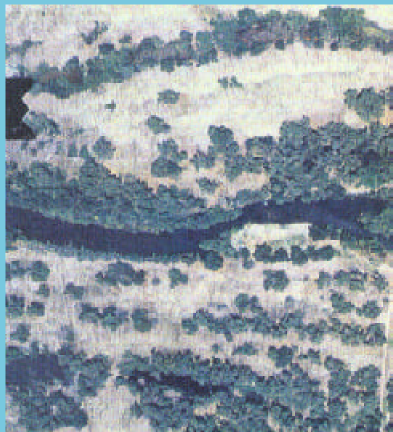

Merced River Corridor Restoration Plan Baseline Studies

Volume II: Geomorphic and Riparian Vegetation Investigations Report

April 18, 2001

Stillwater Sciences

MERCED RIVER RESTORATION BASELINE STUDIES

VOLUME II
GEOMORPHIC AND RIPARIAN VEGETATION INVESTIGATIONS REPORT

FINAL REPORT

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PREFACE

The purpose of this report is to provide the results of the Phase II geomorphic and riparian baseline evaluations that were conducted for the Merced River Corridor Restoration Plan. Previous drafts of this report were reviewed by Dr. William Dietrich (University of California at Berkeley – Department of Earth and Planetary Sciences), Dr. G. Mathias Kondolf (University of California at Berkeley – Department of Landscape Architecture and Environmental Planning), Dr. Joe McBride (University of California at Berkeley – Department of Environmental Science, Policy, and Management), Dr. Richard Harris (University of California Extension), Ted Selb (Merced Irrigation District), Scott McBain (McBain and Trush), Dr. William Trush (McBain and Trush), and John Bair (McBain and Trush). The draft report was also presented to the Merced River Technical Advisory Committee (on August 22, 2000) and to the Merced River Stakeholder Group (on September 11, 2000), who provided valuable review and comments.

Scott McBain and John Bair participated in the design and implementation of all field work conducted for this project and the analysis of vegetation data. Their input and insight are reflected throughout this report. Beth Hendrickson of California Department of Water Resources provided valuable field assistance and review of the draft report. Ralph Boniello and Jeff Opperman conducted much of the field work for the vegetation studies. Their assistance in data collection, methods refinement and general troubleshooting is appreciated.

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1 INTRODUCTION

1.1 Project Background

The goal of Merced River Corridor Restoration Plan project is to develop a publicly supported, technically sound, and implementable plan to improve geomorphic and ecological function in the Merced River corridor from Crocker-Huffman Dam (River Mile[a] [RM] 52) downstream to the confluence with the San Joaquin River (RM 0) (Figure 1.1–1). The project is a joint venture being led by the Merced County Planning and Community Development Department (the County) and Stillwater Sciences working closely with the California Department of Fish and Game (CDFG), California Department of Water Resources (CDWR), Merced Irrigation District (Merced ID), and local stakeholders.

The project is being implemented in three phases as shown in Figure 1.1–2. In Phase I, which was funded by the U.S. Fish and Wildlife Service Anadromous Fish Restoration Program (AFRP), the Merced River Stakeholder Group and Merced River Technical Advisory Committee (TAC) were established. In Phase II, baseline geomorphic and ecological analyses were conducted and social, infrastructural, and institutional issues and concerns that will define opportunities and constraints for restoration in the Merced River corridor were identified. This phase was funded by CALFED and began in April 1999. In Phase III, which was also funded by CALFED and began in October 2000, field and modeling efforts will be completed to develop restoration design guidelines and the Restoration Plan will be developed.

The Stakeholder Group and Technical Advisory Committee were formed to provide input to the baseline studies (Phase II) and the restoration planning process (Phase III) (Figure 1.1–3). The Stakeholder Group provides input from a broad spectrum of interests in the watershed, including landowners, riparian water users, aggregate miners, dairy operators, ranchers, farmers, environmental groups, and local management and regulatory agencies. Although Phase I initiated the Stakeholder and TAC processes, these groups are intended to continue beyond the timeframe of this project to support the long-term interest of the local community in the Merced River. Additional support for the stakeholder process has been provided through a grant from the AFRP to the East Merced Resource Conservation District. The TAC provides focused technical input to study designs and reviews draft study reports prior to presentation to the Stakeholder Group. The TAC participants are primarily agency representatives with management or regulatory interests in the river; some landowners and riparian water users also participate.

A Scientific Advisory Team provided peer review of baseline study designs, analyses, results, and conclusions. Peer reviewers included: Dr. William Dietrich (University of California at Berkeley – Department of Earth and Planetary Sciences), Dr. G. Mathias Kondolf (University of California at Berkeley – Department of Landscape Architecture and Environmental Planning), Dr. Joe McBride (University of California at Berkeley – Department of Environmental Science, Policy, and Management), and Dr. Richard Harris (University of California Extension).

[a] River miles represent the distance along the river channel upstream from the San Joaquin River.

1.2 Project Objectives and Approach

The components of the Phase II baseline evaluations included the following:

- identifying social, institutional, and infrastructural opportunities and constraints to restoration projects in the corridor;
- developing a quantitative understanding of river hydrology, morphology, floodplain connectivity, and sediment supply and transport; and
- assessing riparian vegetation composition and distribution in the Merced River and identify relationships to geomorphic features and processes.

The results of the social, institutional, and infrastructural opportunities and constraints evaluation are provided in a separate report (Stillwater Sciences and EDAW 2001), which will be finalized as Volume I of the Phase II report. This evaluation identifies social, institutional and infrastructural factors affecting potential future restoration opportunities within the river corridor, including land ownership patterns, existing land use and zoning, water supply, water rights, flood control regulations, and other factors. During Phase III, the Stillwater Sciences and EDAW (2001) report and subsequent revisions will be used in conjunction with the geomorphic and riparian technical evaluations described herein to work with the Stakeholder Group, the Technical Advisory Committee, and the broader public to identify feasible restoration projects to be included in the Restoration Plan.

The results of the Phase II geomorphic and riparian vegetation evaluations are presented in Sections 4 through 6 of this report. The objectives of these baseline evaluations were to (1) develop a quantitative understanding of river morphology, floodplain connectivity, and sediment supply and transport; and (2) assess riparian vegetation composition and distribution in the Merced River and identify relationships to geomorphic features and processes. Specific tasks included: (1) identify major sources of fine sediment; (2) assess coarse sediment supply and transport; (3) assess floodplain width and connectivity downstream of Crocker-Huffman Dam to the San Joaquin River confluence; (4) map riparian vegetation assemblages from Merced County's eastern boundary to the San Joaquin confluence; (5) evaluate relationships between vegetation cover type, geomorphic position, and inundation regime; and (6) assess seedling recruitment and establishment on active channel and floodplain surfaces.

The geomorphic and vegetation baseline evaluations were conducted at two scales: river-wide and site-specific. River-wide analyses included field reconnaissance, review and interpretation of maps and aerial photographs, and development of a computer-based Geographic Information System (GIS) of the river corridor. Reconnaissance-level field surveys were conducted by plane and boat for the entire river from Crocker-Huffman Dam (RM 52) to Hatfield Park (RM 1) to gain a general understanding of the river and provide much of the information presented in the reach descriptions in Section 5.1. The GIS was developed using both available coverages and new coverages developed for this project. Coverages in the GIS are shown in Table 1. Metadata describing these coverages are provided in Appendix A. Site-specific evaluations were conducted at three sites (referred to as the "Stevinson," "Snelling," and "Cuneo" sites) to assess floodplain connectivity, transport processes, and riparian vegetation composition and year-class structure.

Table 1. Coverages Included in the Merced River GIS

Coverage	Source
Active Channel Boundary – 1915, 1937, 1967, 1979, 1993, 1998[1]	Vick 1995 (1915–1993) Stillwater Sciences (1998)
Floodplain and Terrace Geomorphology[1]	Stillwater Sciences
Riparian Vegetation[1]	Stillwater Sciences and Chico State University
Bank Revetment and Erosion[1]	Stillwater Sciences
Levees[1]	Stillwater Sciences
Channel Bathymetry (confluence to State Route 99)	Corps of Engineers
Floodplain Topography (confluence to State Route 99)	Corps of Engineers
January 1997 Inundation Boundary	Corps of Engineers
Roads	Merced County Planning and Community Development Department
Cities	Merced County Planning and Community Development Department
Land Use	Merced County Planning and Community Development Department
Zoning	Merced County Planning and Community Development Department
Property Ownership	Merced County Planning and Community Development Department

[1]These coverages were developed as part of the Phase II evaluations.

As restoration planning moves into Phase III, a better understanding of additional ecosystem attributes and biological communities in this system may become necessary. Potentially important parameters that were not assessed in the Phase II studies include water quality, water temperature, fish species composition and distribution, and ecosystem trophic structure. Merced ID is currently working with the CDFG to evaluate habitat needs for increasing chinook salmon (*Oncorhyncus tshawytscha*) production in the Merced River by assessing the needs for each freshwater salmon life stage (i.e., upstream migration, spawning, egg incubation, fry and juvenile rearing, and outmigration). The CDFG-Merced ID study will supplement the Phase II studies. Components of this study, such as monitoring water temperature, chinook salmon population abundance and distribution, and chinook salmon smolt survival are currently underway.

2 BASIC CONCEPTS

The lower Merced River downstream of Crocker-Huffman Dam is an alluvial river-floodplain system. Alluvial rivers are dynamic systems that are affected by inputs and processes across a range of scales. The geomorphic and vegetation baseline evaluations are based on the conceptual model illustrated in Figure 2–1. This model attempts to illustrate linkages between physical inputs, physical processes, and biological responses. In this simplified model, natural watershed inputs (e.g., water, sediment, nutrients) combined with natural disturbance and anthropogenic alterations to these inputs drive physical processes (e.g., sediment transport, channel migration, thermal loading) that, it turn, determine geomorphic attributes of the river-floodplain system and physical habitat structure. These geomorphic attributes and habitat structure drive biological responses and are important determinants of plant and animal species abundance, distribution, and composition. For instance, flow (a watershed input) determines the timing, frequency, extent, and duration of floodplain inundation (a fluvial process). This inundation regime is an important factor in determining which riparian plant species get established on the river floodplain each year, thus, driving vegetation species composition and age class structure (habitat structure). The resulting vegetation structure provides physical habitat for bird species that utilize the riparian corridor (biotic response).

A conceptual diagram of a healthy alluvial river is shown in Figure 2–2. In this figure, the river channel is sinuous, with alternate point bars and pools at meander bends and riffles in the transitions between meander apexes. In cross section, the river channel is multi-staged, consisting of a low flow channel, an active channel, and a bankfull channel (Figure 2–2). The low flow channel carries summer and fall baseflows. The active channel includes both the low flow channel and unvegetated point bars. The bankfull channel extends to the top of the vertical channel banks. The floodplain lies outside of the bankfull channel and is inundated at flows exceeding the 1.5- to 2-year flood recurrence interval. Under natural conditions, this floodplain supports a self-sustaining riparian woodland.

Trush et al. (2000) describe key inputs and processes required to maintain a healthy alluvial river system and attributes of a healthy alluvial river system. These inputs and processes include:

- temporally variable streamflow patterns;
- channel morphology that is scaled to flow conditions and sediment supplies that are balanced with sediment transport capacity;
- frequent scour of the bed surface and periodic scour of the bed sub-surface;
- channel migration and/or avulsion;
- frequent floodplain inundation; and
- a self-sustaining, diverse riparian corridor.

These attributes and processes are described in more detail below.

Temporally Variable Streamflow Patterns

In most river systems, streamflow conditions are highly variable. In the eastside Central Valley rivers, natural flow conditions are characterized by low flows in summer and early fall, large but brief flow peaks in winter generated by rain storms, and prolonged high flows in spring generated by snowmelt from upper Sierra Nevada watersheds. Each of these components of the natural hydrograph drives processes that shape and sustain the river-floodplain system. Alteration of any of these components causes alterations to the river ecosystem structure and function.

Channel Morphology that is Scaled to Flow Conditions and Sediment Supplies that are Balanced with Sediment Transport Capacity

Channel morphology refers to the size, shape, and slope of the channel and the character of the sediment or rock comprising the river bed and banks. This morphology is determined by the complex interactions between flow, boundary sheer stress, and sediment supply (Dietrich and Gallimatti 1991). Factors determining channel morphology include flow magnitude, slope, and depth; the quantity and character of sediments in motion in the channel; and the character and composition of the channel bed and banks (Leopold and Maddock 1953).

In an undisturbed alluvial system, the channel is sized to convey a certain discharge, termed the "dominant discharge" or "bankfull flow" (Wolman and Miller 1960, Leopold et al. 1964). This is the flow that over time transports most of the river's sediment load. While the recurrence interval of this flow varies, it is often related to floods having a recurrence interval of 1.5 to 2 years (Leopold et al. 1964). Flows exceeding this discharge spill out over the channel banks onto the river floodplain.

In addition, at equilibrium the river's sediment supply is balanced with its sediment transport capacity. Under this condition, sediment is exported from a reach at approximately the same rate at which it is supplied to the reach. This equilibrium does not imply a static condition but rather reflects a dynamic balance between sediment erosion and deposition, referred to as a "dynamic equilibrium" (Schumm 1977). In this dynamic equilibrium, sediment is transported through or temporarily stored within the channel. Banks erode, oxbows cut off, and meanders migrate, but the overall channel width, depth, and slope fluctuate only narrowly over time because they are in equilibrium with the flow and sediment supplied from the watershed.

Frequent Scour of the Bed Surface and Periodic Scour of the Bed Subsurface

Frequent scour of the bed surface is needed to maintain the active and bankfull channel morphology. As flow in the river increases, the threshold for mobilizing grains on the channel bed surface is eventually surpassed. This threshold varies depending on channel width, depth, and slope, and the sediment grain size. Looking at individual years, the channel bed may not be mobilized at all in low flow years but may be mobilized several times in flood years. In general, over the long-term the channel bed surface is mobilized on the order of once each year for a period of several days. Larger floods that exceed this threshold of surface mobilization may be required to rejuvenate alternate bar sequences. Trush et al. (2000) suggest that floods exceeding the 5- to 10-year recurrence interval are required to scour the channel bed to a sufficient depth to mobilize alluvial bars.

Periodic Channel Migration and/or Avulsion

During lateral migration, the river channel erodes floodplain and terrace deposits on the outside bank of meander bends and deposits sediment on a bar on the inside of meander bends. This process of erosion and deposition maintains the equilibrium channel width and maintains diverse in-channel and riparian habitats. As the bank on the outside of the bend erodes, sediment is deposited on the point bar at the inside of the bend, causing the bar to grow laterally. The erosion on the outside of the bend maintains deep pools, and trees falling into the river from the eroding bank provide important cover and habitat structure for many aquatic species. The new deposits on the point bar on the inside of the meander bend provide new surfaces for recruitment of native riparian trees.

Frequent Floodplain Inundation

The floodplain is the flat area adjoining the river channel that was deposited by the river under the present climatic conditions and which is overflowed at times of high flow (Dunne and Leopold 1978, Nanson and

Croke 1992). Typically, the floodplain immediately adjacent to the river is maintained at an elevation equal to the bankfull stage (Wolman and Leopold 1957, Leopold et al. 1964). Floodplain inundation provides flood peak attenuation and promotes exchange of nutrients, organisms, sediment, and energy between the terrestrial and aquatic systems. Junk et al. (1989) argue that flood pulses are the principle driving force responsible for the existence, productivity, and interactions of the major biota in river-floodplain systems. In addition, the pulse creates a dynamic edge effect, preventing long-term stagnation and allowing rapid recycling of organic matter and nutrients. All of these flood pulse processes contribute to the high rates of primary productivity documented in functioning floodplain systems. In addition, floodplain inundation is necessary to maintain a healthy riparian ecosystem, as discussed below.

Self-sustaining, Diverse Riparian Corridor

Riparian zones, defined by Gregory et al. (1991) as "three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems," provide multiple benefits to instream and terrestrial ecosystems and are widely recognized as centers of biodiversity and corridors for dispersal of plants and animals in the landscape (Gregory et al. 1991, Johannson et al. 1996). Riparian forests filter nutrients and agricultural chemicals from runoff; stabilize channel banks; and provide leaf litter to aquatic food webs, large woody debris and overhead shade for fish habitat, and migratory corridors for terrestrial wildlife (CALFED 1999, Naiman and Descamps 1997, Mitsch and Gosselink 1993, Malanson 1993).

Riparian vegetation dynamics are tightly coupled to river processes. Sediment erosion and deposition as well as inundation patterns strongly influence riparian plant species composition, distribution, and age class structure and drive the process of riparian community succession. Succession is the progressive change in plant species composition over time in response to outside disturbances, such as floods and fire, or internal competition among different plant species (Oliver and Larson 1996, Malanson1993). Along geomorphically active, meandering streams, riparian vegetation typically exhibits successional gradients perpendicular to the channel, with the youngest stands occurring closest to the active channel margin (Figure 2–2) (Gregory et al. 1991, McBride and Strahan 1984, Walker and Chapin 1986). Through the process of channel migration and formation of alternate bars, the river creates bare surfaces on which riparian pioneer species, such as willows and cottonwoods, can become established. As this vegetation matures, it traps fine sediment, thus contributing to the development of the floodplain. As the floodplain surface develops, later successional species become established and eventually replace the early pioneers. As channel migration and bar deposition continue, a series of successional bands develops on the floodplain (often in conjunction with topographic ridges and swales), with the youngest band occurring at the channel margin and vegetation age increasing inland (Johnson et al. 1976, Strahan 1984, Scott et al. 1996).

Alteration of any of the inputs or processes controlling channel and floodplain morphology can redefine the system's equilibrium state, causing adjustment to the new flow and sediment supply conditions and potentially having far-reaching effects on the structure and function of the river-floodplain ecosystem. Key alterations that have affected ecosystem structure and function on the Merced River include damming and flow regulation, levee construction, aggregate mining, bank protection, and clearing of riparian forests. These factors and their subsequent effects on the Merced River are described in Sections 3 through 6 of this report.

3 THE MERCED RIVER WATERSHED AND THE RESTORATION CONTEXT

3.1 Geographic and Geologic Setting

The Merced River drains a 1,276-square-mile watershed on the western slope of the Sierra Nevada range in the southern portion of California's Central Valley and joins the San Joaquin River about 87 miles south of Sacramento (Figures 3.1–1 and 1.1–1). Elevations in the basin range from 13,000 feet NGVD[b] at its crest in Yosemite National Park to 49 feet NGVD at the San Joaquin River confluence. The basin experiences a Mediterranean climate, having wet winters and dry summers. Similar to other rivers originating from the west side of the Sierra Nevada mountains, flow in the Merced River is typified by late spring and early summer snowmelt, fall and winter rainstorm peaks and low summer baseflows. Annual water yield from the Merced River averages 996,500 acre-feet (for the period 1903–1999).

In the upper watershed, the river originates in the Sierra Nevada batholith of Jurassic-Cretaceous age and flows westward through granitic rocks of the Yosemite Valley, entering metamorphic terrain of the western Sierran foothills between El Portal and the Merced Falls Dam. The river drains about 230 square miles of the granitic terrain and about 60 square miles of metamorphic and marine sedimentary terrain. In this mountainous area, the Merced River flows through confined bedrock valleys or steep bedrock gorges.

The river leaves the confines of the upland landscape near Merced Falls Dam and enters the eastern Central Valley, which is characterized by a sequence of steeply sloping, westerly nested Quaternary alluvial fans (Harden 1987). These alluvial fans were sequentially deposited, such that younger fans overlie older fan deposits. The westward shifting of these depositional fans has been linked to progressive uplift and westward tilting of the Sierra Nevada range throughout the Tertiary and Quaternary periods (Bateman and Wahrhaftig 1966). The oldest fans in the Merced River area (the Riverbank Formation and North Merced Gravel) lie at the base of the western Sierra Nevada foothills, and the youngest fan (the Modesto Formation) lies close to the San Joaquin River in the Central Valley. During the Pleistocene, climate-driven cycles of high sediment loads and high flows resulting from glacial formation and retreat drove the formation of these alluvial fans. During this period, the Merced River underwent phases of fan construction and dissection (Wahrhaftig and Birman 1965, Marchand and Allwardt 1981). The valley floor of the modern (Holocene) Merced River is entrenched into these Pleistocene fan formations, which form the bluffs that border the valley floor.

Near Crocker-Huffman Dam (the upstream end of the study reach), the river valley broadens, and the river becomes a highly dynamic, multiple channel (anastomosing) system. (Figure 3.1–2). Historically, these channels, which included the current mainstem channel as well as Ingalsbe, Dana and Hopeton sloughs, occupied the entire width of the valley floor (up to 4.5 miles wide) in the Snelling vicinity. Downstream of the Dry Creek confluence, the valley width narrows and the historical channel was a single-thread, meandering system (Figure 3.1–2). This narrowing and conversion from the braided to the meandering system may have been a response to downstream fining of sediment texture (due to sediment transport-related gravel attrition). With this downstream fining, river bank textures become finer and less erodible, thus driving the conversion to a single-thread channel.

[b] National Geodetic Vertical Datum, a standard vertical datum used throughout the United States.

The Merced River and its floodplain historically supported a dense riparian woodland. While much of the Central Valley upland and foothills were historically covered by sparsely wooded grasslands, pre-settlement riparian zones supported dense, multistoried stands of broadleaf trees, including valley oak (*Quercus lobata*), Fremont cottonwood (*Populus fremontii*), western sycamore (*Platanus racemosa*), willow (*Salix* spp.), Oregon ash (*Fraxinus latifolia*), box elder (*Acer negundo*), and other species (Thompson 1961, 1980, Holland and Keil 1995, Roberts et al. 1980, Conard et al. 1980). These riparian forests varied greatly in width, from a narrow strip in confined reaches to several miles wide on broad alluvial floodplains (Thompson 1961). Local accounts of the Merced River describe the rich aquatic and terrestrial fauna supported by riparian habitats (Edminster 1998). Katibah (1984) estimates that the Merced River and the lower San Joaquin River (from the Merced confluence to Stockton) supported over 90,000 acres of riparian forest, part of more than 900,000 acres of historical riparian forest for the whole Central Valley. No historical estimates of riparian forest extent specific to the Merced River are available.

3.2 Anthropogenic Modifications to the Merced River Corridor

The Merced River corridor has been significantly modified by dams and flow regulation, flow diversion, gold and aggregate (sand and gravel) mining, levee construction, land use conversion in the floodplain, and clearing of riparian vegetation. These anthropogenic modifications to the river system are described in the sections below.

3.2.1 Flow Regulation and Diversion

Flow in the Merced River is regulated by two large dams. In addition, flows released downstream of the dams are diverted at two Merced ID canals and at numerous smaller riparian diversions. Dams and diversions in the Merced River are described below. The effects of the dams and diversions on flow conditions in the river are described in Section 4.

3.2.1.1 Mainstem Dams and Flow Diversions

Four mainstem dams affect flow conditions in the lower Merced River (Figure 1.1–1 and Table 2). The two largest dams are New Exchequer Dam (which impounds Lake McClure) and McSwain Dam (which impounds Lake McSwain). These dams, which are known collectively as the Merced River Development Project, are owned by Merced ID and are licensed by the Federal Energy Regulatory Commission (FERC). Merced Falls Dam and Crocker-Huffman Dam are low diversion dams which divert flow into the Merced ID Northside Canal and Main Canal, respectively. Merced Falls Dam is owned by Pacific Gas and Electric; Crocker-Huffman Dam is owned by Merced ID. Three additional small dams—MacMahon, Green Valley, and Metzger dams—are located on tributaries upstream of the New Exchequer Dam. These dams have a combined reservoir capacity of 835 acre-feet[c]. Also, Kelsey Dam impounds a small (972 acre-feet) reservoir on Dry Creek, the only major tributary to the Merced River downstream of the mainstem dams.

[c] An acre-foot is the volume of water that would inundate one acre of land to a depth of one foot and is equivalent to approximately 326,000 gallons.

Table 2. Dams Regulated by the California Division of the Safety of Dams in the Merced River Basin

Dam	Stream	Year Closed	Capacity (acre-feet)
Mainstem			
New Exchequer	Merced River	1967	1,024,600
McSwain	Merced River	1966	9,730
Merced Falls	Merced River	1901	900
Crocker-Huffman	Merced River	1910[1]	200
Tributaries to Mainstem			
McMahon[2]	Maxwell Creek	1957	519
Kelsey	Dry Creek	1929	972
North Fork			
Green Valley[2]	Smith Creek	1957	243
Metzger[2]	Dutch Creek	1956	73
		Total:	1,037,237

(sources: CDWR 1984, Kondolf and Matthews 1993)
[1]A diversion dam has been operated at this location since the 1870s.
[2]Dam is located upstream of the New Exchequer Dam.

The New Exchequer Dam replaced the original Exchequer Dam, which was completed in 1926 and had a reservoir capacity of 281,200 acre-feet (28 percent of the total annual water yield from the basin). The reservoir was enlarged when the New Exchequer Dam was constructed immediately downstream of the original dam in 1967. The New Exchequer Dam (located at RM 62.5) controls runoff from 81 percent of the basin and creates the largest storage reservoir in the system, Lake McClure. The maximum reservoir storage capacity at Lake McClure is 1,024,600 acre-feet, equivalent to 103 percent of the average annual runoff from the basin (as measured below Merced Falls Dam, near Snelling). The New Exchequer Dam provides agricultural water supply, power generation, flood control, recreation, and environmental flows including in-stream fisheries flows and flows to the Merced National Wildlife Refuge. Merced ID's State storage water right limits the amount of water that can be stored in Lake McClure to 605,000 acre-feet per year. A minimum pool of 115,000 acre-feet is reserved in Lake McClure to maintain required instream flows for fish.

McSwain Dam is located at RM 56, 6.5 river miles downstream of the New Exchequer Dam, and is operated as a re-regulation reservoir and hydroelectric facility. Storage capacity in Lake McSwain is 9,730 acre-feet.

The Merced Falls and the Crocker-Huffman dams are low-head irrigation diversion facilities. The Merced Falls Dam, which was constructed in 1901, is located at RM 55. The dam diverts flow into the Merced ID's Northside Canal (capacity = 90 cfs) to the north of the river and generates electricity. The Crocker-Huffman Dam, which was constructed in 1910, is located at RM 52 and diverts flow into the Merced ID's Main Canal (capacity = 1,900 cfs). Both of these dams are equipped with fish ladders, but the ladders were blocked by CDFG in the early 1970s in association with the Merced ID's construction of an artificial salmon spawning channel immediately downstream of Crocker-Huffman Dam. Presently, anadromous fish generally do not pass upstream of Crocker-Huffman Dam, although some fall chinook salmon may surmount the dam during high flows (M. Cozart, pers. comm., 2000).

In addition to the Merced ID diversions, the Merced River Riparian Water Users maintain seven riparian diversions between Crocker-Huffman Dam and Shaffer Bridge (Oakdale Road) (Figure 3.1–3). At these diversions, flow is directed into diversion channels by small gravel wing dams that are constructed each year. Downstream of Shaffer Bridge, the CDFG has identified 238 diversions, typically small pumps, used to supply water for agricultural use (G. Hatler, pers. comm., 1999).

3.2.1.2 Required Minimum Flows

Minimum flow requirements in the Merced River are determined by (1) the FERC license for the Merced River Development Project, (2) a Davis-Grunsky[d] contract with the State, and (3) required releases to provide flows for riparian diversions. The required minimum flow varies, depending on month and water-year-type (e.g., wet or dry). Required minimum flows in the river are summarized in Table 3.

Table 3. Required Monthly Minimum Flows in the Merced River

Required Flows (cfs)				
Month	**FERC Normal Years (Dry Years)**	**Davis-Grunsky Flows [1]**	**Riparian [2]**	**Approximate Flow Range**
January	75 (60)	180–220	50	230–270
February	75 (60)	180–220	50	230–270
March	75 (60)	180–220	100	280–320
April	75 (60)	—	175	235–250
May	75 (60)	—	225	285–300
June	25 (15)	—	250	265–275
July	25 (15)	—	225	240–250
August	25 (15)	—	175	190–200
September	25 (15)	—	150	165–175
October 1-15	25 (15)	—	50	65–75
October 16-31	75 (60)	—	50	110–125
November	100 (75)	180–220	50	230–270
December	100 (75)	180–220	50	230–270

(Source: T. Selb, pers. comm., 1999)
[1]Measured at Shaffer Bridge.
[2]Measured at Crocker-Huffman Dam.

[d] The Davis-Grunsky Act is legislation that provides financial assistance to public agencies for water development, recreation, and fish and wildlife enhancement.

3.2.1.3 Flow Limitations for Flood Control

The New Exchequer Dam provides flood control for the lower Merced River. The flood control operations are defined by the Corps of Engineers, and a total of 350,000 acre-feet of storage space in the reservoir is reserved for the (rain) flood pool (October 31 through March 15). An additional 50,000 acre-feet are reserved for the "conditional space" associated with the forecasted spring snowmelt (March 1 through May 15). In addition, the Corps of Engineers limits maximum discharge in the Merced River to 6,000 cfs, as measured at the Merced River near Stevinson gauge, located at RM 4.4. During the January 1997 flood, the Merced ID received an emergency variance from the Corps of Engineers to release approximately 8,000 cfs from the dam. During this release, flows in the lower river reached 8,279 cfs at the Merced ID Crocker-Huffman gauge and 8,130 cfs at the Merced River near Stevinson gauge. In the upstream reaches of the project area, the channel accommodated this flow, although the Route 59 bridge was closed due to the danger of bridge failure. In the lower reaches of the river private levees were breached at several locations, and agricultural and dairy lands were flooded (Figure 3.2–1). Damage from seepage and high water tables was also reported by some landowners in the lower river.

3.2.2 Discharges to the River

In addition to the diversions described above, there are also several discharges into the Merced River downstream of Crocker-Huffman Dam, including return flow from Merced ID diversions, an interbasin transfer from the Tuolumne River and Mustang Creek, wastewater treatment discharges, and private agricultural drains. Merced ID owns and maintains three operational spills that discharge excess irrigation water and storm water runoff to the Merced River: the Northside Canal Spill, the Livingston Canal Spill, and the Garibaldi Lateral Spill. The Northside Canal Spill discharges approximately five river miles upstream of Cressey, the Livingston Canal Spill discharges approximately one river mile upstream of State Route 99, and the Garibaldi Lateral Spill discharges approximately three river miles downstream of State Route 99.

Turlock Irrigation District operates two spills that discharge into the Merced River: the High Line Spill and the Lower Stevinson Spill. The High Line Spill is located near Griffith Avenue (RM 15.6) and discharges excess irrigation water diverted from the Tuolumne River and storm flows from the Mustang Creek watershed that are intercepted by the Highline Canal. The Lower Stevinson Spill is located just upstream of the town of Stevinson. This spill discharges excess irrigation water diverted from the Tuolumne River and shallow ground water that has been pumped from the nearby region.

3.2.3 Levees

No state or federal levee system has been constructed on the Merced River, and existing levees are limited to small, privately owned structures. The levee system is, however, extensive, especially downstream of the State Route 99 bridge (RM 20.5). Upstream of State Route 99, levees are isolated and discontinuous. The extent of levees and the effects of levees on floodplain width are described in more detail in Section 5.5.

3.2.4 Gold and Aggregate Mining

The lower Merced River has been mined extensively for gold and aggregate. Placer (gold) dredging occurred in the valley from 1907 through 1952. During this period, seven gold companies operated ten dredges in the Merced River in the vicinity of Snelling (Vick 1995). Dredges had earthmoving capacities of 1.4–3.4 million yd^3/yr and excavated the channel and floodplain deposits to bedrock, usually a depth of 20–36 feet (Clark, no date). After recovering the gold, the dredgers redeposited the remaining tailings in long rows on the floodplain. These tailings consist of fine sand and gravel overlain by cobbles and boulders (Goldman 1964), a stratification pattern that likely resulted from the sluicing and discharge process. Tailings currently cover approximately 7.6 square miles of floodplain in the Snelling vicinity (Figure 3.2–2); the volume[e] of these tailings is estimated to be approximately 24 million yd^3. Based on preliminary field surveys, McBain and Trush (2000) estimated that approximately 3.6 million yd^3 of tailings occur on lands owned by Merced ID, Merced County, and the CDFG (Table 4). Some dredger tailings on private properties are currently being mined for aggregate, including tailings near Merced Falls and near the Snelling Road bridge.

Table 4. Total Volume of Dredger Tailings on Merced River Floodplain Owned by the County, CDFG, and Merced ID

Gravel Inventory Sites	Volume (yd^3)
Merced ID	1,390,000
Merced County	355,000
CDFG	1,850,000

(Source: McBain and Trush 2000)

Large-scale aggregate mining began in the Merced River and its floodplains in the 1940s and continues today. Aggregate mines have excavated sediment directly from the river channel, creating large in-channel pits, and from the adjacent floodplains and terraces. Floodplain and terrace pits typically were separated from the channel by narrow, unengineered berms, but many of these berms have been breached by high flows, resulting in capture of the river channel by the pits. While in-channel mining has been discontinued, floodplain and terrace mining continue today.

Vick (1995) identified 24 aggregate mining sites in the river extending from RM 44.8 (near Snelling) to RM 26.5 (at Cressey). Mines identified included eight intact terrace pits, two breached terrace pits, six captured terrace pits, and eight in-channel pits. At intact mines, berms isolating the channel from the mine pit were not breached. At breached mines, the berm was broken at one location. At captured mines, the berm is broken at more than one location and the river channel flowed through the mine pit. Of these mines identified in 1995, one breached terrace pit and one intact terrace pit (both located immediately upstream of the Route 59 bridge) were captured in the January 1997 flood. Including the mines captured in 1997, in-channel and captured pits currently occupy 7.3 miles (or 40 percent) of the gravel-bedded reach of the river.

Three aggregate mines, which are operated by Calaveras Materials Inc. and Santa Fe Aggregates, are currently active in the river corridor. Calaveras Materials Inc. operates two permitted sites just downstream of the Route 59 bridge. An additional mine, the Woolstenhulme Ranch site (456-acres), is currently in the permitting process.

Santa Fe Aggregates, Inc. operates the Bettencourt Ranch mine near RM 34 and the Doolittle Mine near RM 4.6. The Bettencourt Ranch mine was permitted in 1989 and has approximately three to four years of permitted reserves, depending on market demands. The current permitted area is 160 acres. Upon completion of the mining operation, the site will be reclaimed to open space, wildlife habitat, and agriculture. The mine pits are separated from the river by a berm that is approximately 100 to 200 feet

[e] This assumes an average depth of 3.5 feet, based on McBain and Trush (2000).

wide. The Doolittle Mine is located in a dredger tailings area. Tailings will be removed to the floodplain or terrace elevation.

4 EFFECTS OF FLOW REGULATION AND DIVERSION ON HYDROLOGY

As described in Section 2, many of the attributes and processes that define a healthy river ecosystem are driven by the hydrologic characteristics of the system. Typical of rivers on the east side of the Central Valley, natural flow conditions in the Merced River were characterized by low flows in summer and fall, large but brief peak flows in winter due to rain storms and rain-on-snow events, and prolonged high flows in spring and early summer from snowmelt in the upper watershed. Under pre-dam conditions, these natural flows maintained the channel width and depth, transported coarse and fine sediment, and supported floodplain and riparian processes.

Natural flow conditions in the Merced River have been modified by flow regulation (i.e., dam operation) and flow diversions. Ground water withdrawals also may have affected summer low flow conditions in some reaches. This section describes how flow regulation and flow diversion have altered seasonal flow patterns and flood peaks in the Merced River downstream of Crocker-Huffman Dam. The effects of these changes in flow conditions on sediment transport and riparian vegetation establishment are discussed Sections 5 and 6.

4.1 The Natural Hydrograph

The Merced River's natural hydrograph can be broken into four components: summer baseflows, fall and winter peak flows, winter baseflows, and spring and summer snowmelt (Figure 4.1–1). Summer baseflows begin at the end of the snowmelt recession and end with the first storm in late fall. Under pre-dam conditions, summer baseflows typically began between late June and August and ranged from 100 to 300 cfs, with monthly flows averaging 304 cfs, 123 cfs, and 224 cfs for August, September, and October respectively (based on flow at the Merced River near Exchequer gauge for the period 1902–1913, 1915–1920). Through the fall and winter, rainstorms and rain-on-snow events generated brief, sharp peaks in flow. Large-magnitude, short-duration floods caused by rain-on-snow events typically occurred in late December through February; moderate-magnitude events extended through March. Winter baseflows, which occur over the same time period as fall and winter peak flows, are the stable flows that occur between fall and winter storm events. These baseflows are fed by shallow groundwater return and generally increase in magnitude throughout the winter as soils become saturated. Prior to flow regulation, winter baseflows in the Merced River generally ranged from approximately 200 to 1,700 cfs (measured at Merced River near Exchequer gauge) depending on water-year-type. During dry and critically dry years, winter baseflows were about the same magnitude as summer baseflows. The spring and summer snowmelt period was the wettest period of the natural annual hydrograph. During this period, snowmelt from the upper watershed produced high flows that spanned several weeks or months and receded slowly beginning in late spring or early summer. Prior to flow regulation, spring and summer snowmelt on the Merced River typically began in mid-March and ended between late June and August, when flows returned to summer baseflow levels. The peak of the snowmelt typically occurred between late March and June, and the recession limb generally lasted until mid-to-late July but extended later during wetter years. Under natural conditions, these spring snowmelt flows and the slow recession limb drove many processes that characterize a healthy alluvial river system. For instance, high spring flows inundated floodplains and delivered fine sediment to floodplains and riparian zones. In some years, the slow recession limb coincided with the timing of seed release of cottonwoods and other riparian trees and supported seed germination and seedling establishment. In addition, these spring high flows supported chinook salmon juvenile and outmigrant life stages.

4.2 Effects of Flow Regulation and Diversion on Seasonal Flow Patterns

The effects of flow regulation and diversion were assessed using streamflow gauge data from the lower Merced River. A schematic diagram of gauge locations is shown in Figure 4.2–1. The combined effects of flow regulation and flow diversion have greatly reduced flow magnitude in the lower river downstream of Crocker-Huffman Dam and have shifted temporal seasonal flow patterns. Unregulated and regulated monthly flows in the Merced River are shown in Table 5 and Figure 4.2–2. Without flow regulation, average monthly flows in the Merced River were highest during the spring snowmelt peak (April through June) and lowest during late summer and early fall (August through October). With flow regulation, flow conditions at Merced Falls (i.e., the reach downstream of McSwain Dam but upstream of the Northside and Main Canal diversions) are similar in pattern though reduced in magnitude compared to unregulated conditions through the winter and spring (December through June). During summer and early fall (July through October), flow magnitude is increased by 80B880 percent as irrigation flows are delivered from the storage reservoirs to the diversion canals. Average flows in November are essentially unchanged.

Table 5. Comparison of Unregulated and Regulated Flows in the Merced River (1968B1998)

Month	Average Monthly Flow (cfs) [percent change compared to unregulated flow]		
	Estimated Unregulated Flow 1968-1998[1]	Merced Falls Dam 1968-1998[2]	Crocker-Huffman Dam[3]
October	151	871 [427]	271 [79]
November	352	389 [11]	189 [-46]
December	641	571 [-11]	270 [-58]
January	1,583	813 [-49]	415 [-74]
February	1,749	1,138 [-35]	568 [-68]
March	1,982	1,352 [-32]	545 [-73]
April	2,464	1,842 [-25]	529 [-79]
May	3,954	2,300 [-42]	498 [-87]
June	3,211	2,353 [-27]	424 [-87]
July	1,195	2,146 [80]	251 [-79]
August	279	1,753 [528]	150 [-46]
September	143	1,401 [880]	214 [50]

[1] CDWR (1994a)
[2]USGS Merced River near Merced Falls Dam gauge (no. 11270900)
[3]Merced ID Crocker-Huffman gauge

Downstream of Crocker-Huffman Dam, flow regulation and diversion have reduced flow variability in the river. Under unregulated conditions, average monthly flows varied over an order of magnitude from a low of 143 cfs in September to a high of 3,954 cfs in May. With flow regulation and diversion, average monthly flows in the lower river vary from a low of 150 cfs in August to a high of 568 cfs in February. Flow regulation and diversion have also altered monthly average monthly flow magnitude in the lower river. Average monthly flows in September and October are 50B79 percent higher than unregulated flows, while average monthly flows during November through August are 46B87 percent lower, with the greatest flow reductions occurring from April through July (Table 5).

Alterations to the seasonal hydrograph can be further illustrated by comparing unregulated and regulated flows for individual years representing a range of water-year-types (i.e., dry-to-wet). This analysis requires estimated or measured daily inflow to Lake McClure and daily flow data downstream of the mainstem dams and diversions. Necessary data were available for the period 1977B1996. For the analysis, five water year types ranging from critically dry to extremely wet were defined. The water year definitions were developed by identifying exceedence probabilities of the total annual water yield for all water years in the period 1902B1998. Total water yield for each of these years was ranked and plotted using the Weibull plotting position method (Linsley et al. 1975), and the resulting distribution was divided into five water year classes symmetric about the median water yield (Figure 4.2–3 and Table 6). One year having a total annual water yield within the defined range was chosen to graphically represent each water-year-type for the hydrograph components analysis (Table 6). Hydrographs showing inflow to Lake McClure, regulated flow at Merced Falls, and regulated flow at Crocker-Huffman Dam for each of the these representative years are shown in Figures 4.2–4A through 4.2–4E.

Table 6. Exceedence Probabilities and Total Water Yield of Water-Year-Types, 1902–1998

Water-year-type	Exceedence probability	Total water yield (millions of acre-feet)	Representative water year
Critically Dry	0.85 - 1.0	< 0.476	1992
Dry	0.6 – 0.85	0.476 – 0.733	1981
Normal	0.4 – 0.6	0.733 – 1.09	1979
Wet	0.15 - 0.4	1.09 – 1.56	1993
Extremely Wet	0 - 0.15	>1.56	1982

In general, flow regulation and diversion in the Merced River have reduced fall and winter peak flows, reduced winter baseflows, reduced the spring snowmelt peak, and accelerated the rate of the snowmelt recession. Summer baseflows (at Crocker-Huffman Dam) have been relatively unaffected. Additional riparian diversions downstream of Crocker-Huffman Dam, however, further reduce baseflows throughout the summer period. The effects of flow regulation and diversion on daily flows for each hydrograph component are described in more detail below.

Summer Baseflows

Overall, the effects of the dams and the Northside and Main Canal diversions have had a relatively minor effect on summer baseflow magnitude, with the exception of increasing baseflows in October. Downstream of Crocker-Huffman Dam, flows in the river are further reduced by numerous riparian diversions. Flow releases required for riparian diversions for August, September, and October are 175 cfs, 150 cfs, and 50 cfs, respectively (Table 3), which is 116 percent, 70 percent, and 23 percent of average monthly flows measured at Crocker-Huffman Dam for the period 1968B1998 for these months, respectively. In the critically dry, dry, and median water years analyzed, riparian diversions between Crocker-Huffman Dam and Shaffer Bridge (RM 32.5) reduced summer baseflows downstream of Crocker-Huffman Dam by 60 percent, 62 percent, and 40 percent, respectively, and fell to as low as 26 cfs (based on flows measured at the Merced River at Shaffer Bridge gauge). In the wet and extremely wet years analyzed, the Merced River at Shaffer Bridge gauge was not operating. Summer baseflows at the Merced River near Stevinson gauge (RM 1.1) were 21 percent lower than at Shaffer Bridge during the critically dry year but were approximately the same as at Crocker-Huffman Dam during the dry and median years. During the wet year summer baseflows at Stevinson were approximately 35 percent lower than at Crocker-Huffman Dam. During the extremely wet year, summer baseflows at Stevinson were approximately 40 percent higher than at Crocker-Huffman Dam.

Fall and Winter Peak Flows

Flow regulation has substantially altered fall and winter peak flows. During dry and critically dry water years, the effect is not observed until late in the winter because natural winter peaks are generally absent and, when they do occur, they are of small magnitude. For the dry and critically dry years analyzed (Figures 4.2–4A and 4B), the first substantial winter peaks occurred in February and, in both years, unregulated peaks were less than 4,000 cfs. The dams stored flows from these peaks, and downstream of the dams, flows remained constant throughout the winter, spring, and summer. In the median, wet, and extremely wet years (Figures 4.2–4C through 4E), the first substantial unregulated peaks began as early as November, but these peaks were stored by the reservoirs and flows in the lower river remained constant until mid-February or later. This pattern is typical of the operation of water supply and flood control reservoirs, which are operated to store winter and spring high flows until the storage pool encroaches into the required flood control pool. For the water years shown, instantaneous winter peak flows were reduced by 50–80 percent by regulation, and regulated peaks tended to be longer in duration and smaller in magnitude than peak inflows to Lake McClure.

Winter Baseflows

Flow regulation has reduced winter baseflows in the lower river relative to unregulated conditions. For the years analyzed, unimpaired winter baseflows ranged from 697 cfs in critically dry years to 2,040 cfs in extremely wet years. For all of the years assessed, regulated winter baseflows were similar to unregulated flow magnitude until the first or second substantial storm. These storms increased unregulated baseflow, but flows downstream of the dams remained constant until mid-February in the median and extremely wet years, until April in the wet year, and throughout the winter, spring, and summer in the dry and critically dry years. These stable, reduced baseflow conditions reflect water supply and flood control operations (described above) combined with minimum flow requirements. Under the Merced ID’s Davis-Grunsky Contract, required minimum flows from November through March range from 180 to 220 cfs. These required flows are eleven percent unregulated winter baseflow magnitude in the extremely wet water year analyzed and 50 percent in the critically dry water year analyzed.

Spring and Summer Snowmelt

Flow regulation and diversion have reduced the magnitude of the snowmelt peak and have accelerated the snowmelt recession limb. Under unregulated conditions, the spring snowmelt peak typically spanned several weeks or months and receded in early to mid-summer. For the water years assessed, the magnitude and duration of the peaks and the relative effects of regulation and diversion on the peaks and recession varied. For the critically dry and dry years (Figures 4.2–4A and 4B), the unregulated snowmelt peak began in late March, peaked at approximately 3,000B5,000 cfs, and receded in mid-May (during the critically dry year) and mid-June (during the dry year). During these years, the spring snowmelt was completely absorbed by the reservoirs, and no spring peak flows occurred in the lower river. During the median water year (Figure 4.2–4C), unregulated spring snowmelt began in March, peaked at approximately 8,500 cfs in May, and receded over June and early July. Downstream of the dams, the spring snowmelt peaked in March at approximately 2,500 cfs and rapidly receded in late March and early April then peaked again at approximately 1,100 cfs in late May and early June. During this year, the magnitude of the May–June snowmelt peak, which is critical for rearing and outmigrating salmon and for riparian tree germination and establishment, was reduced by 87 percent, and the duration was reduced by approximately six weeks. During the wet and extremely wet years (Figures 4.2–4D and 4E), unregulated spring snowmelt began in March, combined with rain-on-snow events. Rain-on-snow peaks occurred in April and May, snowmelt peaks of approximately 8,500 cfs occurred in late May and early June, and snowmelt peaks receded in July and early August. Flow regulation reduced snowmelt peaks to approximately 2,200B5,000 cfs, shifted the recession limb to late May and early June, and accelerated the rate of recession. What is most notable when comparing unregulated and regulated spring flows is that regulated spring flows in the wet year (Figure 4.2–4D) are approximately the same in magnitude and temporal pattern as the unregulated spring flows in the critically dry year (Figure 4.2–4A), indicating that even under wet conditions (which have an exceedence probability of 0.15B0.4) the river and its adjacent riparian corridor must function under what would be drought conditions in the unregulated system. Only during extremely wet years (which have an exceedence probability of 0B0.15), do spring flow conditions downstream of the dams and diversions approach natural median water-year-type flow conditions.

4.3 Effects of Flow Regulation and Diversion on Flood Magnitude

The New Exchequer Dam is operated both for water supply and for flood control. As such, the reservoir is operated to store peak flows for water supply while maintaining the required flood control pool. In addition, the Corps of Engineers limits the maximum flow release from the Crocker-Huffman Dam to 6,000 cfs, as measured at the Merced River near Stevinson gauge (downstream of Dry Creek). The combined effect of the water supply and flood control management is to reduce flood magnitude downstream of the dams. Floods are important drivers of the river-riparian system. As discussed in Section 2, small magnitude, frequent floods are required to maintain the channel size, shape, and bed texture, while larger, infrequent floods provide beneficial disturbance to both the channel and its adjacent floodplain and riparian corridor. As discussed in Volume I of this report, however, much of the Merced River floodplain has been converted to agricultural and residential uses, and large floods obviously conflict with the human uses in the river corridor and their related economic values. This section describes how flow regulation has affected flood magnitude and timing in the Merced River. The social and economic issues affected by flooding and flood control are discussed in Volume I (Stillwater Sciences and EDAW 2001).

Flow regulation has affected both flood timing and flood magnitude in the lower river. The effects of flow regulation on flood timing were assessed by comparing estimated daily inflow to Lake McClure to regulated flows downstream of Crocker-Huffman Dam. Under natural conditions, the highest flows of the year occurred during fall and winter from rain or rain-on-snow events or during the spring from snowmelt (Table 7). With the operation of New Exchequer Dam, storage of snowmelt runoff has generally shifted the timing of annual peak flows from spring to fall and winter. Under unregulated conditions (represented by inflow to Lake McClure for the period 1977–1996), the annual peak flood occurred during the period from April through June in 60 percent of years. In the remaining 40 percent of years, the annual flood occurred between October and March (Table 7). With flow regulation (represented by flows at Crocker-Huffman Dam for the same period), 25 percent of the annual peaks occurred between April and June, 10 percent occurred between July and September, and 65 percent occurred between October and March (Table 7).

Table 7. Comparison of the Timing of Regulated and Unregulated Peak Flows (1977-1996)

Period	Inflow to Lake McClure		Downstream of the Crocker-Huffman Dam	
	Number of peaks	Percent of peaks	Number of peaks	Percent of peaks
October-March	8	40	13	65
April-June	12	60	5	25
July-September	0	0	2	10
Total	**20**	**100**	**20**	**100**

Flow regulation has also reduced annual flood magnitude. The effect of flow regulation on flood magnitude was assessed by comparing pre-dam and post-dam floods. Prior to flow regulation, floods exceeding 15,000 cfs were common, occurring in 11 of the 21 years of record, and the mean annual flood (Q_{maf})[f] (at the Merced River near Exchequer gauge) was 16,200 cfs (Figure 4.3–1). Following the completion of New Exchequer Dam, the Q_{maf} in the reach upstream of the Main Canal Diversion was reduced by 72 percent to 4,560 cfs (Figure 4.3–1). In the reach downstream of the diversions the Q_{maf} was reduced by 83 percent to 2,793 cfs (Figure 4.3–2). Since the construction of New Exchequer Dam, peak flows below Crocker-Huffman dam have not exceeded the 1997 flow of 8,279 cfs (measured at the Merced ID Crocker-Huffman gauge).

Pre-dam and post-dam flood magnitudes for the 1.5-, 2-, 5-, 10- and 50-year recurrence intervals are shown in Table 8. This comparison indicates that flow regulation has reduced peak flow magnitude by up to 87 percent, with the greatest reduction occurring for smaller magnitude floods. Channel forming floods (represented by the $Q_{1.5}$ or Q_2) have been reduced by 85**B**87 percent. Prior to dam construction and flow regulation, channel forming floods were on the order of 10,000**B**14,000 cfs. Since dam construction, floods of this magnitude no longer occur. The largest flood that has occurred since completion of the New Exchequer Dam was smaller than the pre-dam $Q_{1.5}$, and the 6,000-cfs flood release limit imposed by the Corps of Engineers is only 60 percent the pre-dam $Q_{1.5}$. Larger floods that under natural conditions would drive channel cut-off events and support riparian vegetation recruitment and diversity have been eliminated.

[f] The average of annual peak flows for each year for a given period.

Table 8. Comparison of Instantaneous Annual Peak Floods Under Pre-Dam and Regulated Conditions

Recurrence Interval (years)	Pre-Dam	Post-Dam	Percent Reduction
	Unregulated flow (WY 1902–1925) at Exchequer[1]	Regulated flow (WY 1968–1997) at Snelling[1]	
1.5	10,062	1,338	87
2	13,692	2,097	85
5	24,006	4,675	80
10	31,526	6,836	78
50	49,177	12,513	75

[1] Flood magnitudes and recurrence intervals are based on a Log-Pearson III distribution of instantaneous peak flow data.

5 GEOMORPHIC AND RIPARIAN BASELINE EVALUATIONS

5.1 Reach Delineation

The Merced River downstream of Crocker-Huffman Dam can be divided into five reaches, as defined by channel and floodplain morphology and anthropogenic alterations to the channel and floodplain (Figure 5.1–1). These reaches are the:

- Dredger Tailings Reach (from Crocker-Huffman Dam [RM 52] to RM 45.2, approximately 1.2 RM downstream of the Snelling Road Bridge);
- Gravel Mining 1 Reach (from RM 45.2 to Shaffer Bridge [RM 32.5]);
- Gravel Mining 2 Reach (from Shaffer Bridge to RM 26.8, approximately 0.3 RM downstream of the Santa Fe Boulevard Bridge);
- Encroached Reach (from RM 26.8 to the Hultberg Road [RM 8]); and
- Confluence Reach (from RM 8 to the San Joaquin River confluence [RM 0]).

Reach attributes are summarized in Table 9. Geomorphic and vegetation conditions in these reaches are described in more detail below.

Table 9. Summary of Geomorphic Attributes of Each Reach

Reach Name	River Mile	Channel Slope[1]	Bed Material
Dredger Tailings Reach	52–45.2	0.0023	cobble, gravel
Gravel Mining 1 Reach	45.2–32.5	0.0015	cobble, gravel
Gravel Mining 2 Reach	32.5–26.8	0.0008	gravel, sand
Encroached Reach	26.8–8	0.0003	gravel, sand
Confluence Reach	8–0	0.0002	Sand

[1] Measured from 1:24,000-scale topographic maps (U.S. Geological Survey)

5.1.1 Dredger Tailings Reach

The Dredger Tailings Reach extends from Crocker-Huffman Dam to RM 45.2, approximately 1.2 RM downstream of the Snelling Road bridge. The reach-averaged channel slope in this reach is 0.0023 (Figure 5.1–2), and the channel bed is composed of very coarse gravel and cobbles. The median particle size of surface substrates (D_{50}) ranges from 36 to 128 mm; the 84th percentile particle size (D_{84}) ranges from 85 to 270 mm (Figures 5.1–3 and 5.1–4). The channel is armored and in many locations scoured to bedrock.

In this reach of the river, the channel and floodplain have been dredged for gold. As a result, the channel has been depleted of coarse sediment and the adjacent floodplain has been raised and covered with dredger tailings piles, which confine the channel and floodplain width (Figure 5.1–5). The combined effects of gold dredging and upstream reductions of sediment supply and peak flows have converted this reach from a complex, multiple-channel system (shown in Figure 5.1–6) to a single-thread system. The remnant channels (referred to as “sloughs”) have since been converted to agricultural irrigation and return-flow ditches (Figure 5.1–7). Also, the confinement of the river channel width creates high shear stresses, even during moderate flow events, which scour sediment from the channel. As a result of these high shear stresses combined with the lack of a coarse sediment supply caused by upstream dams and removal of in-channel sediment, the channel in this reach is typified by long, deep pools that have been scoured to bedrock or to a coarse, cobble armor layer. Almost no alluvial bars occur in this reach.

The riparian zone on either side of the channel in the Dredger Tailings Reach is typically 100 feet wide or less. Non-native grasses and forbs dominate the tailing surfaces and floodplain areas. Non-native trees, shrubs and vines are common along roads and the edges of the tailing areas, but in general, native woody plants dominate larger riparian patches. Vegetation between the channel and the tailing piles typically consists of mixed riparian tree species. Sparse, weedy herbaceous assemblages occupy the tops of tailing piles, and cattail marsh (*Typha latifolia*) or cottonwood-Goodding's black willow (*Salix gooddingii*) assemblages occupy tailing swales. Riparian vegetation in the Dredger Tailings Reach has encroached into the channel and demonstrates a relatively mature age structure, with few young trees establishing. During reconnaissance field surveys, seedling recruitment was observed on narrow alluvial bars, but few patches of established saplings were evident. Several seedling patches were surveyed at RM 48.2 as part of the Snelling Site evaluations, which are described in Section 6.2.

CDFG and CDWR have implemented several gravel augmentation projects in this reach to increase the area of spawning habitat available to fall chinook salmon. In addition, CDFG is working with local riparian water diverters who construct wing dams on the Merced River. In the past, these dams have been constructed from gravel and cobble scraped from the riverbed. CDFG currently provides the diverters with gravel suitable for chinook salmon spawning to construct these wing dams. During high flows, spawning gravel from these dams is washed downstream and redeposited in the river.

5.1.2 Gravel Mining 1 Reach

The Gravel Mining 1 Reach extends from RM 45.2 to Shaffer Bridge (RM 32.5), just upstream of the Dry Creek confluence. The reach-averaged channel slope is 0.0015 (Figure 5.1–2), and the channel bed is composed of coarse gravel, very coarse gravel, and cobble. The D_{50} ranges from 25 to 90 mm; the D_{84} ranges from 48 to 150 mm (Figure 5.1–3 and 5.1–4). The channel-bed surface in this reach does not appear to be armored and the bed subsurface contains a large volume of sand. The CDFG and CDWR are currently assessing bed mobility in the upstream portion of this reach as part of an ongoing habitat enhancement project design.

This reach occupies the downstream portion of the multiple channel system described for the Dredger Tailings Reach above. As in the Dredger Tailings Reach, the river in this reach has been converted to a single-thread system and floodplain sloughs have been converted to irrigation ditches and drains. This reach contains some remnant off-channel oxbow and slough features, indicating former meander cutoffs and channels.

The Gravel Mining 1 Reach has been extensively mined for aggregate both on the floodplain and in the channel (Table 10, Figure 5.1–8). CDFG and CDWR are currently implementing The Merced River Salmon Habitat Enhancement Project (Figure 5.1–8), a four-phase project to reconstruct the channel and floodplain through 4.3 miles of the Merced River that have been excavated for aggregate mining. The objectives of the project are to: (1) reduce predation on young salmon by non-native fish by isolating habitat in river-captured mining pits that serve as predator habitat; (2) restore or enhance salmon spawning habitat; (3) enhance passage of adult and juvenile salmon; (4) resize the channel and floodplain to restore some natural river processes; and (5) reestablish riparian vegetation. In addition to the mining pits being addressed by the CDFG/CDWR project, four terrace and four in-channel mines occur in this reach. Two of the terrace mines are active. The four in-channel mines occupy 4.4 miles (35 percent) of this reach.

Table 10. Terrace and In-Channel Aggregate Pits in the Gravel Mining 1 Reach

Pit Identification	Mine Name	RM	Length[1] (ft)	Width[1] (ft)	Depth[2] (ft)
In-channel Pits					
GM1 – C1	Unknown	38.9–39.3	1,500	800	No data
GM1 – C2	Unknown	35.1–35.4	1,000	200	6-9
GM1 – C3	Unknown	33.9–34.4	2,200	400	5-8
GM1 – C4	Unknown	36.3–36.9	2,000	100	4
Terrace Pits					
GM1-T1	Carson Pit I	—	2,800	2,300	No data
GM1-T2	Carson Pit II	—	1,100	450	No data
GM1-T3	Silva Expansion	42	No data	No data	No data
GM1-T4	Bettencourt Ranch	33.2–34.1	4,500	1,500	No data

[1] Measured from 1998 aerial photographs (scale: 1:6,000)
[2] Depth from water surface measured in the field (June 2000)

The width of riparian vegetation on each bank in Gravel Mining 1 Reach typically varies from 100 to 500 feet. Former aggregate mines extend to the channel margin, eliminating much of the riparian vegetation, and steep banks and pit berms do not provide the low-gradient, alluvial surfaces necessary for seedling recruitment. In parts of the channel where mining pits have been captured by the river, vegetation assemblages are highly fragmented on banks, former berm surfaces, and mid-channel bars. Remnant oxbow and slough features contain patches of marsh and seasonal wetland habitats and are typically bordered by linear stands of riparian scrub, valley oak forest, and remnant cottonwood and mixed riparian forest.

5.1.3 Gravel Mining 2 Reach

The Gravel Mining 2 Reach extends from Shaffer Bridge to RM 26.8, approximately 0.3 RM downstream of the Santa Fe Boulevard Bridge (RM 27.1). This reach includes the Dry Creek confluence and the remaining in-channel mines. The reach-averaged channel slope is 0.0008 (Figure 5.1–2), and the channel bed is composed of sand, gravel, and cobble. The D_{50} ranges from 22 to 85 mm; the D_{84} ranges from 33 to 130 mm (Figure 5.1–3 and 5.1–4). As in the Gravel Mining 1 Reach, the channel-bed subsurface contains large volumes of sand. The channel in this reach is incised, with documented incision of up to five feet since 1964 (Vick 1995).

As in the Gravel Mining 1 Reach, this reach has been extensively mined for aggregate both on the floodplain and in the channel, and five in-channel or captured mining pits and three terrace pits (including one pit that was isolated from the channel by a CDFG/CDWR project) occur in this reach (Table 11, Figure 5.1–8). Under current conditions, two miles (35 percent) of this reach are occupied by in-channel or captured mines. An additional 1.3 miles (23 percent) are bordered by terrace mines that are isolated from the channel by berms.

In 1996, the CDFG, working with the CDWR and with funding from the Four Pumps Agreement, completed the Merced River Predator Control Project, Magneson Site Project (Figure 5.1–8). This project isolated a pit (referred to as GM2-T3 in Table 11) that had captured the river channel. The pond was left in place behind the repaired berm to retain recreational fishing opportunities important to the landowner. (Figure 5.1–9).

Table 11. Aggregate Pits in the Gravel Mining 2 Reach

Pit Identification	Mine Name	RM	Length[1] (ft)	Width[1] (ft)	Depth (ft)
In-channel Pits					
GM2-C1	River Rock	31.5–.2.1	2,000	600	4-13[2]
GM2-C2	Silva/Turlock Rock	30.0–30.6	3,300	400	13-19[2]
GM2-C3	Turlock Rock	28.7–28.9	1,400	200	23[2]
GM2-C4	Cressey Sand and Gravel	27.2–27.4	1,400	300	11-29[2]
GM2-C5	Turlock Rock	26.7–27.1	1,800	800	10[2]
Terrace Pits					
GM2-T1	Turlock Rock	31.1–31.4	2,100	900	No data
GM2-T2	Turlock Rock	29.7–29.9	800	600	20[3]
GM2-T3	Turlock Rock	29.2–29.5	1,600	500	20[3]

[1] Measured from 1998 aerial photographs (scale: 1:6,000)
[2] Measured from water surface in the field (June 2000)
[3] Source: Vick (1995)

This reach receives large amounts of sand from Dry Creek. Much of the sand supplied from Dry Creek is being captured by the in-channel mining pits. The pit located at the mouth of Dry Creek (GM2-C1) was excavated by the River Rock mining company in the 1940s and 1950s. This pit was originally excavated as a terrace pit, but was later captured by the channel. Davis and Carlson (1952) reported the depth of the pit to be 30 feet shortly after excavation. The current depth is 11B13 feet upstream of the Dry Creek confluence and 4B10 feet downstream of the Dry Creek confluence, indicating that the pit has filled in substantially over the past 45–50 years. The Silva Gravel/ Turlock Rock pit (GM2-C2) also shows evidence of sand accumulation. Currently the channel depth in the pit is approximately 13B19 feet and a large sand bar has deposited at the pit margin.

The riparian zone width in Gravel Mining 2 Reach is narrower than in upstream reaches, approximately 50 feet (or one tree canopy width) on each bank in most places. As in the Gravel Mining 1 Reach, gravel pit berms extend to the channel margin and hinder the recruitment of riparian species because bank revetment, steep slopes, and the construction of access roads adjacent to the channel eliminate the hydrologic and topographic conditions necessary for seedling establishment. Vegetation in this reach is highly fragmented, as in the Gravel Mining 1 Reach, and also includes off-channel oxbow and slough features. Extensive revetted banks support little native riparian vegetation, and field observations indicate that they are establishment points for the invasive giant reed (*Arundo donax*). Unlike in the Gravel

Mining 1 Reach, dense stands of mature eucalyptus (*Eucalyptus* spp.) occur in this reach. The distribution of eucalyptus stands along the river is discussed further in Section 6.1.2.

5.1.4 Encroached Reach

The Encroached Reach extends from RM 26.8 (approximately 0.3 RM downstream of the Santa Fe Boulevard Bridge) to Hultberg Road (RM 8). The reach-averaged channel slope is 0.0003 (Figure 5.1–2). Within this reach, the channel substrate transitions from gravel to sand bed. This transition zone is lengthy, extending from RM 25.5 to RM 16.5 (almost half the length of the reach). No quantitative assessment of sediment character is available for this reach. The downstream portion of this reach may be subject to backwater effects from the San Joaquin River.

Within this reach, agricultural development in the former floodplain and riparian corridor confines the channel between private levees. Aerial photographs indicate that this reach historically exhibited an alternate bar-pool morphology. Flow regulation, levee construction, and elimination of channel migration have simplified the channel, and active bars are generally absent (Figure 5.1–10). Throughout most of this reach, the channel cross section is generally trapezoidal, exhibiting no clearly defined low flow channel or active bars. The riparian zone ranges from 50 to 300 feet wide on each bank and is composed primarily of mixed riparian forest and willow species.

5.1.5 Confluence Reach

The Confluence Reach extends from Hultberg Road (RM 8) to the San Joaquin River confluence (RM 0). An aerial photograph depicting typical conditions in this reach is shown in Figure 5.1–11. The reach-averaged channel slope is 0.0002 (Figure 5.1–2). This reach is entirely sand-bedded and is subject to backwater effects from the San Joaquin River. Where meanders are not armored, active sandbars and diverse riparian communities are present. The most extensive and continuous stands of native vegetation remaining along the Merced River corridor are located in this reach just upstream from the San Joaquin confluence (RM 0–3).

Riparian vegetation in the Confluence Reach typically extends from 500 to 1,500 feet on each bank from the river channel and includes dense remnant valley oak and cottonwood forests. The understories of these forests consist of box elder, Oregon ash, Goodding's black willow, blue elderberry (*Sambucus mexicana*), and California wild grape (*Vitis californica*), as well as scattered non-native species such as tree of heaven (*Ailanthus altissima*), edible fig (*Ficus carica)*, and mulberry (*Morus alba*). These forest stands, which contain very large individual valley oaks up to 85 inches diameter (at breast height), occupy the river's historical floodplain and presumably were never cleared. These stands represent the nearest approximation to pre-settlement Central Valley riparian gallery forests in the Merced River corridor (Thompson 1961 and 1980, Conard et al. 1980, Roberts et al. 1980, Holland and Keil 1995, Edminster 1998).

5.2 Sediment Supply

Sediment supply from the upper watershed to the lower river is intercepted by New Exchequer Dam (and previously by Exchequer Dam). Downstream of the dams, stored sediment has been removed from the channel and floodplain by mining. As a result, current sources of sediment to the lower river are limited to bed and bank erosion and input from Dry Creek.

The historic (i.e., pre-dam) supply of sediment to the lower river can be estimated from reservoir capacity surveys. Between 1926 and 1946, the Exchequer Dam reservoir lost 3,354 acre-feet of capacity due to deposition of suspended load and bedload (Dendy and Champion 1978). Based on an average specific weight of 62 pounds/ft^3 (Dendy and Champion 1978), this volume of sediment deposition in the reservoir indicates a *minimum* sediment yield of 4.5 million tons from the 1,022-square mile contributing upper watershed during the 19.6-year period between the surveys, or an average of 231,000 tons/year. Published estimates of bedload as a percentage of suspended load range from two to six percent in lowland rivers (gradient 0.0004 to 0.0023) to 8 to 16 percent in mountainous rivers (Collins and Dunne 1989, 1990). Assuming that bedload is 5B10 percent of total suspended load in the Merced River, pre-dam annual bedload yield during this period was between 11,000–21,000 tons/year. These estimates assume that all sediment from the contributing watershed was trapped by the dam.

With the dams in place, bedload supply from the upper watershed to the lower river has been cut off. At the same time, bedload stored in the river channel and floodplain has been removed by gold dredging and aggregate mining. Vick (1995) estimated the volume of stored bedload removed from in-channel, captured, and breached aggregate mines from 1942 through 1993 based on mine area (determined from aerial photographs) and mine depths (determined from a small sample of cross sections in mining pits) and concluded that the volume removed ranged from 7B14 million tons of bedload, or 350B1,350 times the natural annual bedload supply from the upper watershed.

Because dams trap sediment from the upper watershed, bank and bed erosion and inputs from Dry Creek are the only potentially important sources of sediment to the river. Bank erosion throughout the river has been decreased by the reduction in peak flows and by bank revetment. The total length of eroding banks and bank revetment in each reach of the river was mapped during field surveys conducted in 1999 and 2000 (Table 12 and Figures 5.2–1A through 5.2–1D). In the Dredger Tailings Reach, channel banks are armored by dredger tailings. Current flow conditions are not sufficient to mobilize these tailings and initiate bank erosion; bank erosion is limited to one location covering 0.4 percent of the total reach length. In the Gravel Mining 1 Reach, bank revetment covers five percent of the total reach length, armoring the apexes of approximately half of the meanders in the reach. Four percent of the total bank length in the Gravel Mining 1 Reach is eroding. In the Gravel Mining 2 Reach, the majority of the reach consists of in-channel pits, and consequently flow velocities and potential erosive forces are low. Erosion is limited to isolated locations covering one percent of the reach, while revetment covers seven percent of the reach. In the Encroached Reach, 21 percent of the bank length is armored with revetment, and nearly every meander apex is armored. Five percent of the bank length is eroding. In the Confluence Reach, 11 percent of the bank is armored, and six percent of the bank length is eroding.

Table 12. Bank Erosion and Revetment in the Merced River

Reach	**Length of Eroding Bank (feet [percent])**			**Length of Bank Revetment (feet [percent])**		
	Left bank	**Right bank**	**Total**	**Left bank**	**Right bank**	**Total**
Dredger Tailings	254 [1%]	0 [0%]	254 [0.4%]	0 [0%]	0 [0%]	0 [0%]
Gravel Mining 1	3,470 [5%]	2,292 [3%]	5,762 [4%]	2,376 [4%]	3,999 [6%]	6,375 [5%]
Gravel Mining 2	0 [0%]	388 [1%]	388 [1%]	1,419 [5%]	3,041 [10%]	4,460 [7%]
Encroached	4,277 [4%]	6,091 [6%]	10,368 [5%]	21,388 [22%]	19,700 [20%]	41,088 [21%]
Confluence	3,930 [9%]	1,359 [3%]	5,289 [6%]	2,715 [6%]	6,688 [16%]	9,403 [11%]
Total	11,931 [4%]	10,130 [4%]	22,061 [4%]	27,898 [10%]	33,428 [12%]	61,326 [11%]

Dry Creek joins the Merced River at RM 32.7 and is the only major tributary to the river downstream of Crocker-Huffman Dam. Conditions in Dry Creek and the Dry Creek watershed are described in Section 5.7. Sediment supplied from Dry Creek consists primarily of sand but also includes gravel, as demonstrated by the surface texture of the delta deposited at the mouth of the creek (Figure 5.2–2). The creek, however, enters the river at an in-channel mining pit (GM2–C1), which captures most of the sediment delivered from the Dry Creek watershed.

5.3 Sediment Transport Thresholds and Bedload Transport Rate

As discussed in Section 2, under equilibrium conditions the river's power to transport sediment is in balance with the volume of sediment supplied from the watershed. In this equilibrium, sediment is delivered to a given reach of the river at approximately the same rate at which it is exported out of that reach. When large dams or in-channel pits intercept sediment supply, the sediment transport capacity of the river (i.e., the volume of sediment that *can* be transported under current flows) can exceed the sediment supply. This excess sediment transport capacity can result in channel incision and armoring of the channel bed. Conversely, flow regulation can reduce sediment transport competence (i.e., the size of sediment that can be transported) and thus eliminate or reduce channel scour, resulting in a static-channel. This section discusses the river's ability to transport sediment under historic and current flow conditions.

5.3.1 Methods

Sediment supply thresholds were evaluated using a combination of empirical observations and numerical modeling. Field data for this assessment were collected at two sites in the Dredger Tailings Reach **B** the Snelling Site and the Cuneo Site (Figure 5.3–1). An additional site in the Gravel Mining 1 Reach will be evaluated in Phase III of the project.

The Snelling Site is located 3.8 river miles downstream from Crocker-Huffman Dam, near the town of Snelling. Data collected at this site included channel and floodplain topographic cross sections, bed surface texture, and water surface elevations. Additional data were collected for the vegetation assessment (see Section 6). Seven cross sections across the active channel and floodplain were surveyed using a TopCon AT-G2 autolevel, stadia rod, and survey tape (Figure 5.3–2). Within the bankfull channel, points were surveyed at every slope break or at five-foot intervals, whichever distance was shorter. On the remainder of each cross section, points were surveyed at every slope break or at ten-foot intervals, whichever distance was shorter. Permanent endpins were placed at each end of each cross section, and the location of the section and the pins was mapped onto aerial photographs. Bed surface texture was documented by mapping all facies units (i.e., areas in which the sediment texture is homogenous) within the active channel and conducting pebble counts (Wolman 1954) within each facies unit-type. The facies map, particle size distribution curves, and cross sections from these surveys are provided in Appendix B. Water stage was recorded at cross section 0+00 using a Global Water WL-14 WaterLogger. This depth recorder was installed on October 1999 and recorded water surface elevation at flows from 190 to 3,259 cfs.

The cross section, bed texture, and stage data from the site combined with flow data from the Merced ID Crocker-Huffman gauge were used as input to a sediment transport model used to predict flows required to initiate bed mobilization and bedload transport rates under pre- and post-dam flow conditions. Cross section 1+90 and a moderately coarse facies unit (Pebble Count 1) were used as input data. The reach-averaged slope used in the model was 0.002, as determined from U.S. Geological Survey 1:24,000-scale topographic maps and historical channel surveys (Blodgett and Bertoldi 1967).

The sediment transport model is based on a modified version of Parker's (1990a, b) surface-based bedload equation, implemented in a program developed by Stillwater Sciences. The details of this model are provided in Appendix C. Some of the assumptions of the model are as follows:

- The equation is adoptable from the original wide rectangular channel to a natural channel by replacing the water depth in the equation with a hydraulic radius;
- The reference Shields stress (i.e., the Shields stress at which sediment transport begins) is the original value given by Parker (equal to 0.0386). According to the Parker equation, sediment transport drops to an indistinguishable value (i.e., zero) if the Shields stress is less than the reference stress. Note that the normalized shield stress (ϕ_{sgo}) is the ratio between the Shields stress and reference stress, and both the Shields and the reference stresses are dimensionless.
- The roughness is assumed to be $2D_{sg}\sigma_{sg}^{1.28}$, which is an approximation of the original value ($2D_{s90}$) given by Parker, where D_{sg} is surface geometric mean grain size and σ_{sg} is the geometric standard deviation of the surface layer material. D_{s90} is the 90^{th} percentile grain size of the surface layer.
- Channel curvature is excluded from the calculation. As a result, no convective acceleration is considered.
- The flow is assumed to be uniform throughout the reach, and one representative cross section is used to represent the whole reach.

Marked rock experiments were used to provide empirical data to compare to the model results. Marked rocks were deployed at five cross sections (1+90, 4+20, 9+60, 13+95, and 17+75) in December 1999. Rocks deployed along the cross sections were representative of the D_{84} of the facies unit in which they were placed. We assumed that mobilization of the D_{84} would represent mobilization of the channel bed as a whole. Smaller particles can also be used for these experiments, but they may be mobilized when the bed is in marginal transport and, therefore, may underestimate flows required to initiate significant bed mobilization. The rocks were placed at three-foot intervals along each of the cross sections. Rocks for each cross section were painted a unique color, and each rock was individually numbered so that it could be identified during recovery. Rocks were recovered on June 24, 2000. The peak flow experienced during the period from placement to recovery was 3,259 cfs (Figure 5.3–3). The locations of the marked rocks during the recovery surveys are shown in Appendix D.

The Cuneo Site is located 1.2 river miles downstream of Crocker-Huffman Dam at the Merced ID's Cuneo Fishing Access (Figure 5.3–1). This site was used to assess historic and current sediment texture, as well as historic and current bedload transport conditions. The site consists of a formerly active bar that has been converted to a floodplain as a result of flow regulation. Because the bar was not dredged, the sediment texture on the bar is representative of sediment that was mobilized under pre-dam flow conditions. In addition, the site is located downstream of several CDFG/CDWR gravel augmentation sites and is one of the few depositional areas observed in the river channel. Recent in-channel sediment deposits at this site are indicative of sediment texture that is mobile under post-dam hydrologic conditions. At this site, one cross section was surveyed and two pebble counts were conducted—one on the fossilized bar and one in the channel—to document historical and current bed texture (Figure 5.3–4). The cross section was surveyed using the same equipment and methods described for the Snelling Site above. Permanent endpins were placed at each end of each cross section, and the location of the section and the pins was mapped onto an aerial photograph. Data from this site will be used for sediment transport modeling in Phase III of the project.

5.3.2 Results

At the Snelling Site, the model predicted that the threshold of incipient motion (i.e., flows sufficient to mobilize the bed) is reached at approximately 4,800 cfs (approximately a 5-year flood under post-dam conditions) and that the average annual bedload transport rate (Q_s) is approximately 550 tons/year (Figure 5.3–5). In Figure 5.3–5, the normalized Shields stress is the ratio between the surface-based Shields stress and reference stress and is defined so that sediment transport drops to an indistinguishable level when the normalized Shields stress is less than one (Parker 1990a, b).

The sediment transport model results at the Snelling Site are consistent with the empirical tracer rock experiments. Flow during the time that the tracer rocks were deployed reached 3,250 cfs, which has a recurrence interval of approximately three years. Tracer rocks on all transects were transported downstream during this flow, suggesting that the bed was mobilized by the Q_3. Recovery rates and distance transported are shown in Table 13. Tracer rocks typically overestimate bed mobility because they sit on top of the bed surface and protrude into the flow rather than being interlocked with other particles in the riverbed. As a result, the tracer particles may be mobilized at flows that are insufficient to mobilize the bed surface. The high recovery rate of the tracer rocks suggests overestimation of bed mobility; 88 percent of particles deployed were recovered. If the entire river bed had been in motion during these flows, many of the tracer particles would have been buried and would not have been recovered. The high recovery rate coupled with the propensity for tracer rocks to overestimate mobility indicates that the actual threshold of bed mobilization at this site is probably greater than 3,200 cfs, which is consistent with the model results.

Table 13. Recovery of Tracer Particles at the Snelling Site

Cross Section	D_{84} (mm)	No. deployed	% recovered	% mobilized	Mean distance traveled (ft)	Max. distance traveled (ft)
1+90	80	39	70	63	1.8	6.2
4+20	80	38	100	39	5.8	41.1
9+60	73, 134	35	63	27	6.4	27.8
13+95	73, 131	32	100	63	3.0	10.6
17+75	121	32	100	66	3.2	11.8

Under equilibrium conditions, the channel bed would be expected to be mobilized by 1.5B to 2Byear flood. If this is the case, then under pre-dam conditions the historic bed texture would have been mobilized by flows of approximately 10,000B13,600 cfs. Flows in this range have not occurred since construction of New Exchequer Dam. The pre-dam bed texture, as indicated by the pebble count on the Cuneo Site fossilized bar, is coarser than the currently mobile sediment, as represented by the recent deposit at the Cuneo Site, indicating a reduction in the river's sediment transport competence (Figure 5.3–6).

Even though these results are based on only two locations in the river and on relatively crude data, they tell an important story about sediment transport dynamics in the Dredger Tailings Reach. First, under pre-dam conditions, the bed in this reach was coarse but was likely mobilized by small, relatively frequent floods that occurred about every 1–2 years. With the reduction in flood magnitude caused by flow regulation, the bed is currently immobile at flows up to the Q_5. As a result, the channel bed and formerly active bars are static. Potential effects of this reduction on bed and bar mobilization include increased infiltration of sand into the riverbed, which could reduce the survival of chinook salmon eggs and larvae and adversely affect benthic macroinvertebrate communities, and vegetation encroachment onto formerly active bars. Potential actions for increasing bed mobility (and thus increasing geomorphic function and habitat complexity) include increasing flows (to the extent feasible), introducing gravel of a size that would be mobilized under the current flow conditions, increasing channel confinement, or some combination of these. These alternative actions will be evaluated during Phase III of the project.

5.4 Sediment Transport Continuity

Bedload impedance reaches are locations that interrupt sediment transport continuity (McBain and Trush 2000). These reaches are typically in-channel or captured aggregate mining pits and dredger pools, where channel slope, depth, and width have been modified to the extent that all bedload being transported from upstream reaches deposits into the pit. Reaches downstream of the pit are deprived of upstream bedload supply, causing scour of the bed and banks which restores the bedload supply. Bedload impedance reaches were identified in the field by the presence of a coarse depositional lobe at the upstream end of a large pool or pit.

A total of 11 bedload impedance reaches were identified by field reconnaissance (Table 14). Two were located in the Dredger Tailings Reach; four were in the Gravel Mining 1 Reach; and five were in the Gravel Mining 2 Reach. This series of impedance reaches causes the bedload supply to be continuously reset to zero at the downstream end of each impedance reach. Efforts to improve sediment supply and transport conditions in the gravel-bedded reach of the river, therefore, must consider the effects of these impedance reaches on potential restoration benefits. For instance, gravel added to the river upstream of these sites will be captured in the impedance reaches and not delivered downstream. If the impedance reaches are not repaired, additional gravel would need to be added downstream of each impedance reach to supply the reach downstream.

Table 14. Bedload Impedance Reaches in the Merced River

Reach Name	River Mile	Cause of Impedance
Dredger Tailings 1	50.8-51.4	Dredging
Dredger Tailings 2	50.4-50.6	Dredging
CDFG/CDWR Restoration Reach	40-43.5[1]	Aggregate mining
GM1 – C1	38.9-39.3	Aggregate mining
GM1 – C2	35.1-35.4	Aggregate mining
GM1 – C3	33.9-34.4	Aggregate mining
GM2-C1	31.5-32.1	Aggregate mining
GM2-C2	30.0-30.6	Aggregate mining
GM2-C3	28.7-28.9	Aggregate mining
GM2-C4	27.2-27.4	Aggregate mining
GM2-C5	26.7-27.1	Aggregate mining

[1] Note that Phase I (RM 40-40.5) of the restoration project has been constructed.

5.5 Floodplain Connectivity

Floodplain extent and connectivity in the Merced River have been affected by both flow regulation and levee construction. Flow regulation has reduced flood magnitude and thus has reduced the extent and frequency of floodplain inundation. In addition, in the reach from Crocker-Huffman Dam to Shaffer Bridge, the river has been converted from a multiple-channel system to a single-thread system, and remnant sloughs have been converted to irrigation canals and drains. This elimination of channels has further reduced the surface area of inundation in this reach. The extent of the floodplain is further limited by levees, which prevent inundation in some reaches. This section describes historic and current floodplain extent and the effects of flow regulation and levees on floodplain extent in the lower river.

5.5.1 Effects of Reduced Flood Peaks

5.5.1.1 Methods

Floodplains under historic and current flow conditions were identified from review of current stereo aerial photographs (scale 1:6,000, U. S. Bureau of Reclamation 1993), historical aerial photographs (scale 1:21,000, Agricultural Stabilization and Conservation Service 1937), channel and floodplain cross sections (Blodgett and Bertoldi 1967), mapping of inundation during 6,510-cfs discharge (measured at the Merced River near Stevinson gauge) that occurred in June and July, 1967 (Blodgett and Bertoldi 1967) and during a 8,279-cfs discharge (measured at the Merced ID Crocker-Huffman gauge) that occurred in January, 1997 (USACE, unpublished data), and relevant geologic maps and literature (Wagner et al. 1990, Blodgett and Bertoldi 1967, Harden 1987, Marchand and Allwardt 1981, Huntington et al. 1977). The interpreted floodplain surfaces were drawn onto orthorectified aerial photographs and digitized into a GIS. The geomorphic surfaces were spot-checked in the field, but field verification was not extensive.

The data interpretation and quality control process for development of this GIS coverage are described in more detail in Appendix A.

For this analysis, the active river channel and floodplain surfaces were defined as follows:

- The active river channel is the area that is scoured under the current regulated flow conditions and includes the low flow channel and unvegetated alluvial bars.
- Current floodplains are surfaces that are inundated at a 6,000-cfs flow (the maximum release allowable under Corps of Engineers flood control rules) in the absence of levees. Some of these floodplain areas are now isolated from the river by levees.
- Current terraces/former floodplains are surfaces that were inundated by intermediate and occasional high floods prior to dam construction. These surfaces are no longer subject to inundation due to reduction in peak flows following completion of New Exchequer Dam.
- Terraces are abandoned Holocene floodplains that were not inundated under pre-dam hydrologic conditions in the recent past.

Levees were identified from stereo aerial photographs (scale 1:6,000, U. S. Bureau of Reclamation 1993). At the Ratzlaff Reach restoration project (RM 40.0–40.5), which was completed in 1999 (after the photographs used for the analysis), levees were identified from post-construction aerial photographs and project designs contained in the final project report (CDWR 2000). Levees were identified and classified based on their association with geomorphic surfaces (i.e., current floodplain or current terrace), delineated onto orthorectified aerial photographs (Merced County Planning and Community Development Department 1998), and digitized on-screen into the GIS. The GIS levee coverage was also checked against an unpublished levee coverage developed by the California Department of Water Resources using a query of their topographic data (CDWR, unpublished data). Identification of levees focused on structures that were substantial enough to alter floodplain inundation. Small roads along the river and small levees constructed to hold irrigation water on fields were not included in this analysis. The data interpretation and quality control process for development of this GIS coverage are described in more detail in Appendix A.

Historic floodplain width and current floodplain width (with and without levees) were computed using the GIS developed for this project. Measurements were made at 102 transects located at ½mile intervals along the channel.

5.5.1.2 Results

Floodplain extent has been significantly reduced by flow reduction, elimination of floodplain channels that was facilitated by flow reduction, and gold dredging that has converted former floodplains to tailings piles. Historic and current floodplain surfaces are shown in Figures 5.5–1A through 5.5–1D. The greatest reduction in floodplain width occurred in the region that was formerly a multiple-channel system, from Crocker-Huffman Dam downstream to RM 34 (Figure 5.5–2). Under pre-dam conditions, the floodplain width in this region averaged 7,710 feet. Under current conditions, floodplain width has been reduced by an average of 7,340 feet (or 95 percent) due to a combination of flow reduction, channel elimination, and gold dredging. Downstream of RM 34, pre-dam floodplain width was much narrower, averaging 2,580 feet under pre-dam conditions. Flow reduction has reduced floodplain width by an average of 2,140 feet (or 83 percent) under current conditions.

Levee construction has also reduced floodplain width. Levees identified by this analysis are shown in Figures 5.5–1A through 5.5–1D. The extent of levees for each reach is summarized in Table 15. No levees occur in the Dredger Tailings Reach. In the Gravel Mining 1 and Gravel Mining 2 reaches, levees occur primarily in association with active or abandoned aggregate mine pits. Levees are by far most extensive in the Encroached Reach, where they extend along 26 percent of the right bank current floodplain and 29 percent of the left bank current floodplain. In addition, levees in this reach extended along six percent of the right bank current terrace and ten percent of the left bank current terrace. No floodplain levees were identified in the Confluence Reach, though two levees extending along seven percent of the right bank current terrace.

Table 15. Extent of Levees by Reach

Reach/Levee Type	Levee Length (feet)		Percent of Total Length with Levees	
	Left Bank	Right Bank	Left Bank	Right Bank
Dredger Tailings Reach				
floodplain levees	0	0	0	0
terrace levees	0	0	0	0
Gravel Mining 1 Reach				
floodplain levees	11,671	9,877	17	15
terrace levees	0	0	0	0
Gravel Mining 2 Reach				
floodplain levees	1,457	5,300	5	18
terrace levees	0	0	0	0
Encroached Reach				
floodplain levees	28,803	26,279	29	26
terrace levees	10,357	6,263	10	6
Confluence Reach				
Floodplain levees	0	0	0	0
Terrace levees	0	2,978	0	7

The effect of levees on current floodplain width is shown in Table 16. Levees have no effect on floodplain width in the Dredger Tailings, Gravel Mining 2, or Confluence reaches. In the Gravel Mining 1 Reach, levees limit floodplain width by six percent. In the Encroachment Reach, levees reduce current floodplain width by 276$\pm$507 feet (mean$\pm$standard deviation), or 53 percent.

Table 16. Merced River Historic Current Floodplain Width With and Without Levees

Reach	Average Current Floodplain Width[1] (feet)			Percent Reduction in Floodplain Width	
	Historic	Current		By Flow Regulation	By Levees
		Without levees	With levees		
Dredger Tailings	2,441±1,828	66±102	66±102	97	0
Gravel Mining 1	10,625±3,631	555±477	523±482	95	6
Gravel Mining 2	5,129±1,596	46±81	46±81	99	0
Encroached	1,793±681	521±510	245±216	71	53
Confluence	1,581±426	595±605	595±605	62	0

[1] Mean ± standard deviation

Reduction in flood flows was, by far, more important than levees in reducing floodplain width and connectivity on the Merced River. Flood control and subsequent conversion of floodplains to other uses has resulted in a 91 percent reduction in floodplain area throughout the 52-mile corridor. Under current, regulated flow conditions, levees have a very limited effect on floodplain width and connectivity except in the Encroached Reach.

5.5.2 Channel Migration Potential

In addition to limiting sediment supply from bank erosion, bank revetment also prevents channel migration, a key attribute of a functioning alluvial river (see Section 2). The extent of bank revetment in each reach was discussed in Section 5.2.

Under current conditions, the potential for migration in the Merced River is limited by reduced flows, which reduces sheer stress (i.e., erosive force) exerted on channel banks, and by dredger tailings and bank revetment which armor the channel banks. Flows required to initiate channel migration on unrevetted banks have not been assessed by this study. Some level of channel migration, however, is assumed to occur because bank erosion occurs under current flow conditions. Current bank erosion and channel migration rates, however, are likely much lower than under pre-dam conditions. The most severe limits to channel migration are in the Encroached Reach, which is almost completely revetted. Revetment also limits channel migration, though to a lesser extent, in the Confluence Reach.

Channel migration could potentially be re-initiated in some reaches of the river, within certain constraints required to protect structures and other property values. In the Dredger Tailings Reach, removal of the tailings adjacent to the river may increase bank erosion and channel migration potential. In downstream reaches, particularly the Encroached and Confluence reaches, removal of bank revetment would likely increase bank erosion and migration, but to a lesser degree than under pre-dam conditions. This would require extensive coordination with property owners and would potentially require development of an easement program to compensate landowners for allowing bank erosion.

5.6 Vegetation Encroachment

In natural alluvial river systems, geomorphic processes such as flooding, erosion, and sediment deposition maintain the channel shape and cross section width. Through these processes, the river maintains a multistaged channel (which includes the low flow, active, and bankfull channels) and a floodplain (Figure 5.6–1). With reduced flow magnitude, scour of alluvial bars in the active channel is reduced, which allows riparian trees to become established in the former (pre-dam) active channel. This process is referred to as "riparian encroachment." Vegetation establishment on formerly active bars has caused the river channel to become narrower and has eliminated the multi-staged form of the channel (Figure 5.6–2). The resulting channel is simple in cross section, with the current active and bankfull channel limited to the pre-dam low flow channel.

Vick (1995) assessed the effects of flow reduction on channel width in the Merced River. This assessment was based on review of aerial photographs from 1937 and 1993. The active channel boundary from these photographs was digitized into a GIS. Georeferencing and rectification were accomplished by registering the photographs to known points on 1:24,000-scale USGS quadrangle maps and rubbersheeting the images. In the electronic files, 113 transects spaced at $^{1}/_{3}$-mile intervals were overlain onto the active channel boundary maps, and change in active channel width was computed. This analysis concluded that vegetation encroachment into the active channel reduced channel width from Crocker-Huffman Dam to RM 15[g] by 85±115 feet (mean±standard deviation), or 33 percent of the mean 1937 channel width. At the time of the 1937 photographs, the Exchequer Dam had been closed for 11 years. This analysis, therefore, did not document channel response in the first 11 years after dam closure and likely underestimated the reduction in channel width caused by Exchequer and New Exchequer dams.

This reduction in channel width reflects the lack of bed scour and the static condition of the channel bed. As a result, the area of aquatic habitat in the Merced River has been reduced and the river channel is currently characterized by a simplified cross section, with no active bars and no clearly defined low flow channel. In addition, the encroached riparian vegetation is not scoured and new barren surfaces for recruitment of riparian trees are not created, resulting in a relatively even-aged, simplified riparian vegetation community. This encroachment of riparian vegetation into the active channel is one of the largest scale and most difficult issues to address in the restoration plan.

5.7 Conditions in Dry Creek

Dry Creek, the only major tributary to the Merced River downstream of the dams, drains a 110-square mile watershed and joins the Merced River at RM 32.7. The watershed is underlain by a series of nested alluvial fans of the Turlock Lake and Modesto formations. Soils in the watershed are generally sand and silty loam of the Horncut, Bear Creek, and Yokohl soil series (USDA 1991). The upland valley floor formations underlying the watershed consist of semiconsolidated alluvium that under natural conditions would be expected to have lower sediment delivery rates than the geologic units underlying upper Merced River watershed (i.e., upstream of the dam). A sediment budget has not been developed for Dry Creek, but simple calculations can provide a rough picture of historic and current sediment supply from the Dry Creek watershed. Using an assumed sediment delivery rate of 130 tons/square mile/year, sediment delivery from the Dry Creek watershed to the mainstem Merced River was likely on the order of 14,000 tons/year under pre-disturbance conditions, with the majority of this sediment consisting of sand and silt.

Field reconnaissance and review of channel cross sections in Dry Creek indicate that sediment supply from Dry Creek to the Merced River under current conditions has been increased relative to undisturbed conditions by channel incision and resulting bank and terrace failures, as well as erosion from orchards in the upper watershed. Some coarse sediment is delivered from Dry Creek, as is evidenced from the sediment composition of the delta deposited at the creek mouth, which has a D_{50} of 28 mm and a D_{84} of 57 mm (Figure 5.2–2). Channel incision in Dry Creek was documented by field reconnaissance surveys and by review of bridge inspection records for bridges on Oakdale, Turlock, and Keyes roads, which cross the creek approximately 0.5, 3.5, and 11 miles upstream from the confluence with the Merced

[g] The 1937 photographs covered the area from Crocker-Huffman Dam (RM 52) to RM 15.

River, respectively. These bridges have been inspected by the California Department of Transportation (CalTrans) approximately every two years (Table 17).

Table 17. Available Bridge Inspection Reports for Dry Creek

Bridge	Distance Upstream from Confluence (miles)	Construction Date	Inspection Reports
Oakdale Road	0.5	1964	1987, 1991, 1993, 1995, 1999
Turlock Road	3.5	1975	1985, 1987, 1990, 1993, 1995, 1999
Keyes Road	44	––	1987, 1989, 1991, 1992, 1994, 1996

At the Oakdale Road and Turlock Road bridges, CalTrans bridge surveys note incision of approximately three feet, which has exposed bridge footings and which was confirmed by reconnaissance surveys conducted for the Phase II studies. At Keyes Road, CalTrans surveys reported no evidence of channel incision between 1987 and 1996 and none was observed in the field. Channel incision will likely continue to migrate upstream in Dry Creek until a stable slope is achieved or a geologic control is reached. As incision migrates upstream, bank erosion rates in upstream reaches will increase and sediment delivery to the Merced River will increase.

During field reconnaissance, extensive erosion from orchards in the Dry Creek watershed was observed. Sediment (silt and sand) eroded from orchards has completely filled some small tributary channels to Dry Creek. This sediment eroded from orchards, combined with sediment supplied by channel incision and bank erosion, have greatly increased sediment supply to the mainstem river from this watershed.

6 VEGETATION BASELINE EVALUATIONS

One of the attributes of a healthy river system described in Section 2 is a self-sustaining, diverse riparian corridor. Riparian vegetation performs many functions in natural river systems such as filtering runoff and nutrients, providing habitat for terrestrial wildlife, and supplying shade, energy from leaf litter, and woody debris as habitat for in-stream organisms. Land use activities such as farming and dredger mining have cleared large floodplain areas along the Merced River, greatly reducing the extent of riparian forest compared to pre-settlement conditions. Hydrologic and geomorphic changes following flow regulation have also altered the physical processes that sustain riparian forests, changing species distributions, abundance, and successional processes. The analyses described this section examine the current riparian zone conditions, including vegetation extent, species composition, invasion of the corridor by non-native species, and recruitment of native riparian trees.

Vegetation spatial patterns and successional processes were assessed at two resolutions: the river-corridor scale, and at a site-specific scale. The river-corridor study included: (1) classification and mapping of riparian vegetation along the 52-mile study reach plus an additional 3.5 miles upstream of Crocker-Huffman Dam; and (2) documenting cottonwood establishment along the river from boat surveys. Intensive investigations were conducted at study sites where some riparian and geomorphic processes were intact. At these sites, surveys were conducted to: (1) detect changes in vegetation distribution over time; (2) document current vegetation composition and structure; and (3) evaluate cottonwood recruitment and establishment.

6.1 Vegetation Distribution and Species Composition

Riparian vegetation was mapped along the Merced River from Merced County's eastern boundary at Hornitos Road (RM 55.5) to the San Joaquin River confluence (RM 0). The objectives of the mapping were to document the location, extent, and general composition of remaining riparian vegetation in the corridor, assess the degree of invasion by non-native species, and prioritize reaches for preservation and restoration. The vegetation maps were developed as a digital coverage in the project GIS.

6.1.1 Methods

Mapping was conducted by Stillwater Sciences and the Geographic Information Center (GIC) at California State University Chico using a combination of aerial photograph interpretation and field verification. Methods used to develop the maps are described below. Metadata and quality control procedures for the GIS coverage are provided in Appendix A.

The vegetation classification system used for the vegetation mapping was designed jointly by Stillwater Sciences, the GIC, and McBain and Trush and generally corresponds to classification systems used throughout the Sacramento and San Joaquin basins (CSUC 1998, McBain and Trush 2000, Jones and Stokes Associates 1998). The following criteria were used in organizing the classification system: (1) each cover type had a unique color infrared signature that allowed it to be distinguished as separate and relatively homogenous assemblages; (2) wherever possible, each cover type represented "functional" vegetation assemblages (i.e., assemblages that are indicative of a similar magnitude of inundation, scour, and human disturbance); and (3) cover types dominated by non-native invasive trees or giant reed were identified. In developing this system, several other classifications were considered, including those of Holland (1986) and the California Native Plant Society (Sawyer and Keeler-Wolf 1995). These systems were either too detailed for this mapping effort or did not satisfy the criteria listed above. The classification system developed for this project reflects a compromise between the need to identify vegetation cover types that are indicators of key physical processes and the realistic limitations of photointerpretation of vegetation signatures. The vegetation classification system and the corresponding cover types from other published classification systems are shown in Table 18.

Vegetation assemblages were identified and mapped from color infrared aerial photographs (scale 1:24,000) taken in May 1999. Photographs were scanned at 400 DPI, orthorectified, and enlarged electronically to approximately 1:6,000 at the GIC. Boundaries of cover type polygons were digitized on-screen in ArcInfo (version 7.2.1). Natural color stereo aerial photographs taken in 1993 (scale 1:6,000, U.S. Bureau of Reclamation 1993) were used to resolve topographic relief and to aid in identification of cover types that could not be clearly identified from the infrared photographs, which were not available as stereo pairs.

Field verification of the vegetation maps was conducted between fall 1999 and spring 2000 from public and private access roads and in June, 2000 by boat survey within the Merced River channel. Upstream of Shaffer Bridge, polygon designations were verified at publicly accessible locations on the river, such as parks and bridges, and the study sites selected for intensive geomorphic and riparian evaluations. Downstream of Shaffer Bridge to the confluence with the San Joaquin River, polygon designations were verified by boat. Verification was based on visual estimate of canopy dominance as summarized in Table 19. Consequently, vegetation maps were ground-truthed largely in the lower half of the river corridor, and most of the verified polygons were located adjacent or close to the river. A randomized polygon verification method was considered for field verification, but property access and field logistical issues made this approach prohibitively difficult. The boat survey method that was adopted allowed a larger total number of polygons to be verified. Field-checked polygons were entered into the project GIS, and miscoded polygons were corrected.

Of the 3,008 total polygons delineated for all fifteen cover classes, 693 were field-verified, representing an overall sampling rate of 23 percent. At least 15 percent of the total number of polygons for each vegetation cover type was verified, except for the Blackberry Scrub, Marsh, and Tamarisk cover types. Reasons for undersampling these cover types include low numbers of total polygons and lack of visibility during the boat surveys because of floodplain locations that were distant from the active channel. Dredger Tailing patches were not checked, and Disturbed Riparian patches were delineated in the field. Photointerpretation accuracy for cover classes ranged from 33 percent to 86 percent of all polygons checked, and averaged 64 percent across all vegetation cover types.

Some systematic misinterpretation occurred for cover types without clear infrared signatures, and photointerpretation accuracy was higher for polygons larger than 1.5 acres. Mapping woody non-native tree species from aerial photographs was problematic because of small stand sizes and patchy distributions. The boat and ground surveys proved to be a more effective method than photointerpretation of identifying and mapping exotic species within the Merced River's highly patchy and heterogeneous riparian zone. Many of the accuracy problems were corrected in the final map version or otherwise adjusted during field checking, and the final vegetation maps are considered to be a reliable and appropriate tool for natural resource planning and management within the Merced River corridor. Map verification results and accuracy issues are discussed in more detail in Appendix E.

Table 18. Merced River Corridor Restoration Plan Vegetation Classifications, Identification Criteria, and Corresponding Classifications in Other Vegetation Mapping Systems

Classification	Description	California Natural Diversity Database (Holland 1986)	California Native Plant Society Series (Sawyer and Keeler-Wolf 1995)
Box Elder	>50% crown canopy box elder (*Acer negundo).* Box elder, a component of the mixed riparian forest subcanopy, is often found in monospecific stands where there is no overstory	Great Valley cottonwood riparian forest (61410) [in part] Great Valley mixed riparian forest (61420) [in part]	Box elder[1] Fremont cottonwood series [in part]
Blackberry Scrub	>50% crown canopy Himalaya berry (*Rubus discolor*) or California blackberry (*R. ursinus*)	None	Himalaya berry[1]
Cottonwood Forest	>50% crown canopy Fremont cottonwood (*Populus fremontii).* Contains various subcanopy species and combinations	Great Valley cottonwood riparian forest (61410)	Fremont cottonwood series Goodding's black willow series Arroyo willow series Red willow series Mixed willow series
Disturbed Riparian	areas adjacent to the river with little native plant cover, such as revetted banks.	None	Disturbed/Misc. exotics[1]
Dredger Tailings	dredger tailings, which include bare substrate and sparse non-native grasslands, cottonwood and willow riparian stands disconnected from the channel, and wetland and pond communities	Great Valley cottonwood riparian forest (61410) [in part] Great Valley willow scrub (63410) [in part] Non-native grassland (42200)	California annual grassland series Fremont cottonwood series Goodding's black willow series Arroyo willow series Bulrush series Cattail series Bulrush-catttail series Duckweed series
Eucalyptus	>50% crown canopy eucalyptus (*Eucalyptus* spp). Found in fairly monospecific stands on heavily modified banks	None	Eucalyptus series Eucalyptus[1]
Giant Reed	clonal monospecific stands of giant reed (*Arundo donax),* often on revetted or otherwise disturbed banks	None	Giant reed series
Herbaceous Cover	herbaceous communities, including grassland terraces, tailing transitional areas, and some seasonal wetlands	Non-native grassland (42200)	California annual grassland series

Classification	Description	California Natural Diversity Database (Holland 1986)	California Native Plant Society Series (Sawyer and Keeler-Wolf 1995)
Marsh	areas with surface water supporting emergent plants, found in some backwater channels and in some dredger tailing swales	Coastal and valley freshwater marsh (52410)	Bulrush series Cattail series Bulrush-catttail series Duckweed series
Mixed Riparian Forest	riparian hardwood forest with at least three species co-dominant, composition varies along river, but often includes Oregon ash (*Fraxinus latifolia)*, white alder (*Alnus rhombifolia)*, box elder (*Acer negundo)*, valley oak (*Quercus lobata)*, and willow (*Salix* spp.)	Great Valley mixed riparian forest (61420) Elderberry savanna (63440)	Fremont cottonwood series Narrow-leaf willow series Goodding's black willow series Arroyo willow series Red willow series Mixed willow series White alder series Blue elderberry series
Mixed Willow	areas almost exclusively willow, including narrow leaf willow (*Salix exigua)*, Goodding's black willow (*S. gooddingii)*, arroyo willow (*S. lasiolepis)*, and red willow (*S. laevigata)*	Great Valley willow scrub (63410)	Arroyo willow series Goodding's black willow series Narrow-leaf willow series Pacific willow series Red willow series Mixed willow series
Riparian Scrub	early seral stage vegetation (shrubs and small trees) of various species that may indicate some form of regular disturbance or scour	Buttonbush scrub (63430) Great Valley willow scrub (63410)	Buttonbush series Narrow-leaf willow series Mixed willow series
Tamarisk	areas exclusively almost exclusively tamarisk (*Tamarix* spp.), an invasive exotic plant	Tamarisk scrub (63810)	Tamarisk series
Tree of Heaven	>50% crown canopy tree of heaven (*Ailanthus altissima)*, an invasive exotic tree species	None	Tree of heaven[1]
Valley Oak Forest	>50% crown canopy valley oak (*Quercus lobata)*, occurs on terraces, and younger stands have established on former floodplains that are no longer frequently inundated	Great Valley valley oak riparian forest (61430) Valley oak woodland (71130)	Valley oak series

[1] Series or vegetation types described and mapped by McBain & Trush (2000) for the Tuolumne River Restoration Plan, for which there was no good match using series described by Sawyer and Keeler-Wolf (1995).

6.1.2 Results

6.1.2.1 River-wide Distribution and Species Composition

The vegetation GIS coverage includes 3,008 individual polygons (patches) totaling 8,232 acres for 15 cover types (Table 19). In addition to the 13 vegetation cover types totaling 3,923 acres, the riparian corridor includes 31 polygons covering 4,308 acres of Dredger Tailings and 12 polygons covering 19 acres designated Disturbed Riparian. The Dredger Tailings and Disturbed Riparian cover types were included because of the historical occurrence of vegetation in these areas and their potential for future restoration but are treated separately from the vegetation cover types in calculating summary statistics, which are listed in Table 19. Floristic, structural, and ecological characteristics of the 15 mapped cover types are described in more detail in Appendix F. A list of plant species documented in the Merced River riparian corridor by these surveys is provided in Appendix G.

Table 19. Merced River Vegetation Map Patch Summary

Cover Class	Cover Type Dominated by Native Species?	Number of Patches[1]	Total Area (acres)	Percent of Total Vegetation Area	Mean Patch Size (acres)	Median Patch Size (acres)	Max Patch Size (acres)	Min Patch Size (acres)
Vegetation Cover Type								
Blackberry Scrub	Partly	108	48	1	0.4	0.3	4.9	< 0.1
Box Elder	Yes	38	19	<1	0.5	0.3	3.9	0.1
Cottonwood Forest	Yes	360	437	11	1.2	0.5	24.4	< 0.1
Eucalyptus	No	55	46	1	0.8	0.5	4.6	< 0.1
Giant Reed	No	59	12	<1	0.2	0.1	2.0	< 0.1
Herbaceous Cover	No	348	1,363	35	3.9	0.7	149.5	< 0.1
Marsh	Yes	74	65	2	0.9	0.5	5.8	< 0.1
Mixed Riparian Forest	Yes	479	880	22	1.8	0.7	84.2	< 0.1
Mixed Willow	Yes	526	404	10	0.8	0.4	10.4	< 0.1
Riparian Scrub	Yes	483	297	8	0.6	0.4	8.4	< 0.1
Tamarisk	No	2	0.4	0	0.2	0.2	0.3	< 0.1
Tree of Heaven	No	17	10	<1	0.6	0.3	1.8	< 0.1
Valley Oak Forest	Yes	416	342	9	0.8	0.3	27.3	< 0.1
Total		**2,965**	**3,923**	**100**				
Other Cover Type								
Disturbed Riparian	No	12	19		1.6	0.3	12.8	0.1
Dredger Tailings	No	31	4,308		138	4.3	665	< 0.1
Total		**43**	**4,327**					

[1] Patch totals represent the minimum polygon count for each cover type, in which adjacent polygons of the same type were merged during data editing. The digital GIS coverage retains the unmerged polygon configuration, which has higher polygon counts for some cover types (but the same total area for each type), because accuracy assessment data stored as polygon attributes in the GIS would have been lost during the merging process.

The Merced River riparian corridor downstream of Crocker-Huffman Dam is generally more fragmented and narrow compared to local historical accounts (Edminster 1998). Studies of changes in riparian vegetation in the Central Valley indicate that the vast majority of historical riparian forest has been cleared since 1850. Katibah (1984) estimated that of 921,000 acres of pre-settlement riparian forest in the Central Valley, only 102,000 acres (11 percent) remain, of which 49,000 acres are in a "disturbed and/or degraded" condition.[h] The 53,000 remaining acres of non-degraded vegetation represents less than six percent of the original total. No subtotal of historical vegetation coverage along the Merced River is available to compare against the current extent mapped for this project.

The extent and condition of vegetation varies considerably between reaches (Figures 6.1–1). A wide range of conditions occurs, from a thin band of trees one tree canopy wide in leveed reaches to large patches of relatively intact floodplain vegetation near the confluence of the San Joaquin River (Table 20). In the Dredger Tailings Reach, forest cover types (Mixed Riparian, Valley Oak, and Cottonwood) generally occur on the banks, often encroaching into the active channel, and the riparian zone on either bank is typically 100 feet wide or less. Non-native grasses and forbs dominate the tailing surfaces and floodplain areas. In the Gravel Mining 1 Reach, the riparian zone varies from 100 to 500 feet wide on each bank. Cottonwood and Mixed Riparian Forest occur in patches along the banks, though Riparian Scrub and non-native Herbaceous assemblages dominate revetted banks and gravel pit berms. Berms are typically steep and are poor environments for native vegetation. Downstream of Shaffer Bridge, the Gravel Mining 2 Reach riparian zone narrows to 50 feet (or one tree canopy width) on each bank in most places. Vegetation in this reach is highly fragmented, as in the Gravel Mining 1 Reach, and extensive revetted banks typically support patches of non-native giant reed but little native riparian vegetation. Dense stands of mature eucalyptus are common along Dry Creek and on the mainstem river near the Dry Creek confluence. In the Encroached Reach, the riparian zone ranges from 50 to 300 feet wide on each bank and is composed primarily of Mixed Riparian Forest and Mixed Willow cover types. Where levees bound the channel, almost all riparian vegetation occurs within the levees, and these sections are typically the narrowest riparian areas on the river. The occurrence of box elder and Goodding's black willow increases downstream through this reach. In the Confluence Reach, riparian vegetation extends from 500 to 1,500 feet from the river channel on each bank and includes dense Valley Oak, Mixed Riparian, and Cottonwood Forest stands. Floodplain areas also contain large grassland and herbaceous patches, with many old oxbow features. This reach contains the best remnant patches of native riparian vegetation along the river, which should become high priorities for preservation.

Plant species composition, age structure, and canopy structure and complexity along the Merced River exhibit distinct longitudinal patterns that are generally associated with reach transitions. Some cover types exhibit longitudinal or cross sectional shifts in species composition or canopy structure that are observable in the field but not from aerial photographs. Some of these trends appeared to be correlated with shifts in geomorphic or hydrologic conditions or changes in land use. Other vegetation trends were not obviously associated with physical changes in the landscape.

Spatial shifts in species composition were observed for the Mixed Riparian Forest and Mixed Willow cover types. Species composition within the Mixed Riparian Forest subcanopy shifted from a high

[h] Katibah (1984) and The Bay Institute of San Francisco (1998) estimated the extent of pre-settlement riparian forest from the distribution of alluvial soils on soil maps, which was assumed to represent the historic floodplain. This is a reasonable assumption for the Sacramento Basin, since historical accounts document vast expanses of unbroken riparian forest (Thompson 1961). For the drier San Joaquin Basin, however, the evidence is less clear that forest covered most floodplain areas, and there appear to have been large areas of herbaceous, slough, and wetland communities in addition to the Fremont cottonwood, willow, and valley oak stands (Edminster 1998). This uncertainty about the historical extent of riparian forest coverage makes estimates of losses since settlement difficult to calculate and affects assumptions about the riparian vegetation restoration potential in floodplain areas.

Table 20. Summary of Riparian Vegetation Cover Type Patterns for Each Reach

Reach Name	Location	Riparian Zone Width, Each Bank (feet)	Dominant Vegetation Cover Types
Dredger Tailings	RM 52–45.2	100	*Along banks:* • Mixed Riparian Forest • Valley Oak Forest • Cottonwood Forest *In dredger tailings as fragmented patches:* • Herbaceous (non-native) • Riparian Scrub • Mixed Willow (mostly Goodding's black willow) • Cottonwood Forest (some senescent) • Marsh
Gravel Mining 1	RM 45.2–32.5	100–500	*Throughout reach, generally associated with modified banks and gravel pits:* • Riparian Scrub • Herbaceous (non-native) *Along banks, 1–2 tree canopy width:* • Cottonwood Forest • Mixed Riparian Forest
Gravel Mining 2	RM 32.5–26.8	50	*On former floodplains:* • Eucalyptus • Cottonwood Forest (1-tree canopy width, typically senescent) *On gravel pit berms:* • Riparian Scrub • Disturbed Riparian *Associated with revetment:* • Giant Reed
Encroached	RM 26.8–8	50–300	• Mixed Riparian Forest • Mixed Willow (mainly narrow-leaf willow, with Goodding's black willow increasing downstream) • Riparian Scrub
Confluence	RM 8–0	500–1,500	• Cottonwood Forest • Mixed Riparian Forest • Valley Oak Forest • Mixed Willow (especially Goodding's black willow) • Herbaceous (especially non-native assemblages)

occurrence of white alder (*Alnus rhombifolia)* and London plane tree (*Platanus* x. *acerifolia)* in upstream reaches (Dredger Tailing Reach) to a dominance of box elder downstream of Shaffer Bridge, sometimes grading into monospecific stands (mapped as Box Elder cover type) in the lower river. In several locations where remnant patches of Central Valley gallery forest occurred, box elder trees provided an armature for wild grape to access the canopy, and thick mats of vines completely cover the trees. Oregon ash, valley oak, and several willow species commonly occurred within the Mixed Riparian Forest subcanopy throughout the river.

Mixed Riparian Forest subcanopy species composition also varied with elevation above and distance from the channel. In the Dredger Tailings Reach, for example, understory species occurring near the channel included narrow-leaf willow (*Salix exigua*), arroyo willow (*Salix lasiolepis*), Oregon ash, California button willow (*Cephalanthus occidentalis* var. *californica*), tree of heaven (non-native), California blackberry (*Rubus ursinus*), and Himalaya berry (*Rubus discolor*) (non-native). On the higher floodplain, willow species were absent, and box elder, California buckeye (*Aesculus californica*), and edible fig (non-native) occurred. The cross-sectional pattern is likely driven by several factors, including: (1) soil moisture, which decreases with increasing elevation above the channel, favoring more drought-resistant plants on the banks and tailings; (2) differences in shade tolerance, with less tolerant species occurring on exposed bars and banks; and (3) fragmentation of the riparian zone by dredging, agriculture, and roads, which provided an introduction route for the non-native species.

The Mixed Willow cover type shifted from a dominance of arroyo and narrow-leaf willow in the upstream reaches (upstream of Shaffer Bridge) to a mix of Goodding's black willow and narrow-leaf willow downstream of Shaffer Bridge. Change in tree habit was also reflected in the species shift. Upstream willows were primarily shrubs or small trees, whereas downstream willows show a dual pattern of low narrow-leaf willow shrubs on bars and large Goodding's black willow trees on higher banks.

6.1.2.2 Species of Concern

Some native plant species and assemblages are of special concern due to their ecological importance in the riparian zone or their present scarcity within California's remnant native riparian assemblages. These species and their observed distributions in the Merced River riparian zone are described below.

Blue elderberry (Sambucus mexicana)

Blue elderberry is a native shrub or small tree and is the unique habitat for the valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*), which is listed as threatened under the federal Endangered Species Act. The valley elderberry longhorn beetle (VELB) historically occurred throughout the Central Valley from Redding (Shasta County) to Bakersfield (Kern County), but population levels are declining (Arnold et al. 1994). These beetles are dependent on elderberry plants during their larval stage; larvae bore into and feed on the pith of roots, branches, and trunks for one or two years before emerging as adults. Adults eat the foliage and possibly the flowers of the plants. In addition to their value as habitat for the VELB, mature plants produce blue-black, edible berries, which are an important source of summer food for many species of songbirds and small mammals (Martin et al. 1951).

Blue elderberry shrubs occur as an understory species in Cottonwood Forest, Valley Oak Forest, Mixed Riparian Forest, and Box Elder stands. It is common along the Merced River corridor and is typically located in fully or partially open areas higher on the bank than willow and California button willow. Its occurrence is sporadic in Dredger Tailings Reach, but densities generally increase in downstream reaches. Near the confluence with the San Joaquin River (RM 0 to RM 4), blue elderberry is a prominent understory species in various forest cover types and an overstory tree in Herbaceous cover type patches on remnant floodplains.

Western sycamore (Platanus racemosa)

Both historical accounts and field observations for this project indicate that western sycamore does not commonly occur in the Merced River corridor, though it is present on many other Central Valley rivers. In the Sacramento Basin, western sycamore occurs in the subcanopy of cottonwood- or valley oak-dominated stands, or co-dominates in mixed stands with Oregon ash, box elder, and white alder (Thompson 1961, Holland and Keil 1995, Conard et al. 1980). Its center of distribution is in the southern California Coast Ranges, but large stands are documented almost as far north as Redding (Griffen and Critchfield 1972). Data for the San Joaquin basin are incomplete, but several small stands have been documented on the Tuolumne and San Joaquin rivers, and larger stands have been documented on the Kings and Kern rivers (Griffen and Critchfield 1972).

During field surveys for this project, only a few western sycamore trees were observed and all were within public parks along the channel. London plane tree, which is a non-native sycamore species planted as a landscape tree, was encountered more frequently, typically as naturalized individuals scattered within Mixed Riparian Forest stands. No single factor has been identified to explain the relative scarcity of western sycamore trees within the San Joaquin basin compared to adjacent northern and southern regions; several authors have noted its uncommon distributional patterns (Griffen and Critchfield 1972; Holstein 1984).

6.1.2.3 Non-native Invasive Species

The Merced River riparian corridor, like most California landscapes, is host to many non-native invasive plant species. Descriptions of the most common non-native species, their observed distribution in the Merced River corridor, and the risk of further invasion are described in Table 21. All non-native plant species observed in the corridor are included in the species list in Appendix G.

Table 21. Primary Non-native Species Occurring in the Merced River Corridor

Non-native Species (or assemblage)	Observed Distribution within Merced River Riparian Zone	General Invasibility[1]	CalEPPC Exotic Pest Plant List[3]
Woody or Persistent Perennial Species			
Eucalyptus (*Eucalyptus* spp.)	widely established on Dry Creek and on the mainstem river at the Dry Creek confluence	Moderate	A-1
Tree of Heaven (*Ailanthus altissima*)	commonly distributed throughout the river; dense patches occur at Merced Falls Road between Crocker-Huffman Dam and Snelling, McConnell Park, and along the irrigation canal at RM 3.5	Moderate	A-2
Giant reed (*Arundo donax*)	Crocker-Huffman Dam to San Joaquin confluence, primarily small patches on disturbed areas such as revetted banks	Serious	A-1
Himalaya berry (*Rubus discolor*)	widespread in disturbed riparian areas such as roadsides and revetted banks and adjacent to fields; is less common in undisturbed areas, where native blackberry is common	Moderate	A-1
Edible fig (*Ficus carica*)	occurs in disturbed riparian areas, especially in the Dredger Tailings reach, both in full sun on tailings and adjacent to fields and in Mixed Riparian Forest understory	Potential	A-2
Tamarisk (*Tamarix* spp.)	generally absent from river corridor; one patch documented on Merced Falls Road, between Merced Falls and Crocker-Huffman Dam	Serious	A-1

Non-native Species (or assemblage)	Observed Distribution within Merced River Riparian Zone	General Invasibility[1]	CalEPPC Exotic Pest Plant List[3]
Tree tobacco (*Nicotiana glauca*)	common understory shrub on leveed banks downstream of Dry Creek	Moderate	not listed
Pokeweed (*Phytolacca americana*)	increasing abundance towards San Joaquin River confluence	Unknown	not listed
Mulberry (*Morus alba*)	occurs between McConnell Park and San Joaquin River confluence; assumed naturalized from landscaped areas	Moderate	not listed
Silver maple (*Acer saccharinum*)	scattered within Mixed Riparian Forest at the Snelling Study Site, presumed to occur throughout Dredger Tailings Reach	Unknown	not listed
London plane tree (*Platanus* x, *acerifolia*)	Hatfield Park, McConnell Park, Henderson Park, and naturalized within Mixed Riparian Forest.	Moderate	not listed
Osage orange (*Maclura pomifera*)	occurs in Mixed Riparian Forest subcanopy in Dredger Tailings Reach	Moderate	not listed
Herbaceous Species			
Non-native annual grassland assemblages	high floodplains, terraces, dredger tailings, high-flow channel beds throughout river corridor	see note[2]	not listed
Yellow star thistle (*Centaurea solstitalis*)	high floodplains and terraces at all study sites, large, dense patches at Stevinson Site	Serious	A-1
Black mustard (*Brassica nigra*)	occurs as significant component of Herbaceous Cover at both Snelling and Stevinson Sites	see note[2]	B
Poison hemlock (*Conium maculatum*)	disturbed grasslands throughout river corridor	Moderate	B
Lamb's quarters (*Chenopodium* spp.)	gravel bars throughout river corridor	Moderate	not listed
Knotweed (*Polygonum* spp.)	river margins, high-flow channels, and wetlands throughout river corridor	Moderate	not listed
Aquatic Species			
Water hyacinth (*Eichhornia crassipes*)	not common within river channel, some patches observed in ponds in Dredger Tailings Reach	Serious	A-2
Brazilian water weed (*Egeria densa*)	distribution not well-known, but dense beds observed in the active channel and in dredger tailings ponds	Serious	A-2

[1] Sources: Randall et al. (1998), Dudley (1998), Dudley and Collins (1995), EPA/SFEI (1999), McBride, pers. comm. (2000).
[2] Not rated by sources cited, but already widespread (i.e. invasion has already occurred in many areas).
[3] Designations from the California Exotic Pest Plant Council 1999 list of Exotic Pest Plants of Greatest Ecological Concern in California (CalEPPC 1999). The most invasive wildland pest plants with widespread distributions are designated A-1, whereas those with regional distributions are designated A-2. Wildland pest plants of lesser invasiveness are designated B.

Four of the cover types documented in the vegetation mapping—Eucalyptus, Giant Reed, Tamarisk, and Tree of Heaven—are dominated by non-native canopy species. Summary statistics, including total number and acreages of patches for these cover types, are listed in Table 19. Because the cover types reflect canopy dominance, the small acreage represented by these cover types represents a small fraction of the actual proportion of non-native species occurring in the corridor, most of which are herbaceous plants. Several woody or persistent perennial species, such as eucalyptus, tree of heaven, and giant reed have become established along the Merced River. Eucalyptus is especially pervasive on Dry Creek and on the mainstem river for five miles upstream of the Dry Creek confluence (RM 31.5 to RM 36.7). These stands are dense and appear to exclude native riparian species. Eucalyptus is generally considered to be a benign or moderately invasive genus (Dudley and Collins 1995, Randall et al. 1998, McBride, pers. comm., 2000) and may not spread rapidly beyond its presently established areas. Tree of heaven is considered to be moderately invasive, and giant reed is considered to be seriously invasive. These species occur in dense, spreading patches at numerous points on the river and constitute a future threat. Tamarisk (*Tamarix* spp), another highly invasive species, occurs very infrequently in the Merced River corridor and does not currently appear to be a serious invasion threat. More detailed information on the invasion patterns of these species is included in the cover type descriptions in Appendix F.

In addition to cover types that are dominated by non-native species, perennial non-native species also occur as subdominant canopy species or as subcanopy species in other cover types. Several landscape or commercial trees, including mulberry, London plane tree, silver maple (*Acer saccharinum*), and Osage orange (*Maclura pomifera*) occur sporadically in the corridor and have naturalized after introduction into cultivated areas. Of these species, only mulberry appears to be spreading aggressively and constitutes a widespread invasion threat. Several pervasive non-native shrub and vine species, such as edible fig, Himalaya berry, and tree tobacco (*Nicotiana glauca*), as well as pokeweed (*Phytolacca americana*) (a perennial species) were observed to occur extensively within the subcanopy of many cover types. Edible fig is a domesticated shrub or small tree that invades the riparian forest understory and other places with perennially wet soils, including levees, canal banks, and dredger tailings. Himalaya berry is highly invasive in disturbed areas, such as roadsides and revetted banks, forming dense, monospecific thickets that displace the native California blackberry. Tree tobacco and pokeweed are less commonly distributed, but densities increase in downstream reaches, especially on levees and adjacent to roads.

Non-native grasses, forbs, and understory shrubs are widely distributed within and often dominate the following cover types: Blackberry Scrub, Disturbed Riparian, Dredger Tailings, Herbaceous Cover, Marsh, and Riparian Scrub. Some of the more commonly occurring non-native herbaceous species in these cover types include wild oat (*Avena* spp.), ripgut brome (*Bromus diandrus*), rabbitsfoot grass (*Polypogon monspeliensis*), bluegrass (*Poa* spp.), black mustard (*Brassica nigra*), poison hemlock (*Conium maculatum*), and knotweed (*Polygonum* spp.). Because these herbaceous plants are not identifiable from aerial photographs, the vegetation maps cannot accurately quantify the total degree of invasion by these species. However, when the main cover types dominated by non-native grasses and forbs (listed above and including Dredger Tailings) are aggregated, they represent well over half of the riparian area mapped in the Merced River corridor.

Because distributions for key invasive woody and persistent perennial species, particularly tree of heaven, giant reed, and to a lesser extent eucalyptus, are fairly limited within the corridor, restoration efforts should focus on early and vigorous eradication of high priority species before further invasion occurs. Unlike many other California rivers, where giant reed and/or tamarisk now dominate riparian zones, such restoration efforts are feasible on the Merced River if implemented with strong public education and support.

6.2 Intensive Site Investigations

As a complement to the corridor-wide mapping, intensive studies were conducted at three sites along the river to assess current riparian vegetation conditions and the effects of recent changes in hydrologic function. The objectives of the site-specific evaluations were to: (1) document current vegetation species composition and canopy structure; (2) assess vegetation response to flow regulation; (3) assess the relationship between vegetation distribution, geomorphic surfaces, and hydrology; and (4) assess recruitment of pioneer riparian trees. These surveys were conducted as pilot studies and focused on assessing trends and developing hypotheses to be tested in future work. The site evaluations included analysis of time-series aerial photographs, field surveys of channel and floodplain topography, characterizations of vegetation composition and structure, and surveys of riparian seedling survival.

Table 22. Summary of Study Site Field Surveys and Analyses Used to Evaluate Riparian Vegetation Functional Relationships

Field Surveys and Analyses	Stevinson (RM 2.2)	Snelling (RM 48.2)	Cuneo (RM 50.8)
• aerial photograph analysis	X	X	X
• channel and floodplain cross section surveys		7	1
• transect(s) of vegetation cover type distribution, canopy structure, and geomorphic position	1	6	1
• species lists for common vegetation cover types	X		
• relevés (species composition and cover by canopy strata) for common vegetation cover types		X	X
• seedling surveys		X	
• water stage monitoring		X	
• hydraulic and sediment transport modeling		X	

Study sites were selected that had experienced minimum disturbance from agriculture, urban development, and gold and aggregate mining. To the extent feasible, sites were chosen that exhibited active channel bars, mixed-age stands of riparian vegetation, and actual or potential for riparian vegetation recruitment. To represent the range of natural variation in the river corridor, two sites were selected in the gravel-bedded reach at RM 48.2 (the Snelling Site) and RM 50.8 (the Cuneo Site) and one was selected in the sand-bedded reach at RM 2.2 (the Stevinson Site) (Figure 5.3–1). The Snelling Site (Figure 5.3–2) is located on an undredged remnant floodplain and was selected for study because it contains active gravel bars (which indicate some level of sediment transport and channel function), diverse native riparian vegetation, and recruitment of native cottonwood and willow seedlings. The Cuneo Site (Figure 5.3–4) is a partially-vegetated bar on the north bank of the river. It was selected because it was an active bar under pre-dam hydrologic conditions and could illustrate vegetation response to flow regulation. The Stevinson Site (Figure 6.2–1) is located in the Confluence Reach and occupies the floodplain area inside a broad river meander near Hatfield State Park. This site contains some of the best remnant stands of riparian vegetation on the Merced River and was chosen as a reference site for assessing pre-settlement conditions.

6.3 Vegetation Response To Flow Regulation

One of the objectives of the intensive site studies was to assess the response of riparian vegetation to flow regulation. In heavily altered systems, vegetation species composition, stand structure (age and size distribution), and successional processes (recruitment, establishment, and succession) can change as a result of flow regulation. As described in Section 2, typical vegetation responses include encroachment into the active channel, loss of species and stand diversity, loss of young native tree cohorts, and invasion of the riparian zone by non-native species.

6.3.1 Methods

Coarse-scale changes in riparian vegetation extent and condition along the Merced River since construction of Exchequer Dam in 1926 were assessed using analysis of time-series aerial photographs. For each study site, historical aerial photographs were reviewed from several series ranging from 1937 to 1998 (Table 23) to evaluate vegetation change over time. Because the earliest series was taken eleven years after dam construction, pre-dam conditions were inferred from tree size and recent geomorphic activity apparent in the 1937 photographs. In addition, flood maps (USACE, unpublished data) outlining areas inundated by the January 1997 flood (8,279 cfs maximum flow) were reviewed. Three periods of differing hydrologic conditions were considered in the analyses: (1) pre-1926; (2) 1926–1967; and (3) 1967–present.

Table 23. Aerial Photograph Series Analyzed for Time-series Changes in Hydrology, Geomorphology, and Vegetation Conditions

Year	Date	Photo Source	Scale	Coverage	Mean Daily Flow for Photo Date (cfs)
1937	July 31B Aug 2	ASCS[1]	1:21,000	Crocker-Huffman Dam to RM 15	276[3]
1950	Feb. 18 and Mar. 10	ASCS[1]	1:20,000	Crocker-Huffman Dam to San Joaquin River	58 (Feb. 18)[4] 546 (Mar. 10)[4]
1967	May 1	ASCS[1]	1:20,000	Crocker-Huffman Dam to San Joaquin River	3,259[4]
1979	Not known	ASCS[1]	1:23,500	Crocker-Huffman Dam to San Joaquin River	--
1993	June 8	BOR[2]	1:6,000	New Exchequer Dam to San Joaquin River	649[4]
1998	Aug. 21	Merced County	1:6,000	Merced County eastern boundary to San Joaquin River	854[4]

[1] U.S. Agricultural Stabilization and Conservation Service
[2] U.S. Bureau of Reclamation
[3] USGS Merced River near Livingston gauge (no. 11271500)
[4] Merced ID Crocker-Huffman gauge

6.3.2 Results

6.3.2.1 Snelling Site

Historically, the Snelling Site was a vegetated island between the Merced River main channel and two high-flow channels to the north (Figure 6.3–1). Mixed riparian forest lined the main channel banks, and the active channel exhibited extensive alluvial bars that were barren of vegetation. The stand of large cottonwoods that borders the high flow channel is evident on the 1937 photographs, and very likely established under pre-Exchequer hydrologic conditions. Sometime after 1950, the northern half of the site was cleared for pasture and the most northern high-flow channel was filled. In 1967, the area was freshly graded, with very few of the riparian trees remaining. The southern part of the site remained wooded, continuing the pattern of slow vegetation encroachment into the formerly active channel.

Under current conditions (see Figure 5.3–2), vegetation encroachment has narrowed the active channel. Figure 6.3–2 shows the current sequence of vegetation cover types on a cross section on the site. Vegetation on all cross sections surveyed at the site are shown in Appendix B. Cottonwood establishment along high-flow channels (located at the far right edge of Figure 6.3–2) has ceased since dam construction. The mature cottonwood stands along the high flow channels are approximately 65 to 80 years old (based on aerial photograph evidence), and field surveys confirm that these stands lack young trees and are not regenerating. Recruitment at the site may be limited by lack of bare alluvial surfaces and competition for light. Maximum life span for Fremont cottonwoods is 100 to 150 years (Braatne et al. 1996), indicating that these mature trees are late in their natural life cycle. As these trees die off, the dominant cottonwoods will be replaced by other riparian tree species. Site surveys confirm that recruitment of pioneer species such as willow and cottonwood is occurring only along the active channel margin, and that these recruits do not survive through the winter into the following year.

6.3.2.2 Cuneo Site

Prior to dam construction, the Cuneo Site was an active channel bar. By 1937, dredging had modified the entire north bank of the river except for the Cuneo bar, and dredging was still underway along the south bank. By this time, woody vegetation had established in a thin band along the bar margin and on the bar surface, but the trees were very small and likely germinated after completion of Exchequer Dam in 1926. A cluster of valley oak trees that currently occurs on the bar surface is visible only as scrub or saplings in the 1937 photograph. By 1950, valley oaks on the bar surface were larger, and vegetation at the channel edge had matured and spread further inland along the bar surface. Vegetation encroachment has continued at the Cuneo Site until the present and has likely contributed to stabilization of the bar surface and channel margin. Sediment stains on trees left by the January 1997 flood confirm that the site was inundated by the 1997 flood flow, which less than the pre-dam bankfull flow.

6.3.2.3 Stevinson Site

The Stevinson Site is located on a current floodplain. The 1950 aerial photographs (the earliest available for this site) suggest that the pre-dam active channel was not much wider than it is currently. From 1950 to the present, no overall increase in vegetation encroachment is apparent, though the area of exposed substrate and scrub vegetation varies between the photograph years. Riparian forest stands to the south of the river appear to be less dense currently than in 1950, possibly due to a combination of natural senescence within the mixed riparian forest and a lack of recruitment due to grazing. Field observations suggest that the narrow point bars in the reach are frequently colonized by cottonwood and willow seedlings, but the lack of observed sapling cohorts indicates that these seedlings do not survive.

6.4 Relationship Between Vegetation Distribution, Geomorphic Surfaces, and Hydrology

6.4.1 Methods

Vegetation species composition and structure were documented using vegetation transects and relevé surveys. These surveys were conducted in fall 1999 and spring 2000.

At the Snelling and Cuneo sites, vegetation surveys were conducted in conjunction with the geomorphic surveys described in Section 5. At the Stevinson Site, channel bathymetry and floodplain topography were not surveyed in the field, but were plotted from Sacramento-San Joaquin River Comprehensive Plan

Digital Line Graph (DLG) files. The DLG files presented data in two-foot contours, which were generated from hydrographic surveys and photogrammetric analysis (USACE, unpublished data).

At all three sites, vegetation structure and composition were documented in six-feet wide belt transects along the cross sections on both left- and right-bank floodplains. Vegetation patches were identified by cover type. For each cover type, horizontal position along the cross section, canopy structure, canopy height, species composition, and stem diameter classes were documented. Horizontal position along the cross section was documented by recording where the cover type boundary intersected the survey tape. Canopy layer heights were visually estimated.

At the Snelling and Cuneo sites, species composition and structure within common vegetation cover types were documented using relevé surveys (modified from Sawyer and Keeler-Wolf 1995). A relevé is a rapid method of assessing species composition, density, and canopy structure within a discrete vegetation patch of homogenous composition and is an alternative to the time-consuming point-intercept transect method. Once vegetation patch boundaries were delineated along each cross section, relevé plots (65.6 feet by 32.8 feet [20 m by 10 m]) were randomly located within patch boundaries. Within each plot, all species observed were listed and their canopy stratum (tree, shrub, ground) and cover class were documented. Cover classes followed the CNPS series relevé protocol (Sawyer and Keeler-Wolf 1995). Percent cover class was visually estimated. Results of all relevés are tabulated in Appendix H. No relevés were conducted at the Stevinson Site; at this site, lists of species occurring within common vegetation types were compiled.

At the Snelling Site, hydraulic modeling was used to determine water stage elevation at each of the vegetation transects for a range of flows. Flows were modeled using a HEC-RAS (version 2.2), a one-dimensional hydraulic model. Inputs to the model included the surveyed cross sections, flow data, channel slope, and a roughness coefficient for both the channel bed and floodplain. Flow data from Merced ID's Crocker-Huffman gauge were used. Water stage monitoring at cross section 0+00 was used to define the downstream boundary condition for the model. Bed and floodplain roughness coefficients were 0.045 and 0.07 respectively, based on commonly accepted values for the channel type.

In addition to using the combination of vegetation transects and hydraulic modeling to assess the relationship between vegetation species composition and inundation frequency, cores were collected from ten valley oak trees that had established on a relict bar surface at the Cuneo Site. Once the ages of these trees are determined, the year and hydrologic conditions under which they established can be identified. These cores will be analyzed in Phase III of the project.

6.4.2 Results

Many studies have documented associations between riparian vegetation assemblages and fluvial landforms (Harris 1987, Hupp and Osterkamp 1985, Osterkamp and Hupp 1984). These associations result from the interrelationships between physical processes such as inundation, scour, and deposition and plant communities that both depend on and in turn influence those physical processes. Data from the Stevinson, Snelling, and Cuneo sites also document associations between vegetation and geomorphic position and demonstrate a toposequence, or cross-sectional pattern, across the floodplain. Figure 6.4–1 represents a generalized toposequence of current riparian vegetation compiled from study site cross sections and field observations. Vegetation transects from the Cuneo and Stevinson sites are shown in Figures 6.4–2 and 6.4–3, respectively.

Understanding the relationships between vegetation assemblages and topography and the hydrogeomorphic processes which are correlated with topography will be useful for developing future restoration designs, including re-grading sites to provide hydrologic conditions (i.e., inundation frequency and duration) that favor specific plant species or assemblages. Table 24 describes general relationships observed at the Snelling Site using data from the six vegetation transects coupled with water surface elevations generated from the hydraulic model. These transects are included in Appendix B.

Table 24. Topographic Position of Cover Types with Regard to Flow Regime at the Snelling Site

Cover Types	Associated Geomorphic Surfaces	Elevation with regard to current flow regime	Evidence of change in distribution after regulation?
Blackberry Scrub	former floodplain/current terrace	Patches dominated by native or mixed native/non-native occur typically at the current Q_2	Unknown
	disturbed terraces	Himalaya berry (non-native) thickets range from $Q_{1.5}$ to Q_{10}	Yes, encroachment onto revetted banks.
Cottonwood Forest	former floodplain/current terrace	Stands of mature trees (probable pre-dam cohort) occur higher than the current $Q_{1.5}$ but lower than current Q_5. Cottonwood seedlings recruit within current active channel, lower than current $Q_{1.5}$ elevation	Yes, current recruitment occurs lower than pre-1926 mature trees.
Herbaceous Cover	active channel and current floodplain (wetland spp.)	Located at the $Q_{1.5}$ elevation for wetland swales and high flow channels	Unknown
	former floodplain/ current terrace (grassland spp.)	Between the Q_5 to Q_{10} elevations for annual grasslands	No, extent is unchanged.
Mixed Riparian Forest	current floodplain and former floodplain/current terrace	Generally under the Q_2 elevation, some between the Q_2 to Q_5 elevations	Yes, encroachment into former active channel.
Mixed Willow	active channel and current floodplain	Generally between the $Q_{1.5}$ and Q_5 elevations	Unknown
Valley Oak	former floodplain/current terrace and terrace	Generally at the Q_{10} elevation or greater	Yes, current recruitment occurs lower than pre-1926 mature trees.

Analysis of aerial photographs of the Snelling Site indicates that some of the cover types have changed their distributions since construction of Exchequer Dam in 1926, and field work confirms that some cover types (e.g., Mixed Riparian Forest) have established at different elevations since dam construction, whereas others (e.g., Cottonwood Forest) are no longer establishing at all. These shifts provide evidence that flow regulation has changed the elevation range at which certain species establish. This situation makes interpretation of vegetation topographic patterns for reference or restoration purposes more difficult, because observed patterns may be the result of a former hydrologic regime. Distinct associations between specific vegetation cover types and geomorphic surfaces are described in more detail below.

Mixed Riparian Forest typically occurred at the edge of the post-dam bankfull channel and on low floodplains. Aerial photographs and field observations at the Snelling and Cuneo sites indicate that this cover type has encroached into the former active channel since dam construction. The Mixed Willow cover type is also associated with active channel and current floodplain surfaces and typically encroaches into the channel in response to decreased flood frequency. Because current flows are not sufficient to scour vegetation from bank areas, encroachment by these cover types will likely continue.

Mature Cottonwood Forest stands were generally associated with former floodplains/current terraces, surfaces that no longer experience the inundation frequency and overbank sediment deposition necessary for recruitment. At the Snelling Site, recruitment of cottonwood seedlings was documented within the active channel and not within the elevation range of the mature Cottonwood Forest patches (see Section 6.5.2). Mature cottonwood trees occurred on surfaces that are inundated by floods having a 1.5 to 5-year post-dam recurrence interval. This elevation range is low compared to that reported by other studies of cottonwood ecology, which document large establishment events occurring after floods with recurrence intervals of ten to one hundred years (Stromberg et al. 1993, Stromberg 1997, Rood et al. 1998, Rood and Mahoney 2000). The aerial photographs indicate that these trees established at approximately the time of dam construction, so it is unclear if recruitment occurred under the pre- or post-dam hydrologic regime.

Mature Valley Oak Forest stands typically occurred on terrace and former floodplain/current terrace surfaces that are currently inundated by 10-year recurrence interval floods or greater. At the Snelling and Cuneo sites, valley oak seedlings and small trees were establishing within Mixed Riparian Forest stands on lower geomorphic surfaces than under pre-dam conditions.

Some cover types occur on both low and high surfaces. Herbaceous assemblages on former floodplains/current terraces are typically dominated by annual grasses and non-native forbs, whereas more mesic low areas, such as seasonally wet high-flow channels on current floodplains and in the active channel, are often dominated by sedges (*Carex* spp.), waterpepper (*Polygonum hydropiperoides)*, and mugwort (*Artemisia douglasii*). Blackberry Scrub occurred on current floodplains (often associated with Mixed Riparian Forest) in mixed patches of native California blackberry and non-native Himalaya berry and on high, typically disturbed terraces or tailings areas, principally as dense Himalaya berry thickets.

Major implications of these relationships for restoration project design are: (1) pre- and post-dam vegetation establishment history needs to be understood when using reference sites to design grading and revegetation plans; (2) cottonwoods, willow, and valley oak seedlings currently establish at lower bank positions than historically; and (3) encroachment of mixed willow and mixed riparian forest will likely continue to occur on restored sites unless flow and sediment supply issues are addressed.

6.5 Vegetation Recruitment and Establishment

Riparian forests require periodic seedling recruitment and subsequent establishment to replace mature and dying trees, maintain the stand through time, and reset the process of vegetation succession. Recruitment refers to seedling germination following seed release. Establishment refers to the life stage when a plant has developed a sufficient root and shoot architecture to survive annual environmental conditions (especially inundation and scour) and develop into a reproducing adult. Succession refers to a progressive replacement of different plant communities over time in response to internal competition among different plant species or outside disturbances such as floods and fire.

Central Valley riparian forest initiation begins with the colonization of bare, moist alluvial surfaces after large floods by seedlings, typically Fremont cottonwoods, willows and other fast-growing species. These pioneer species are physiologically adapted to the highly variable hydrologic and geomorphic regimes of alluvial river floodplain systems. Willows and cottonwoods can sustain high rates of root growth (up to 1–1.5 inches per day) to keep up with rapid ground water decline (Stromberg 1997, McBride et al. 1989, Mahoney and Rood 1998). Most riparian species are also physiologically adapted to survive prolonged flooding and scour, and they maximize dispersal through high seed output, long seed-floating time, or clonal growth (Johansson et al. 1996, Braatne et al. 1996).

Successful cottonwood recruitment depends on the specific hydrology (flood frequency and duration) of the germination site combined with favorable seed dispersal timing. Site hydrology is a function of river flow, topography, and substrate composition. Seed release timing varies for riparian trees and is often related to their dispersal mechanism; light-seeded, wind-dispersed species tend to release seeds in spring, when newly de-watered banks are exposed, and large-seeded, water-dispersed species tend to release in fall and winter, when seeds can float up onto floodplains (Figure 6.5–1). This combination of hydrologic conditions and seed release timing has been formalized by Mahoney and Rood (1998) and others into a 'recruitment box' model (see Section 6.5).

Under natural conditions, only a fraction of recruited cottonwood seedlings will become established. Annual or seasonal fluctuations in groundwater tables, the timing and magnitude of larger flood events, substrate conditions, and biotic factors (such as competition or herbivory) all influence whether a cohort of seedlings survives long enough to successfully establish a new stand of mature trees. Certain sites, sometimes referred to as "safe sites" or "nurse sites," are more likely than others to provide conditions conducive to successful establishment. Field observations suggest that floodplain depressions, high flow channels, and other off-channel sites that historically received overbank flooding and sediment deposition provide suitable recruitment conditions as well as protection from later floods under natural conditions. As a result, willow and cottonwood establishment is also episodic, and riparian stand structure is often dominated by several prominent cohorts that established after flood events. The coupling of the recruitment box model and the safe site concept should provide a useful tool for restoration planning.

Succession of riparian plant assemblages occurs over time, as floodplains accrete sediment and soil development occurs, providing conditions for less flood-dependent and more shade-tolerant species such as Oregon ash, box elder, and valley oak to establish and eventually dominate. Along geomorphically active, meandering rivers, riparian assemblages typically exhibit successional gradients that run perpendicular to the channel, with the youngest stands closest to the active channel margin (Figure 6.5–2). Succession can occur as a continuous process, but it is often punctuated by episodic disturbances and establishment events (i.e., large floods). The vegetation successional pattern at many sites is, therefore, patchy and depends on flood history, site topography, and local variations in physical disturbance.

If biologically important physical conditions change in a river corridor and pioneer species no longer are able to establish, the riparian forest composition over time shifts from pioneer species to later-successional species, and plant diversity, and habitat complexity become simplified. Observations from numerous reconnaissance trips and field work at the study sites indicated that establishment of pioneer species is limited on the Merced River, and natural succession and disturbance cycles are disrupted. The objectives of the vegetation recruitment and establishment analysis were to: (1) document patterns of seedling recruitment and establishment within the river corridor; (2) understand seedling survival patterns by following a cohort of seedlings from October 1999 to June 2000; and (3) analyze recruitment and establishment patterns in relation to hydrologic and geomorphic conditions using the 'recruitment box' model.

6.5.1 Methods

River-wide recruitment and establishment of Fremont cottonwoods and willows on bars and floodplains was assessed by boat surveys conducted in fall 1999 and spring 2000. Areas where seedlings (< 1 year old) had recruited in the same year and where saplings (1 to 5 years old) had established in prior years were recorded onto aerial photographs to provide a qualitative description of spatial patterns of recruitment.

In addition to the river-wide assessment, seedling surveys were conducted on gravel bars at the Snelling Site to quantify seedling recruitment and overwinter survival. Six gravel bars were surveyed in October 1999 to document recruitment. Surveys were conducted using a 10.8-ft^2 (1.0-m^2) plot frame laid contiguously along a transect that extended from the channel margin to the upland edge of the bar. Within each plot, seedling or sapling species and age, substrate, and surface moisture condition were recorded; age was assessed by stem buds scars. The transects were monumented with rebar for later resurveying. In June 2000, follow-up surveys were conducted. Only one transect (cross section 13+95) had a sufficient number of seedlings in both years to evaluate recruitment patterns and is the only transect discussed in the results section below. Observed seedling recruitment was compared to recruitment predicted by the box model.

6.5.2 Results

6.5.2.1 River-wide Recruitment and Establishment

During the boat surveys conducted from Shaffer Bridge to the confluence with the San Joaquin River in spring 2000, recruitment of cottonwood and willow seedlings was observed only where bare, shallow, fine-grained alluvial surfaces occurred. These surfaces were relatively scarce throughout the river corridor. Fine-grained bars and seedling recruitment patches occurred sporadically in the Dredger Tailings Reach (including the Snelling Site), at McConnell State Park in the Encroached Reach, and throughout the Confluence Reach. Most seedlings observed apparently recruited from seed, though at McConnell State Park some young Goodding's black willow shoots appeared to be vegetative sprouts from flood-damaged older trees. The wide geographic dispersal of seedling patches, combined with observations of heavy willow and cottonwood seedfall during spring 2000 indicate that seed source is not a limiting factor for establishment of pioneer riparian species.

Few patches of cottonwood or willow saplings (age 2+ years) were observed during the boat surveys, suggesting that at many locations, young seedlings do not survive to reproductive maturity. Extensive reconnaissance of the Merced River found very few saplings or young trees of these species, and of those found, their size, location, and associated flood debris suggested that most or all established following the January 1997 flood. Small groups of cottonwood saplings estimated to be three years old were observed at several locations along the river, including the lower end of the Gravel Mining 1 Reach (RM 32.5), downstream of Shaffer Bridge (RM 32.5), McConnell State Park (RM 23.3), and at the Stevinson Site (RM 2.2) on floodplain surfaces approximately three feet above summer low water stage. Other than the presumed 1997 cohort, no additional young cottonwood stands were observed on riverbanks and floodplains.

In natural river systems, inter-annual environmental conditions are extremely variable and cottonwoods and willows do not establish every year. As discussed above, these species typically establish episodically after moderate-to-large floods. Given their life history, it is reasonable to expect that several distinct age cohorts of cottonwoods and willows resulting from past flooding events would be apparent in patches along the river corridor. The boat survey observations indicated that seedling recruitment was relatively abundant (at least in 2000) but that establishment of sapling cohorts does not occur.

Though natural establishment of cottonwoods appears to be very limited, establishment is occurring on floodplain sites that have been artificially cleared or graded. Cottonwood seedlings and one- to five-year old cottonwood saplings were observed thriving in areas that were recently graded, including the Kelsey Ranch located on a terrace north of the river near RM 53, the Hardin property just downstream of the Snelling Road bridge (RM 46.4), and the GM2-T1 aggregate mine downstream of Shaffer Bridge (RM 31.5). Hydrology, topography, soil texture, and lack of competition from annual grasses at these locations likely facilitate germination, and the location away from the river channel protects seedlings from prolonged inundation. These sites may be useful as model sites for floodplain restoration; factors such as soil texture and water table dynamics at these graded sites should be studied to use as design parameters.

6.5.2.2 Observed Seedling Recruitment and Survival

To test the hypothesis that willow and cottonwood seedlings were recruiting but not surviving to maturity, a cohort of seedlings was followed at the Snelling Site to assess overwinter survival. In the initial surveys in October 1999, a total of 126 seedlings were counted within the 150-square foot transect at cross section 13+95, including a large cohort of cottonwoods less than one year old and smaller groups of arroyo willow and California button willow (Figure 6.5–3). The 1999 cottonwood cohort was located within 12 feet of the channel edge (adjacent to edge of water at summer baseflow). Maximum density was 7 seedlings/ft^2. Further inland on the transect, seedling densities dropped to approximately 2 seedlings/ft^2 or less, and composition shifted to more upland species in the following progression: silver maple (non-native), Oregon ash, and valley oak. Total elevation change was approximately four feet over the 50-foot length of the transect.

When the transect was resurveyed in June 2000, many fewer seedlings were documented than in the previous year. The maximum density was 2.3 seedlings/ft^2. Seedling survival from the previous year was four percent or less for cottonwood, arroyo willow, and California button willow, and 67 percent for silver maple seedlings, which were located farther from the channel edge (Figure 6.5–3). Almost all of the seedlings documented in the June 2000 survey were less than one-year-old (i.e., germinated that spring); 78 percent of the cottonwoods, 40 percent of the arroyo willows, and all of the California button willows were new recruits. Though it appeared that fewer cottonwoods recruited in 2000 than in 1999 (Figure 6.5–4), an exact comparison was not possible because there was still some potential that more seedlings would germinate following the June survey (though this was not likely, given cottonwood's early spring seed release period).

The pattern of seedling recruitment and mortality at cross section 13+95 suggests that cottonwood, arroyo willow, and California button willow readily germinate on bars in the active channel but do not survive beyond the first year (Figure 6.5–5). Seedling mortality between surveys was likely caused by either scour or prolonged inundation. Site conditions in June 2000 did not show evidence of scour, suggesting that seedling mortality was due to prolonged inundation. The seedling surveys conducted at the Snelling Site support the river-wide observation that cottonwood and willow seedlings readily recruit along the Merced River but do not survive to reproductive maturity. Because of the limited scope of these baseline studies, these seedling data should be interpreted as suggestive, rather than definitive, of conditions elsewhere on the river.

6.5.2.3 Comparison to the Recruitment Box Model

Riparian tree recruitment depends on local hydrologic conditions during the seed release period. Early successional species such as cottonwood and willow release many seeds that are viable for a short time, typically 2–3 weeks (Braatne et al. 1996) and require bare, moist substrates to germinate. Seedling recruitment, therefore, occurs on the surfaces that happen to be moist and bare during the seed release period. Mahoney and Rood (1993, 1998) describe this window of optimal conditions for riparian plant establishment as the "recruitment box," defined in space (topographic elevation with respect to river stage) and time (period of seed release and viability) (Figure 6.5–6). The sloping line within the recruitment box represents the maximum survivable rate of water table decline; hydrograph drops steeper than this line will not support successful establishment. New cohorts of cottonwood and willow seedlings typically form narrow bands parallel to the river channel after floods (Figure 6.5–7). These bands can be quite narrow on sloped river banks, because the recruitment box is constrained at the higher elevations by the seedling's ability to maintain contact with the receding water table following spring floods, and at lower elevations by inundation and scour the following winter.

Figure 6.5–8 shows the recruitment box conditions at cross section 13+95 at the Snelling Site. The Snelling analysis used the conceptual model developed by Mahoney and Rood (1993, 1998). The vertical axis reflects river discharge at the Merced ID Crocker-Huffman gauge for 1998 and 1999. Elevation of the cottonwood seedling cohort and (assumed) pre-dam cottonwoods are also plotted on this axis; surveyed elevations were converted to discharge using the rating curve generated by the Snelling Site hydraulic model. The rate of water table decline was also plotted using the rating curve.

The recruitment box model indicates several points:

- The 1999 seedling cohort established below the range of root crown elevations of the pre-dam cottonwoods (Figure 6.5–8). The seedlings recruited within the current bankfull channel, and the mature trees are inundated at a 1.5- to 5-year recurrence interval.
- The Merced River ramping rate was within tolerable limits (1.5 inches/day) during only the last part of the 1999 cottonwood seed release period, when flow was below 500 cfs. Before this point, seedlings would not have established because the bank dewatering rate was faster than seedling root growth rates.
- Flows in winter/spring 2000 were high enough to submerge the 1999 seedling cohort for several months. This condition could explain the low seedling survival from 1999 to 2000. It is possible that the high water table prevented the 1999 seedlings from developing deep root systems, thus making them vulnerable to being uprooted by relatively modest winter flows.
- Recruitment conditions in 2000 were similar to those in 1999. The river stage decline was very rapid during the seed release period and leveled out near baseflow levels.
- During the flow period covered by the surveys, peak flows reached the lower part of the elevation range of pre-dam cottonwoods. The only recent year that river stage reached the upper elevation range of these mature trees was 1997, when flow exceeded 8,000 cfs.

The recruitment box concept may also be used to develop hypotheses of connections between river regulation, species composition shifts, and vegetation encroachment. Reduction in peak flows since flow regulation during the spring seed-release period may favor establishment by shrub species that encroach into the active channel. Peak flows that occur in winter, which are more common since flow regulation, are not conducive to establishment of large tree species, such as Fremont cottonwood and Goodding's black willow, because these species release seeds later in the spring. Less frequent spring peak flows combined with increased summer irrigation flows favor late summer-seeding species such as narrow-leaf willow, which tend to spread as shrub thickets onto active channel bars and banks.

6.6 Conclusions

These investigations indicate that riparian processes in the Merced River corridor are impaired in the several ways. Riparian zone area has decreased since settlement by over 90 percent by some estimates. Encroachment of riparian vegetation into the former active channel is widespread throughout the river corridor since construction of New Exchequer Dam and has resulted in a confined and simplified channel (Figure 5.6–2). This vegetation encroachment onto formerly active bars prevents establishment of pioneer riparian species and arrests natural vegetation successional patterns.

Flow regulation has also created artificially stable conditions that induce riparian seedlings to recruit lower on banks than historically, where they do not survive scour or inundation from moderate flows later in the year. Currently, spring peak flows are insufficient for cottonwood cohorts to establish on sites, such as high-flow channels and high floodplains, that are safe from subsequent scouring and flooding. Lower flood peaks and lack of sediment supply limit deposition of fine sediment on floodplains, thus cutting off the supply of bare, moist substrates away from the channel that are necessary for cottonwoods to germinate and survive to maturity. These conditions contribute to the decline of cottonwood-dominated forest stands throughout the river corridor.

Despite these impaired processes, some conditions provide key opportunities for restoration in the Merced River corridor. For example, seed source and dispersal ability for most tree species do not appear to limit regeneration of riparian forest stands. For wind-dispersed species, such as willows and Fremont cottonwood, seed source is abundant and dispersal is widespread throughout the river corridor. Valley oak, box elder, and Oregon ash, which have larger seeds and less dispersive ability, are well-distributed throughout the river corridor and are naturally establishing currently on post-dam floodplains. In contrast, white alder, which is concentrated only at upstream sites, and western sycamore, which is absent from the study reach, appear to have very limited potential for natural seed germination. It is important to note that good seed source availability does not ensure that a desired species mix will occur naturally on restoration sites; many projects may require active revegetation.

Another promising condition is that natural establishment of cottonwoods occurs on some floodplain sites that have been artificially graded or mined for gravel. Vegetation patterns, soil conditions and hydrology at these sites provide adequate conditions for establishment in the absence of natural hydraulic and geomorphic processes, and should be studied to provide model criteria for restoration projects using similar floodplain reconstruction methods. Floodplain scraping may be a viable active restoration approach where passive strategies are not feasible.

As described in Section 6.1.2.3, non-native invasive grasses and forbs dominate herbaceous communities on the Merced River, and some non-native tree and shrub species have established and pose a threat to further invasion within the corridor. However, most of the more problematic woody and persistent perennial species, particularly tree of heaven, giant reed, and to a lesser extent eucalyptus, have limited distributions in the corridor. Restoration efforts should focus on early eradication of these high priority species before further invasion occurs. Unlike many California rivers, where giant reed and/or tamarisk now dominate riparian zones, the eradication and control of some non-native tree species appears feasible.

7 GEOMORPHIC OPPORTUNITES AND CONSTRAINTS FOR RESTORATION

As discussed in Section 1, the Merced River Corridor Restoration Plan will be developed in Phase III of this project, which began in fall 2000 and will extend through December 2001. This plan will encompass a spectrum of objectives including restoration of geomorphic and ecological processes and attributes and protection of private property and water rights. The Stakeholder Group has begun exercises to define their restoration objectives and concerns. This process will continue in Phase III so that a complete set of objectives that addresses ecological as well as social issues is adopted into the plan. Achievement of these objectives will be accomplished by implementing a suite of restoration actions. Appropriate restoration actions will be developed and selected by the Project Team, the TAC, and the Stakeholder Group, based on their ability to achieve social and/or ecosystem benefits within key constraints, such as protection of riparian water rights and landowner support.

This section describes opportunities and constraints to improving geomorphic and riparian ecosystem conditions in the Merced River. Major constraints to restoring geomorphic and riparian ecological processes and attributes in the Merced River include: (1) drastic reduction in the flood magnitude, frequency, and duration and the resulting reduction in bedload transport under current dam operations; (2) elimination of floods exceeding 6,000 cfs that will likely continue due to the Corps of Engineers limit to flood releases; (3) the presence of vulnerable structures (such as the City of Livingston sewage treatment plant) and vulnerable land uses in the floodplain; (4) lack of coarse sediment supply due interception of bedload by the large dams; (5) limits to channel migration caused by reduced flows, bank revetment, and development in the floodplain; (6) the extent of bedload impedance reaches throughout the Gravel Mining 1 and Gravel Mining 2 reaches; and (7) chronic fragmentation and clearing of riparian vegetation for floodplain development. There are, however, numerous opportunities for improving or preserving channel and floodplain function within the corridor. These opportunities are briefly described below. Additional opportunities will undoubtedly be identified through the Stakeholder Group and Technical Advisory Committee coordination process. Additional opportunities and constraints will also likely be identified as this project is integrated with the results of the CDFG-MID chinook salmon study program, which will continue during Phase III.

Geomorphic and riparian vegetation issues that could be addressed by the restoration plan are summarized for each reach in Table 25. Opportunities and constraints for restoration in each reach are discussed below.

Table 25. Summary of Geomorphic and Riparian Vegetation Issues for Each Reach

Reach Name	Geomorphic and Riparian Issues
Dredger Tailings Reach	• Lack of bed-mobilizing flows • Lack of coarse sediment supply • Conversion of floodplain to tailings • Channel confinement • Isolation and fragmentation of riparian stands and wetlands • Vegetation encroachment into the formerly active channel • Limited seedling establishment of cottonwood, valley oak, and other native riparian species • Risk of tree of heaven of invasion
Gravel Mining 1 Reach	• Lack of bed-mobilizing flows • Lack of coarse sediment supply • Bedload transport impedance at in-channel pits • Risk of capture of floodplain pits • Bank revetment and resulting channel confinement and prevention of channel migration • Fragmentation of riparian vegetation by pits • Lack of seedling establishment sites on steep pit berms and revetted banks
Gravel Mining 2 Reach	• Lack of bed-mobilizing flows • Lack of coarse sediment supply • Bedload transport impedance at in-channel pits • Channel incision and resulting floodplain isolation • Large volume of sand supplied from Dry Creek • Fragmentation of riparian vegetation by pits • Lack of seedling establishment sites on steep pit berms and revetted banks • Extensive invasion by eucalyptus (especially on Dry Creek and on the mainstem at Dry Creek confluence) • Giant reed established on revetted banks
Encroached Reach	• Agricultural development in the former floodplain and riparian corridor • Disconnection of the floodplain from the river by levees • Bank revetment and resulting prevention of channel migration • Elimination of vegetation successional patterns due to levees and bank revetment
Confluence Reach	• Bank revetment limits channel migration, though to a lesser extent than in upstream reaches

Dredger Tailings Reach

In this reach, the channel is confined by dredger tailings and is scoured to bedrock or a coarse armor layer. In addition, floodplain functions are greatly reduced by conversion of the floodplain riparian corridor to tailing piles. Despite the coarseness of the substrate in this reach and the limited amount of suitable spawning substrates observed in the field, this reach is important for chinook salmon spawning. In recent redd surveys conducted by the CDFG, more than half of the redds observed in the river occurred in this reach (Table 26). During field surveys conducted in November 1999, numerous chinook salmon redds were observed in small depositional areas at the Snelling and Cuneo sites.

Table 26. Recent Fall Chinook Spawning Distribution in the Merced River

Reach	Redd Distribution[1] (percent of redds observed)	
	1997[2]	1998[3]
Dredger Tailings	52	70
Gravel Mining 1	30	30
Gravel Mining 2	17	no survey
Encroached	no suitable habitat	no suitable habitat
Confluence	no suitable habitat	no suitable habitat

[1]Based on peak redd counts. Surveys conducted by CDFG.
[2]Survey extended from RM 51.95 to RM 27.9.
[3]Survey extended from RM 51.95 to RM 32.1.

This reach has the potential to provide extensive chinook salmon spawning and rearing habitat as well as a six-mile-long contiguous riparian corridor. Opportunities for improving channel and floodplain function in this reach include: (1) re-creating the floodplain by removing tailings to an elevation appropriate for current flow conditions; and (2) adding coarse sediment to the channel that is sized to be mobile under current flow conditions. Coarse sediment would need to be added in two phases: a large transfusion to immediately increase gravel storage in this reach, and a long-term coarse sediment augmentation program to maintain storage after high flows. These actions would provide the geomorphic benefits of increasing the frequency of bed mobilization, balancing sediment transport capacity with sediment supply, increasing channel complexity, and creating a functional floodplain with a self-sustaining, diverse riparian corridor. In addition, if properly implemented on a large scale, these actions could increase flood attenuation and reduce flooding risk downstream. A possible constraint to this type of project is the potential for debris from vegetation on restored floodplains to get lodged at the Snelling Road bridge during flood events.

In Phase III of this project, Stillwater Sciences will use a reach-scale bedload transport model to develop restoration project design guidelines and evaluate the potential effects of gravel augmentation projects in this reach. The reach-scale model will predict: (1) coarse sediment transport competence and capacity based on channel morphology and flow magnitude; and (2) bed texture based on the texture of the coarse sediment added to the river by an augmentation program. In addition, the model will allow the user to vary sediment supply volume, sediment texture, peak flow regime, and channel cross section to evaluate the resulting transport rates, incipient motion thresholds, and bed texture. Although there are inherent uncertainties in numerical modeling, this approach will provide a means to conduct predictive exercises and to make quantitative forecasts for different sediment management options and to test these predictions during post-implementation monitoring.

Gravel Mining 1 Reach

The primary issue in this reach is the presence of in-channel mining pits that intercept bedload and likely provide habitat for largemouth bass. Based on studies conducted in the Tuolumne River (TID/MID 1991a, 1991b), captured and in-channel pits are thought to provide suitable habitat for largemouth bass (*Micropterus salmoides*), which prey on juvenile salmon and can significantly reduce survival of chinook salmon smolts emigrating from the river. In an effort to reduce bass habitat in the Tuolumne River, the

Tuolumne River Technical Advisory Committee is implementing projects to reconstruct the channel and floodplain through two large, in-channel aggregate pits. Bass abundance and salmon survival are currently being monitored at the Tuolumne River pits to assess the restoration project's success at reducing predator abundance and increasing salmon survival (Stillwater Sciences 1999, 2000; McBain and Trush and Stillwater Sciences 1999, 2000). Large numbers of largemouth bass may also reside in the in-channel pits in the Merced River, and predation by largemouth bass may be an important factor limiting chinook salmon production from the Merced River. This hypothesis, however, has not been tested, and the factors limiting chinook salmon production in the Merced River have not been identified.

Another potential restoration opportunity in this reach is the eradication or management of non-native vegetation, particularly eucalyptus along Dry Creek and on the Merced River mainstem near the Dry Creek confluence. Because the trees in this stand are mature, eradication efforts would likely require vegetation removal and replanting with native species. Under the current flow regime, it is unlikely that the floodplain surfaces in this reach will be sufficiently inundated to promote recruitment by native species. A potential constraint to eucalyptus removal along Dry Creek may be the vulnerability of the banks to erosion. Still, vegetation removal and replanting could potentially be conducted along the Merced River, and the lack of large eucalyptus patches downstream of the Dry Creek confluence suggests that vegetative recolonization from upstream sites may not be a serious threat if eucalyptus patches remained on Dry Creek. Large eucalyptus trees, however, can also provide important rookery habitat for herons and egrets. Any eucalyptus eradication or management program included in the restoration plan would need to address these values and ensure that heron and egret rookeries and potential rookery sites are not adversely affected.

Gravel Mining 2 Reach

The primary issues in this reach are channel incision and the presence of in-channel mining pits. Landowners in the upper half of this reach have expressed interest in and support for restoring in-channel and terrace mining pits. As in the Gravel Mining 1 Reach, elimination of these pits could provide the benefits of: (1) eliminating bedload impedance reaches; (2) increasing channel complexity; (3) balancing bedload transport capacity with bedload supply; and (4) restoring floodplain function and a diverse riparian corridor. These projects would also likely reduce suitable habitat for largemouth bass and thus increase chinook salmon production from the river.

Encroachment Reach

The primary issues in this reach are elimination of channel migration and disconnection of the river channel from its floodplain caused by levee construction and bank revetment. Opportunities for restoring these functions in this reach are extremely limited due to the conversion of the floodplain to agricultural land uses, which limit the river-floodplain corridor to approximate 250 feet in width. Increasing floodplain connectivity and reinitiating channel migration in this reach would need to be supported by a voluntary easement program that would compensate landowners who choose to participate in restoration project. Interest among landowners in participating in these types of easements and related economic issues has not been assessed.

Confluence Reach

This reach provides some of the largest and most contiguous patches of floodplain and riparian habitat in the corridor. The major issue in this reach is the presence of revetment that limits channel migration at some locations. This reach provides excellent opportunity for preservation of floodplain and riparian habitats. The Stevinson Corporation is pursuing conservation easements on approximately 500 acres of its land at the mouth of the river, and more land may be put under easement in the future. In addition, revetment could be removed from appropriate locations to reinitiate channel migration, where feasible.

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