at the RM 220.0 site (Figure 8-34). Recalling that the surface flow during the June 2001 pulse ended at approximately RM 223, the small groundwater response observed at RM 220.0 suggests that the longitudinal groundwater response ended at approximately RM 220.
- Local influences on shallow groundwater elevations at the RM 222.1 site (Figure 8-33) are not apparent at the other sites during the Pilot Project flows (Figure 8-32). Shallow groundwater elevations rose in response to the June and September pulse flows, but there are other rises in the shallow groundwater table in November, December, and January that are not related to instream releases (Figure 8-33). Perhaps the groundwater elevation increases are due to cessation of local groundwater pumps, and/or irrigation with surface water that recharges the shallow groundwater aquifer. Regardless, in Reach 2, shallow groundwater monitoring results illustrate that shallow groundwater elevations fluctuate greatly through the year.

8.6.5.2. Vegetation Results

Similar to monitoring of the 2000 pilot project, vegetation monitoring during 2001 occurred before the pulse flows (June 2001) and after the pulse flows (November 2001). Vegetation analysis was complicated to an unknown degree by herbicide spraying in the channel, although extensive amounts of vegetation appeared to be killed by the spraying. Highlights from the vegetation monitoring include:

- The number of plants decreased 50% from 2000 to 2001; of the approximately 6,000 seedlings of the 2000 cohort, almost all of them appeared dead by the June 2001 monitoring cycle. Hydrologic conditions were favorable for seedling establishment and survival in 2000, because perennial flows occurred at all monitoring sites throughout the summer (JSA and MEI, 2002b). Conditions in 2001 were unfavorable even with the pulse flow releases, because downstream sites were dry most of the year and the two downstream-most sites were dry even through the 2001 pulse flows. Stress or mortality from lack of water in the root zone is one of several mortality agents. Others include herbivory, herbicide spraying, bed scour, and prolonged inundation.
- Of the 1,892 plants sampled before the June 2001 pulse release, 95% of the plants (1,774 individuals) were narrow leaf willow (*S. exigua*) or Goodding's black willow (*S. gooddingii*). Fremont cottonwood (*Populus fremontii*) made up less than 1% of the plants (12 individuals), Oregon ash (*Fraxinus latifolia*) made up 1.3% of the plants (25 individuals), and western sycamore (*Platanus racemosa*) made up less than 1% of the plants (3 individuals). Box elder was not observed in the sampling transects.

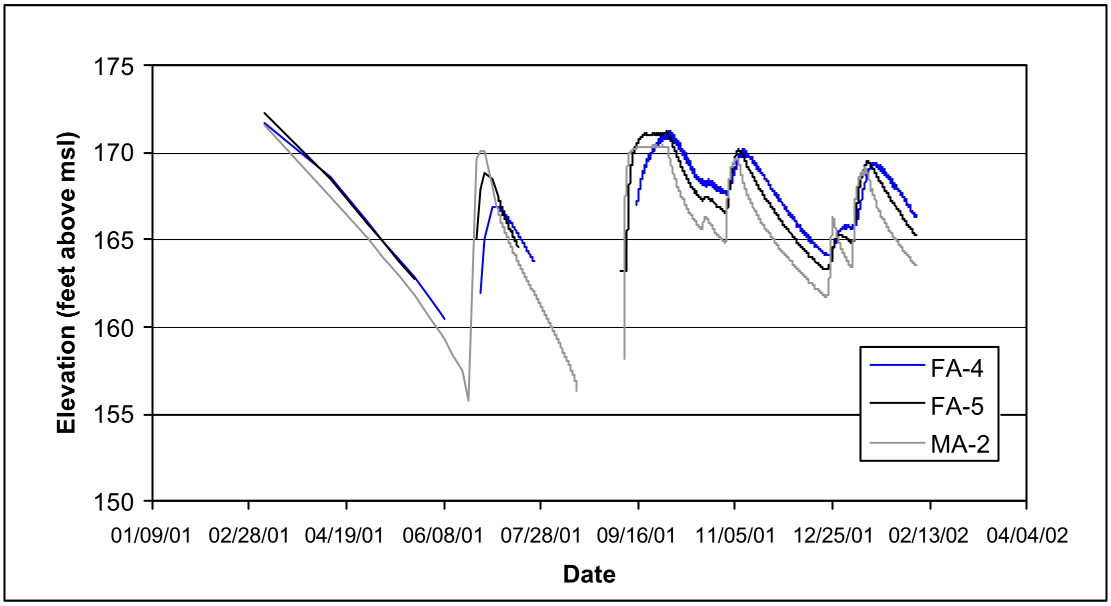


Figure 8-33. Summer 2001 Groundwater elevation trends from three alluvial wells at the RM 222.1 study site (downstream of Gravelly Ford). Cross section thalweg elevation is 171.33 ft.

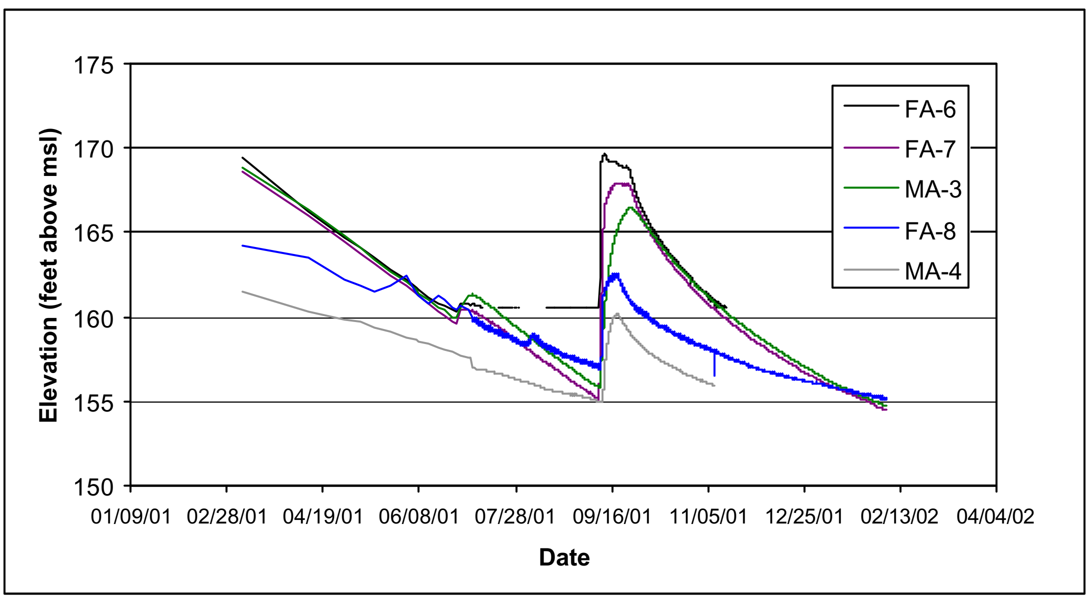


Figure 8-34. Summer 2001 Groundwater elevation trends from five alluvial wells at the RM 220.0, RM 218.2, and RM 217.7 study sites (downstream of Gravelly Ford). Cross section thalweg elevations are 168.83 ft (FA-6, FA-7, MA-3), 163.66 ft (FA-8), and 161.60 ft (MA-4).

- The November 2001 monitoring counted 1,450 plants, a decrease of 23%. The percentages of remaining plant species were similar to the June 2001 monitoring survey, with over 95% (1,379 individuals) of the plants being narrow leaf willow and Goodding's black willow.
- Most plant individuals (59%) were class 1 seedlings or saplings (less than 1.5 meters tall). The balance (40%) were size class 2 (greater than 1.5 meters tall but less than 10 centimeters dbh). However, these size distributions do not imply that the plants are failing to reach maturity because most of the plants were narrow-leaf willow, which do not generally grow larger than size class 2.
- Some longitudinal trends in abundance of certain species were observed. Oregon ash and buttonwillow were documented almost exclusively (95%) at monitoring sites upstream of Gravelly Ford. Approximately 60% of the Fremont cottonwood plants were also observed upstream of Gravelly Ford. Downstream, the most common species were sandbar and black willows.

8.6.5.3. Summary

The pilot projects' results suggest that selected woody riparian species can survive when shallow groundwater elevations are far below the thalweg of the river channel (e.g., 15 feet or more at some sites for short durations. However, only certain species can survive these extreme conditions and diversity is limited. While not a stated conclusion of the pilot project reports, restoring a perennial and seasonally variable flow regime will likely improve riparian plant establishment on both lower elevation surfaces and higher channel surfaces, and will likely encourage greater species diversity beyond narrow leaf willow and Goodding's black willow.

Since 2000, willow saplings' dynamics have varied at the monitoring sites (Table 8-20). From 2000 to 2001, the density of sandbar willow stems less than 1.5 m high decreased substantially along all monitoring transects. This density decrease was accompanied by a density increase of larger stems (those greater than 1.5 m high) at only two sites, indicating that substantial willow mortality had occurred, with little recruitment into larger size classes (with the caveat that narrow-leaf willow rarely grows to the largest size class). For Goodding's black willow, changes have been more varied (Table 8-20). Additional seedling and sapling recruitment (size class 1) of Goodding's black willow occurred at four of the 12 monitored sites. At two sites, mortality of all saplings was complete, but at several other sites, a decrease in density of stems less than 1.5 m high was accompanied by an increase in stems greater than 1.5 m high; these findings suggest successful willow growth to larger sizes. Perhaps the success to larger size classes was a result of the location of the plants with respect to the surface water location. However, the density differences between monitoring sites did not correspond to differences in groundwater elevations.

Table 8-20. Density of willow saplings along Pilot Project transects in 2000 and 2001.

Study Site Location	Year	*Salix Gooddingii*				*Salix exigua*	
		Size Class 1[a] (plants/HA)	Size Class 2[b] (plants/HA)	Size Class 3[c] (plants/HA)		Size Class 1[a] (plants/HA)	Size Class 2[b] (plants/HA)
RM 234.4	2000		186	159		2,800	783
	2001	NS	NS	NS		NS	NS
RM 229.3	2000	28	14	0		1,028	222
	2001	413	124	14		83	41

Table 8-20., Continued

Study Site Location	Year	*Salix Gooddingii* Size Class 1[a] (plants/HA)	*Salix Gooddingii* Size Class 2[b] (plants/HA)	*Salix Gooddingii* Size Class 3[c] (plants/HA)	*Salix exigua* Size Class 1[a] (plants/HA)	*Salix exigua* Size Class 2[b] (plants/HA)
RM 227.1	2000	342	291	6	2,203	382
	2001	265	416	0	265	170
RM 226.2	2000	15	0	0	3,701	67
	2001	345	427	0	480	157
RM 225.2	2000	86	60	0	3,395	224
	2001	466	255	0	86	186
RM 223.2	2000	85	7	0	285	48
	2001	24	24	0	132	31
RM 222.1	2000	795	164	0	2,428	369
	2001	833	89	0	592	434
RM 221.1	2000	36	879	0	490	907
	2001	79	0	0	50	22
RM 220.0	2000	61	142	0	411	27
	2001	0	0	0	32	7
RM 219.1	2000	137	258	5	212	5
	2001	0	0	0	35	0
RM 218.2	2000	55	1,930	86	1,633	94
	2001	164	232	0	138	0
RM 217.7	2000	36	0	0	276	182
	2001	0	0	0	216	205
RM 212.0	2000	96	507	139	149	32
	2001	64	149	0	21	16

[a] SC1 = Size class 1, stems less than 1.5 m high.

[b] SC2 = Size class 2, stems greater than 1.5 m high, with a diameter less than 10 cm.

[c] SC3 = Size class 3, diameter greater than 10 cm.

Another key observation of the pilot project is that surface flow losses to infiltration can be severe in Reaches 1B, 2A, and 2B. These reaches of the San Joaquin River are locations where groundwater overdraft has been severe (see Chapter 4). Results suggest that surface flow losses (and likely some evapotranspiration losses) to infiltration can be very severe (over 600 cfs "lost" to infiltration in 10 miles of river as the groundwater "hole" is filled). Once the initial groundwater recharge occurs with surface flows, the steady-state seepage loss rate is approximately 100 cfs in Reach 2A based on 1999 synoptic flow measurements. Recharging the shallow groundwater aquifer could require a substantial flow from the river, and the recharge effects could be hampered by shallow groundwater pumping nearby based on the response of shallow groundwater tables shown in Figure 8-33. Pumping could impair flow restoration and continuity efforts through this reach.

The pilot projects documented the germination and establishment of riparian vegetation, and described shallow groundwater hydrology, in the most-difficult-to-restore reaches of the San Joaquin River. Monitoring should be continued in these reaches, and expanded to other priority reaches where riparian establishment is desired.

8.7. RIPARIAN VEGETATION LIFE HISTORY AND CONCEPTUAL MODELS

Hydrology and fluvial geomorphology play a central role in determining the ecology of woody riparian vegetation (e.g., Hupp and Osterkamp 1985, Mahoney and Rood 1998, Scott et al. 1999, Bradley and Smith 1986, Shafroth et al. 1998, Shafroth et al. 2000). Critical plant life-history stages respond to varying flow regimes; these responses determine the elevational and lateral distribution and extent of riparian plant species. Seed dispersal, germination, establishment, vegetative growth, and survival are all mediated by flow-related events. Thus, the timing, magnitude, duration, and frequency of flows affect the elevational distribution, extent, and community structure of riparian vegetation. The following sections describe a combination of conceptual models illustrated in the riparian scientific literature, as well as unpublished conceptual riparian models developed for the Central Valley.

Developing conceptual models requires an understanding of key life-history stages, timing, and strategies of each riparian species. Individual riparian plant species typically have four life-cycle stages: initiation, establishment, maturity, and senescence (Figure 8-35). For convenience in conceptual modeling, these stages are defined as follows:

- *Initiation* begins after a seed lands on exposed, moist substrate and germinates; this stage continues through the first growing season.
- *Establishment* begins after the first growing season and continues until the plant has enough resources to begin sexual reproduction.
- *Maturity* begins when a plant first flowers and produces seeds.
- *Senescence* follows maturity, when seed production and reproductive capacity eventually decline.

The structure of riparian stands is a result of hydrologic, climatic, and fluvial processes interacting with the life history of individual species. Primary causes of plant mortality include seedling desiccation, seedling scour, lateral erosion, density dependent mortality (shading), herbivory, disease, and infestation (Figure 8-35). Over time, these processes influence mortality rates at each life stage, resulting in variable and dynamic riparian stands. For example, a particular year may exhibit high seedling mortality associated with a scouring high flow, while later, more moderate floods may encourage seedling survival on certain bank surfaces.

The following sections summarize some of the linkages between hydrology, fluvial geomorphology, and key life history components of woody riparian vegetation. We focus on the linkages of spring-seeding woody riparian species (willows and cottonwoods) because they were historically the dominant woody riparian species in the study area, more is known about their life history needs, and they are ecologically desirable species to restore.

8.7.1. Dispersal and establishment of key riparian species

For this discussion, dispersal phenology is defined as the seasonal timing of seed dispersal for a given species. Understanding a species' dispersal phenology is critical when linking to hydrologic and geomorphic processes, because the seed dispersal period often defines the window of time when favorable environmental conditions are needed to generate a successful cohort of new plants. This is especially true of willows and cottonwoods because the seeds have a very short period of viability (a few days) and need to land in open habitat with sufficient soil moisture for establishment immediately after they disperse or establishment will not occur.

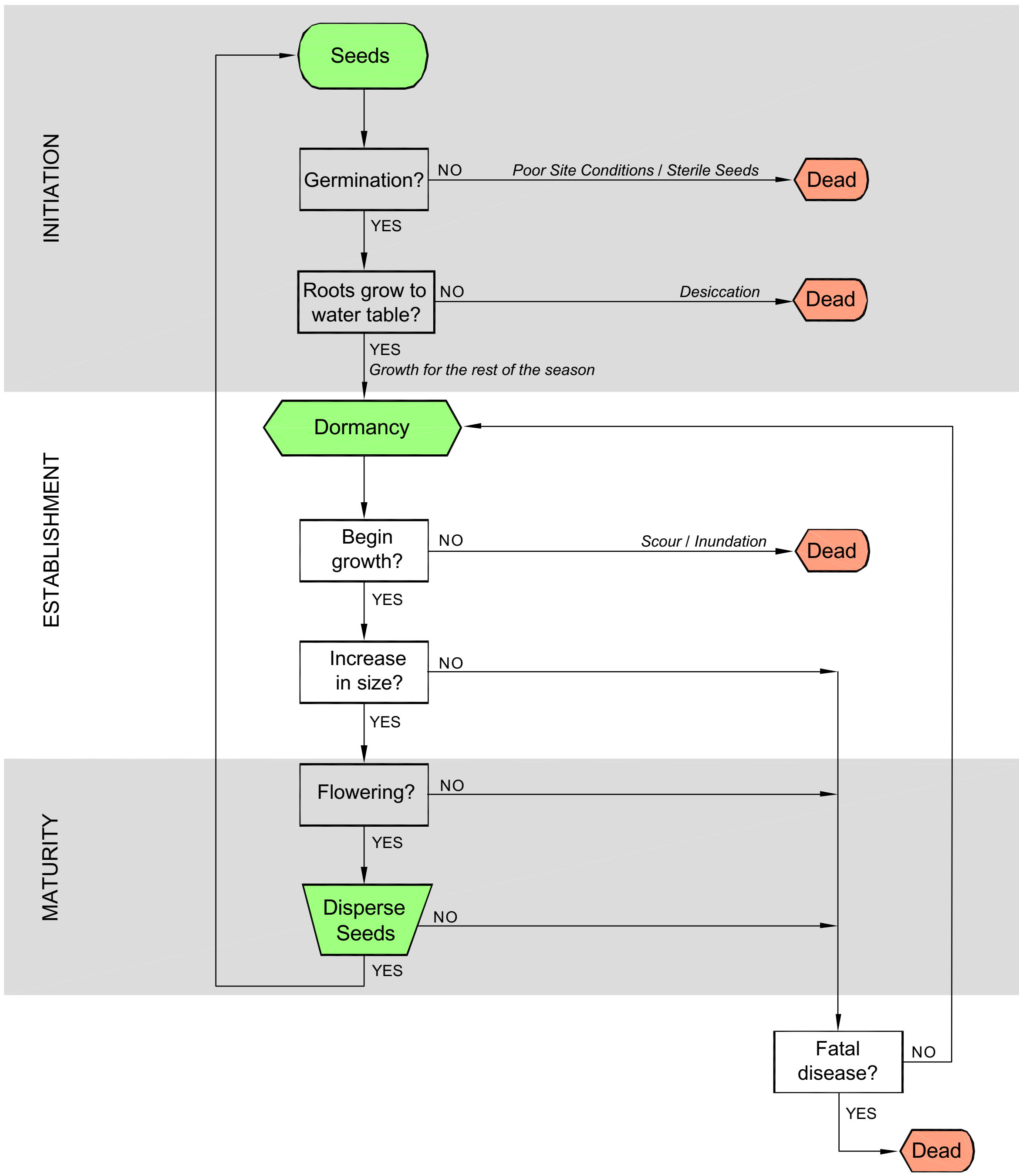


Figure 8-35. Generalized woody riparian plant life cycle, showing life stage and mortality agents that affect life stages.

Peak seed dispersal periods of riparian species vary considerably from species to species and may also vary from year to year with variation in annual climatic conditions (Wolfe and Associates 1999). Data on seed dispersal timing can be useful for managing target (i.e., desired) species. For example, to increase the success of natural regeneration of a target species such as Fremont cottonwood or black willow, flow releases can be developed to coincide with seed dispersal times to increase the success of natural regeneration of those species. Conversely, to discourage regeneration of exotic species, flow releases could be managed to avoid exotic species' seed dispersal times.

Two studies have documented seed maturation and dispersal phenology for Fremont cottonwood and several willow species along the San Joaquin River. The first study was conducted from June 6 through September 24, 1999 (Wolfe and Associates 1999), and the second was conducted from April 2 through June 26, 2002 (Stillwater Sciences, unpublished data). Additional field observations on the Tuolumne River were recorded in the fall of 1996 through the spring of 1998 (McBain and Trush, 2000) and on the San Joaquin River in the spring of 1998 (EA Engineering, 1999). Although some variation in phenology is expected among years and sites, the data from these studies can be used to establish general patterns of peak seed dispersal for the species studied.

Species in the willow family disperse seed in the spring and summer. Arroyo willow is the first of the local species to release seed, generally from mid-February through late March; with peak dispersal in the first half of March (Figure 8-36). Fremont cottonwood is the next species to disperse seed; typically during April and May, with a peak in late April through early May (Figure 8-36). Goodding's black willow, red willow, and narrow-leaf willow all generally disperse seed towards the end of or subsequent to the cottonwood dispersal period. Although the limited data show narrow-leaf willow to have the longest and latest seed dispersal period, extending into mid-August (Figure 8-36), there is some evidence from the 1999 Pilot Project that longer seed viability of Goodding's black willow may extend its potential germination period into the early fall. In contrast to the willows and cottonwoods, some of the other common riparian hardwood species exhibit seed dispersal in the fall (Figure 8-36). Box elder, for example, generally releases seed from mid-September through October with a peak in mid-October. White alder typically releases seed during October, with a peak in mid-October. Valley oak also disperses seeds (acorns) in the fall.

The seed dispersal phenology data collected in the spring and summer of 2002 by Stillwater Sciences (unpublished data) indicate that much variation in seed dispersal timing can occur among individuals both within and between sites (Figures 8-37 through 8-39). Cottonwoods observed at the Lost Lake site (RM 265) and Highway 140/165 site (RM 133) tended to exhibit synchronous seed dispersal with a peak during the last week of April (Figure 8-37). The length of the seed dispersal window was approximately one month at the Highway 140/165 site and two months at the Lost Lake site. A "middle" site at Firebaugh (RM 194) experienced the longest period of seed dispersal, with seed dispersal occurring from early April until the study terminated in late June. This extended seed dispersal period resulted from several different patterns among individual trees, with some trees peaking early, some later, while others had multiple or extended peaks.

In addition to variation in seed dispersal timing, there was also much variation in seed production among sites and among individual trees. At the downstream site (Highway 140/165), relatively few seeds were produced (<40 open catkins per tree at peak release), but at the Lost Lake site, trees produced many seeds (>100 open catkins per tree at peak release). The Firebaugh site trees exhibited the most variability; four of the ten observation trees produced many seeds, while the other six produced few seeds.

The 2002 data indicate that Goodding's black willow is the next species after cottonwood to start dispersing seed, beginning in early to mid-May and peaking in late June or later (Figure 8-38). The 2002 study ended before the peak seed dispersal occurred for this species. Sandbar willow began

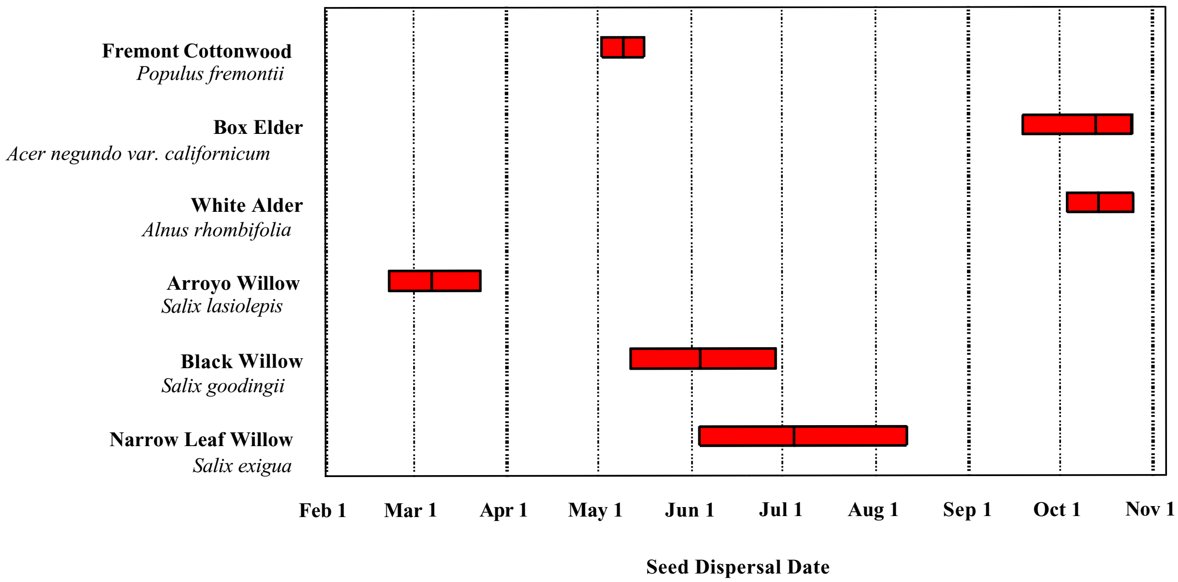


Figure 8-36. Generalized woody riparian vegetation seed dispersal periods for six common species, from EA Engineering (1999).

dispersing seed around the first of June in 2002, with seed dispersal strongly increasing by the end of June (Figure 8-39). The primary difference in the 2002 seed dispersal between the two willow species was that black willow began releasing seed 2 to 3 weeks earlier than sandbar willow. There may also have been differences in the duration and termination of seed release in 2002, but data collection stopped before any such pattern could be documented. Observations during the 1999 Pilot Study, which documented establishment of black willow seedlings after September releases, suggest either an extended period of seed viability or of dispersal for this species. The latter seems plausible given the site-to-site and individual-to-individual variation in phenology observed in this and other riparian species (Figure 8-37). Given the copious seed production of individual trees, even a few late dispersing individuals could account for this observation.

The 1999 study, which began in June and ran through September, documented a similar pattern for the three willow species studied (narrowleaf, black, and red willow), with seed dispersal generally beginning in early June and 90% or more of all seeds dispersed by late June or early July (Wolfe and Associates 1999). Differences in the timing of seed dispersal initiation among the three species may have been missed since the study was not started until June 6.

8.7.2. Establishment conceptual model: spring seed dispersal species

For successful recruitment, Fremont cottonwood (*Populus fremontii*) and willows (*Salix* spp.) are particularly dependent on specific hydrologic events during and immediately following their seed release periods. Establishment and survival of these early successional species are important for new patches of riparian vegetation, which facilitates the establishment of other species. Within new patches of willows and cottonwood, other tree species such as box elder and Oregon ash, often become established concurrently or at a later date, which initiates succession towards mixed riparian forest and understory. In this riparian system, the later-successional species, including box elder, Oregon ash, western sycamore, and valley oak, are more tolerant of shade than are cottonwood and willows; the establishment of late-successional species is less dependent upon specific hydrologic events.

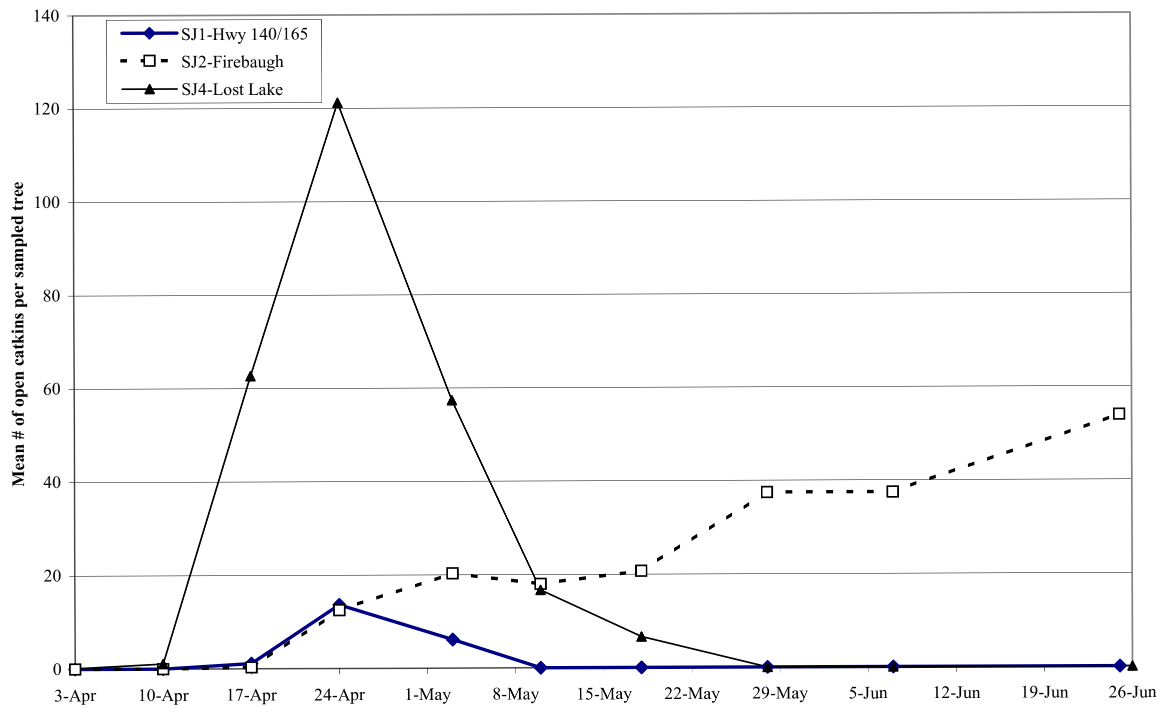


Figure 8-37. Spring and summer 2002 phenology data for Fremont cottonwood at three sites in the San Joaquin River study reach.

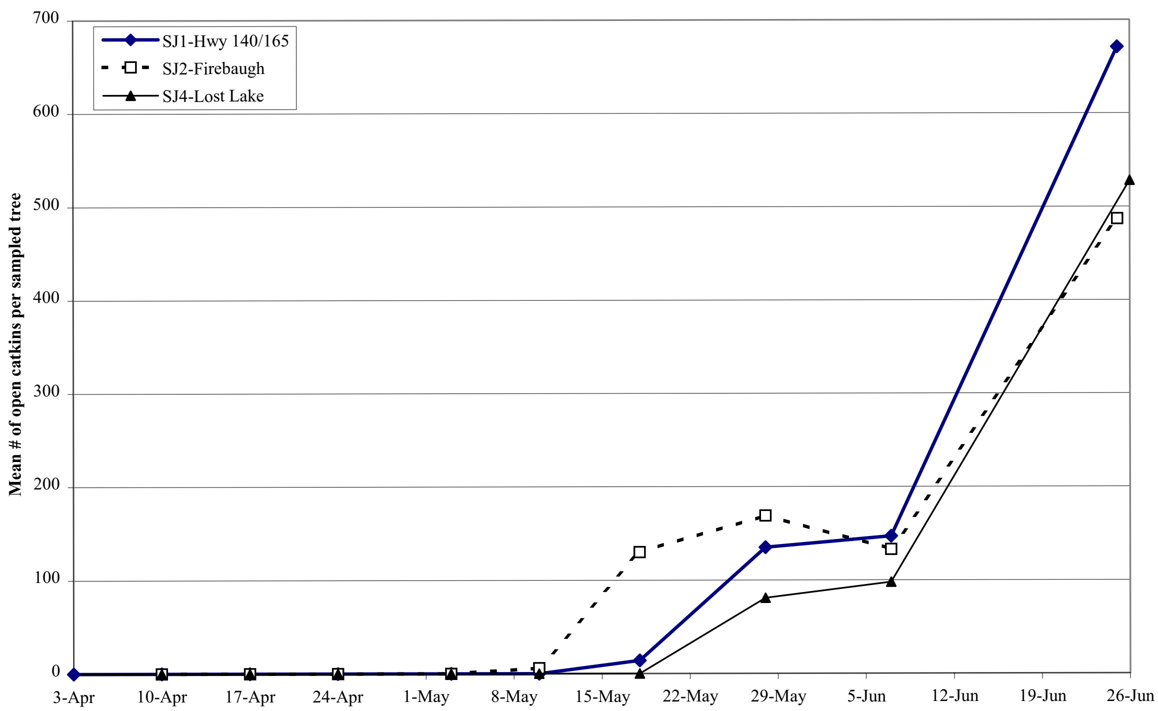


Figure 8-38. Spring and summer 2002 phenology data for black willow at three sites in the San Joaquin River study reach.

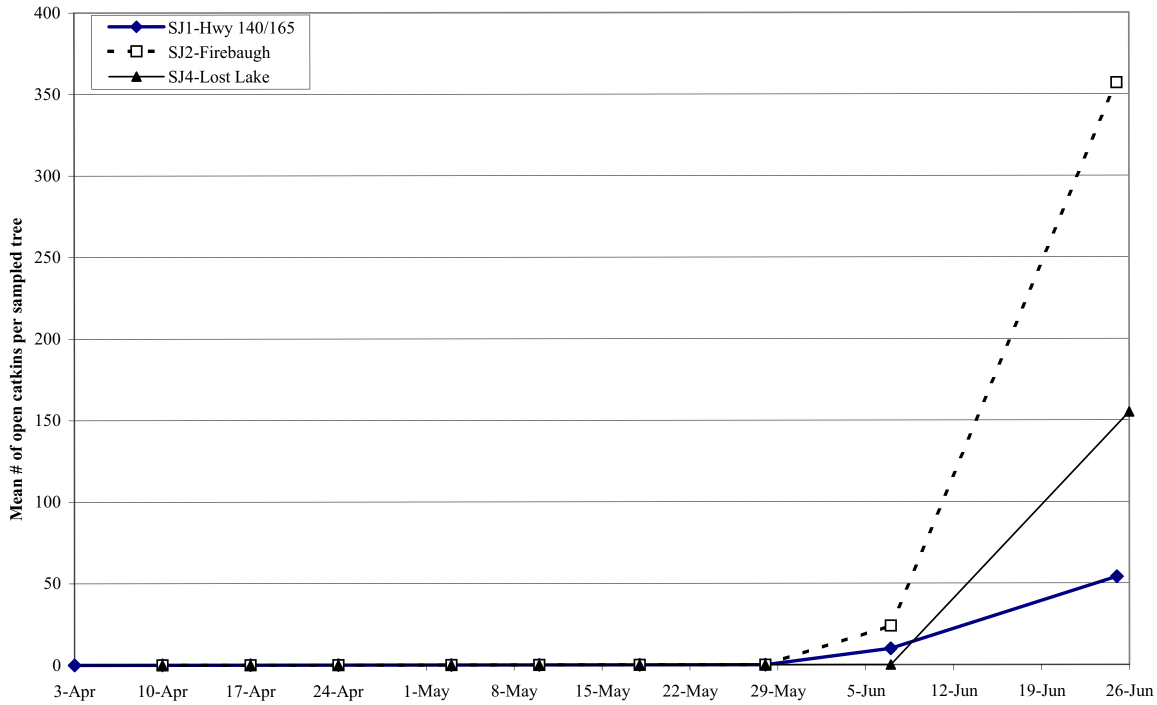


Figure 8-39. Spring and summer 2002 phenology data for narrow-leaf willow at three sites in the San Joaquin River study reach.

Cottonwood and willows dominate early successional vegetation along the San Joaquin River, as they do along many western rivers. These shade-intolerant species produce very small and short-lived seed. As described above, each of these species has a different period of seed dispersal during the spring or early summer. Consequently, successful recruitment of these species, and thus also the establishment of new patches of cottonwood-willow forest, depends upon suitable river flows coinciding with the period of seed dispersal. These flows must deliver seed to appropriate surfaces and maintain a moist substrate while germination and initial stages of establishment occur. The snowmelt hydrograph, which is characterized by a prolonged period of moderate flows in the spring and early summer months, provides suitable conditions for recruitment of these species (Figure 8-40). Even under unimpaired hydrologic conditions, suitable recruitment conditions did not occur every year, but at irregular intervals, depending on the species, the stream, and the water year. Recruitment of cottonwoods typically occurred during wetter water years.

Establishment of cottonwood is a higher restoration priority than establishment of willows because Fremont cottonwood is typically less successful than willows at regenerating under highly regulated conditions. Since the completion of Friant Dam, flow modifications have constrained cottonwood regeneration, and the frequencies of early season flows required for cottonwood seed dispersal and germination have been severely reduced. Therefore, successful cottonwood regeneration along the San Joaquin River has been correspondingly reduced. Willows, in particular narrow-leaf willows, disperse their seeds later in the season and over a longer time period, resulting in greater opportunities for regeneration. Narrow-leaf willow also aggressively propagates from root sprouts, much more so than cottonwood.

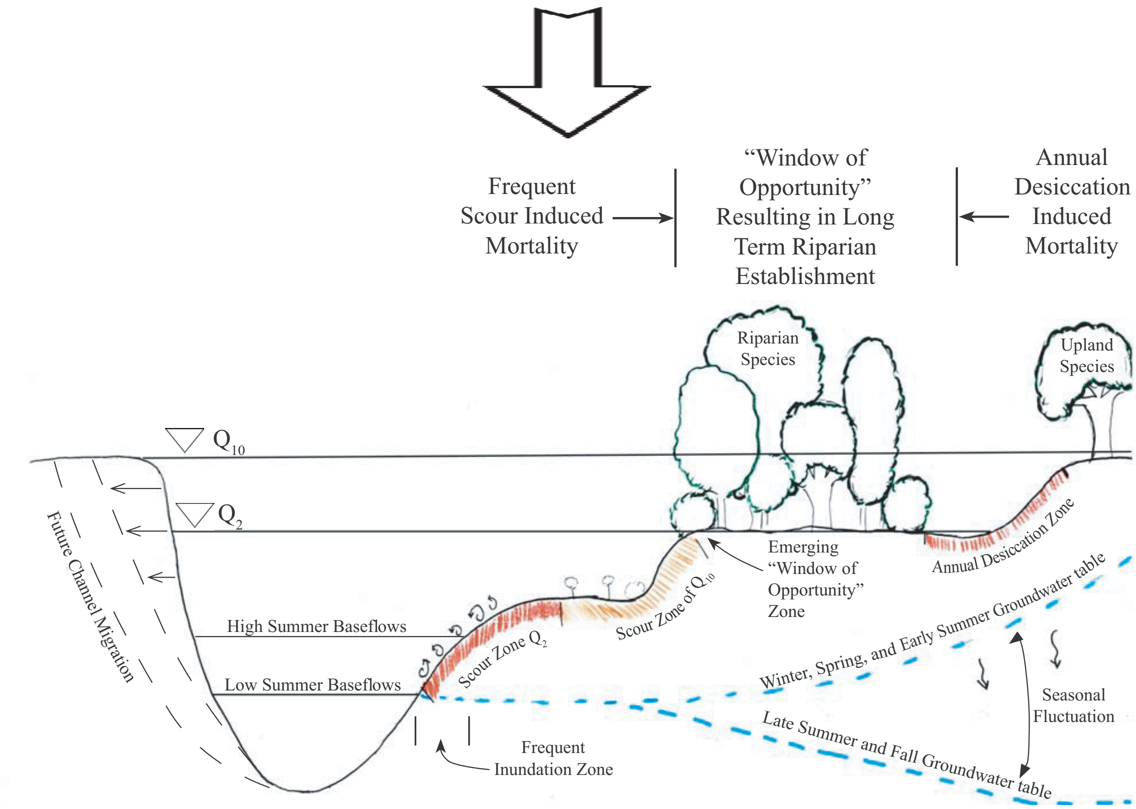
INITIATION AND ESTABLISHMENT PROCESS

Early Seeding Plant Box Recruitment Model
Species: Cottonwood and Willows
Time of Seed Dispersal: Spring / Summer

Fall Seedling Plant Rafting Recruitment Model
Species: Alder, Ash, Sycamore, Valley Oak
Time of Seed Dispersal: Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

	Scour	Desiccation	Inundation
Process:	Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period



- The 2 year flood (Q_2) removes seedlings
- The 10⁺ year flood (Q_{10}) removes small trees / shrubs, maintaining channel width

(ADAPTED FROM KONDOLF AND WILCOCK 1996)

Figure 8-40. Spring seeding woody riparian life history conceptual model (cottonwood and willow species).

Seeds of Fremont cottonwood and willow are commonly dispersed through the air or by floating on water, and large numbers of seeds wash onto shorelines and bars as water levels recede. Prior to and/or during seed dispersal, large flows tend to create seed beds as herbaceous plants are scoured away and/or fine sediment is deposited (Figure 8-40). Following this seed bed preparation, the river stage during the dispersal period must be sufficiently high to distribute seeds to a surface “safe” from scouring by subsequent flows, but low enough to prevent desiccation of seedlings once the river recedes. Mahoney and Rood (1998) suggest that this intermediate bank zone lies between 2 and 7 feet above the late summer, low-flow stage in many western rivers. However, these elevations vary between river systems, and successful recruitment appears to occur at higher elevations along larger rivers.

Asexual reproduction of cottonwoods and willows needs to be considered in the conceptual model as well. Both willows and cottonwoods are well known for their facility to develop roots and resprout from fragments ranging from portions of stems to whole downed trees. This capacity for resprouting is routinely taken advantage of in restoration projects and erosion control projects in which cuttings are directly planted into moist soil (e.g., “pole cuttings”) or bundles of cuttings (“wattling”) are placed in moist soils along banks or shores in a system to control erosion. With both methods, a high percentage of the cuttings “take” and develop into new plants, provided that soil moisture conditions are satisfactory. Recent experience on the Cosumnes River showed significant post-flood establishment of cottonwoods both from seed and from living plant material, such as branch fragments, deposited in the flood. Subsequent monitoring by Tu (Tu 2000; Swenson, et al. in press) showed that cottonwoods established from cuttings grew taller and survived better than cottonwoods grown from seed. There was extensive mortality of cottonwood seedlings from desiccation during the first season of growth. No seedlings of willows were found at this site during the study, however, there was extensive regeneration of willows from branch fragments (Tu 2000). Establishment from plant fragments represents an important complement to establishment from seed after major floods in which living plant material is broken loose and carried downstream and may be the dominant mode of reproduction at some sites in some years.

Roberts (personal communication 2002) has documented extensive clonal patches of cottonwood in Utah that have resulted from suckering or root-sprouting. He hypothesizes that initiation of these patches is stimulated by a major flooding event that exposes and perhaps damages portions of the root system. He believes that this mode of reproduction is especially important in mountain streams systems with narrow-leaved cottonwood, and possibly less important in valley bottoms with Fremont cottonwood. It may also be important on regulated streams in which the flooding regime required to stimulate recruitment from seeds no longer exists.

A moist substrate must be maintained for approximately a week after seed dispersal flows, to allow seeds to germinate (Scott et al. 2000). After germination, river stage must decline gradually so that seedlings root growth can follow the declining capillary fringe and allow the seedling to establish. If river stage declines too quickly following germination, seedlings could die from desiccation (Figure 8-40). To supply seedlings with adequate water as their roots grow toward the water table, the decline in river stage should not exceed 1 to 1.5 inches per day (Mahoney and Rood 1998, Shafroth et al. 1998, Scott et al. 2000). This decline in river stage guideline assumes a soil substrate that is coarse, such as sand or a sandy loam.

Soil properties also influence seedling recruitment. Soil texture greatly affects the water holding capacity of the soil; coarser-textured soils with a higher porosity require a slower decline in river stage because their soil water drains so rapidly. Along the San Joaquin River, textures generally become finer downstream. Saline or alkaline soils also become more common in lower reaches

(U.S. Soil Conservation Service 1962a, 1962b; 1971; 1990; JSA 1998). Although soil textures are primarily sands to sandy loams, many of San Joaquin soils exhibit considerable variability, and within soil mapping units, inclusions of several different soils are common (U.S. Soil Conservation Service 1962a, 1962b; 1971; 1990).

Historically, flows suitable for cottonwood and willow establishment did not occur in most years. In numerous river environments in the western U.S., historical records and tree aging studies indicate that the combination of factors leading to a large-scale recruitment event typically occurs once every 5 to 10 years (Mahoney and Rood 1998, Scott et al. 1997, Stromberg et al. 1991). In an area with little channel movement, Scott et al. (1997) determined that recruitment of mature cottonwoods on the upper Missouri River was most likely on surfaces inundated by floods with a recurrence interval of more than 9 years. Hughes (1994) wrote that long-term cottonwood establishment was associated with even longer flood return intervals (30 to 50 years) along some non-meandering rivers.

Beyond providing suitable conditions for establishment, flows must be sufficient to maintain existing riparian vegetation year-round. Cottonwoods and willows are very susceptible to drought stress. In California, dry summer conditions limit these and other riparian tree species to areas with readily available shallow groundwater. Therefore, flows following seedling establishment must be sufficient to maintain the elevation of the riparian groundwater surface within 10 to 20 feet of the ground surface elevation over the long term (JSA and MEI 2002b).

8.7.3. Establishment conceptual model: fall seed dispersal species

The establishment of late season seed dispersers, such as Oregon ash and white alder, has received less attention than the willows and cottonwood. A conceptual model of late season seed dispersers begins with seeds dispersing during the fall and winter months (Figure 8-41). Seeds deposited in water accumulate along debris lines and germinate in the moist substratum during the following spring. Once seeds germinate, the hydrologic factors required for survival to maturity are the same as those needed for spring seeding species (i.e., need to avoid mortality from desiccation, scour, toppling). As surface water levels recede to baseflow conditions, seedlings whose root growth cannot keep pace with the receding ground water levels die. Additional mortality from summer drought may occur later in the season. Surviving seedlings, approximately 6 months old at the end of the summer, are then subject to mortality during flood flows causing bed scour. Thus, for established seedlings to survive their first winter, a relatively dry year after initial establishment, or a chance event such as channel migration away from the seedlings, is generally required for the established seedlings to survive their first winter. As the surviving seedlings continue to grow a deeper and more extensive root system, the risk of drought and scour-induced mortality diminishes.

The establishment of valley oak and western sycamore, which are also fall seed dispersers, may follow a similar pattern. However, because they generally grow on geomorphic surfaces that are either higher and/or farther from the active channel (e.g., terraces), valley oak and sycamore establishment likely depends on a combination of less frequent events. These species may not be as dependent on fluvial processes and surface-water hydrology as the aforementioned species, but more dependent on soil characteristics and rainfall patterns prior to and during the establishment years.

8.7.4. Window of opportunity conceptual models: riparian establishment and maturity

Riparian vegetation establishment and growth to maturity requires a combination of factors to occur (Figure 8-35). Under unimpaired conditions, the San Joaquin River's streamflow hydrology was characterized by pronounced snowmelt runoff and winter storm periods, although the magnitude

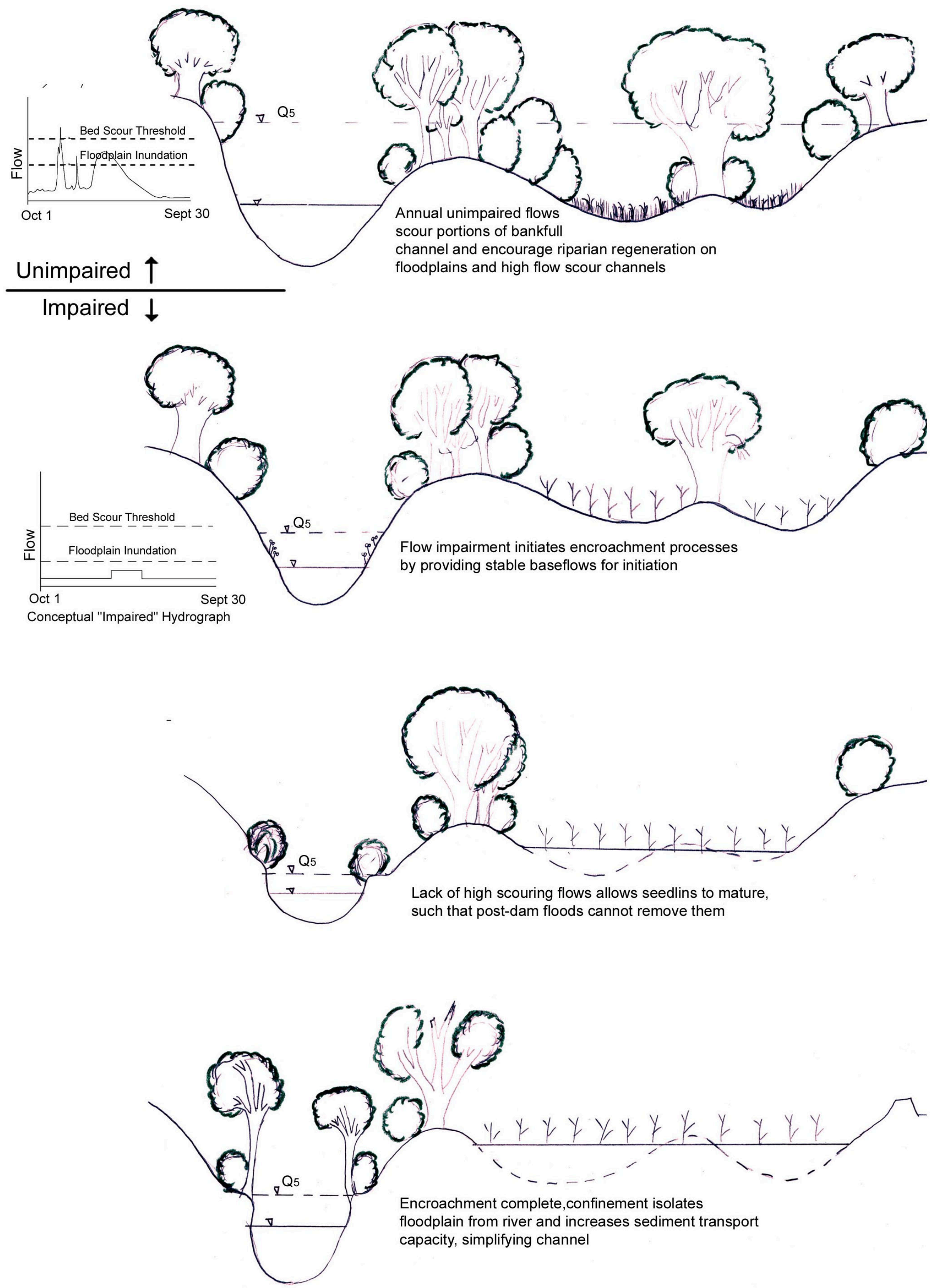


Figure 8-41. Fall seeding woody riparian life history conceptual model (alder, ash, valley oak, and other species).

varied from year-to-year. Some years provided favorable conditions for initiation of one or more riparian species, but a rapidly declining hydrograph limb after initiation frequently caused death by desiccation. In other years, hydrologic conditions were adequate for establishment, but a moderate scouring flow during the following winter removed established seedlings along the low flow channel margin (Figure 8-42). Larger floods would scour a wider band of established seedlings. Integrating these establishment requirements with scour and desiccation mortality results in a conceptual "window of opportunity", where riparian vegetation may avoid scour and desiccation mortality, thus reaching maturity (Figure 8-42). On the San Joaquin River under historical conditions, this window of opportunity varied between reaches, due to differences in fluvial geomorphology and hydrology (see Figures 8-19 through 8-28). The windows of opportunity in the downstream reaches (Reaches 3 through 5) likely operated only on a narrow elevational band on the natural levees bordering the primary channel margins. Compared to downstream reaches 4 and 5, upstream reaches (Reaches 1, 2, and portions of 3) likely had wider bands of woody riparian vegetation associated with moderate size floodplains, side channels, and scour channels. However, confining bluffs and terraces well above the presumed groundwater elevation would have limited the width of potential riparian zone to less than 1 mile in Reach 1.

The window of opportunity was likely much greater in most reaches during unimpaired conditions, because hydrologic conditions were more favorable to most species, and because floodplain surfaces were less disturbed by agricultural and other human land uses. Also, the unimpaired shallow groundwater surface elevation was likely much closer to potential initiation surfaces (see Chapter 4) than at present conditions; thus, the desiccation zone shown on Figure 8-42 was likely much less pronounced. However, in Reach 1 and Reach 3, riparian forest has actually increased (Tables 8-6, 8-7, and 8-10), likely due to riparian encroachment (see Section 8.7.6 below).

8.7.5. Conceptual relationship between riparian vegetation and channel form and processes.

The abundance and composition of riparian habitats varied among reaches, due to differences in channel processes, channel form, and soils. First, substrate varied greatly in the study area, with cobble, gravel, and sand in Reach 1; sands and silts in Reaches 2 and 3; and silts and clayey soils in Reaches 4 and 5.

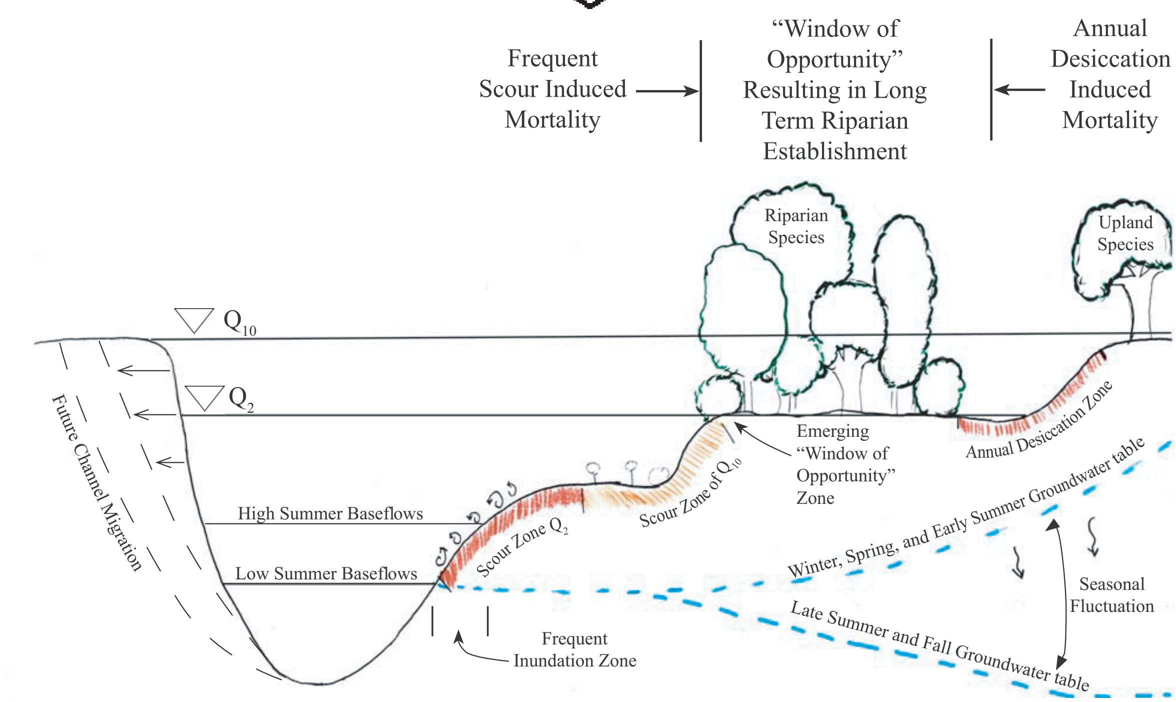
Second, under unimpaired conditions, sediment supply decreased in the downstream direction as it was deposited as bars, floodplains, and riparian levees. Moderate volumes of sediment were delivered from the Sierra Nevada to Reach 1 (primarily cobbles, gravel, and coarse sand). As sediment-laden water flowed down through the reaches, sediment settled out, such that sediment supplies in Reaches 3, 4, and 5 were extremely low. This longitudinal trend in sediment supply determined a longitudinal gradient in channel morphology (Figure 8-43). The supply of cobbles, gravels, and sand in Reach 1 resulted in a semi-braided channel morphology, with sporadic floodplains, many side-channels, many high flow scour channels on floodplains, and minor levees along the primary channels. Downstream, the channel became more sinuous, with oxbow lakes, larger floodplains, and more pronounced levees along the primary channel. Further downstream in Reaches 3, 4, and 5, the combination of low sediment supply and grade control by the Merced River delta caused a meandering channel morphology with multiple channels. The reduced sediment supply prevented extensive floodplains, with levees along the primary channel becoming the primary depositional feature (Figure 8-43). Vast tule marshes existed beyond these levees, extending up to three miles beyond the primary river channel.

INITIATION AND ESTABLISHMENT PROCESS

<u>Early Seeding Plant Box Recruitment Model</u>		<u>Fall Seedling Plant Rafting Recruitment Model</u>	
Species:	Cottonwood and Willows	Species:	Alder, Ash, Sycamore, Valley Oak
Time of Seed Dispersal:	Spring / Summer	Time of Seed Dispersal:	Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

	Scour	Desiccation	Inundation
Process:	Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period



- The 2 year ßood (Q_2) removes seedlings
- The 10^+ year ßood (Q_{10}) removes small trees / shrubs, maintaining channel width

(ADAPTED FROM KONDOLF AND WILCOCK 1996)

Figure 8-42. Conceptual model of "window of opportunity" (Kondolf and Wilcock 1996) that results in long-term riparian vegetation morphology in dynamic alluvial rivers.

This longitudinal trend in channel morphology caused longitudinal trends in riparian vegetation species and morphology. Upstream reaches contained a wide variety of species, including numerous willow species, Fremont cottonwood, sycamore, valley oak, and white alder. In downstream reaches, the canopies of these species began to taper off. As discussed in Section 8.6.1, the amount of valley oak and cottonwood present in downstream reaches under unimpaired conditions is uncertain. Figure 8-43 illustrates valley oak and cottonwood on the riparian levees along primary channels; however, we believe willow species (primarily black willow) dominated the canopy. Additionally, white alders ended at the gravel-bed to sand-bed transition (the approximate boundary between Reaches 1 and 2), to be replaced by box elder. White alders prefer coarser substrate (cobbles to coarse sands), while box elder prefers finer substrates found in sand-bedded reaches.

Unimpaired hydrograph components interacted with geomorphic surfaces in ways that influenced riparian initiation and establishment. For example, channel migration caused by moderate and extreme winter floods caused delivery of mature riparian vegetation to the San Joaquin River (large woody debris). Channel migration also assisted in building point bars and floodplains on the insides of migrating bends, thus creating new seedbeds for riparian germination and establishment (Table 8-21). Table 8-21 summarizes these and other important inter-relationships between unimpaired hydrology, geomorphic features, and riparian vegetation.

8.7.6. Conceptual model of riparian encroachment due to flow regulation

The 1914 CDC maps (ACOE 1917) and the 1937 aerial photographs document that under pre-Friant Dam flow and sediment regime, riparian vegetation along the primary channels did not grow along the low water edge, but was separated from the low water edge by exposed gravel or sand bars (see Figures 8-19, 8-21, 8-23, 8-25, and 8-27). This occurred because the window of opportunity for vegetation was controlled by bed scour during winter storms and spring snowmelt.

Once upstream dams and diversions reduced the magnitude of high flows, bed scour decreased, which allowed plant establishment closer and closer to the low flow channel. As seedlings establish and mature along the low flow water surface, the reduced magnitude, duration, and frequency of floods no longer scoured the seedlings, allowing them to mature (Figure 8-44). Flow and sediment regulation has continued such that the contemporary flow regime can no longer remove mature vegetation.

As the riparian vegetation establishes and matures along the low flow channel, fine sediments deposit amongst the vegetation during those infrequent flows that are capable of suspending fine sediments. Over time, this trend of fine sediment deposition along the low flow channel creates new levees called riparian berms. Riparian berms and the process creating them are very common on regulated rivers in the western US, and have been studied by Pelzman (1973), McBain and Trush (1997), and others. This encroachment process sometimes increases riparian cover compared to unimpaired conditions. However, the combination of riparian berms and a reduced flow regime confines the river and disconnects the river from its historic floodplain. The confinement increases shear stress during infrequent moderate flows, resulting in simplified channel morphology and its associated aquatic habitat (McBain and Trush 1997).

8.8. SUMMARY

The changes in riparian and wetland vegetation in the San Joaquin Valley have been dramatic. The following sections summarize the changes in vegetation communities, followed by a summary of vegetation restoration opportunities and constraints. Conceptual models that may help guide future vegetation restoration efforts are not summarized in this section; we refer the reader to Section 8.7 for this information.

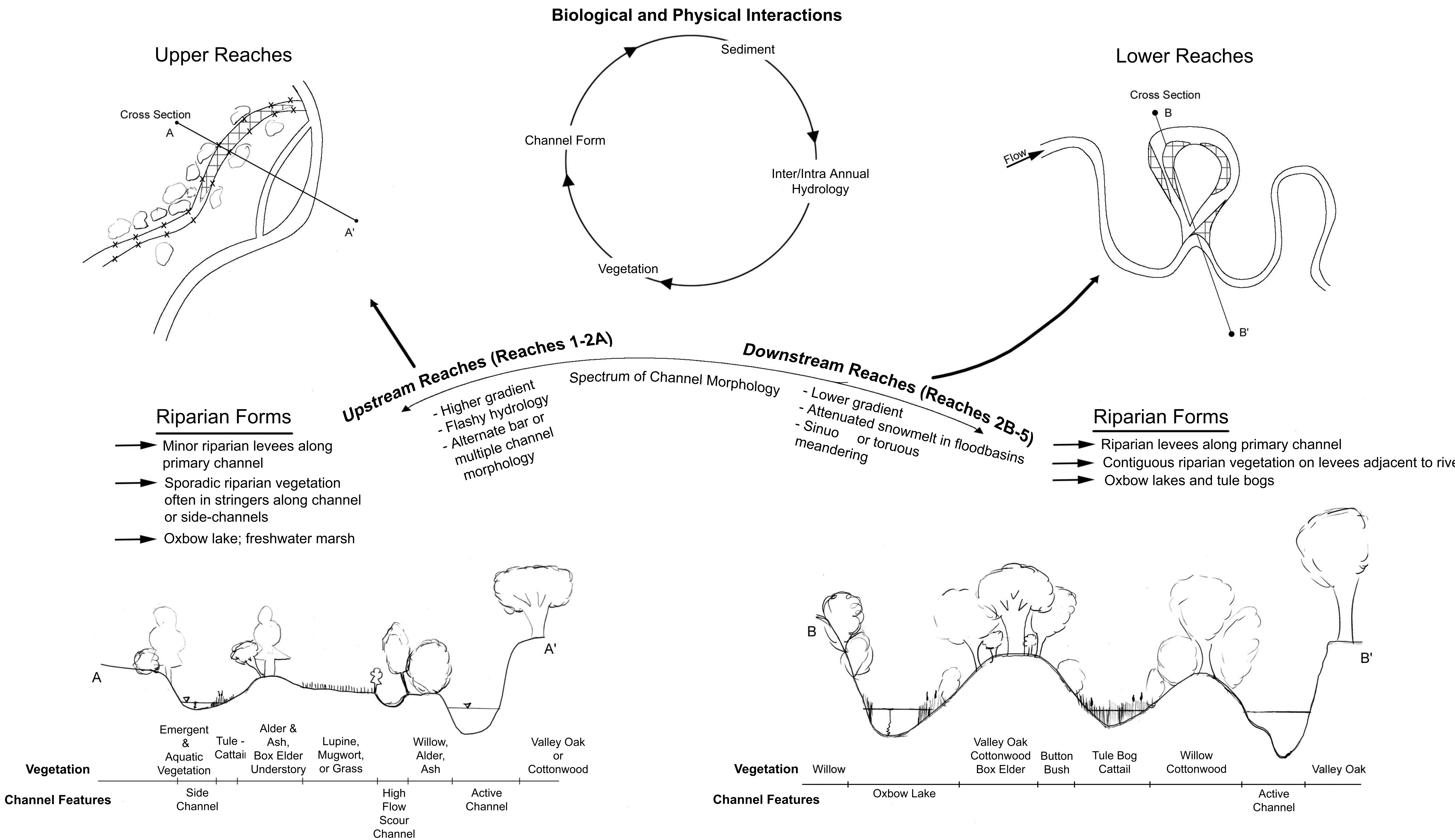


Figure 8-43. Conceptual model of riparian establishment and species composition relationships with channel form and processes in different reaches of the San Joaquin River study area.

Table 8-21. Matrix of interactive effects of individual hydrograph components and fluvial geomorphology on woody riparian vegetation.

Geomorphic Feature ⇨ **Hydrograph Component ⇩**	**Point Bar**	**Floodplains**	**Terraces**	**Outside of Meander bends**	**Oxbows**
Winter/spring baseflow	Promote inundation mortality of seedlings Prevent germination by inundating the active channel margins	Maintains or recharges ground water, promoting late season growth and maximum growth after plants break dormancy	Maintains or recharges shallow groundwater aquifer, facilitating maximum growth in establishing, mature, and senescent vegetation	Maintains or recharges shallow groundwater aquifer	Maintains or recharges shallow groundwater aquifer, sustaining off channel wetlands
Winter Floods	Significantly mobilize channel bed, scouring previous years seedlings	Builds and adds nutrients to floodplain by fine sediment and organics deposition Promotes inundation mortality in physiologically sensitive plant species. Deposits seeds, establishes short term seed bank waiting for suitable germination conditions	Deposits seeds, establishing a short term seed bank for future suitable germination conditions	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Overbank flow can refill sloughs and oxbows, potentially introducing additional plant species
Extreme winter floods **(during normal or above normal water years)**	Move and reorganize in-channel woody debris Realign channel by jumping channel or cutting off sharp meander bends creating wetlands	Scour or topple mature and senescent vegetation, creates new seed beds Mobilize wood jams Fine sediment deposition promotes root suffocation of certain species	Builds and add nutrients to terrace by fine sediment and organics deposition Promotes inundation mortality in physiologically sensitive plant species. Fine sediment deposition promotes root suffocation of certain species	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Oxbow may be recaptured by the channel and the wetland reoccupied by the main channel Fine sediment and organics deposition creates greater topographic variation and increases nutrient availability

Table 8-21, Continued.

Geomorphic Feature ⇨ Hydrograph Component ⇩	Point Bar	Floodplains	Terraces	Outside of Meander bends	Oxbows
Snowmelt peak	Prevent germination by inundation of point bar Scour establishing seedlings Promote inundation related mortality	Encourages seed germination by providing high soil moisture Discourages germination near the active channel by inundation	Encourages seed germination by providing high soil moisture	Channel migrates against the outside of the bend, causing limited mortality to mature and senescent vegetation, introducing large woody debris	Surface and groundwater recharges, creating the specialized environmental conditions required by ephemeral herbaceous plant species.
Snowmelt recession	Prevent plant germination by inundation	Facilitates seed germination over a wide elevation range Drops in river stage causes desiccation mortality to plants that had germinated earlier in the spring	Drops in river stage causes desiccation mortality to plants that had germinated earlier in the spring	Recharges ground water promoting maximum growth after breaking dormancy	Surface and groundwater recharges, creating the specialized environmental conditions required by ephemeral herbaceous plant species. Water table draw down causes desiccation related mortality
Summer baseflows	Plant germination on point bar occurs late in the growing season, reducing initiation and encouraging scour during the next years flow regime Sustains herbaceous perennials along the summer baseflow water surface elevation	Desiccate seedling germinated through the late winter and spring	Low water tables stresses plants, leading to desiccation related mortality Sustains herbaceous perennials surviving along the summer baseflow water surface elevation	Desiccate seedlings that germinated through the late winter and spring	In below normal water years, some portions could dry up, causing widespread mortality to aquatic and emergent vegetation

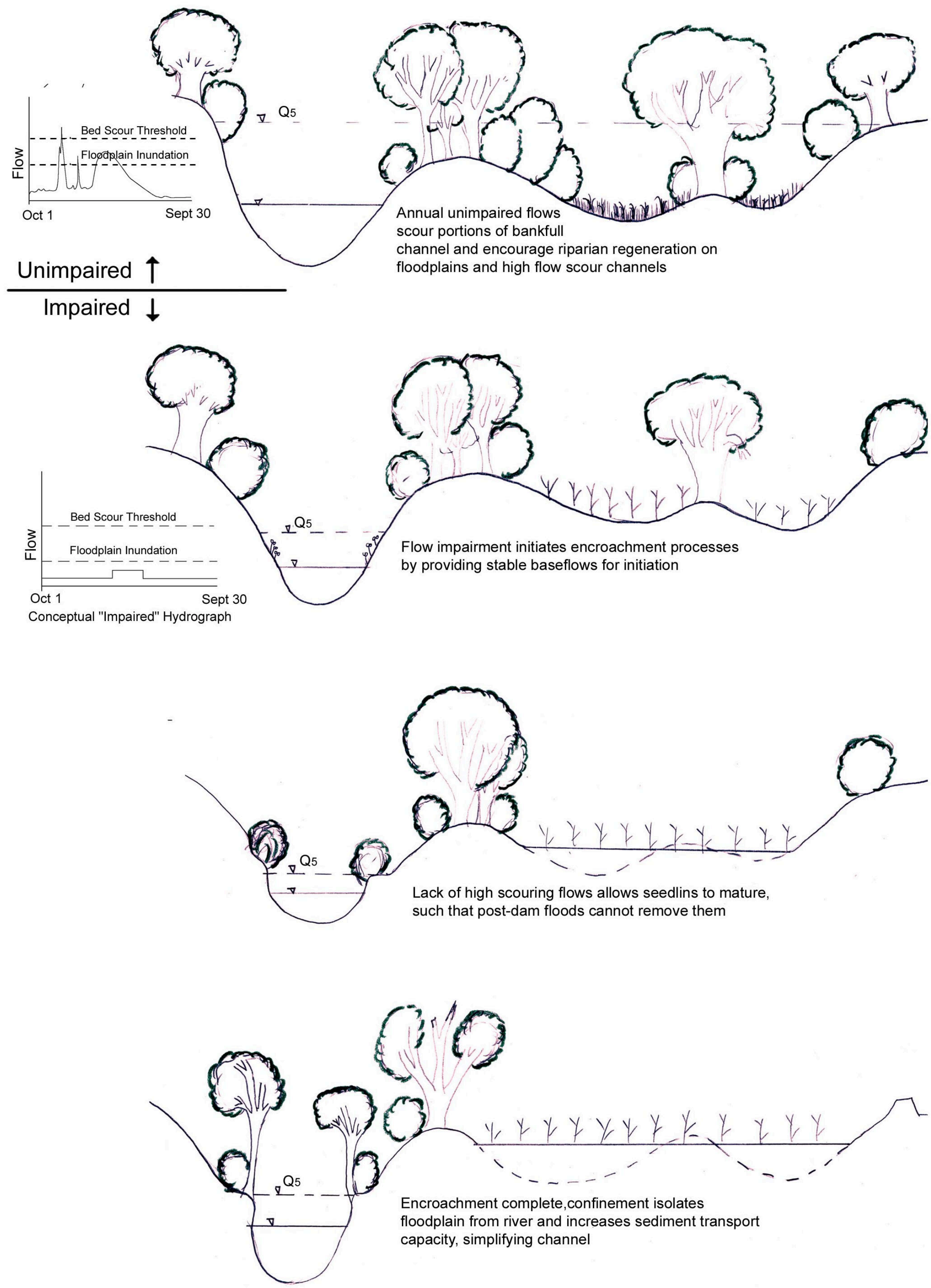


Figure 8-44. Conceptual model of riparian encroachment due to flow and sediment regulation.

8.8.1. Evolution from historical conditions

In the late 1700s and early 1800s, the original Spanish explorers of the San Joaquin Valley found a landscape populated by Native Americans who subsisted by hunting, fishing, and gathering wild plant foods. The Native Americans were known to use fire in upland ecosystems to increase the yield of certain food plants and to improve conditions for game. They fished for salmon and other species in the river, and hunted waterfowl in the marshes. The spread of domestic livestock by the Spanish and Mexican settlers, coupled with the spread of exotic plant species from the Mediterranean, led to dramatic changes in vegetation species composition, especially in the valley's extensive grasslands. By the 1830s, American and French Canadians entered the San Joaquin Valley and hunted beavers, mink, and river otter (Preston 1981), leading to the near eradication of these species. With the onset of the Gold Rush, the tempo, intensity, and magnitude of human effects on the hydrology and vegetation of the San Joaquin River increased rapidly, especially when compared to the background effects of land use by Native American harvesting and periodic burning of vegetation, and later Spanish and Mexican cattle ranching. Thereafter, human population and land uses increased along the river, and its resources were directly and indirectly affected by activities including logging in the riparian zone, agricultural conversion, instream mining, flow and sediment regulation, and irrigation and flood control.

These activities, most of which continue today, resulted in a drastic depletion of wetland habitat, such as tule marshes on the floodplain of the San Joaquin River. Significant reductions of riparian forest habitat also continue along the river and sloughs. Estimates of historic wetland and riparian vegetation (including vast tule marshes) are not quantified specifically for the study area, but estimates of changes for the entire San Joaquin Valley could be as high as a 95% reduction (TBI 1998). The comparison between 1937 and 1993 (JSA 1998b) showed a slight increase in riparian forest (potentially from riparian encroachment), and an approximate 50% decrease in riparian scrub (Figure 8-9). The changes in certain habitat types shown on Figure 8-9, particularly wetland, open water, and riparian scrub, is likely underestimated because the width used to perform the inventory (1,000 ft beyond escarpment or levee) is probably much narrower than the pre-1850 extent of the floodway.

Current activities affecting the river include continued agricultural development (such as drainage, irrigation, and flood control projects), in-channel aggregate mining, accelerating urban development, and the initiation of habitat restoration activities. The greatest historical change in habitat between 1937 and 1957 occurred when Friant Dam, Friant-Madera Canal, Friant-Kern Canal, and the Delta-Mendota Canal were completed, dramatically affecting the hydrology of the San Joaquin River. The reduced flow regimes caused Reaches 2A, 2B, and 4A to be dry most of the year, and caused the upper portion of Reach 4B to now be dry in all years. In these reaches, areas of wetland, riparian scrub, and riparian forest declined dramatically between 1937 and 1957. Releases from Friant Dam maintained continuous flow year-round in Reach 1, and releases of Delta water from Mendota Dam provide continuous flow in Reach 3. Riparian vegetation in these reaches encroached onto the river's sand and gravel bars. Operation of Friant Dam reduced the frequency of moderate and high flows, which historically scoured the channel and deposited new sand and gravel bars, which would restart the successional cycle of riparian vegetation. Without these scouring flows, vegetation in Reaches 1A, 1B, and 3 developed from sand and gravel bar (riverwash) vegetation to riparian scrub and then to riparian forest. Agricultural return water in Reaches 4B and 5 maintained some riparian vegetation in these areas, although water quality is reduced and riparian forest species coverage and diversity is limited.

Conversion of native vegetation types to agriculture, aggregate mining, and urban development has also strongly affected the San Joaquin River's wetlands and riparian habitat. Agricultural lands reached their maximum extent in 1957 for Reaches 1A, 1B, 3, and 5; 1978 for Reach 2A; and 1993 in Reaches 2B, 4A, and 4B. Urban and aggregate extraction lands are now at their maximum historical extent, and will likely continue to increase in the future. The most dramatic increase in urban development occurs in Reaches 1A (Fresno); smaller increases have occurred in Reach 3 (Firebaugh). Most aggregate mining occurred in Reaches 1A and 1B, with some smaller scale sand extraction in Reach 2A. Some of the aggregate extraction has converted riparian habitat to deep open water ponds. Further expansion of aggregate mining is limited by resource availability and several operations are in the process of closing down extraction sites as they are mined-out.

The change in hydrologic and geomorphic processes from unimpaired conditions creates some opportunities and constraints to future riparian and wetland restoration efforts. First, prolonged inundation and limited sediment supply for floodplain development under historical conditions in Reach 4 and Reach 5, and to a lesser degree Reach 3, created a condition of extensive low-lying tule marshes, and riparian vegetation (predominately black willow) was confined to narrow (few hundred feet wide) sediment berms that were higher elevation and drained. The dramatic change in topography and inundation patterns in this reach would make restoration of functional tule marshes more difficult to accomplish, but because future hydrology will likely not have prolonged periods of inundation (months), there is opportunity to restore larger-scale riparian (cottonwood-willow) forests that did not historically occur in those reaches. An additional change from historical conditions has been the increase in white alder and box elder in Reach 1 as part of the riparian encroachment process, and the reduction in dominance of cottonwood. Cottonwood regeneration and survival is closely tied to the historical disturbance regime (channel changes resulting from flood events) and the snowmelt hydrograph, whereas white alder and box elder are more susceptible to scour mortality (they are shallow rooting plants). The reduction in high flow regime has reduced cottonwood recruitment and extent, and allowed white alder and box elder to become the dominant canopy species in Reach 1 as part of the riparian encroachment band along the low flow channel. A significant challenge to future restoration in Reach 1 will be to reduce the encroachment of white alder and box elder, and encourage cottonwood recruitment on floodplains, side channels, and high flow scour channels.

As is the case with most Central Valley rivers, the spread of perennial invasive exotic species is affecting substantial areas of riparian habitat along the river, especially in the understory. These exotic species can spread extensively without additional human intervention to remove them. These invasive exotic species reduce the biological diversity in the riparian zone. While a native species, narrow-leaf willow also presents a problem to regulated rivers due to its invasive nature. Removal of the disturbance regime by flow and sediment regulation, combined with reduced variability of flows, encourages narrow-leaf willow to encroach along the low flow channel and cause riparian encroachment. This riparian encroachment process can also reduce plant diversity in the riparian zone.

Recently developed conceptual models suggest conditions necessary to establish key riparian tree species. More effort is spent on strategies applicable to willows and cottonwoods, which release their short-lived seeds in spring or early summer, and less effort on species such as white alder, ash, oak, and sycamore that release their seeds during the late summer or fall. These conceptual models are based on historic flood and flow conditions, and we acknowledge that these historic conditions cannot be re-created today. However, using these conceptual models, key conditions can be simulated and/or recreated by managing flow releases, managing sediment supply, reconfiguring flood plains, and artificial propagation of riparian vegetation.

8.8.2. Opportunities and Constraints

The San Joaquin River presents many opportunities for restoring native terrestrial habitat, but it also introduces important constraints. Opportunities can be categorized as to whether they primarily involve hydrologic, geomorphic, or other management approaches (such as vegetation manipulation). Although these approaches are discussed separately, in practice a combination of approaches would normally be employed for successful restoration.

8.8.2.1. Opportunities

Improving seasonal instream flows that encourage riparian initiation and establishment presents a significant hydrologic opportunity to improve vegetation conditions along the study reach. Flow releases to initiate natural regeneration of riparian vegetation would be needed with approximately a 10-yr recurrence (Scott, personal communication 2000); however, the yearly flow regime must be sufficient to maintain summer groundwater tables shallow enough to support the survival of established plants (i.e., no more than about 10 feet below the ground surface). Flood flows would also help develop new seed beds by fine sediment deposition and/or scouring herbaceous plants. Flood flows would also assist scouring out plants that are initiating too close to the low flow channel (thus, discouraging riparian encroachment). Establishment flows would be released as peak flows during the seed dispersal period of desirable plant species, then the flows would need to decline slowly to allow seedling establishment. This approach has been applied more to spring seeding species (willow and cottonwood) rather than fall seeding species, but once seed germination has occurred, the ramp down guidelines should be applicable for all species. Under regulated conditions, peak flows during the dispersal periods of riparian tree species are abruptly ended to conserve water, and the ramp-down rate is too steep to prevent desiccation of new seedlings. Gradually ramping down flows allows seedling roots to keep up with the capillary fringe of a declining water table. The summer low flow groundwater table needs to be near the ground surface to allow survival of riparian plants.

Geomorphic opportunities to improve riparian restoration are those that modify the shape of the channel and floodplain to benefit native vegetation regeneration. Geomorphic approaches include mechanically lowering floodplain surfaces, removing bank armoring to re-establish later channel migration and floodplain creation, and constructing microtopography on floodplain surfaces that are closer to the groundwater table. Measures that enlarge the active floodplain, by setting back or breaching levees, also fit in this category. Restoring the river's access to abandoned side channels, oxbows, or backwaters is another approach. Dredging the entrance to such abandoned features, or connecting such features by another means to another water source, may be required.

Vegetation management opportunities include removing existing exotic and/or invasive vegetation to artificially reset the succession cycle, planting native vegetation, and improving grazing management. Artificial plantings could use a variety of planting methods, including container stock, pole cuttings, seeds, and other horticultural methods. Irrigation, using either a drip system or flooding, is usually involved. Modification of the grazing regime may require modifying seasonal grazing frequency and intensity of cattle or other livestock in riparian areas. Managed livestock grazing could potentially be used to reduce undesirable plant species.

Additional riparian vegetation opportunities include:

1. The modest flood control storage in upstream dams still allows flood flows to occur downstream of Friant Dam (e.g., 1995, 1997, 1998) and from the Kings River via Fresno Slough. These floods could be reasonably re-operated (primarily the receding limb of the hydrograph) to better enable natural riparian regeneration to occur during those high flow years.

2. While the land-base to conduct riparian and wetland restoration is small, key areas do exist. There are many opportunities in Reach 1 to coordinate with the San Joaquin River Parkway and Conservation Trust to improve riparian vegetation on their lands, and the large number of aggregate pits provides substantial opportunities for revising reclamation plans and improving wetland conditions. Much of Reach 4B and 5 is owned by the State of California and the US Fish and Wildlife Service, and is relatively undisturbed wetland and floodplain habitat. However, project levees presently isolate many of these areas from the river.

3. Low-lying lands subject to frequent flooding are often of marginal agricultural value, but of great value as potential riparian restoration areas. A variety of mechanisms exist to make it financially feasible for a willing landowner to retire the land from cultivation and allow restoration activities to take place. Land management agreements, tax incentives, conservation easements, and mitigation banks for wetlands or endangered and threatened species are examples of mechanisms that may have economic benefit to the landowner. Fee title and conservation easement purchases from willing sellers has been an approach applied to tributaries of the lower San Joaquin River that may be mutually beneficial to both restoration efforts and the landowner and represent an opportunity in the study area. Following are two examples:

   - Certain reaches have low-lying agricultural fields with a shallow groundwater table protected by levees or dikes (e.g., Reach 2B and Reach 4). These shallow groundwater conditions would provide an opportunity for riparian restoration efforts in areas outside the current levees or dikes, such that they could be reconnected to the river and revegetated if the levees or dikes were set back further with the agreement of the landowner.
   - Certain reaches have low-lying agricultural fields protected by small berms (e.g., Reach 3). The vulnerability of these surfaces to inundation and the low cost required to re-connect them to the river (removing or breaching small berms) results in these types of areas being a favorable opportunity for riparian restoration with the agreement of the landowner.

4. Examples of improved grazing management in the western US has shown that continued livestock grazing can co-exist with riparian restoration if done properly. This may include adjustments in the season or duration of grazing, changes in stocking rates, or exclusion of cattle from riparian areas, depending upon management objectives. For example, livestock grazing could to be managed to avoid adverse impacts to seedling establishment or to reduce exotic grasses and enhance tree and shrub establishment. This approach depends upon the cooperation of the landowners and a planning assistance and financial incentives are available from a variety of sources as indicated above.

5. Increased releases of San Joaquin River water from Friant Dam to the Merced River confluence would improve water quality through all reaches, and reduce the salinity concentrations in Reaches 3 through 5. The degree if water quality improvement depends on a number of factors, and is not evaluated in this report.

6. Irrigation in downstream reaches (Reaches 3 through 5) is primarily provided by surface water supplied by the Delta Mendota Canal rather than by groundwater pumping, thus the elevation of the shallow groundwater table in downstream reaches on the west side of the San Joaquin Valley is near the channel bed elevation of the San Joaquin River. This is in contrast with Reach 1B and Reach 2, where the shallow groundwater table can be from 0 to 15 feet deep (or deeper, see Chapter 4). The shallow groundwater table in these downstream

reaches provides an opportunity for riparian restoration because riparian vegetation initiated further away from the river can utilize the shallow groundwater table for establishment and maturity. The depleted groundwater table in Reach 2 is a constraint for riparian establishment and maintenance, as instream flows will need to assume a greater role in vegetative success by directly providing water to the plants, or indirectly via subsurface recharge of the shallow groundwater table.

7. If perennial flows were restored to all reaches, the San Joaquin River flows would tend to maintain the shallow groundwater table within the floodway (see Section 8.6.4). This increase in the shallow groundwater table elevation may be enough that artificial riparian vegetation propagation could focus on using willow and cottonwood cuttings, thus avoiding the need for container stock and irrigation. This approach could drastically reduce the cost and infrastructure needed for artificial propagation.
8. The infrastructure on the San Joaquin River may also provide some restoration opportunities for controlling how flows are routed through the reaches. Chowchilla Bifurcation Structure, Mendota Pool, Sack Dam, Sand Slough Control Structure, Reach 4B headgates, and Mariposa Bifurcation Structure could be used to better control flow magnitude in certain reaches to improve riparian regeneration.
9. As discussed in Chapter 10, opportunities for riparian restoration may be greater on adjacent lands that are prone to flooding, and those lands that typically grow annual or row crops. The value of the land, as well as the cost to restore, is typically lower than lands with more infrastructure and investment (e.g., vineyards and orchards).

8.8.2.2. Constraints

The primary constraint to vegetation restoration is the reduced flow and sediment regime induced by cumulative dams and diversions. Another primary constraint is the lack of a land base upon which riparian vegetation restoration could occur. Additional constraints to vegetation restoration along the San Joaquin River are many, and may include invasive species effects, reduced flood control capacity due to increased hydraulic roughness from increased vegetation, conflicting land uses or infrastructure, regulatory obstacles, insufficient funding, and institutional and political obstacles. The following constraints may need to be addressed to restore riparian vegetation and wetlands. Although numerous, many of the following constraints can be avoided by implementing appropriate techniques designed to avoid or reduce these constraints.

1. The depleted groundwater table in Reach 2 constrains natural riparian regeneration because the depth to the summer groundwater table under existing conditions can exceed 15 feet, which is greater than the rooting depth of many woody riparian species.
2. The reduction in the groundwater table elevation in all reaches, combined with the loss of artesian springs and reduction of flows from the Kings River, has reduced the ability of the San Joaquin River to support seasonal and perennial wetlands in Reaches 3-5.
3. Invasive native and exotic species may benefit from disturbance caused by restoration actions, and may out-compete desired native species.
4. Water quality limitations, especially high salinity, may constrain restoration on some sites in Reaches 4 and 5. In the absence of improved water quality, restoration planning would need to emphasize native salt tolerant species. Even if water quality were improved by increased Friant Dam releases, residual salts in the soils and channel sediments may continue to impair riparian regeneration for some time.

5. Herbivore browsing may cause plant mortality, especially those plants that are installed in a restoration project. In Reach 1, the dramatic increase in aggregate pits has likely increased beaver populations to the point where they may have a significant impact on revegetation efforts. Additionally, creating riparian floodway corridors may increase deer browsing. Livestock grazing would be another possible constraint.
6. Increasing vegetation in the channel or floodplain may increase flood stage by increasing hydraulic roughness. Agencies responsible for maintaining conveyance within the flood control system are currently required to remove or spray vegetation that may reduce conveyance. Increasing floodway conveyance with setback levees and/or modification of the channel geometry would be a means to offset hydraulic conveyance impacts of additional riparian vegetation, and reduce the need for spraying to maintain hydraulic capacity.
7. Upstream dams trap all size classes of sediment, including the finer sands and silts that create and maintain floodplains. The remaining fine sediment supply downstream of Friant Dam is derived from the sandy loam soils along the San Joaquin River channel margins with contributions from tributaries such as Little Dry Creek and Cottonwood Creek, and the amount, frequency, and duration of silt deposition on floodplains is greatly reduced, making limited silt supply a constraint to floodplain and riparian restoration.
8. As discussed in Chapter 10, riparian restoration may conflict with existing land use. Because riparian restoration efforts would have a very small land base under existing conditions, significant improvement in vegetation along the study reach will require cooperative agreements with private landowners.
9. As discussed in Chapter 11, riparian restoration efforts may be considered by the local communities as incompatible with existing land use and the local economy. While this perception may be correct under certain circumstances, much progress has been made on the lower portions of the San Joaquin River tributaries in developing means to increase riparian vegetation that are mutually beneficial to the river corridor and local landowners.
10. Artificial riparian revegetation can be costly (e.g., up to $16,000/acre); wetland restoration is even more so. Funding commensurate with the scale of desired restoration needs to be secured for the entire duration of the restoration project. Additionally, due to the scale of riparian restoration needs within the study area, methods of reducing the unit-cost of riparian and wetland restoration need to be developed.
11. Fires periodically occur in the existing riparian areas, and often burn both younger maturing plants, as well as older mature and senescent plants. These fires are caused by a combination of factors, and may represent a future constraint to riparian restoration.

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