Evaluation of Setback Levees on the Sacramento River

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Abstract

This report presents a preliminary analysis to determine the effect that setback levees would have along a specified reach of the Sacramento River. This was done using a three-scenario strategy such that recommendations could arise from the analysis of several setback width options. The project reach ranges from river mile 143, just south of Colusa, to river mile 84, near the Sutter and Yolo bypasses. Three setback scenarios were analyzed, and the inter-levee distance was 3000ft, 6000ft, and 9000ft, respectively. Each scenario was analyzed in terms of hydrology, ecology, and economics. The floodplain inundation depth and the change in channel velocity were determined for each scenario at several cross sections using a number of standard flood recurrence intervals. An overview of river meandering processes was given in order to help explain the potential ecological benefits of setback levees. The change in riparian habitat was predicted by comparing the study reach to ecologically similar reaches having a wider inter-levee distance. To determine the effect of setback levees on riparian biota, the habitat requirements of indicator bird species were examined. In addition, changes in the hydraulic parameters were used to describe the ecological consequences to fish habitat. The cost estimates of implementing the scenarios were compared to the benefits of creating increased area for riparian habitat, which were estimated using a willingness to pay report for wetland habitat.

The analysis of the three scenarios indicates that benefits increase with increased inter-levee distance, and scenario three was found to provide the greatest benefits. For the aquatic ecosystem, this scenario establishes the most desirable conditions for improving habitat because channel velocity is decreased and there is great potential for backwater habitat formation. In terms of the terrestrial ecosystem, the area of willow, cottonwood and mixed riparian communities (the most common communities found in Sacramento Valley riparian habitat) is maximized under this scenario. This scenario also allows the most freedom for channel migration to occur over time, potentially establishing a more diverse range of aquatic and terrestrial habitats. Furthermore, economic analysis shows this scenario to be the most attractive, as the calculated cost/benefit ($238 million/$1.1 billion) ratio is at a minimum (0.23).

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Executive Summary

Development and flood control efforts over the past century have drastically altered the Sacramento River Valley by reducing the quantity and quality of natural habitats. As the human population of the Sacramento Valley grew, early settlers began to construct levee systems for protection, the relics of which exist today in the form of an intricate, thousand-mile network. Both CALFED and the Sacramento and San Joaquin River Basins Comprehensive Study, have proposed setback levees as an alternative flood control strategy that would allow for the restoration of riparian habitat. We conducted a preliminary analysis to determine the effect that setback levees would have along a specified reach of the Sacramento River. This was done using a three-scenario strategy such that recommendations could arise from the analysis of several setback width options.

The project reach ranges from river mile 143, just south of Colusa, to river mile 84, near the Sutter and Yolo bypasses. Three setback scenarios were analyzed and the corresponding inter-levees distances were 3000 feet, 6000 feet and 9000 feet. Each scenario was analyzed in terms of hydrology, ecology, and economics. The floodplain inundation depth and the change in channel velocity were determined for each scenario at several cross sections using a number of standard flood recurrence intervals. An overview of river meandering processes was given in order to help explain the potential ecological benefits of setback levees. The change in riparian habitat was predicted by comparing the study reach to ecologically similar reaches having a wider inter-levee distance. To determine the effect of setback levees on riparian biota, the habitat requirements of umbrella bird species were examined. In addition, changes in the hydraulic parameters were used to describe the ecological consequences to fish habitat. The cost estimates of implementing the scenarios were compared to the benefits of creating increased area for riparian habitat, which were estimated using a willingness to pay report for wetland habitat.

Of the three scenarios analyzed, scenario 3 (inter-levee distance of 9000 feet) was the optimal scenario in terms of all parameters involved. For the aquatic ecosystem, this scenario establishes the most desirable conditions for improving habitat because channel velocity is decreased and there is great potential for backwater habitat formation. In terms of the terrestrial ecosystem, the area of willow, cottonwood and mixed riparian communities (the most common communities found in Sacramento Valley riparian habitat) is maximized under this scenario. This scenario also allows the most freedom for channel migration to occur

over time, potentially establishing a more diverse range of aquatic and terrestrial habitats. Furthermore, economic analysis shows this scenario to be the most attractive, as the calculated cost/benefit ($238 million/$1.1 billion) ratio is at a minimum (0.23).

Project Objective

The overall goal of the project was to predict the potential effects of setback levees along the Sacramento River in terms of water depths at different flow regimes, river velocities, river meandering, riparian habitat and the ecology of species which depend on this habitat, and the associated costs and benefits.

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Background

Historical Background

One hundred and fifty years ago the Sacramento Valley had few human inhabitants and was very much different from what it is today. The Sacramento River meandered through the valley and with its regular floods allowed the valley to flourish. On lands near the river which were inundated regularly, marsh vegetation dominated, while the drier lands further from the river were covered with extended perennial grassland and scattered Valley Oaks (Sacramento River Advisory Council 1998). Immediately adjacent to the river, on the natural levees (formed by rivers that flood regularly and deposit sediment on their banks), there were dense riparian forests that supported complex ecosystems.

The riparian forest grew directly adjacent to the river on the natural levees that were 5 to 20 feet high and 1 to 10 miles wide (Sacramento River Advisory Council 1998). Before European settlement, the riparian forest in the Central Valley covered 373,000 ha (921,000 ac) of land. The estimated area covered by riparian forest in 1984 was 41,300 ha (102,000 ac).

The California Gold rush began in 1849 and brought people from all over the country to an area that until then had very few human residents (Kelley 1989). As the gold rush progressed, there were a large number of people who found that they could earn a much more reliable income by farming on the fertile floodplain. Still others continued the search for gold. In 1852 hydraulic mining began and large cliffs were washed away to find the gold hidden within. The sediments from the mining were washed into the river, and soon the riverbed began to rise, decreasing the flow conveyance capacity of the channel and increasing flooding (Kelley 1989). In order to try to protect themselves against the floods, farmers built artificial levees. There followed a long period of trial-and-error protection systems that varied in strategy depending on the political party in power. Democrats believed that each farmer should build his own levee, while Republicans believed a large plan for the entire valley based on the advice of engineers was more appropriate. Hydraulic mining came to an end with the 1884 Supreme Court ruling of *Woodruff v. North Bloomfield et al.* which prohibited the discharge of mining debris into streams, but flooding continued to bring economic hardship to the people of the Sacramento Valley (Kelley 1989).

The Sacramento River Flood Control Project, a region-wide plan, was implemented in the 1920's, and its structures are still in place today. This plan called for the straightening of channels and construction of high levees on either side, so that the maximum water carrying capacity for the river would be achieved. In addition, there are two major bypass systems, Sutter and Yolo, into which water can be directed during high flow times.

This system of levees has greatly improved flood protection in the Sacramento Valley, as well as maximized the amount of land that can be used for agriculture. The system has, however, greatly affected the natural behavior of the river. The reinforced levees prevent natural erosion of channel banks, decreasing the recycling of sediment between floodplain and channel as well as decreasing the river's freedom to for meanders with associated bars, pools, and riffles. In addition, the riparian forests which once flourished along the Sacramento River and supported countless plant and animal species have been greatly reduced.

Current Levee System

The Sacramento Valley flood management system includes levees and bypasses. The levee system consists of Project and Non-Project levees. Project levees are federally authorized and include State maintained levees. The Sacramento River Flood Control Project is a system of 1,000 miles of levees, five major overflow weirs, two sets of outfall gates, three major drainage pumping plants, 95 miles of bypass floodways, overbank floodway areas, and channel enlargement in the lower reach of the Sacramento River (U.S. Army Corps of Engineers 1999). Over the years, the U.S. Army Corp of Engineers and the State Reclamation Board have also built levees as part of flood control projects in the region. Non-Project Levees include those built and maintained by private parties and local municipalities. Some maintenance costs for Non-Project levees may be reimbursed to the owners by the State and Federal Governments, while others may not (Department of Water Resources 1999). The levees north of river mile 176 on the Sacramento River are Non-Project levees.

Reclamation Districts 70, 1660, and 1500 are responsible for maintaining the eastern levees of the Sacramento River for a major portion of our study reach. The Sacramento River West Side Levee District maintains the western levees. Levees located in areas where no Reclamation or Levee District exists are maintained by the DWR (Sacramento River Advisory Council 1998). The DWR, with assistance from the local agencies, also inspects state-sponsored levees and confirms that they are up to the Corps standards. If local agencies fail to maintain the levees, the state can take over and bill the appropriate entity. Additional inspections are done each autumn to confirm that deficiencies have been repaired. While the Corps was contracted to design and construct the flood control project, it has no responsibilities with respect to maintenance. The reconstruction of failed levees is a complicated and costly process, including not only the Corps, but also the State Reclamation Board, Federal Emergency Management Agency, and local maintenance agencies (Department of Water Resources 1999).

The current levee system in our study reach (RM 144 to RM 84) constrains the historic natural meanders of the Sacramento River. Two flood management diversions occur within this reach of the river. The Tisdale weir directs heavy flows into the Tisdale bypass, which empties into the Sutter bypass. The Tisdale weir is 1,150 feet long, 11ft. high, and 38 ft. wide. Tisdale weir operation begins when flows exceed 23,000 cfs (U.S. Army Corps of Engineers 2000). The Fremont weir directs flows into the Yolo bypass. The Fremont weir is 9,518 ft. long, 6 ft. high, and 35 ft. wide. Flows exceeding 62,000 cfs automatically divert over the weir into the Yolo bypass (U.S. Army Corps of Engineers 2000). The Yolo and Sutter bypasses are connected to the Sacramento River at approximately RM 84 to RM 80, where the Feather River joins the Sacramento. The Colusa Basin Drainage Canal, which connects to the western bank at Knights Landing, allows for flow redirection to the Knights Landing Ridge Cut, which diverts water for agricultural purposes and flood overflow.

Reach (RM)	Width (ft)	Height (ft)	Bypasses
145 – 142	650	ND	
142 – 141	1300	ND	
141 – 139	650	ND	
139 – 138	2300	ND	Bottle Slough Outfall Gates – east bank (RM 138)
138 – 131	750	14-16	
131 – 127	2100	14-17	
127 – 126.5	750	17	
126.5 – 125.5	2100	14	
125.5 – 120	500	15	
120 – 119	1200	12	Tisdale bypass – east bank (RM 119)
119 – 107.5	500	14-18	
107.5 – 106	4000	15	
106 – 105.5	500	14	
105.5 – 103.5	4500	13	
103.5 – 103	700	12	
103 – 101.5	1700	11	
101.5 – 100.5	500	11	
100.5 – 100	2000	13	
100 – 97.5	750	15	
97.5 – 96.5	2500	14	
96.5 – 90	600	12-14	Colusa Basin Drainage Canal - west bank (RM 90)
90 – 88	750	15	
88 – 87	3000	13	
87 – 84.5	500	12	
84.5 – 80	not constrained		Yolo bypass – west bank Sutter bypass – east bank
80 – 76	750	ND	

Table 1.1: Current Levee System – shows existing inter-levee distances, levee height, and the location of bypasses.

Definition of a setback levee

A setback levee, as described in the Sacramento and San Joaquin River Basins Comprehensive Study, is "an earthen embankment placed some distance landward of the bank of a river, stream, or creek. It develops bypasses for the mainstream, flooding a land area usually dry but subject to flooding at high mainstream stages" (U.S. Army Corps of Engineers 1999). Setback levees allow the streamflow to spread and slow by creating a wider riverbed with increased conveyance capacity of the floodway. They provide floodplain storage benefits and sustain the dynamics of the river system, which depends on recurring flooding events (Mount, 1995). The passage of water and sediment in the channel, and their exchange between the channel and the floodplain, characterizes the physical environment and effects the habitat, biodiversity, and sustainability of the river (Poff et al. 1997). Setback levees would also permit an active natural meander belt, thereby improving the riparian habitat.

Setback levees as a flood management strategy have been proposed on a small scale for the last twenty years. However, their escalating recognition as an important component of large-scale flood management policies is related to the 1993 Mississippi and 1997 Sacramento floods. Both of these catastrophes reconfirmed that not all flood risks can be eliminated, and that the objective should be to reduce the hazard to lives and property.

To date, several small-size setback levee projects have been undertaken. After the floods of 1983, the Santa Clara Valley Water District, CA approved an Environmental Impact Report for flood protection improvements on Coyote Creek, which included setback levees and bypass channels, whose construction was completed in 1995. The report notes that if the protective measures had not been in place during the floods of 1997, flooding would have happened 40 percent faster and had a 57 percent increase in the volume of water (Haaker 2000). Another example of the effects of setback levees is the Cosumnes River. In October 1995, The Nature Conservancy and its state and local partners pierced a levee along Cosumnes, where a cottonwood forest has since developed (1997). Similarly, after another flood event on the Red River in 1997, the St.Paul District of the US Army Corps of Engineers proposed levees and floodwall setbacks, resulting in a green floodplain corridor.

The Central Valley of California has a highly engineered and complex flood control system. However, this system has several flaws, which include an outdated levee system, increased flood peaks, encouragement of flood-prone development, mis-operated flood control reservoirs, and risk of catastrophic failure (Williams 1997). During the 1997 flood, which was California's seventh 100-year flood in the past 40 years, "dozens of major levee breaks caused $2 billion in damage, forced tens of thousands of people to evacuate, killed eight people, turned the Central Valley into a virtual inland sea and put maximum pressure on the U.S. Army Corps of Engineers to fix things" (1997). Following that, Congress , through the Water Resources Development Act and a new program called "Challenge 21", authorized and funded the Army Corps of Engineers to focus on nonstructural flood management methods as well as setback levees.

In spite of their advantages, setback levees have various drawbacks. They are expensive, they impact or eliminate productive farmland, and they require purchasing new levee easements and relocating infrastructure.

Review of Current Research on Setback Levees

Sacramento and San Joaquin River Basins Comprehensive Study

The devastating flooding of the Sacramento valley in January of 1997 brought to light the inadequacies of the current flood management structure and led to the creation of *Sacramento and San Joaquin River Basins Comprehensive Study* by the Sacramento District of the Army Corps of Engineers and the State Reclamation Board. The comprehensive study will develop a plan to increase flood protection and improve ecosystem function on all major rivers and tributaries of the Central Valley (http://www.spk.usace.army.mil/civ/ssj/genInfo/index.htm).

The Executive Committee	
Partners	
Federal	State
Participating Agencies	
U.S. Army Corps of Engineers	The Reclamation Board of the State of California
Fish and Wildlife Service	Department of Fish and Game
Forest Service	State Water Resources Control Board
Environmental Protection Agency	Department of Water Resources
Federal Emergency Management Agency	Department of Parks and Recreation
Bureau of Land Management	Department of Boating and Waterways
Geological Survey	State Lands Commission
Natural Resources Conservation Service	Office of Emergency Services
National Marine Fisheries Service	Department of Food and Agriculture
Bureau of Reclamation	

Table 1.2: Structure of the Comprehensive Study

There are two phases to the Comprehensive Study. Phase I assessed flood management systems and identified flood management and environmental problems. Phase II is analyzing potential solutions, including setback levees. Phase I was completed in June, 1999 and Phase II is set for completion in 2002.

Our group project analyzed a reach along the Sacramento with relatively constrained levees, and evaluated setback levees as a potential management solution. Our analysis was completely independent of this project and it will be interesting to see what their evaluation of setback levees will be for comparison.

Phase I Modeling:

Hydrologic Modeling

The development of extensive hydrologic models of both the Sacramento & San Joaquin began in Phase 1. These models contain historic rainfall-runoff, and current reservoir and flood routing activity. (http://www.spk.usace.army.mil/civ/ssj/genInfo/index.htm)

Ecological Modeling

Conceptual plans for an Ecosystem Function Model (EFM), which will incorporate the hydrologic models, will be used to evaluate biological response to physical processes in both terrestrial and aquatic habitats.

GIS Mapping

The River from River Mile 0 (Collinsville) to 218 (Vina-Woodson Bridge) has been surveyed and an elaborate GIS database will be developed for modeling inputs. When funding permits, the model will be extended to Shasta Dam.

Potential Measures: Setback Levees - Major & Minor

Two potential measures for increased flood protection and ecosystem function have been identified from the Comprehensive plan, namely major and minor setback levees. Minor setbacks are levees that are only a short distance away from the location of the existing levee (typically a few hundred feet). A detailed description of major setbacks will be given below due to their similarity to our project scenarios.

Major Setbacks

Parts of the Sacramento River are fairly constrained, leaving the earthen levee prone to breakage during flooding events. The presence of protective riprap in these areas prohibits riparian vegetation from being established, and levee policy does not allow for the establishment of any woody trees for fear of weakening the structure.

Major setbacks would include the full removal of the levee adjacent to the channel, and recycling the material to build a setback levee at some specified distance from the river. The Army Corps listed these benefits of major setback levees:

- Improved flood risk management throughout the river systems
- Reduced flood risk to lives and property
- Improved flood control system reliability
- Improved flood management
- Minimize flood control system operation and maintenance
- Promote the stability of native species populations, and the recovery of threatened and endangered species.
- Promote natural, dynamic hydrologic and geomorphic processes of the river system.
- Increased and improved riparian, floodplain, and flood basin habitats using an ecosystem approach.

The Army Corps indicates costs associated with major setback will include:

- Cost associated with buying the land
- Water rights
- Flood easements

Phase II

Phase II of the project consists of further calibrating the hydrologic and ecological models, and expanding the GIS database. These complex models will be used to evaluate the potential flood management solutions identified in phase I of the project, including setback levees.

Status Update:

"We certainly plan on looking at set back levees as appropriate measures to be considered under the comprehensive study; however we have not developed our analysis to the level of detail that we can be site specific at this time. More to come, we have you on our mailing list and encourage your interest as our studies proceed." Army Corps of Engineers 1/17/00.

Riparian Ecology Background

Introduction

In order to understand the effects of setback levees on the Sacramento River ecosystem it is necessary to have in-depth background knowledge of that ecosystem. First a detailed description of the riparian forest's importance to the

Sacramento River is given, focussing on successional processes and their intricate relationship to the larger biological system. Second, plant adaptive mechanisms, which help segregate the species into specific communities, are reviewed. Finally, previous manipulations of the Sacramento River and their potential negative effects on the vegetation are outlined.

Importance of Riparian Habitat

Riparian corridors are an integral component of Californian's natural ecosystems. Despite covering less than 0.5% of the state's total land area (Smith 1977), riparian corridors are critical to the functioning and integrity of almost all of the myriad of ecosystems found therein (Manley and Davidson 1993).

The vegetative structure of riparian forest is complex, but four main community types can be distinguished along the Sacramento River (Sacramento River Advisory Council 1998). This complexity in communities underpins the high-value habitat. Riparian habitat is reported to have higher biological diversity than any other forest type in California (Nature Conservancy California 1999). More than 135 species of birds use the Sacramento River riparian areas for nesting, foraging, and resting during migration (Nature Conservancy California 1999). Additionally, more than 250 species of mammals, amphibians, and reptiles reside in the Sacramento Valley and benefit from the riparian forests (Sacramento River Advisory Council,1998). Organic material from the forest is an important component of the aquatic systems' complex food web (The Nature Conservancy 1999). Fish populations benefit from increased riparian habitat because it creates shaded habitat and deposits organic debris into the channel. Riparian forest also preserves water quality by providing a vegetative buffer for pollution sources.

Historical Riparian Zone

The historic riparian landscape structure of the Sacramento River can be separated into three distinctive reaches.

- In the upper river between Redding and Red Bluff, the floodplain was characteristically narrow, constrained by geologic features, and had a steeper gradient (Greco 1999).
- Between Red Bluff and Knights Landing a classic meandering system existed, with a large floodplain up to 5 miles wide (Greco 1999), complete with bars, islands, point bars with pool-riffle systems, oxbow lakes, flood basins, and terraces (Thompson 1961; Keller 1977)(Buer et al.,1989). This area has a bed-slope gradient of 0.00036 (Greco 1999).

- Below Knights landing, the riparian zone narrowed and was dominated by flood basins (Greco 1999).

As early as 1848, residents of the Sacramento Valley noted a general decline in riparian vegetation (Katibah 1984). Previous to this time over 800,000 acres of forested riparian zone existed (Scott and Marquiss 1984). The width of the corridor was largest between Red Bluff and Colusa, river miles 145-245 (Sacramento River Advisory Council 1998). From the city of Colusa to the city of Verona, the riparian forest narrowed but still contained late successional riparian forest. Further extended from the late successional oak woodlands lay vast areas of marshland that were utilized by waterfowl (Sacramento River Advisory Council 1998).

Meandering and Channel Movement

The size of the river, its hydrologic regime, and the geomorphology of the surrounding landscape are the controlling factors in the width of the riparian zone. Riparian corridors on large river systems such as the Sacramento are well developed, extremely complex systems, with seasonal flooding, lateral channel migration, oxbow lakes, and a diverse biological community (Naiman, Decamps et al. 1993). River meandering is a large component of riparian forest formation. The meander is an area in the river with a high frequency of disturbance, creating a complex shifting mosaic of vegetative communities as it moves across the floodplain (Naiman, Decamps et al. 1993).

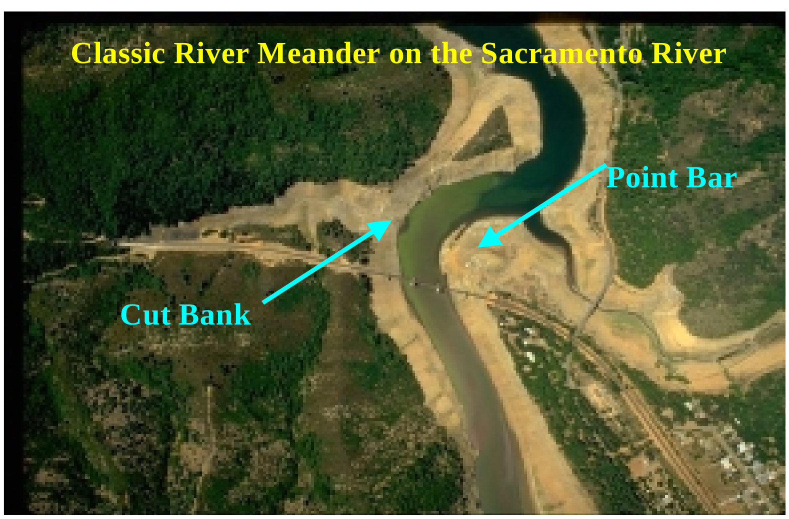

Figure 1.1: Meander on the Sacramento River

Riparian Succession

Succession is defined as a progression towards a stable plant community (Gebhardt, Leonard et al. 1990). The interaction of environmental factors such as soil and water provide a way to discern different community types (Gebhardt, Leonard et al. 1990). Riparian succession is a dynamic process; since conditions change rapidly, the system never attains a stable climax community and a shifting mosaic of all the different communities will ensue across the landscape. Four riparian forest communities have been described for the Sacramento River, representing different stages of succession. Willow Scrub Forest is the first successional stage, Cottonwood Riparian Forest, Mixed Riparian Forest, and Valley Oak Riparian Forest, are the second, third, and fourth successional stages respectively. These categories are used to delineate differences in riparian vegetation in the Sacramento River region.

During flood events, sediment in the water is deposited on the floodplain according to grain size. Larger particles such as cobbles and gravel deposit first, followed by sands and silts. This gradational deposition provides the substrate for early, intermediate, and late successional stages to develop. Willow Scrub and Cottonwood Riparian forests are the first communities to establish on the floodplain and, comprise the early and intermediate stages of succession. These communities tolerate frequent flooding and require coarse to medium textured soils. The last successional stages are the Mixed Riparian and Valley Oak Riparian Forests. These mature forests communities are not adapted to frequent flooding, requiring little water for survival. In fact, too much water is detrimental to these communities because their seeds are susceptible to rotting (Nature Conservancy California 1999).

Riparian Forest Community	Willow Scrub	Cottonwood	Mixed Riparian	Valley Oak
Elevation relative to channel	Even	Low Terrace	High Terrace	Upper High Terrace
Successional Stage	Early	Intermediate	Intermediate	Late

Flooding Frequency	Annually	1-3 Years	3-5 years	More than 5 years
Soil Description	Coarse comprised of cobbles, gravel, & sand	Coarse-Medium comprised of sand to sandy loam	Medium to fine comprised of fine sandy loam to silt	Fine comprised of silt to clay loam
Depth to water table	0-5 feet	5-10 feet	10-15 feet	15-20 feet
Annual flooding duration	20-50%	5-20%	0.1-5%	0.1%

Table 1.3: Sacramento River Riparian Community Characteristics
(CDFG 1999)

Elevation relative to river

Community Type	**Dominant Species**	**Flooding Frequency**
Willow Scrub Forest	Willows (black, red, yellow, arroyo, and dusky) Cottonwoods	Frequent
Cottonwood Forest	Tree Willow, Cottonwood, Black Willow Ash, Box Elder, Buttonbrush, Creeping Rye, Grape, Poison Oak	Occasional
Mixed Riparian Forest	Tree Willow, Cottonwood, Ash, Box Elder, Poison Oak, Grape, Buttonbrush, Sycamore, Black Walnut, Santa Barbara Sedge, Creeping Rye	Occasional
Valley Oak Riparian Forest	Valley Oak, Ash, Black Walnut, Sycamore, Pipevine, Grape, California rose, Poison Oak, Creeping Rye, Santa Barbara Sedge	Infrequent

Frequency, duration, and depth of inundation.

Table 1.4: Dominant Species of Community Types – for a more detailed list of common vegetative species, see Appendix E.

Factors affecting community establishment

The type of vegetative community established depends on several factors (Nature Conservancy California 1999). These parameters help define what habitat is found in a given riparian zone.

- Flood Frequency- Species composition varies with the frequency of flooding. Sites that flood at least yearly will establish almost all species of riparian trees (Nature Conservancy California 1999). Flooding will increase seed dispersal and increase water availability for plants.
- Topographic Heterogeneity- Variation in height along the river channel creates a gradient for communities to separate along.
- Soil Conditions- Riparian species establish on different soil. Valley Oaks and Elderberry require loam to endure long period of drought. Baccaris and Sycamores grow well in sandy soils.

- Depth to Water table- Cottonwoods and willows are phreatophytes (their roots must be in direct contact with the water table).
- Regeneration Potential- Adequate seed germination and dispersal requires seeds of native plants to be available, and flooding events.

Habitat Value of Riparian Species

Riparian vegetation is intricately connected to animal species and contributes to habitat value. The successional habitats and structural diversity in a riparian system creates copious niches, leading to high biological diversity. Over 40% of the mammal and reptile species in the Western United States are dependent on riparian habitat (Faber and Holland 1988). Riparian vegetation provides cover and food essential for species survival. For example, overhanging vegetation (shaded riverine aquatic habitat) provides the shade necessary for juvenile salmon, otter, and beaver (Nature Conservancy California 1999).

Common Name	Habitat Value
California Box Elder	Goldfinches, raccoons, meadow mice, rats, white-footed mice and squirrels consume seeds. Host plant to insects that are prey for song birds during spring migration. Fair-good browse for deer.
Coyote brush	Habitat cover for quail, woodrats, brush rabbits, and many other wildlife. Host plant to insects that are prey for song birds during spring migration.
Mule fat	Host to insects, mainly aphids, which are prey by song birds during spring migration.
Buttonbush	Seeds provide food for birds. Beavers eat the bark, and deer browse on twigs. Host plant to insects which are prey of song birds during spring migration.
Wild clematis	Host to insects which are eaten by song birds during spring & fall migration.
Oregon ash	Seed provides food for various birds and mammals. Beavers feed on bark and twigs. Leaves are important foliage for insects.
California sycamore	Minor food source for purple finches and other birds. Important nesting habitat for many bird species. Provides cavity nesting for birds and mammals.
Fremont cottonwood	Preferred habitat of neo-tropical birds such as the endangered yellow-billed cuckoo, osprey, & Swainson's hawk. Host plant to insects which are eaten by song birds during spring migration. Host plant to insects which are favored by the yellow-billed cuckoo. Seeds are a food source for squirrels, meadow mice, and foxes. Deer browse the foliage.
Valley oak	Acorns provide food source for deer, mallards, wood ducks, pheasant, pigeons, quails, crows, jays, woodpeckers, rabbits, mice, muskrats, squirrels, woodrats, raccoons, and foxes. Provides nesting for owls, woodpeckers, and bluebirds Host plant to hundreds of invertebrates which provide food for song birds and neo-tropical migrants.
California wild rose	Fruit and seeds are a food source for rodents, rabbits, & song birds. Host plant to insects eaten by song birds during spring migration. Fair-good browse for deer. Good habitat cover for a variety of wildlife
Goodding's willow	Twigs, foliage, and inner bark are a food source for beaver, rabbits, and deer. Finches eat buds and other songbirds Rodents consume seeds and young shoots. Host plant to insects eaten by songbirds during spring migration.
Sandbar willow	Twigs, foliage, and inner bark are a food source for beaver, rabbits, and deer. Finches and other songbirds eat buds. Rodents consume seeds and young shoots. Provides important shaded riverine aquatic habitat (SRA) for fish.
Arroyo willow	Twigs, foliage, and inner bark are food source for beaver, rabbits, and deer. Host plant to insects for neo-tropical migrant birds.
Mexican elderberry	Host plant to the endangered valley elderberry long-horn beetle. Foliage are browsed by deer and flowers provide nectar for insects. Quail, orioles, and blackbirds eat the fruit.

Table 1.5: Habitat Value of Riparian Vegetative Species (CDFG 1999)

Adaptive Mechanisms of Riparian Species in the Sacramento River

Natural processes along the Sacramento River provide ideal conditions for plant community establishment. Vegetation along the Sacramento River is adapted to flooded conditions. Most species on the river are phreatophytes, deep-rooted plants that obtain their water from the water table or the layer of soil just above it (Nature Conservancy California 1999). Flooding is also a major component of seed dispersal for riparian vegetative species (Johansson, Nilsson et al. 1996). The communities on the Sacramento River are reliant on the seasonal inundation during flood events. General correlations have been made between natural river processes and plant species (Nature Conservancy California 1999).

Species	**Mechanism**	**Dependence on Sacramento**
Willows/Cottonwoods	Rapid Growth	Needs moist areas to germinate and establish quickly to survive the hot dry summers.
Cottonwoods	Timing of seed release	Releases seeds in Spring, correlates with the receding of flood waters.
Sycamore	Timing of seed release	Releases seeds in January, when water is low, increasing chance that seeds will land on high terrace areas.
Variety of Riparian Species	Seed dispersal	Uses flood waters to carry seeds and disperse.
Variety of Riparian Species	Root Systems	Utilize sand and silt from flood events for rooting.
Variety of Riparian Species	Oxygen Tolerance	Tolerates low oxygen in soils during flooding events.
Variety of Riparian Species	Recovery from flooding	Mechanisms in place to root and survive flooding events.

Table 1.6: Physiological Adaptive Mechanisms of Species Along the Sacramento River (CDFG 1999)

Interconnectivity of the Riparian Environment

Riparian environments are dynamic systems of complex relationships of physical and biotic interactions across different habitats (Allan 1995). Habitats are connected through ecotones, which are transition zones between adjacent habitats (i.e. river and floodplain, groundwater and surface water) (Ward, Tockner et al. 1999). Connectivity refers to the interactions, or transfer of, organisms, matter, and energy across ecotones. Riparian systems experience connectivity over lateral and vertical planes (Cowx and Welcomme 1998; Ward 1998). Natural disturbance leads to connectivity between ecotones and spatio-temporal heterogeneity (Ward 1998). River meandering and floods are natural mechanisms of disturbance that create and maintain habitats like pools and riffles within the stream environment and aquatic habitats associated with the floodplain (side channel habitat and oxbow lakes). River meandering and floods also drive successional processes on the floodplain. High levels of spatio-temporal heterogeneity allow for high biodiversity found in riparian systems (Ward 1998). The Sacramento River system provides habitat for a variety of plants, fish, and wildlife as seen in previous sections of the riparian background and in appendices C, E, and F.

Degradation of Riparian Habitat due to River Channelization

Anthropogenic modifications to many streams have reduced their capacities for connection with ecotones and have resulted in reduced habitat heterogeneity and biodiversity (Cowx and Welcomme 1998; Mensing, Galatowitsch et al. 1998; Ward, Tockner et al. 1999). Channelization of rivers with levees is a historical source of riparian habitat degradation (Cowx and Welcomme 1998; Sacramento River Advisory Council 1998).

Rivers are generally channelized for agricultural purposes, urban development, and flood control. River floodplains are attractive places for agricultural and urban development because they have little topography and fertile soils. The presence of cultivated lands in the riparian zone significantly affects the biological habitat. A fraction as low as 7-16% of agricultural land correlates strongly with disturbances in the biological community (Mensing, Galatowitsch et al. 1998). River channelization has been used to control small scale floods by removing water from the system as quickly as possible by eliminating meanders and minimizing frictional resistance (Mount 1995). All these activities cause the degradation or loss of riparian flood plain habitat.

Specifically, levees constrain the river, limit its migration, and curtail flooding, eliminating the normal successional process. By holding flooding and meandering processes in check, levees limit the lateral connectivity between the river and the floodplain, which is important for maintaining the spatio-temporal habitat heterogeneity necessary to maintain biodiversity.

The Sacramento River, like many rivers, has been heavily modified by dams, levees, and diversions, which have simplified this system and have likely contributed to the decline or extinction of many species that use the riparian environment. There are many species within the Sacramento River system that have been designated with special status due to significant decline in their population sizes (appendix F). The decline of Chinook salmon has been directly linked to disruption of lateral and longitudinal connectivity along the Sacramento River (Fisher 1994; Moyle, Yoshiyama et al. 1995; Yoshiyama, Fisher et al. 1998).

In consideration of the discussion of this section and in light of several studies (Cowx and Welcomme 1998; Mensing, Galatowitsch et al. 1998; Ward 1998; Ward, Tockner et al. 1999), it can be seen that maintaining connectivity across longitudinal, lateral, and vertical planes is important in maintaining habitat heterogeneity and the biodiversity associated with it. Restoration of disturbance and connectivity across ecotones is fundamental for the rejuvenation of ecosystem and biodiversity (Ward, Tockner et al. 1999). Setback levees are believed to be a means for restoring some of the natural functionality and lateral connectivity to riverine environments currently channelized and constrained by traditional levee practices (Cowx and Welcomme 1998).

From the above discussion we have assumed a simple relationship between levees and their impact on the ecosystem, demonstrated in figure 1.2.

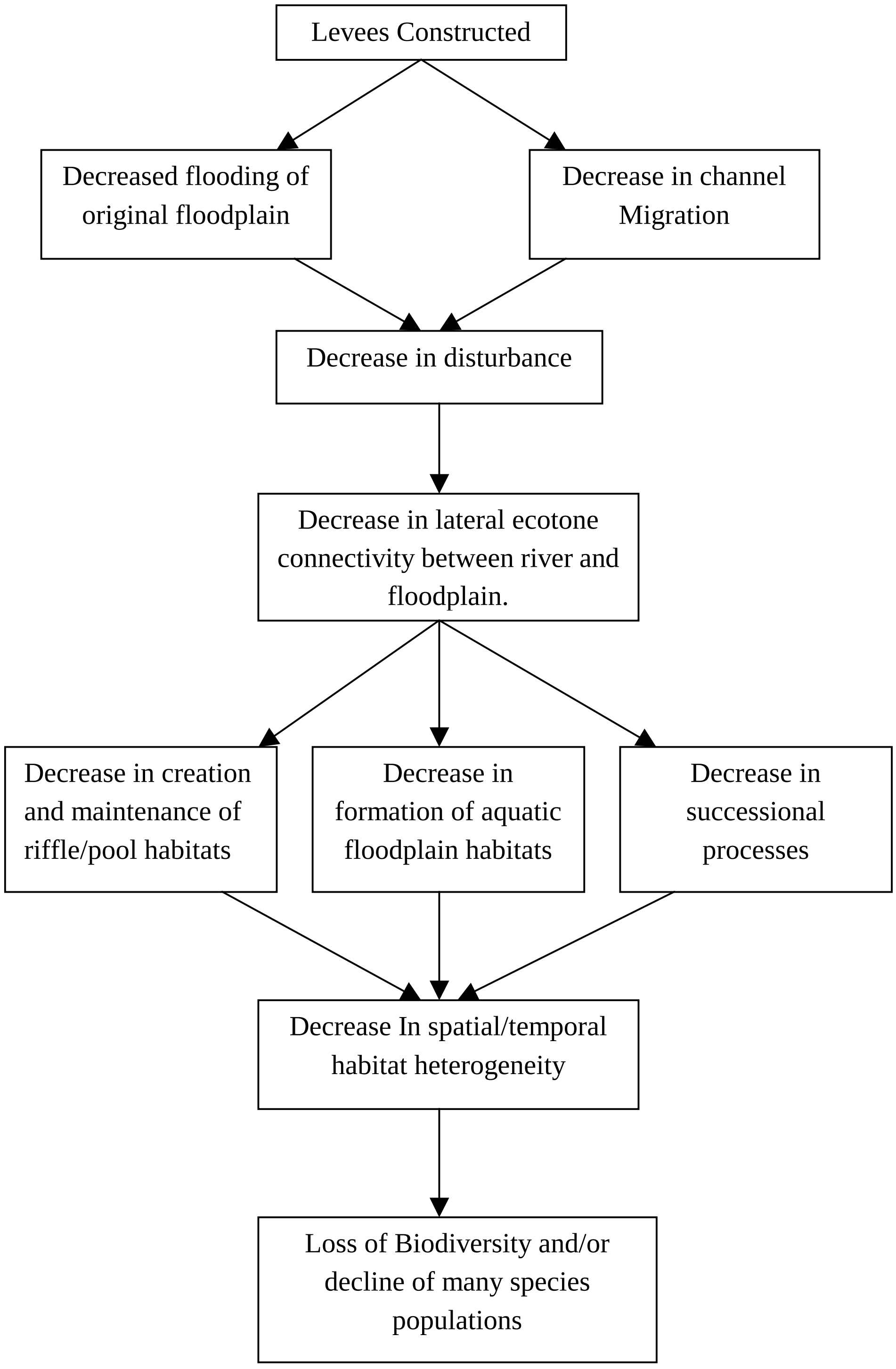

Figure 1.2: Levee Impacts on Ecosystem Flow Chart

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Project Organization

Project Constraints

This project evaluates the potential effects of setting back levees along the Sacramento River. Setback levees have recently been considered along many rivers to improve flood control as well as increase riparian habitat. The Sacramento River was chosen for this analysis because of the importance of the river, as well as the Sacramento Valley, to the state of California. The river not only serves as a major source of water for the state, but the rich agriculture within the valley contributes significantly to the state economy. It is well documented that the Sacramento Valley was once an area of dense riparian forest supported by a meandering river that flooded regularly. Although the current levees protect valuable agricultural land adjacent to the river from flooding, they also constrain the river, preventing the formation of riparian forest which is so critically needed by many species. The river therefore presents a challenge of balancing the economic and ecological interests of the area.

Both the State of California as well as the Federal government have conducted research in this area, providing extensive sources of information. Due to the time given to complete this project (approximately one year), it was important that the information be readily available. Both time constraints and lack of data prevented the project from evaluating the tributaries to the Sacramento River, although the methodology of our analysis should be applicable to studying these tributaries.

The project evaluates the hydrological and ecological implications, as well as the associated costs and benefits, of setting back levees along the Sacramento River. The policy implications will not be evaluated in detail, although a brief review of the agencies involved will demonstrate the complexity of the issues.

River Reach Constraints

The project focuses on the reach of the Sacramento River from river mile 143 to river mile 84. This reach was chosen based on several factors:

- North of river mile 182 there are no levees constraining the river. Between river mile 182 and 175, levees exist only on the west bank of the river (U.S. Army Corps of Engineers 1991). This allows the river to meander toward the east, and an analysis there would not be useful. Although the levees from river mile 175 to river mile 143 are closer to the river channel the river is still able to meander to some extent because the distance between the levees is approximately one mile (about 10 channel widths).

- From river mile 143 to river mile 84 the levees are either directly adjacent to the river or are only set back in small areas.
- Although the levees south of river mile 80 still constrain the river, there are other factors that limit the analysis in that region. The city of Sacramento is located at approximately river mile 63. Just north of that, at river mile 70, there is a large bridge where interstate highway 5 passes over the river. The Sacramento airport lies a short distance away from the river at river mile 73-75. These structures below river mile 84 were considered to present significant limitation in terms of cost. In addition, the Yolo and Sutter Bypass systems connect with the Sacramento River between river mile 80 and 84, tremendously increasing the complexity of the hydrology within that region. Analysis south of this region would also have been difficult due to the limitation of the GIS database that was provided by the California Department of Water Resources, which ends at river mile 76.

Organization of Project

The project is organized into three disciplines: hydrology, ecology, and economics. This allowed research members to work within their specialty, and improved the project’s overall efficiency. All members of the research group met weekly to insure common goals were met, and to exchange information between the different groups. Each scenario within the project was analyzed within these three different emphases, but the synthesis of results and conclusions was the responsibility of the entire group.

Hydrology

The goals of the hydrologic analysis were to provide both a quantitative and qualitative framework for economic and ecological evaluations. For each proposed setback scenario and associated floodplain width, the depth of floodplain inundation for chosen flood recurrence intervals was computed. The analysis also determined how channel velocity changes for a given flood under different scenarios. Furthermore, a qualitative analysis addressed the effect setback levees would have on river meandering patterns.

Ecology

The goal of the ecological evaluation was to determine if setback levees would benefit the Sacramento River system as an ecological unit and if so, the extent to which this would happen under different proposed setback scenarios. Human manipulations of the river system have resulted in an overall simplification of the ecological system, which has led to a general decrease in productivity and diversity within this system. Setback levees are currently being considered as a mechanism to restore some of the environmental complexity to riverine systems that would increase productivity and diversity.

Economics

The goals of the economic analysis were to quantify the potential costs and benefits of setting back levees on a particular reach of the Sacramento River. These include costs associated with setting back the current levee system, such as purchasing land, building new levees, and removing existing levees. These costs were compared to the economic benefits, such as increased riparian habitat and improved salmon habitat. The cost/benefit analysis for each scenario was used to make recommendations for the most suitable scenario.

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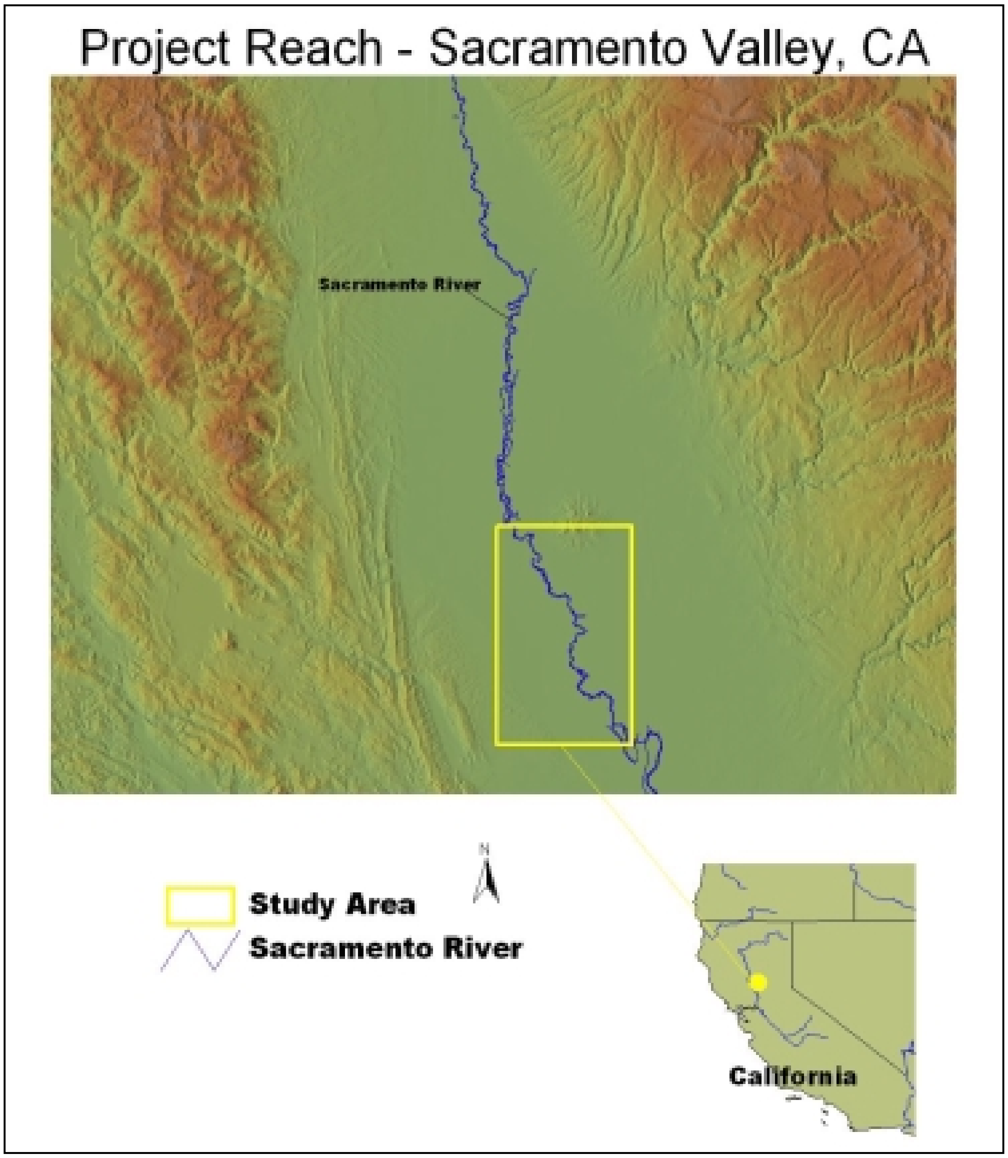
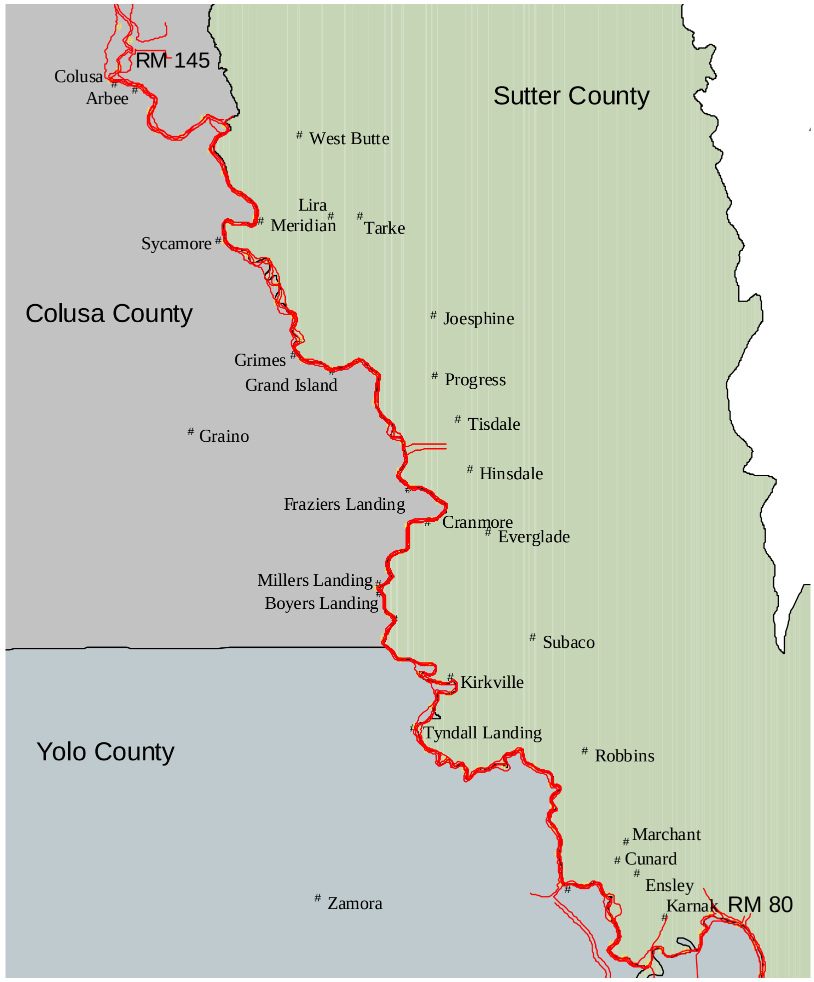
River Reach Characteristics

The area of the Sacramento River chosen for analysis reaches from river mile (RM) 143, just north of the city of Colusa, to RM 84. The levees north of Colusa are not located directly adjacent to the river, but are on average approximately 1 mile apart, which is about ten channel widths. Since this distance still allows the river to meander to a certain extent, the most northern part of our reach marks the first location in the Sacramento River where levees constrain the river to such an extent that it is not able to meander.

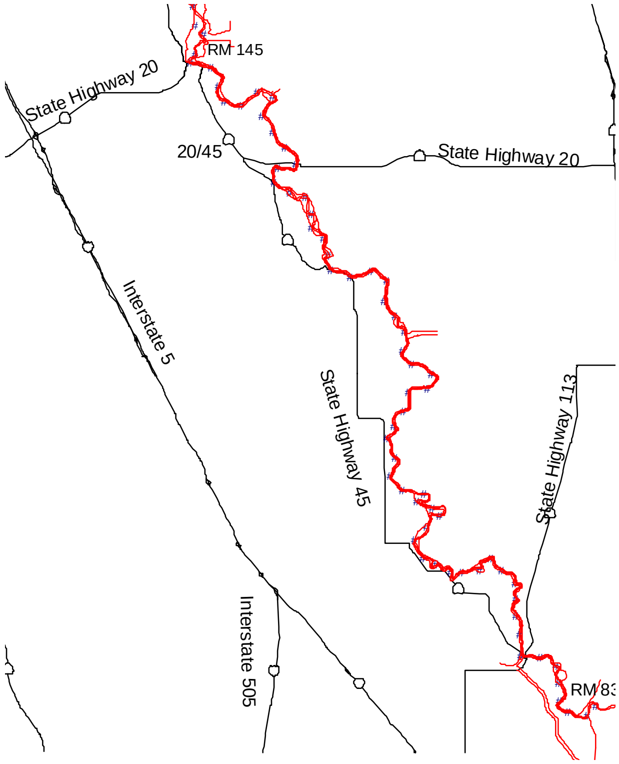
The following maps show the location and characteristics of the reach of the Sacramento that is analyzed in this study. It should be noted that the scenarios developed for this analysis do not propose to move cities or major roads, (see *Preliminary economic analysis to define limitations* section of the Scenario Strategy chapter). For a detailed description of the reach, please see appendix A.



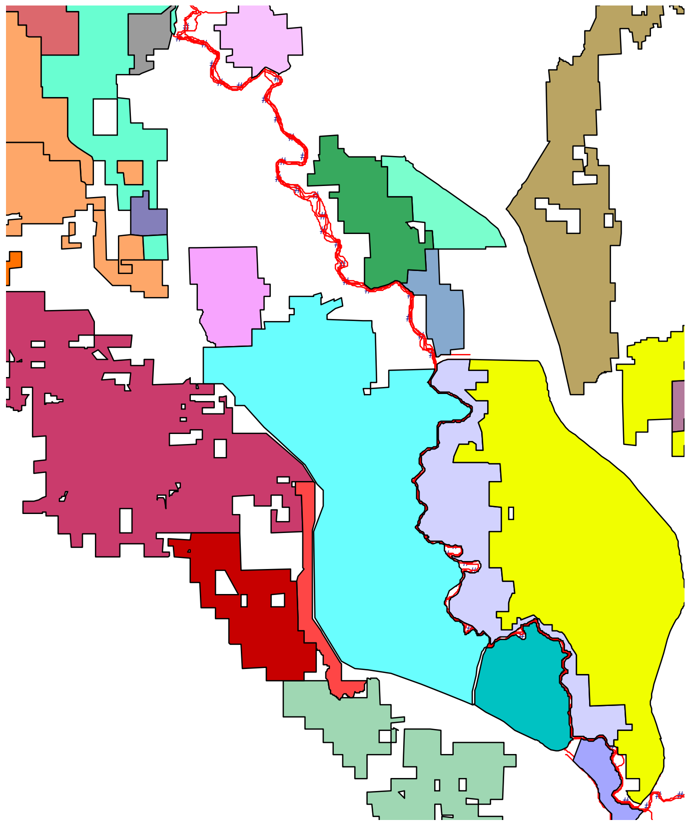
Map 3.1: Map of Project Reach (Department of Water Resources 1998)



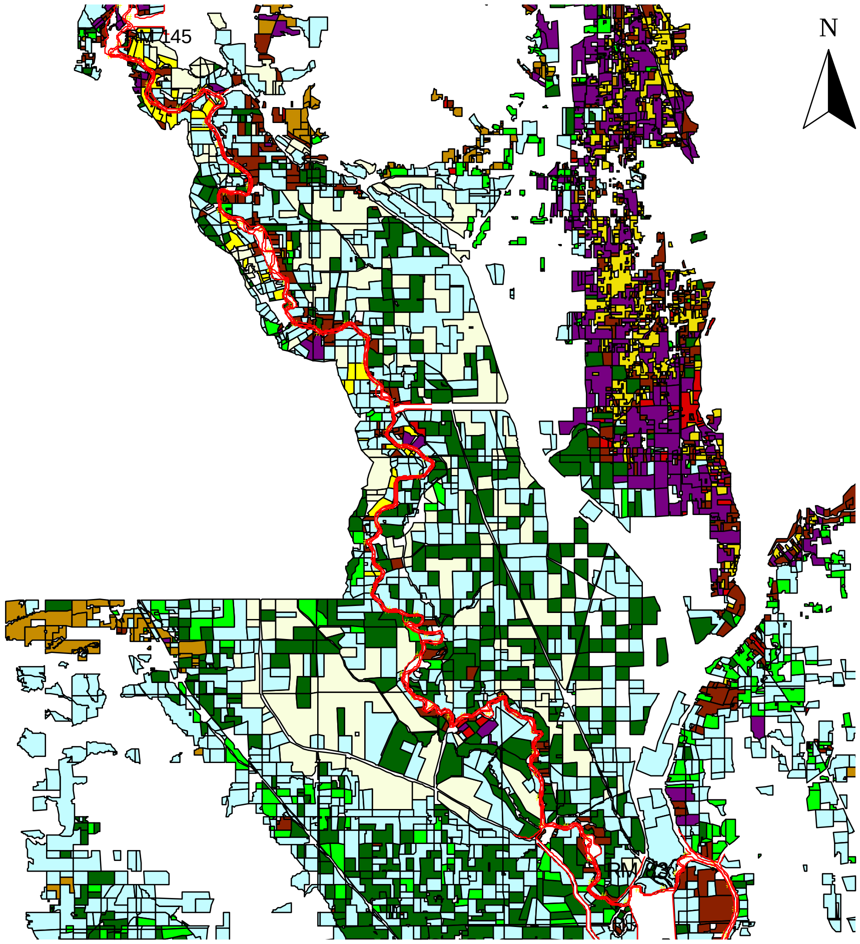
Map 3.2: Counties and Towns (Department of Water Resources 1998) .



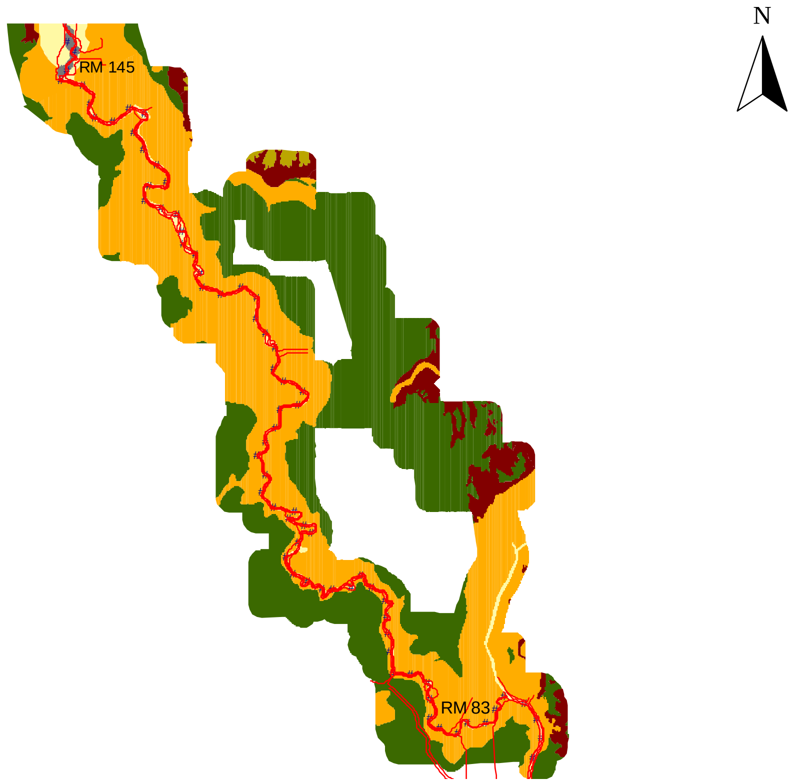
Map 3.3: Highways (Department of Water Resources 1998)



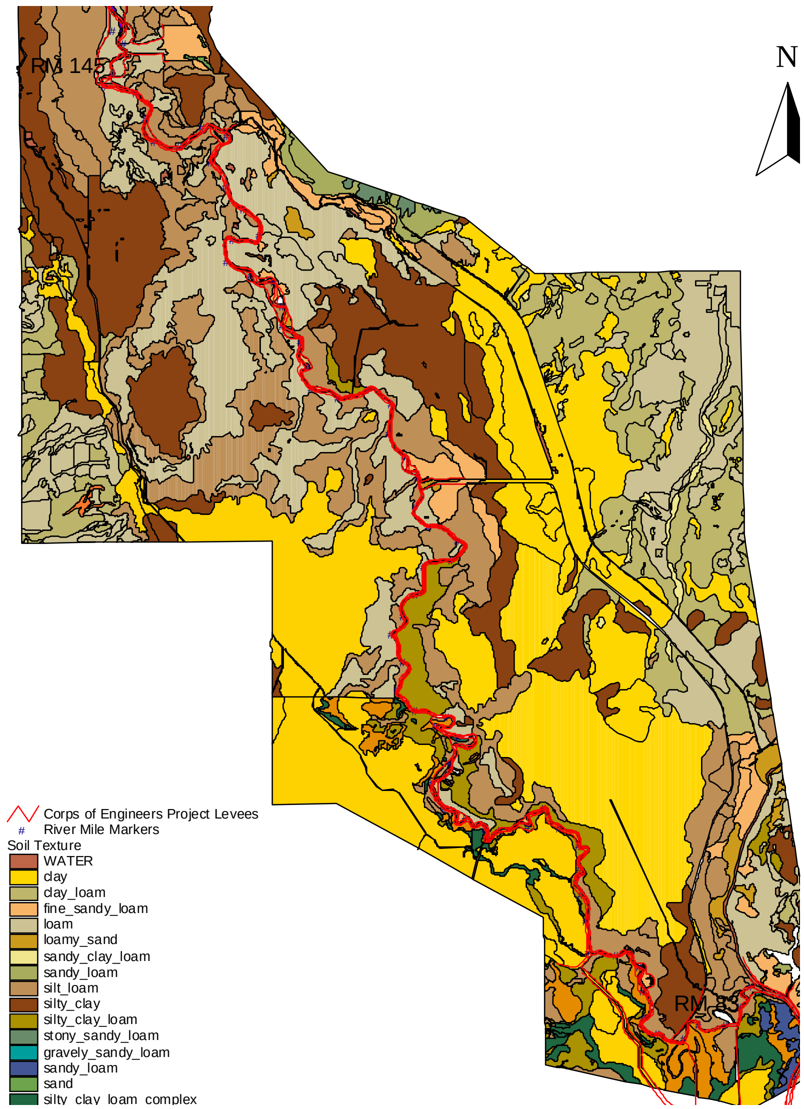
Map 3.4: Water Districts (Department of Water Resources 1998)



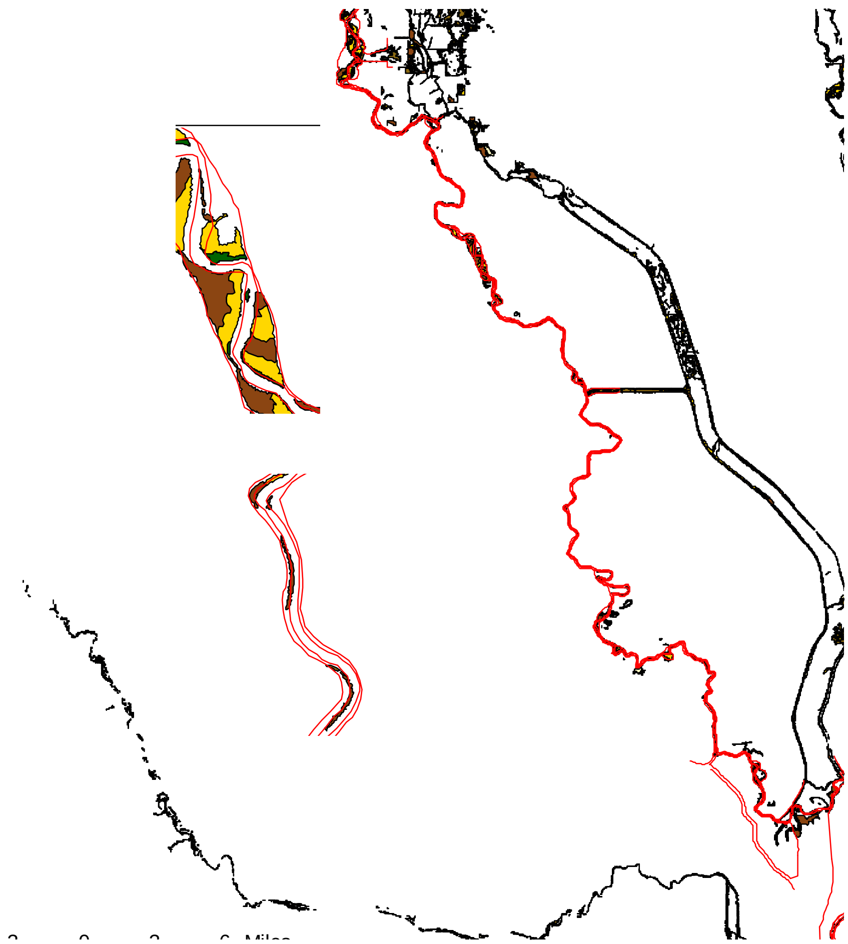
Map 3.5: Land Use (Department of Water Resources 1998)



Map 3.6: Surface Geology (Department of Water Resources 1998)



Map 3.7: Soil Texture (Department of Water Resources 1998)



Map 3.8: Riparian Habitat (Department of Water Resources 1998)

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Scenario Strategy

Introduction

The purpose of the project is to allow recommendations to emerge from analysis of a range of options, rather than analyzing only one setback width. The research was therefore done using three setback width scenarios. This allows readers to see the effects of setting the levees back to several different distances from their current location.

The methodology for selecting the scenarios, as well as a description of the scenarios is given in the *Define Scenarios* section of this chapter. After defining the different scenarios, each was analyzed in terms hydrology, ecology and economics. Hydrologic calculations were used to find the depth of the water on the floodplain between the setback levees at different flood intervals, as well as the change in river velocity and locations of potential meandering. The meandering predictions and river velocities were then used in conjunction with the setback width information to determine the ecological affects of setback levees. The costs and benefits were calculated for each scenario using the calculated wetland acreage created and the area of land that would need to be purchased.

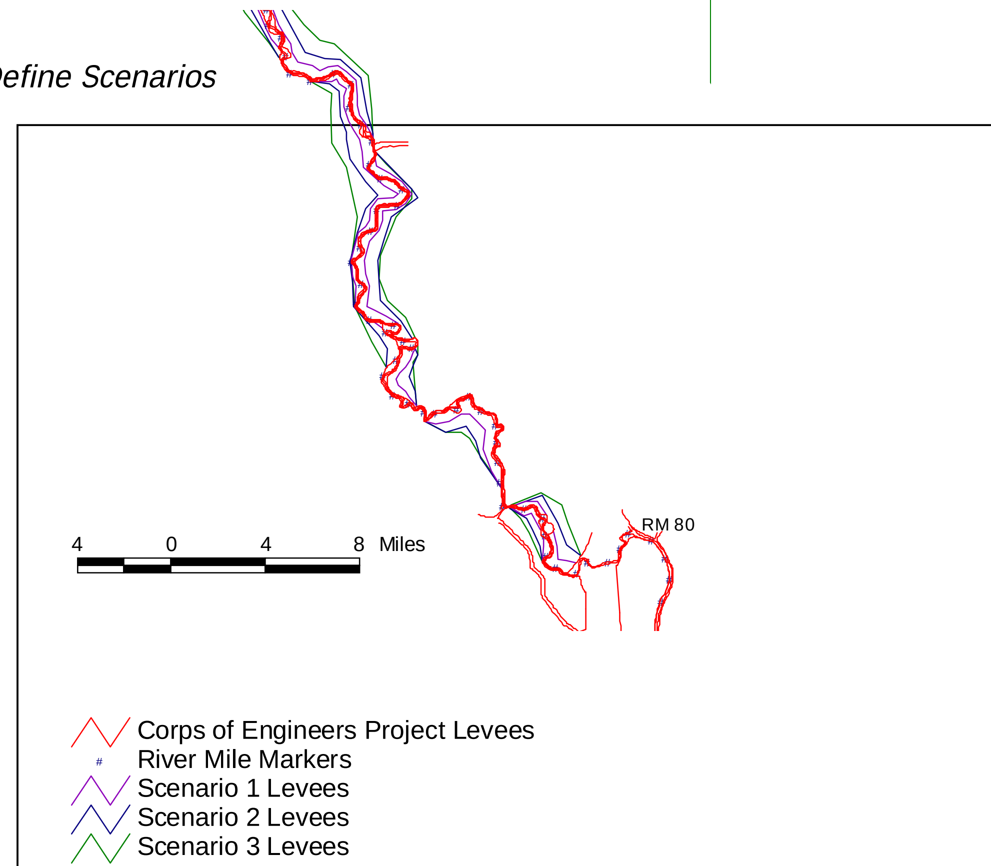
Preliminary Economic Constraints

The reach under study was first examined for obvious economic limitations (city, large road, bridge, etc.). These areas are listed in the Table 4.1, and were determined from aerial photographs (U.S. Army Corps of Engineers 1991). We do not suggest in the scenarios that cities or major bridges be moved; instead, the scenarios attempt to compensate by setting back the levees further on the opposing side of the river.

River Mile	Constraint	Side of River	County
89-90	Knights Landing	West	Yolo
102	Tyndall Landing	West	Yolo
~ 125	Grimes	West	Colusa
134	Meridian	East	Sutter
132	Highway 45	West	Colusa
142-145	Colusa	West	Colusa
~ 125	Grimes	West	Colusa
119-105	Cranmore Road and West Side Canal	East	Sutter

Table 4.1: Preliminary Economic Constraints

Define Scenarios



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Methodology

Hydrology

As stated earlier, the goal of the hydrologic analysis is to establish some hydraulic parameters for the ecological analysis. The following methods were chosen, given the constraints of time and resources, as being the most effective way to carry out the analysis.

Digital terrain models were acquired from the Sacramento office of the Army Corps of Engineers for the study reach (RM 143 to RM 84) along the Sacramento River. Four separate digital terrain files, each covering approximately 20-25 river miles, made up the length of the study reach. These files were viewed within an AutoCAD/SelectCAD interface, and give detailed elevation points and a plan-view of the river outlined by project levees. A total of 23 cross sections, spaced approximately 2 to 5 miles apart, were extracted from the digital terrain files. For each cross section, elevation was given in ten-foot increments across the floodplain and channel (Figure 5.1). Floodplain data extended only a few hundred feet beyond the levees.

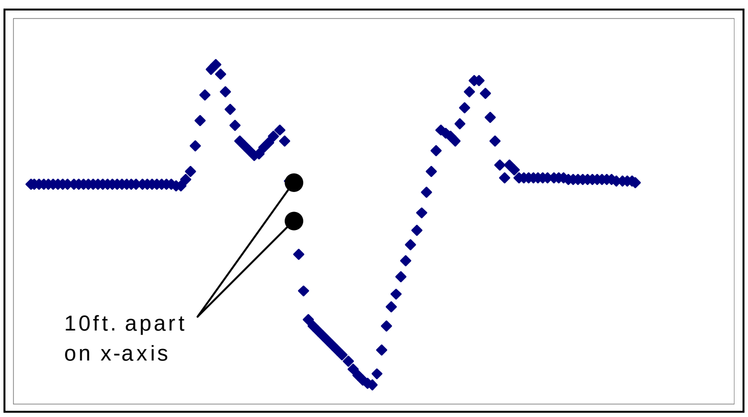


Figure 5.1: Sample cross section taken at RM 122.8.

There are two major assumptions in the following analysis; (1) flow is steady and uniform and (2) calculations made at individual cross sections are independent of one another. Thus, a particular cross section only describes conditions at that cross section and has no influence on the conditions at other cross sections.

For each cross section a rating curve relating discharge to water surface elevation, or stage height (*h*), was constructed. Levee top height was chosen as the initial stage height (the levee top having the lowest elevation was chosen in cases where the two were not at equal elevation). After choosing the stage height values, discharge was then calculated using the Manning equation:
where (*w*) is width in feet, (*s*) is slope, (*R*) is the hydraulic radius, which is

$$Q = 1.49\frac{R^{5/3}s^{1/2}w}{n}$$

approximated by flow depth in feet, (*n*) is the Manning roughness coefficient and (*Q*) is discharge in cubic feet per second.

Estimating Channel Discharge

For total channel discharge (Q_{ch}), separate discharge calculations (Q_1, Q_2, Q_3, *etc.)* were made for ten-foot increments of width, moving from left to right across the channel, and then summed. Flow depth at each ten-foot increment was measured as the difference between the bed elevation and the chosen stage height (Figure 5.2). For each of the four sub-reaches (corresponding to the separate digital files), channel slope was approximated by the average floodplain slope (Figure 5.3). Slope values reported here are similar to slope values reported in other sources (Water Engineering & Technology 1990)(Schumm and Winkley, 1994). Values of the Manning roughness coefficient, for the channel (n = .035) and the floodplain (n = .030), were approximated by comparing values taken from various sources (Chow 1959; Arcement 1989; Mount 1995). For large rivers, there was relatively little variance in the values taken from these sources (ca. $\pm$ .005).

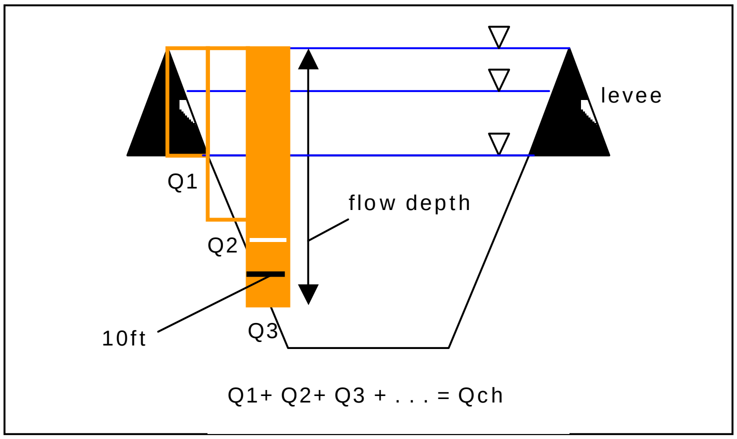


Figure 5.2: Sample Diagram for Flow Depth Calculation

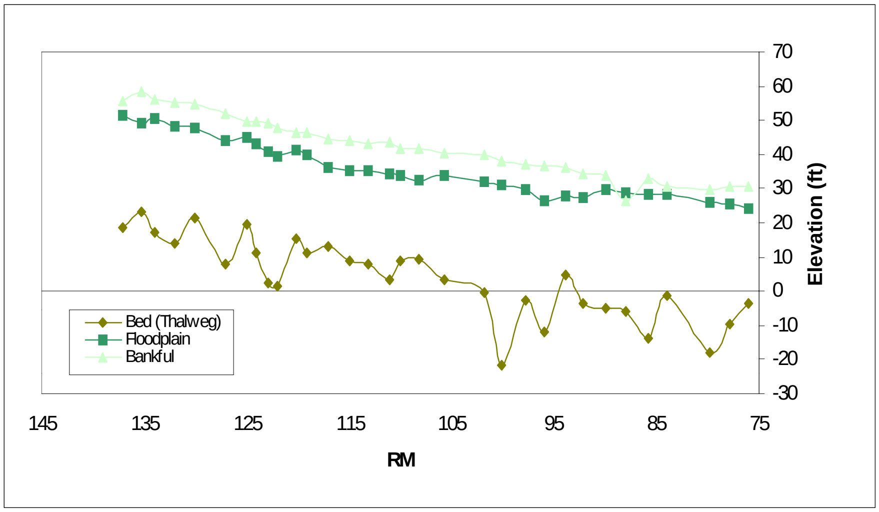


Figure 5.3: Long Profile of Study Reach -using elevation data from cross sections

Rating curves were thus established for each initial cross section relating channel discharge to stage height (Figure 5.4).

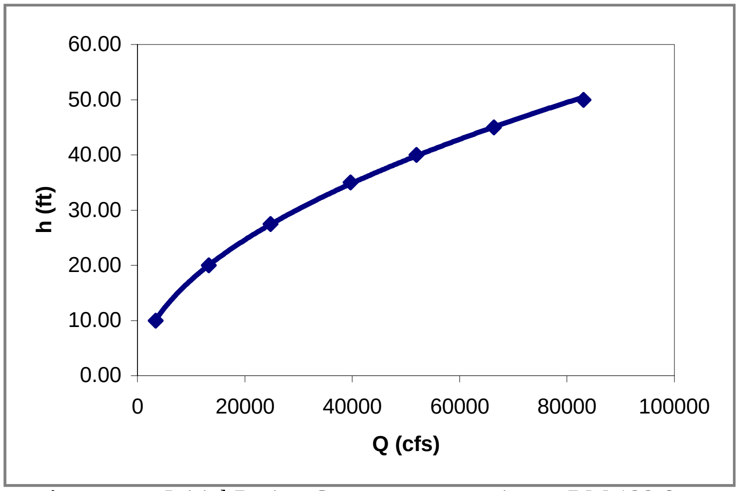


Figure 5.4: Initial Rating Curve - cross section at RM 122.8

Estimating Floodplain Discharge for Setback Scenarios

Rating curves were again calculated at each cross section, this time for each of three setback scenarios previously described. At every cross section, discharge over the left and right floodplain, for each scenario and stage height, was added to the initial channel discharge calculated above. In this manner, total discharge was calculated for the various stage heights under each scenario. The calculation of floodplain discharge, however, was slightly different than the calculation of channel discharge.

From the cross section data, average floodplain elevation, for both the left and right floodplain, was visually estimated. For each scenario and subsequent calculation, this elevation was assumed to be constant across the entirety of the floodplain (i.e.; from the channel boundary to the levee). Another important assumption was that the channel-side of the setback levees is essentially vertical.

It is recognized that this method does not take into account the existence of floodplain micro-topography or the formation of natural levees. Data concerning detailed floodplain micro-topography did not exist in the digital files, nor could it be located given the constraints of time and resources. Furthermore, given the prevalence of a graded landscape along the study reach, a result of agricultural land use (Mount 1995), this approximation of floodplain elevation was deemed reasonable.

For the calculation of discharge over the left and right floodplain, the Manning equation was again employed in much the same manner as above. The calculation of slope, flow depth, and the Manning roughness coefficient is the same as described above for the determination of channel discharge. Width was measured as the distance from the levee to the channel boundary, for the left and right floodplain (Figure 5.5).

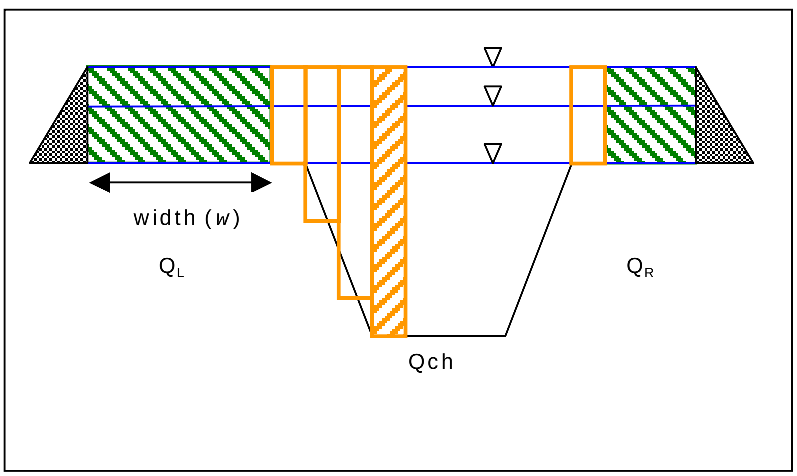


Figure 5.5: Q_L + Qch + Q_R = Qtot

Rating curves were thus established for each cross section, and each setback scenario, relating channel discharge to stage height (Figure 5.6).

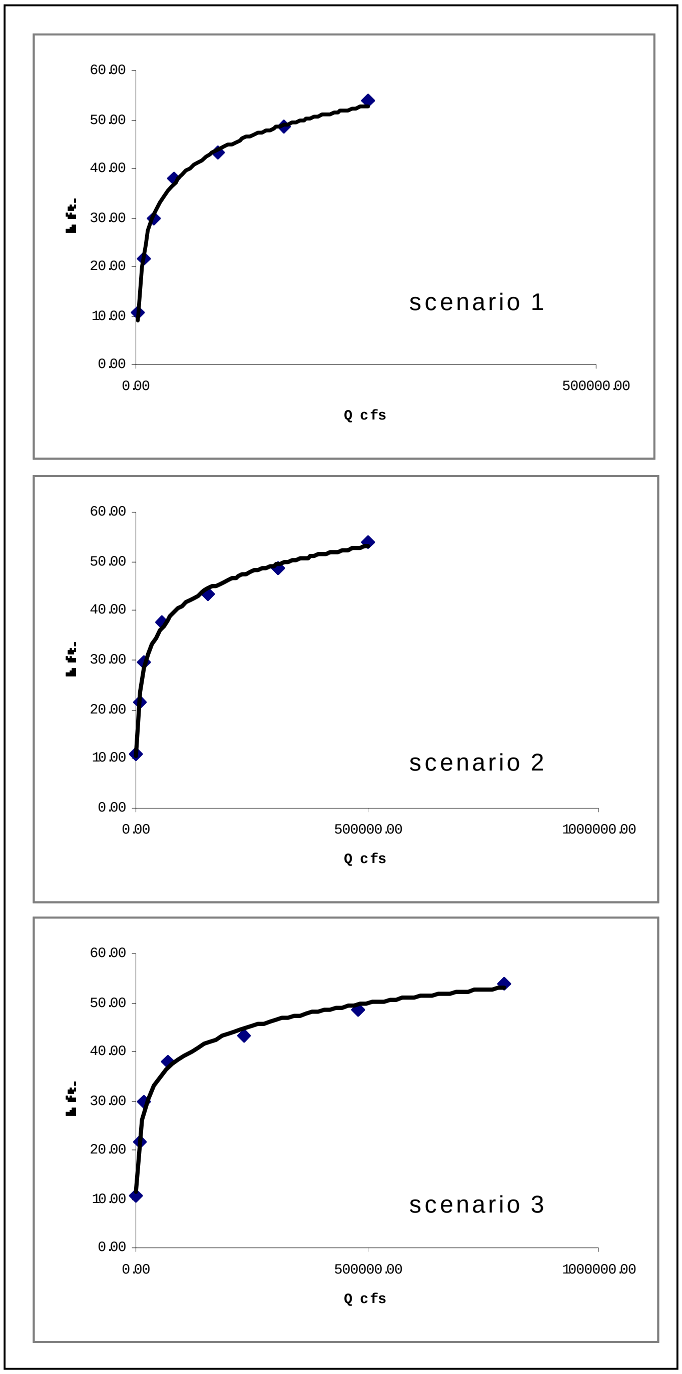


Figure 5.6: Scenario Rating Curves-for cross section at RM 122.8

In the next step, for each cross section and the corresponding setback scenarios, the stage heights for the 2, 5, 10, 25, 50, 100 and 500-year flood intervals were approximated using the rating curves. The magnitude of discharge for each flood return interval was estimated from a flood frequency curve. Average floodplain elevation relative to the bed, for the left and right floodplain, was subtracted from the stage height in order to estimate the flow depth over the respective floodplains.

Constructing Flood Frequency Curves

In order to construct the flood frequency curves, annual peak flow data was obtained from the United States Geological Survey's (USGS) website for three gauging stations within the study reach: the Colusa station (RM 143), the Wilkiens Slough station (RM 117.5) and the Knights Landing station (RM 90) (Appendix H). Using the reported annual peak flows for water years 1944–1998, flood frequency curves were calculated for each gauging station. Data for water years earlier than 1944 was not considered because the Shasta Dam was not in operation at this time and, thus, this period represented a different overall flow regime within the Sacramento River. Using the Weibull, plotting position method, curves for each gauging station were constructed relating discharge to non-exceedence probability. The Log-Pearson Type III and Gumbel Type I (U.S. Water Resources Council 1981; Bedient and Wayne 1992) distributions were then used in an attempt to describe the distribution of the data. The Gumbel Type I method seemed to grossly overestimate the frequent floods, thus, this distribution was not employed. The Log-Pearson Type III method described the distribution of our data well. Therefore, this method was used to estimate the magnitude of discharge for the various flood return intervals, or non-exceedence probabilities as they are shown here (Figure 5.7). Using these estimates for different return intervals, the flow depth over the left and right floodplain was calculated for each given return interval, at each cross section and for each setback scenario (see Results chapter).

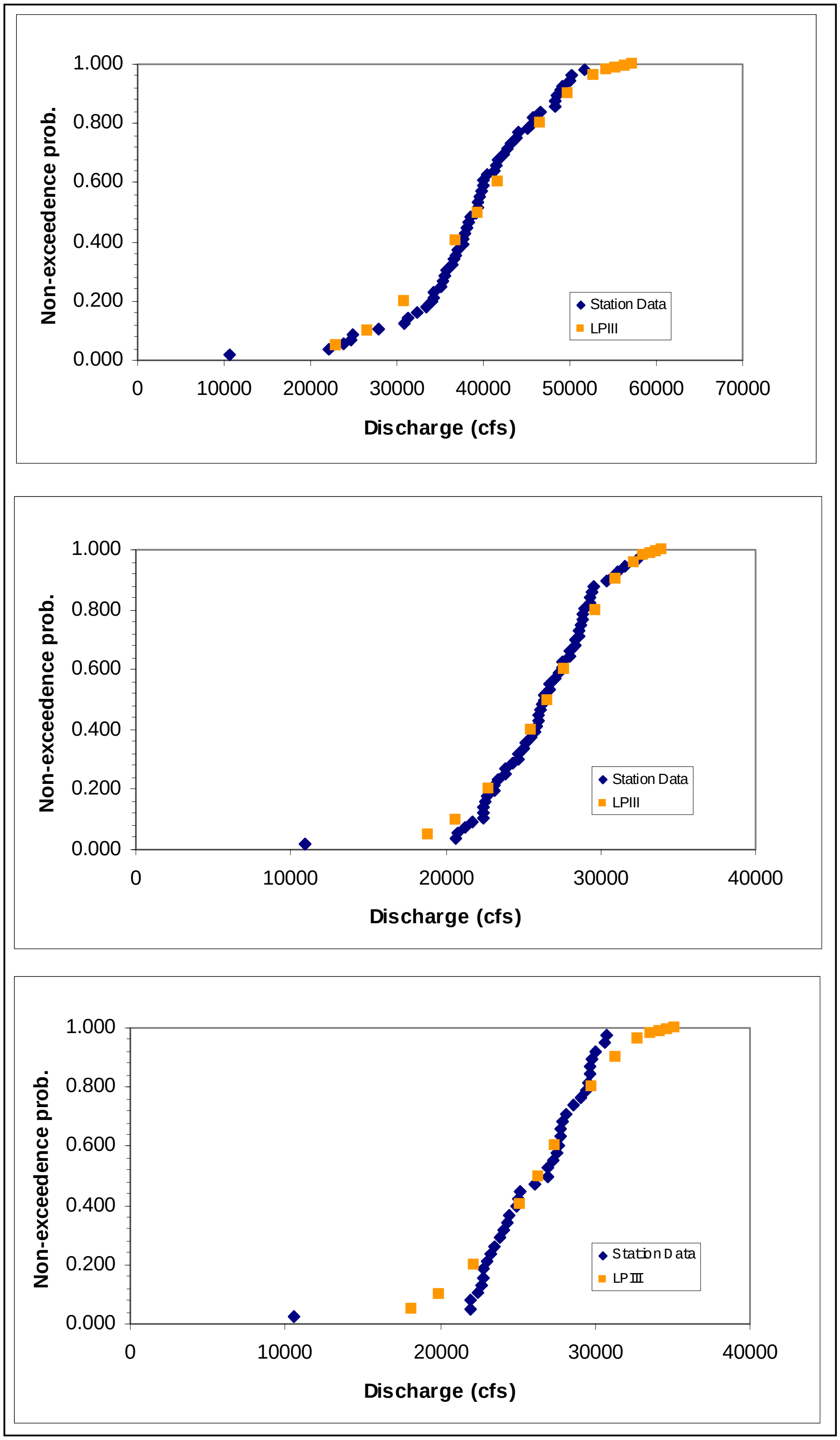


Figure 5.7: Flood frequency plots (from Appendix C)

Velocity Calculations

The average change in channel velocity from the base scenario (adjacent levees) to scenario 3 (widest scenario), for the 2 year and 100 year floods, was calculated for the entire study reach (see Results). For each cross section, and each setback scenario, the channel velocity corresponding to these flows was calculated using the Manning equation for flow velocity:

$$V = 1.49 \frac{R^{2/3} s^{1/2}}{n}$$

where (V) is channel velocity in feet per second. Values for the slope and the Manning roughness coefficient are the same as those used for the calculation of channel discharge. Flow depth was measured from the thalweg (deepest part of the channel) (Appendix I).

Various ecological aspects are dependent upon the channel velocity and the inundation frequency and depth upon the floodplain. The calculated flow depths, and their frequencies, along with the calculated changes in average channel velocity, will thus be used to aid the ecological analysis.

Ecology

Overall Ecological Strategy

The goal of the ecology team was to determine the ecological effect of setback levees to both the terrestrial and aquatic systems on the Sacramento River. To evaluate the effect of setback levees on the terrestrial ecosystem, it is appropriate to determine the riparian vegetative regime that will return to the system. A quantitative vegetation analysis was done to determine the area of four different riparian vegetative communities that would establish under the different setback levee scenarios. The results from the vegetation analysis were used to make qualitative deductions on the effect of the setback scenarios for selected avian species.

A set of avian and fish species were selected, with the assumption that these species would give an overall picture of ecosystem health. These multi-organismal groups are extremely sensitive to the extent of agriculture in the landscape (Mensing, Galatowitsch et al. 1998) and are therefore good indicators of ecosystem vitality in the Sacramento Valley. Life histories of the terrestrial and aquatic can be found in Appendix C and D, respectively. The preferred breeding habitat of each avian species was determined, along with additional caveats such as minimum setback lengths, widths, and sensitivity to habitat fragmentation. These were culminated into a qualitative summary on how setback levees may affect them. Finally, using results of predicted acreage of riparian community types from the vegetation analysis, individual bird species were placed in their preferred setback scenario. The scenario that creates the largest acreage of the species preferred habitat was designated as the ideal scenario for that particular species, resulting in a species list for each setback width scenario. The effect of setback levees on the designated aquatic species were determined by applying a quantitative analysis of changes in stream velocity, streamside vegetation, thin streamside vegetation, and backwater habitat.

Umbrella Species

How setback levees will affect the riparian ecosystem of the Sacramento River drainage was evaluated using a set of umbrella species composed of fish and avian species that historically bred, or were thought to have bred, in the riparian zone. The use of umbrella species to indicate ecosystem vitality or health is common in restoration projects (Noss 1997). Several of the umbrella species used for this analysis are in decline or have special status (i.e. endangered or threatened), which may be indicative of their sensitivity to past environmental degradation. One of the main selection criteria for umbrella species to be used for this project was a requirement for large amounts of good quality habitat. The use of umbrella species assumes that if an ecosystem is conserved or restored in a way that provides for the high ecological demands of the umbrella species, it follows that that ecosystem will also be beneficial to many of the other species that utilize that ecosystem as well. This is thought to be particularly true in zones of high species richness or endemism (i.e. organisms are restricted to a specific habitat) like the Sacramento River. Research has indicated that the use of an aggregated set of species as an umbrella set is more effective than an individual umbrella species (Noss et al 1997).

Using umbrella species to indicate ecosystem vitality and health in restoration projects is not without controversy, since there has not been extensive research to prove its effectiveness at protecting other species within the ecosystem (Noss et al 1997). One critique of using birds as an umbrella species set is the metapopulation dynamics of many bird species that are not inherent in many terrestrial species. Birds can often move quickly and easily between spatially isolated patches within a heterogeneous landscape. Therefore these patches might appear to be *connected*. But that same spatial disjunction may effectively isolate a less mobile terrestrial species, such as small reptile or mammal, and therefore cause it to be isolated in a habitat patch that may be sub-optimal. Corridor habitats established to connect reserve habitat patches may have compounded deleterious impacts on the species. Research has shown that corridor habitats can be “death-traps” because they pull species from source areas into marginal zones that often have high edge-to-area ratios, are less pristine than reserve areas, are invaded by more exotics, and have larger anthropogenic impacts (Soule 1991).

Despite the potential validity of these critiques, birds and fish will be used as the aggregated set of umbrella species for the project conservation. The use of birds as an aggregated set of umbrella species for conservation design efforts in the Sacramento River flood plain is effective because birds occupy a wide range of riparian niches, and their territorial needs are generally larger than all but the mid-size to large terrestrial mammals (California Partners in Flight, CPIF 1999). Fish have been deemed useful species for characterizing environmental conditions in streams and rivers (Cowx and Welcomme 1998).

Designated Umbrella Avian Species

Riparian bird umbrella species were selected based on the following five factors, as determined by California Partners in Flight (CPIF 1999).

- Use of riparian vegetation as their primary breeding habitat in most bioregions of California.
- Special management status—endangered, threatened, or species of special concern on either the state or federal level.
- Experienced a reduction in their historical breeding range.
- Obligate or dependent riparian breeders (see Appendix C) throughout California.
- Breeding requirements that are representative of the full range of successional stages of riparian ecosystems.

Based on the criteria outline above, the species listed in table 5.1 were selected as umbrella species for the project, also as determined by (CPIF 1999).

Species Common Name	**Scientific Name**	**Special Status**
Bank Swallow	*Riparia riparia*	CA Threatened
Black-headed Grosbeak	*Pheucticus melanocephalus*	
Blue Grosbeak	*Guiraca caerulea*	CA special concern
Common Yellowthroat	*Geothlypis trichas*	CA special concern
Least Bell's Vireo	*Vireo bellii pusillus*	Federally and CA Endangered;
Song Sparrow	*Melospiza melodia*	
Swainson's Hawk	*Buteo swainsoni*	CA Threatened
Swainson's Thrush	*Catharus ustulatus*	
Warbling Vireo	*Vireo gilvus*	
Willow Flycatcher	*Empodonax traillii*	CA Threatened; USFS Region 5 sensitive species
Wilson's Warbler	*Wilsonia pusilla*	
Yellow Warbler	*Dendroica petechia*	CA species of special concern
Yellow-billed Cuckoo	*Coccyzus americanus*	CA Endangered; USFS Region 5 sensitive species
Yellow-breasted Chat	*Icteria virens*	

Table 5.1: Avian Umbrella Species

Designated Umbrella Aquatic Species

Aquatic and terrestrial environments are integral components of the riparian ecosystem. It was therefore appropriate to include and aquatic species in the aggregate group of umbrella species as an indicator of the health and vitality of the aquatic system. Chinook salmon was the species chosen as the aquatic umbrella species.

- Several of the runs are endangered, threatened, or declining at state and federal levels.
- Native species of the Sacramento drainage.
- Use of almost entire drainage during life cycle
- Reliance on many different ecosystem processes and functions during life cycle
- High economic value as it is a large commercial and recreational fishery.
- Recent public attention given to the species
- Large amounts of life history data are available for this species for the Central Valley

There are four runs of Chinook Salmon on the Sacramento River, all of which were used in the analysis.

Common Name	Scientific Name	California Status	Federal Status
Winter-run Chinook salmon	*Oncorhynchus tshawytscha*	Endangered	endangered
Spring-run Chinook salmon	*Oncorhynchus tshawytscha*	Endangered[1]	endangered[1]
Fall-run Chinook salmon	*Oncorhynchus tshawytscha*	Threatened[1]	threatened[2]
Late-fall run Chinook	*Oncorhynchus tshawytscha*	Threatened[1]	threatened[2]

Table 5.2: Chinook Salmon. [1] Proposed listing pending.
[2] Candidate for listing pending (Jorgensen, 1999; CDFG, 1999)

Terrestrial Analysis

Vegetation Analysis

A quantitative vegetation analysis was conducted to determine the area of four different communities of riparian vegetation that would form under the different setback levee scenarios. The results from this vegetation analysis were used to make qualitative deductions on the effect of the different setback scenarios for the above mentioned bird species.

Methods for Vegetation Analysis

Riparian vegetation is dependent on many factors, including flood frequency, soil type, depth to the water table, and seed dispersal (Table 1.3). Flood frequency is thought to be the most important variable in determining vegetation type; it determines the amount of water available to the community, the type of soil that it will grow on, provides essential nutrients, and serves as a major seed dispersal mechanism for many riparian shrubs (Johansson, Nilsson et al. 1996). An ideal vegetation analysis would model the extent of floodplain inundated by the one, three, or five-year events that establish the four communities of vegetation along the Sacramento River. However, such a model would require fine topographic resolution, flow models that are beyond the scope of our project.

Instead, we evaluated community composition by a comparative analysis. The reach of the Sacramento River just north of the study reach has an approximate 6000ft inter-levee distance and is hydrologically similar enough to use as a comparative tool. Historical floodplain widths are largest between river miles 105 – 175 and are similar to the widths of our study reach, river miles 84 – 143, with the exception of approximately twenty miles 84-105. The reach from miles 145-175 was analyzed for relative percent cover of the four riparian community types in ten-mile increments. The average percent cover from this analysis was assumed to be the percent cover establishment for our study reach.

Using the Sacramento River Riparian Vegetation (SRRV) GIS data, the areas of the four vegetation communities were tabulated for each ten mile stretch of the river, miles 145-155, 155-165, and 165-175 respectively. The levee to levee distance varied for these three reaches, showing similar trends to our three scenarios. Therefore, these three reaches were used as our basis for differentiating community composition for the three scenarios. The average inter-levee distance for each of the three reaches are:

Miles	Levee to Levee Distance	Corresponding Scenario
145-155	3800	1
155-165	4500	none
165-175	6800	2 and 3

Miles 155-165 were not used because of the dissimilarity of the levee to levee distance from any of our scenario widths. Because these levee to levee distances differ slightly from our scenario widths, we do not expect our quantitative results to exactly predict the acreage of vegetative structure, although similar trends would be expected. Additionally, a qualitative analysis, using general assumptions based on riparian ecology background of community composition, will be used to support our numerical results (Table 5.3).

Expected Abundance (Based on Ecological Background)

Relative Abundance	Scenario 1	Scenario 2	Scenario 3
Levee to Levee Distance	3000 feet	6000 feet	9000 feet
Willow	Low	Low	Low
Cottonwood	Medium	Medium/High	Medium/High
Mixed Riparian	Low	Medium	High
Valley Oak	Insignificant	Insignificant	Insignificant

Table 5.3: Expect Abundance (based on Riparian Ecology Background)

Critical Assumptions

1. Only four communities of riparian zone will become 100% established on the new floodplain. The types of riparian communities are (California State University):
   - **Great Valley Riparian Scrub –** Young primary succession (Willow)
   - **Great Valley Cottonwood Riparian Forest –** Percent cover greater than 80% Cottonwood– one year old or greater. Cottonwood riparian forest represents the second successional stage. Dominant species include: cottonwood, willows, and California Grape.
   - **Great Valley Mixed Riparian Forest -** Neither willows nor cottonwoods dominate – also may contain a mixture of more upland, later successional species that may include valley oak at less than 60% of canopy coverage, black walnut, ash, tree of heaven, and sycamore.

- **Valley Oak –** Canopy coverage must be greater than 60%, must be contiguous or have longest axis greater than the distance from riparian vegetation.

This assumption will slightly overestimation each habitat type because it ignores other communities (herbland cover, disturbed, disturbed riparian, and gravel and sand bars, etc.). However, these coverages are very limited and are assumed to be negligible.

2. Our study reach of the river behaves exactly like the comparative river reach. This assumption ignores heterogeneity in topography, existing vegetation, flooding extent, and channel movement that inherently varies between the two reaches and affects the landscape mosaic.

Avian Species Analysis

The potential effects of setback levees for each of the umbrella avian species were determined using their life histories (see Appendix C). A subset of the thirteen initial species were chosen that had large potential benefits. This subset consists of all birds historically present, and currently breeding, in the ecosystem, but does not include birds that have been extirpated from the site (we cannot assume that setback levees will benefit extirpated species because they may not be habitat limited).

Fragmentation

Continuous corridors of riparian forest are beneficial to wildlife (Meyer 1998). Connectivity enhances movement, access to seasonal foods, and dispersal of animals. Additionally, it helps eliminate isolation of populations and increase genetic integrity (Meyer 1998). Fragmented habitats are prone to "edge effects" (predators easily invade and negatively affect populations). For example, the Cosumnes River Preserve has the largest stand of Valley Oaks left in California, and even that is not big enough to keep parasites and jays out (Lynes 1998). This suggests that the recommended width of setback levees and subsequent riparian habitat created will be prone to edge effects.

Due to general economic constraints and present land use planning, it is not feasible to have a continuous corridor of setback levees along the river (see Define Scenarios in Scenario Strategy Chapter). This may raise questions about the benefit of habitat created by discontinuous setback system. The life histories of the avian species however showed that some avian species show little to no response to habitat fragmentation, and some have even shown a positive response to fragmentation. Although a continuous system would arguable be ideal, we argue that the somewhat fragmented habitat created by our setback scenarios would still provide a net benefit to the ecosystem.

Potential Effects of Setback levees on bird species

(See Appendix C for details)

Bank Swallows: Setting back levees on the Sacramento River should have a large positive impact on the Bank Swallow's population. The limiting factor in Bank Swallow vitality is the lack of suitable habitat along the Sacramento River (Garrison 1999). Creating setback levees along the Sacramento will create new nesting sites for the Bank Swallow and will likely lead to an increase in population. Constraints:

- Only soils prone to erosion will benefit the Bank Swallow. Setback levees in erosion resistant soils will not benefit this species.
- Banks must be a minimum of 10 meters in length for the Bank Swallow to establish itself.

Pacific Coast Black-Headed Grosbeak: This species is adapted to highly diversified conditions and thrives in fragmented environments. This is probably one of the reasons why the population remains stable. Setback levees will have a positive benefit if new successional habitat is formed. Constraints:

- Setbacks must be at least 650ft long and 60 - 165ft wide.
- Will benefit from early and late successional vegetation stages.
- Will not likely benefit more from setbacks wider than 1000 feet (Nest distance to running water)

Blue Grosbeak: The Blue Grosbeak has only occupied 20-40% of its potential habitat in the Sacramento River region because it's breeding range is usually south of this area. Setback levees should therefore have a negligible effect on their populations. Should the breeding range move north, setback levees would benefit this species where intermittent flooding occurs, thereby creating riparian cottonwood forests, which is favored by the Blue Grosbeak.

Common Yellowthroat: Setback levees should have a large potential benefit on the Common Yellowthroat provided that at least one to three acres of marshland/riparian habitat is created.

Least Bell's Vireo: Presently, the Least Bell's does not breed in the Sacramento Valley, so the implementation of setback levees would have a minimal effect. However, if the population did return to this region, habitat areas would be created that this species could utilize for breeding and benefit this species. One and one half to three acres of riparian habitat are needed for nesting success.

Song Sparrow: Because this bird currently breeds in the riparian zone, the impact of setback levees on this species is likely to be significant. Due to its love of water, the primary successional zones of willow and cottonwood forests will be most beneficial.

Swainson's Hawk: The creation of riparian habitat with large trees will have a potentially large effect on the hawk population. They nest in trees associated with every successional stage at a mean density of 30 pairs/39 mi^2 (Woodbride 1998). Research from the Antelope and Owens valleys has shown that the birds will recolonize areas where habitat is recreated (Woodbride 1998). However, there are areas in the Central Valley where suitable habitat exists, but is not utilized. For example, mature trees and open grasslands in Shasta and Tehama County support very few hawks (Woodbride 1998)**.**

Swainson's Thrush: Because Swainson's Thrush does not currently breed on any site in the Sacramento River, it is impossible to say whether or not the species will significantly benefit from increased habitat from setback levees. However, potential benefits exist if populations ever do return to the Sacramento River.

Warbling Vireo: The Warbling Vireo should significantly benefit from setback levees. It is capable of breeding in primary successional riparian vegetation, and is not significantly affected by fragmentation. Due to its preference for deciduous tress, this species should benefit most in mixed riparian forest.

Willow Flycatchers: Because the Willow Flycatcher does not currently breed on any site in the Sacramento River, it is impossible to say whether this species will benefit from setback levees. There is no guarantee Willow Flycatchers will return to the Valley, but it may be an opportunity to provide breeding habitat in a previously central part of its range. If this species does return, the creation of willow forest/ mixed riparian forest will be the preferred habitat.

Wilson's Warbler: Setback levees will have a minimal effect on the current status of Wilson's Warbler. They currently do not breed in the Sacramento Valley and it is impossible to foresee whether setback levees are the limiting variable to their establishment in the valley. However, if the Warbler chose to settle back in the valley, setback levees would benefit the Warbler by creating more habitat, specifically blackberry understory with willow cover ranging from 1-3 acres.

Yellow Billed Cuckoo: The creation of setback levees will only benefit the Yellow Billed Cuckoo if a large amount of cottonwood/willow habitat is formed. Because this species is very susceptible to patch size, it is important to create habitat areas at a minimum of 50 acres, and ideally over 80 acres. In addition, setback width must be at least 300 feet wide and a minimum of 7000 feet in length to benefit the Yellow Billed Cuckoo.

Yellow Breasted Chat: The Yellow Breasted Chat will likely benefit from setback levees. It is a current inhabitant of the Sacramento Valley, depending on willow and cottonwood riparian forest for breeding.

Yellow Warbler: Because the Yellow Warbler uses the riparian zone during its fall migration, additional riparian zone habitat should benefit.

This analysis may be limited by the following factors.

- **Data** – The data that exists on patch size and fragmentation is highly variable and may not be accurate. This may lead to incorrect claims of habitat needed for different species.
- **Extirpation from Sacramento Bioregion-** Many of these species were historically present in the ecosystem but have since been extirpated. The reasons for their disappearance are difficult to assess and cannot be attributed solely to habitat limitation. Therefore in this survey, those species that are currently not present are rated as having a potential low benefit from setback levees.
- **Inherent bias towards early successional stages -** All species analyzed were dependent or obligate riparian species and rely heavily on the riparian zone for survival. Because of the classification scheme, this

may result in a bias towards the Willow and Cottonwood stages. Other avian species may breed in the late successional stage Mixed and Valley Oak habitat in addition to other areas found outside the riparian zone. These species were not included in this evaluation.

The high benefit species chosen are:

- Bank Swallow
- Black Grosbeak
- Common Yellowthroat
- Song Sparrow
- Swainson's Hawk
- Warbling Vireo
- Yellow Billed Cuckoo
- Yellow Breasted Chat

Using the high benefit subset of birds listed above and the percentage composition of the habitat types from each scenario, the preferred scenario for each bird (i.e. most habitat created) was determined. Other life history characteristics were also considered; for example, a species that only breeds a few hundred feet from the river would not gain any additional benefit from further setback. This assumes they are habitat limited and not prone to edge effects.

The following table represents each avian species preferred breeding sites and a high/low potential classification for the thirteen birds.

Name	Willow Scrub	Cotton-wood	Mixed Riparian	Valley Oak	Historically Present?	Currently Present?	Potential Benefit of Setback Levees
Bank Swallow*					X	X	High
Black Grosbeak	**X**	**X**	X	X	X	X	High
Blue Grosbeak	X	**X**			X	X	Low
Common Yellowthroat	X				X	X	High
Least Bell's Vireo	X	X			X		Low
Song Sparrow	X	X			X	X	High
Swainson's Hawk	X	X	**X**	**X**	X	X	High
Swainson's Thrush	X				X		Low
Warbling Vireo	X	X	**X**		X	X	High
Willow Flycatcher	X	X	X		X		Low
Wilson's Warbler	X				X		Low
Yellow Billed Cuckoo	X	X			X	X	High
Yellow Breasted Chat	X	X			X	X	High
Yellow Warbler	X	X			X		Low
% of species utilizing	**93**	**71**	**29**	**14**			

Table 5.4: Preferred Riparian forest for Breeding by Each Riparian Avian Species

*= Dependent on river channel and not successional vegetation
Bold indicates preferred Sites

Aquatic Analysis

Potential Effects of Setback Levees on Chinook Salmon

The project area between river mile 84 and 144 is located in the lower valley. This area is not part of the main spawning grounds, as most of the Chinook are adapted for cooler waters in higher parts of the drainage (for a more detailed account of life histories and the factors for decline of Chinook salmon of the Sacramento River basin see Appendix D). Fall run Chinook salmon would likely be the only salmon that would spawn in the study reach, as this run has traditionally spawned in lower areas of the watershed. However, since most of the spawning is done upstream of the project reach (Appendix D), and gravel of appropriate size is not available or recruited here (Water Engineering & Technology 1990), effects of setback levees on this reach in terms of spawning will not be a primary focus. The most likely uses of this section of river by Chinook salmon would be as a corridor for upstream migration of adults, rearing habitat for juveniles, and downstream migration for smolts.

Therefore, the effects of setback levees were quantitatively examined for stream velocities, depth of water on the flood plain, and streamside vegetation. The results of these analyses were then used to qualitatively evaluate ecosystem process (stream meandering, production of shaded riverine habitat, and allochthonous inputs), which directly and indirectly affect Chinook salmon

Methods For Aquatic Habitat Analysis

Stream Velocities

Average stream velocities at different flow recurrence intervals were obtained from the stream velocity section of the hydrological analysis for each of the 3 scenarios (see hydrology methods and results sections). These velocities were used as support for the qualitative discussion of the riverine habitat as a migration corridor or resting area during high flow events.

Depth of Water on the Flood Plain

The depth of water that results on the floodplain between the setback levees during the 100-year flood (see hydrology methods and hydrology results) was used as support for the qualitative discussion of Chinook salmon access to the floodplain and backwater habitats.

Streamside Vegetation Analysis

Streamside vegetation for this study is considered to be any vegetation emerging from, submerged in, touching, overhanging, or with exposed root mass in the stream. Streamside vegetation is referred to as shaded riverine aquatic habitat (SRAH). SRAH provides Chinook salmon with a local refuge of cooler water, which may help increase juvenile Chinook survivability during the warmer parts of the year (DeHaven 1989). It also provides refuge for juvenile salmon and other fish from predation by predators like Striped Bass. Fallen streamside vegetation can provide inputs of large woody debris for habitat and cover for fish and stream invertebrates. Allochthonous inputs of organic matter through leaf litter and tree fall from streamside vegetation can also provide nutrient input of resources for invertebrates that may serve as food items for juvenile Chinook salmon and other organisms. Though allochthonous inputs are not expected to be as heavily influential in lowland areas of rivers as they are in headwaters (Vannote, Minshall et al. 1980), SRAH is considered a scarce, unique, and highly valuable resource to fish and wildlife (Kehaven 1989), and restoration of SRAH is important for the quality of fish habitat and restoration of fish populations (DeHaven 1989; Wichert and Rapport 1998).

The amount of streamside vegetation was determined for the following three reaches: RM 145 to 175, RM 126-131, and RM 84-144 (the project reach). RM 126-131 is a section of river within the project reach where the distance between project levees ranges from 1500- 2200 feet, and RM 145-175 is a thirty mile section of river directly north of the project reach where the distance between the levees varies from 3800-6800 feet. The latter two reaches were chosen as indicators of the possible resulting streamside vegetation for the project reach once levees are set back. The reach from 145 to 175 will be referred to as the open river section. For the analysis of vegetated streamside, RM 84-144 and RM 145-175 were divided into 10-mile segments. The banks of both sides of the river were considered as potential vegetation sites, therefore for every mile of river there are likely to be at least two miles of opportunity for streamside vegetation.

In the open river section the length of bank with streamside vegetation was calculated by examining riparian GIS layers (Department of Water Resources 1998). Lengths of bank coverage were determined for the four types of riparian vegetation (willow, cottonwood, valley oak, and mixed riparian). The category "gravel and other" designate banks with no streamside vegetation. (The GIS metadata states that some of the designated gravel areas have some early successional growth, likely small/young willows. For the purposes of this study, gravel areas along the streamside will be considered as non-vegetated bank). The bank lengths were recorded and summed for each of the above-designated categories and used to find the percentage of bank with the different streamside vegetation for each reach.

The overall percentage of streamside vegetation was found for RM 145-175 and RM 84-144, through summation of their respective 10-mile segments. These overall streamside vegetation percentages were compared to find the percent change in streamside vegetation, assuming that existing conditions of the open river section (RM145-175) are indicative of the what is expected to be seen in RM 84-144 once the levees are set back. The results of the streamside vegetation analysis of RM 126-131 were used for further qualitative support of changes in streamside vegetation that will likely occur from setback levees. The results of this analysis are qualitatively analyzed for benefits to Chinook salmon in shaded riverine aquatic habitat and increased protection form predation.

In obtaining the above results, the percentage of "thin ”(50-150ft wide) streamside vegetation was also recorded and compiled. These segments were used to examine in habitat quality issues that may not be evident in the GIS layers. SRAH has been greatly depleted along the Sacramento River (Dehaven, 1989), and the benefits from streamside vegetation are less when it is thin. From aerial photos (U.S. Army Corps of Engineers 1991) it can be observed that along some parts of the bank, especially in the project reach, streamside vegetation is actually in low density and/or found on the top of the levees adjacent to the stream. Fish and wildlife studies reported that much of the streamside vegetation of the lower Sacramento River is “clumped” together and does not extend far over the water (DeHaven 1989). It is likely that where the GIS vegetation layer is thin, riparian vegetation may not be very dense or as close to the streamside as it appears. The implications for thin riparian streamside vegetation will be further addressed in the discussion of the results for this section.

Backwater/aquatic floodplain habitats

Backwater habitats include such formations as side water channels, vernal pools, ponds, wetlands, and/or oxbow lakes. They are important to a variety of organisms, and serve the Chinook salmon as migratory pathways and refuge areas during high flow events. Oxbow lakes are visible on the historically active floodplain, which are now currently excluded from the active floodplain by levees (Department of Water Resources 1998). Under setback scenarios, different amounts of these habitats would once again be placed within the active floodplain. The acreage of backwater habitat types was determined to get an idea of increases in aquatic habitat that would be formed under the setback scenarios. Qualitative discussion of additional floodplain aquatic habitat formation are based on examination of the 1991 Army Corp. of Engineer aerial photographs for past evidence of river channel activity and the meander analysis from the hydrology section (see hydrology methods and results). The affects of meandering were used to discuss the short and long time scale changes of streamside vegetation and thin streamside vegetation for the scenarios.

Economics

Costs

Costs associated with setting back levees along the Sacramento River include purchasing the land between an existing levee and a proposed setback levee, removing the paved roads present within that same area, removing the existing levee, and building the new. These costs depend on many variables. Due to the size of the study area, and the data available, the costs in this analysis are only a rough estimate of actual costs of such a project.

Land Costs

The most obvious cost of setting back levees in an agriculturally rich area is the cost of purchasing the land. We assume that the land will be bought outright, and that no agriculture will occur on the land between the levees and the river channel. Although allowing agriculture on this land would likely decrease the cost of the project (flood easements would still need to be purchased), it would also decrease the area available for riparian habitat.

The first step in estimating land cost was to obtain a map of current land use. The California Department of Water Resources (DWR) provided this map as a GIS layer. Using the GIS, the total area of each crop type in the area between an existing levee and a proposed setback levee was calculated. We assumed that the land could be bought at its current market value.

The California Chapter of the American Society of Farm Managers and Rural Appraisers has published land values for most areas of agriculture in California (1998). Table 5.6 shows the low and high value for different crop types within the three counties of the study area. We used the middle of each range as the cost of purchasing such land. In addition to the American Society of Farm Mangers and Rural Appraisers, the United States Department of Agriculture (USDA) also has land value data (Table 5.6) (National Agricultural Statistics Service 1999). Unfortunately, the land values from these two sources are not separated into the same classes as the land use data in the GIS. Because of this, some crops were assigned to a similar crop type. Table 5.7 lists the land use observed in the study area for the different setback scenarios and the land value data it was associated with in order to calculate costs.

County	Land Use	Low	High	Average
Colusa	Rice	$1,500	$3,000	**$2,300**
	Vegetable Crops	$2,200	$3,200	**$2,700**
	Irrigated Field Crops	$2,000	$3,000	**$2,500**
	Rangeland	$300	$400	**$350**
	Almonds	$4,000	$9,000	**$6,500**
	Walnuts	$5,000	$10,000	**$7,500**
	Prunes	$5,000	$8,000	**$6,500**
	Olives	$4,500	$6,000	**$5,300**
Sutter	Rice	$2,200	$3,200	**$2,700**
	Vegetable Crops	$2,200	$3,200	**$2,700**
	Irrigated Field Crops	$2,200	$3,200	**$2,700**
	Rangeland	$7,500	$10,000	**$8,800**
	Walnuts	$7,500	$10,000	**$8,800**
	Prunes	$7,000	$10,000	**$8,500**
	Peaches	$8,000	$12,000	**$10,000**
Yolo	Rice	$1,500	$4,000	**$2,800**
	Vegetable Crops	$1,800	$4,500	**$3,200**
	Irrigated Field Crops	$1,800	$4,500	**$3,200**
	Rangeland	$180	$400	**$290**
	Walnuts	$6,000	$8,500	**$7,300**
	Pears	$7,000	$8,000	**$7,500**

Table 5.5: Land Values - as reported by the American Society of Farm Managers and Rural Appraiser.

Land Use	Land Value
Farm Real Estate	**$2,630**
Cropland	**$5,300**
Pasture	**$1,050**

Table 5.6: Land Values 2 - as reported by the USDA National Agricultural Statistics Service. Values reported by region and state.

Land Use In GIS	Land Use in Land Value Data Used	Land Value
Alfalfa pasture	Pasture[1]	**$1,000**
Almonds	Almonds[2]	**$6500**
Barley	Irrigated Field Crops[2]	**$2,700**
Beans	Vegetable Crops[2]	**$2,900**
Celery	Vegetable Crops[2]	**$2,900**
Corn	Vegetable Crops[2]	**$2,900**
Cotton	Irrigated Field Crops[2]	**$2,700**
Melons, squash, cucumbers	Vegetable Crops[2]	**$2,900**
Mixed Pasture	Pasture[1]	**$1,000**
Oats	Irrigated Field Crops[2]	**$2,700**
Pistachios	Average of Walnuts[2] and Almonds[2]	**$7,500**
Prunes	Prunes[2]	**$7,500**
Rice	Rice[2]	**$2,500**
Safflower	Irrigated Field Crops[2]	**$2,700**
Sugar Beets	Vegetable Crops[2]	**$2,900**
Tomatoes	Vegetable Crops[2]	**$2,900**
Walnuts	Walnuts[2]	**$7,800**
Wheat	Irrigated Field Crops[2]	**$2,700**

Table 5.7: Land Values Used to Calculate Costs [1] (National Agricultural Statistics Service, 1999) [2] (American Society of Farm Managers and Rural Appraisers, 1998)

Costs of Removing Existing Levees and Building New Levees

The costs of removing existing levees and building new ones are governed by the dimensions of the new levee, the source of material, and levee construction standards (a slurry wall within the new levee, a maintenance road on top, rock protection on the water side of the levee). Figure 5.8 is a diagram of a levee with some terminology that will be referred to in this and other sections of this document.

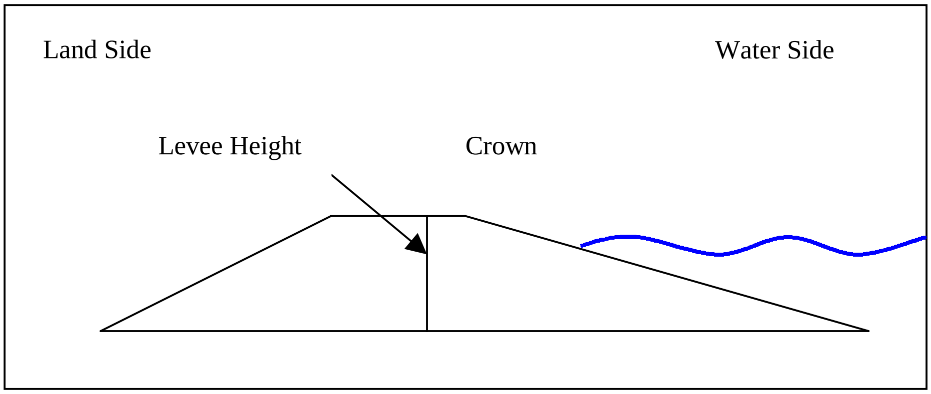


Figure 5.8: Levee Structure

Although the dimensions of a levee are determined only after considering the requirements of the flood protection, general rules of thumb exist. For example, the Army Corps of Engineers (Army Corps of Engineers 1978) states that all levees should have a minimum crown width of 10 feet to allow for a maintenance road. They also state that the slope of the levee flanks must no greater than to 1:2 (one vertical to two horizontals). Levee height is determined by the water height during a particular flood discharge. For example, if the levee is intended to protect against the 100-year flood, then hydrologists calculate the stage height using the estimated water flow of a 100-year flood. The height of the levee should be 2 to 3 feet above this water height. This extra space is called the freeboard and allows foruncertainty in the hydrologic calculations, as well as wave action. Smaller freeboard space is usually used for protecting agricultural lands, while more room is allowed on urban levees.

To determine the specifications required for setback levees in our analysis, we consulted with Joe Sciandrone, an engineer in the Civil Designs Branch of the Army Corps of Engineers. In addition, the Army Corps' engineering manual "Design and Constructions of Levees" was consulted (Army Corps of Engineers 1978).

To build a levee, an inspection trench is first excavated along the proposed levee alignment to examine the soil's natural water content, grain size, compaction, and shear strength. This trench is usually about 5 feet deep, 10 feet wide at the bottom, and has a 1 to 1 slope on both sides (Sciandrone 2000). The next step is to strip the vegetation off of the existing levee, as well as off the land between the existing and setback levee (Sciandrone 2000). The vegetation can either be burned or hauled away, and the cost, as we shall see later, varies greatly between these two options (Fong 2000).

The paved roads between the proposed setback levee and the existing levee will also need to be removed. Because our scenarios do not propose to move highways, we assume that the minor roads that must be removed will not need to be rebuilt elsewhere. The detailed structures of the road, such as the width, are difficult to determine from the aerial atlas as well as from the GIS. The roads in our scenarios are labeled as streets or roads in the GIS, and appear to be small in the aerial photographs. For these reason we assumed that the roads were two lane paved roads which are about 8 yards wide. The length of the roads was measured using the GIS base map layer (Department of Water Resources 1998).

The material from the existing levee can be used to build the new setback levee (Sciandrone 2000). In cases where new levees are built along rivers where there are no levees, the material is taken from nearby land, preferably between the levee and the river channel (Army Corps of Engineers 1978). Because levees already exist along the study reach, we will assume that the material will come from that levee. Approximately 8 inches of material at a time is placed into the trench, after which it is compressed to about 93% of its maximum density (Sciandrone 2000). This is done until the trench is full. The same process will continues, but the width at ground level will be the width of the base of the levee.

The height of the levee and the slope of each side determine the width of the base of the levee. We assume a 3 to 1 slope on the water side and a two to one slope on the land side (Sciandrone 2000). This means that if the levee height is 15 feet and the crown width is 20 feet (again a recommendation from Mr. Sciandrone), then the base of the levee would be 95 feet wide.

In addition to the main structure of the levee, there are several other components that must be considered. First is the option of putting a slurry wall inside the levee. A slurry wall is a layer of impervious material. Because the current levees mostly do not have slurry walls, we assume that setback levees will not require them (Sciandrone 2000). Other components are rock protection on the water side, which helps prevent erosion, and a gravel road on top of the levee. On Mr. Sciandrone's recommendation, the rock protection on the water side is 15 inches thick, while the top of the levee has approximately 4 inches of mixed gravel to serve as the maintenance road.

To find the costs for the different features required to build a levee we consulted Sherman Fong, Senior Cost Engineer at the Cost Engineering Branch in the Army Corps of Engineers. Although costs of these items are not published in any one document, Mr. Fongs's experience provided good first estimates.

Feature	Cost
Excavating trench and replacing material	$6.00 per yard^3
Excavating existing levee and building new levee	$5.00 per yard^3
Water side rock	$35 per ton
Gravel for maintenance road	$12 per ton
Burning vegetation	$400 per acre
Removing vegetation	$2500 per acre
Planning, engineering and design	15% of above total
Construction	10% of above total
Room for Error	25% of above total
Removing paved road	$4.00 per yard^2

Table 5.8: Cost of Building Setback Levee (Fong, 2000)

Cost of Removing vegetation

The cost of removing the vegetation where necessary is $300 per acre (Fong 2000). There is uncertainty in finding where vegetation would need to be removed due to the type of crops present and the time of year removal would be required. We assumed that all land between existing and setback levees would require vegetation removal, which will likely lead to an overestimate of this cost.

Water Rights

Water rights are property rights and can therefore be bought and sold. There are several different water rights that a landowner may have. The first is riparian water rights, which do not require a permit, that allow the land owner to take water from the river if his land is directly adjacent to the river. Riparian water rights can not be bought and sold. License rights require a permit given by the state that states the amount of water as well as the use, and could even specify the time of year. License rights are considered property rights and can therefore be bought and sold.

If a landowner has water rights which allow him to pump water from the river, he is able to sell those property rights separately from the land. If, on the other hand, the landowner has property rights that allow him to pump groundwater, then the water rights are specific to that land. Buying that land would require the purchase of the water rights as well.

Water rights is a complicated issue because there are many variables. The market price of water right, for example, varies with the climate conditions at the time. Information regarding people's water rights is difficult to access, and often requires examining the owners permits or deed. We consulted with Mike Vain at the real estate division of the Army Corps of Engineers to try to get an estimate of the cost of water rights in our study area. Because this issue is so complicate, when the Army Corps does a feasibility analysis, they generally add 10 to 15 percent of the land cost to the total cost to account for these residual property rights (Vain 2000).

We chose not to add the cost of water rights in our analysis. Water rights vary greatly between counties and states, and if an estimate of water rights was done in this analysis, it is doubtful that the methodology would be applicable in other locations. This will lead to an underestimate of the total costs, although we estimate the error will be less than 10%, since land costs are only a fraction of the total costs (see results).

Benefits

There are numerous economic benefits associated with the introduction of setback levees on the Sacramento River. The benefits we considered were improvement of riparian wetland habitat, decreased flood damages, market value of salmon fisheries, and reduced levee maintenance costs. Additional benefits may exist, such as reduced flood insurance costs to consumers, so our combined monetary benefits may be less than the actual total benefits.

Willingness-to-Pay for Wetland Protection and Wildlife Habitat

Economic benefits from non-market amenities, such as ecosystem services or biodiversity, are difficult to quantify. The best arguments for preserving endangered fishes and ecosystems are non-economic; however, they have been relatively ineffective (Moyle, Yoshiyama et al. 1995). Hypothetical survey estimates of willingness to pay (WTP) are the best economic measure of non-market amenities.

Contingent valuation methodology (CVM) uses surveys to discern what people would be willing to pay to maintain or restore environmental amenities. Contingent valuation method is useful in capturing non-use values, yet the values are not exact (White 1996); these numbers are only estimates of environmental benefits. In addition, the measurement techniques and experimental design of contingent valuation may place too high a value on the environment (Diamond and Hausman 1994). Because existence values (the value to a person of knowing that something exists) can be identified for virtually every citizen who may benefit from environmental amenities, it is difficult to limit the scope of contingent valuation surveys. One final criticism cited is the "lack of precision and the presence of bias in responses to contingent surveys are methodological weaknesses, which inhibit reliability" (Diamond and Hausman 1994). However, it is important for our analysis to attempt to quantify non-market environmental benefits. Even though contingent valuation is a controversial area in environmental economics, "it will almost certainly play a role in future public policy decisions"(Portney 1994).

Our study attempted to measure economic benefits for wetland restoration and salmon habitat improvement. Since these amenities are inherently non-use values, we transferred benefit values that were elicited in a contingent valuation survey of the San Joaquin River basin, a similar environmental region. Benefit transfers have been defined as "the transfer of existing estimates of non-market values to a new study which is different from the study for which the values were originally estimated" (Boyle and Bergstrom 1992). A benefit transfer requires a study where a demand relationship has been shown for an environmental amenity, determination of the geographic region that will benefit from the change in environmental quality, and substitution of the values of the independent variables measured for households at the new site (Pearce and Moran 1994).

Values for willingness-to-pay for wetland and salmon improvement were provided by Michael Hanemann, John Loomis, and Barbara Kanninen in a report for Jones and Stokes Associates (Jones and Stokes Associates 1990). WTP was defined in the study as consumer surplus, or the maximum amount an individual would pay while holding income constant. The report attempted to capture the economic value received by society from public trust resources, such as fish and wildlife. Five components are important in this type of valuation:

- Onsite recreational use – direct use value associated with the enjoyment of the area.
- Commercial production – direct economic benefits from increased resource supplies, including profits from increased local fisheries and increased tourism
- Possible future visits – the value someone has for preserving an environment for the explicit reason that they are likely to visit it sometime in the future
- Existence value- reflects a person's value of preserving a natural resource just to know it exists. The knowledge that a species or ecosystem exists has value

- Intergenerational value – reflects a person's willingness to pay to preserve natural resources for future generation.

Projected hypothetical wetland improvements for the Jones and Stokes survey included increasing the total area of high-quality wetlands habitat by 40,000 acres, and increasing the populations of permanent, migratory, and threatened or endangered species by 40–50%. The WTP values were higher among those who reside closer to the resource and diminished with greater distance from the site. Wetland improvement WTP values for San Joaquin Valley residents was $286 per household, while the same WTP values for out-of-state residents was $161 per household (Jones and Stokes Associates 1990). Out-of-state values represent mainly existence, intergenerational, and possible future use values, while values elicited from the site region include all five components.

Hypothetical salmon improvements in the Jones and Stokes survey included increased water flows and hatchery augmentation, resulting in increased fall-run Chinook salmon populations on the San Joaquin Valley river. Our scenario strategies do not include increased flows or hatchery augmentation. Since Loomis, et al. published their WTP values for salmon improvement in 1990, populations of fall-run Chinook salmon have increased from 1,100 to 28,100 in the San Joaquin River (Yoshiyama, Fisher et al. 1998). In addition, 1997 Chinook salmon populations in the Sacramento River were estimated at 387,100 and are much more robust than the 1990 population (28,100) in the San Joaquin River (Yoshiyama, Fisher et al. 1998). Thus, we were not able to transfer the benefits associated with salmon restoration from the Jones and Stokes survey without introducing additional uncertainty to our study.

The Jones & Stokes data were collected in 1990. Of course, the study site of the survey (San Joaquin Valley) and our study our are not identical and economists would expect, *a priori,* that our study site benefits will differ from the benefits of the original study (Kirchhoff, Colby et al. 1997). It is our assumption that the Jones & Stokes data is a good estimate of WTP in the Sacramento River Basin because it is close to the study area and the habitats are comparable substitutes. A comparison of the Sacramento River and San Joaquin River based on the ecological management zones for the assistance in recovery species and species groups provided similar ecosystem diversity for the two regions (CALFED 1999). The CALFED Ecosystem Restoration Program Plan delineated species and species groups based on special concern status by the California Department of Fish and Game (DFG) and the U.S. Fish and Wildlife Service (USFWS), and by status as threatened, endangered, or proposed for listing on the California Endangered Species Act (CESA) or the federal Endangered Species Act (ESA) (CALFED 1999). Of the aquatic, terrestrial, and vegetation species for the regions, 54 percent were present in the San Joaquin River management zone and 44 percent were present in the Sacramento River management zone. 78 percent of the target recovery species in the Sacramento River zone were also present in the San Joaquin River zone (CALFED 1999). Based on this information, we were confident that a benefits transfer of WTP for San Joaquin Valley habitat improvement was applicable to our study area in the Sacramento Valley.

The Survey Methods

The Jones and Stokes surveys were conducted by both telephone and mail. The WTP numbers were collected using double-bounded dichotomous choice bidding method of contingent valuation (i.e. survey questions requiring a yes or no answer). This type of survey gives truer values of WTP than single-bounded methods by employing follow-up questions in response to the original survey results. The first WTP response values were used to obtain the bid (WTP) values for the follow-up survey. Depending on the first response, the follow-up question involves a higher or lower value than was given originally. The initial survey values ranged from $25 - $250. The follow-up values ranged from $25 - $125 if the initial answer was no, and from $110 - $375 if the initial answer was yes (Jones and Stokes Associates 1990). The double-bounded model helps reduce potential errors in estimated willingness to pay values. There is a “gain in efficiency associated with the double-bounded model” (Hanemann, Loomis et al. 1991).

The Jones and Stokes survey consisted of three separate activities. An initial telephone interview was conducted to recruit participants. A cover letter and booklet explaining the survey and most of its questions were then mailed to those who agreed to participate. The answers were collected in a second telephone interview. Survey Samples, Inc. generated a random sample of household phone numbers. Of 4581 calls, 1960 had an eligible respondent who either refused or scheduled an interview. 1239 interview were scheduled, a participation rate of 63.1 percent. At the end of the third phase of the survey, there were 1004 completed responses. Of these, 227 were from the study region, 576 were from other areas in California, and 201 were from outside California (Nevada, Oregon, and Washington were included in the original survey) (Jones and Stokes Associates 1990).

The Jones and Stokes survey began by asking respondents if they would be "willing to vote for the improvement program, if it was the only program they had an opportunity to vote on and it cost every household in California $___ each year in additional taxes" (Jones and Stokes Associates 1990). Since this question states that the restoration program would be the only program voted on, the values may overestimate the actual willingness to pay, since often multiple programs exist and ability to pay is limited. The results of the Jones and Stokes survey showed strong support for the protection of fish and wildlife. This was reflected by the responses to general survey questions concerning wildlife preservation and it was shown that "Protecting habitat for fish and wildlife and just knowing that fish and wildlife exist were seen as important or very important by over 95 percent of the respondents" (Loomis, W.M.Hanemann et al. 1990).

The Jones and Stokes report measured a wide range of program packages including improvement, maintenance, and no action for issues of contamination, status of wetlands, and salmon habitat. We did not include values that included contamination actions and salmon improvement, since setback levees are not expected to have a major effect on contamination from agricultural runoff. Salmon benefits were found to be not transferable. Thus, we only used measurements that included wetland improvement.

Method of Application of Benefits

We applied the WTP values to the Sacramento River basin and California. The independent variables employed in the Jones and Stokes San Joaquin Valley survey include the following.

- the respondent's age, education, and income
- whether bird populations should be increased substantially
- importance of knowing that fish and wildlife exist
- whether lack of water in wetlands/rivers was a threat to fish and wildlife
- total knowledge of fish and wildlife issues
- importance of protecting wetlands
- whether agree/disagree that there are enough wetlands in the region

We assumed these variables were similar for Sacramento Valley and San Joaquin residents. This allowed us to transfer the WTP values for local residents to our study area on the Sacramento River. The independent variables for the California residents were directly applicable since the San Joaquin survey of WTP included in-state residents in its sample population (Jones and Stokes Associates 1990).

Because respondents from Nevada, Oregon, and Washington were not asked to directly pay for the wetland improvement program, these data were not included. This partially corrects for another potential problem with CVM studies, higher stated values of willingness to pay when the respondent will not realistically be asked to pay. The California populations were included in the original survey sample and can be transferred to our study. Population estimates were acquired for 1998 (counties) and 1999 (CA) from the U.S. Census Bureau, based on the 1990 census totals and estimated growth rates (U.S. Census Bureau 2000). The WTP value for local populations was applied to Butte, Colusa, Glenn, Sacramento, Shasta, Solano, Sutter, Tehama, and Yolo counties. Table 5.9 lists the estimated populations for the target counties and state. The county populations were subtracted from the California totals to avoid double-counting of the WTP benefits. The population estimate for the state, minus the target counties, was used for estimating California WTP.

County	Estimated 1998 Population*	State	Estimated 1999 Population*
Butte	194,597	California	33,145,121
Colusa	18,572	Adjusted without counties	
Glenn	26,234		30,934,854
Sacramento	1,144,202		
Shasta	164,349		
Solano	377,415		
Sutter	76,976		
Tehama	54,073		
Yolo	153,849		
County Total	2,210,267		

Table 5.9: Estimated Current Populations * (U.S. Census Bureau 2000)

The Jones and Stokes data provided WTP values per household. We converted the population estimates to households using 3.03 individuals per household in California. This ratio was derived by dividing the 1990 U.S. Census population for California by the number of households used in the Jones and Stokes report. The number of California households was estimated to be 10,209,523 in 1999. The number of Sacramento Valley households was estimated to be 729,461.

Contingent valuation techniques have been criticized for overestimating true values of willingness to pay. It is also possible that the response rates for the Jones and Stokes survey were biased in favor of participants who had a high preference for wildlife preservation. The survey was time consuming and complicated, so potential respondents who may have had a lower preference for improving wetland habitat may have chosen not to participate in the survey. Since contingent valuation is used to estimate hypothetical WTP and not based on actual payments, environmental economists tend to agree that it may overestimate true WTP (Diamond and Hausman 1994; Mundy and McLean 1998). A hypothetical contingent valuation survey measuring market values of environmental damage on property was shown to overestimate true market values by 54 – 60% (Mundy and McLean 1998). To correct for similar potential overestimates and provide conservative estimates of WTP, we chose to transfer only 40% of the WTP values from the Jones and Stokes report (Table 5.10). We assumed that household preference for wetland improvement has remained constant over the past decade. Economic values of WTP have been shown to be not significantly different over time (Carson, Hanemann et al. 1997).

A Consumer Price Index (CPI) was used to correct WTP results for the inflationary effects from 1990 to 1999. The ratio of CPI(1999) to CPI(1990) gives the multiplier for converting 1990 dollars to 1999 dollars. The "All Urban Consumers" CPI was used for the analysis (Bureau of Labor Statistics 2000). This multiplier was used to convert the 1990 values for WTP to 1999 dollars (Table 5.10). The original WTP values for wetland improvement for Sacramento Valley residents and California residents were estimated at $286 and $251 per household, respectively (Loomis, W.M.Hanemann et al. 1990).

	WTP (1990$)	**40% of WTP (1999$)**	**Estimated 1999 Households**	**Aggregated Regional Benefits (millions of 1999$)**
Sacramento River Basin Counties (9)	$286*	$153	729,461	$111.6
California (all)	$251*	$134	10,209,523	$1465.8
Total				$1,577.4

Table 5.10: Willingness to Pay for Wetland Improvement * (Jones and Stokes Associates 1990)

The wetland improvement values shown in Table 5.10 were then partitioned into average benefits per acre. This was used as an approximation of the incremental benefits accrued for our three scenario strategies. The large WTP values are a result of the relative scarcity of the resource (wetland habitat), “thus as more and more wetlands are added, their scarcity decreases and the incremental value is reduced” (Loomis, W.M.Hanemann et al. 1990). The Jones and Stokes survey found WTP for an increase of 40,000 acres of wetland habitat (from 85,000 acres to 125,000 acres). Our three scenarios create 9800, 21,000, and 28,300 acres respectively. This is a large increase from the 181 acres if wetland habitat that exists in the area today (Department of Water Resources 1998). Although the relative increase of wetland habitat is much larger in our study area than in the Jones and Stokes study, both the original acreage and created acreage of wetland habitat are much smaller than those in the San Joaquin study. This implies that the resource is scarcer in our study, and as a result, the benefits we derived may underestimate the true WTP in our reach of the Sacramento River.

The aggregated wetland benefits per acre for both the Sacramento Basin counties and California are:

$$\frac{\$1{,}577{,}431{,}255}{40{,}000 \text{ acres}} = \$39{,}436\text{/acre}$$

The per acre value was calculated by dividing the total WTP by the increase in acreage proposed in the Jones and Stokes survey, and was then applied to our study by multiplying it by the number of acres created by each scenario (see Results). We assumed that the Jones and Stokes WTP was accurate for an increase in wetland habitat of 40,000 acres, when in fact the WTP may not have changed if the survey had proposed either a 20,000 acre or 60,000 acre increase. Because there is no accurate way to predict how WTP may change in this way, we assumed the relationship between WTP and acreage of wetland created was a linear one.

The Jones and Stokes survey was designed to simulate a similar proposition on the 1987 California ballot (Proposition 70) (Jones and Stokes Associates 1990). On the March 7, 2000 California ballot, an environmental bond proposition (Proposition 12) supported the high value of wetland improvement benefits from this analysis. Proposition 12, the Parks and Water bond measure, was passed and will provide \$2.1 billion for environmental improvements. Of this amount, more than half would be applied to improving state park facilities, wildlife habitat acquisition, and land conservancies. In addition, Proposition 13 (the Drinking Water bond) was passed, and will provide \$1.97 billion for environmental water issues including watershed and flood protection (Sacramento Bee 2000). The combined election results from the nine counties in the Sacramento River basin showed strong support (55.7%) in favor of Proposition 12. Proposition 13 received a favorable 57.6% of the popular vote in the same nine counties. Statewide support for the propositions was even more impressive. 63.2% of the statewide voters cast their ballot in favor or Proposition 12, while 64.8% supported Proposition 13 (California Secretary of State 2000). The financial allotment of these initiatives are comparable to the WTP benefits calculated in our study and further support California citizens' strong willingness to pay for environmental amenities.

Benefits from Reduced Flood Damages

Despite the extensive flood protection system along the Sacramento River, substantial damage occurs to the area during high flood periods. The current levee system was designed to contain the 100 year flood (U.S. Army Corps of Engineers 1999), yet levee breaches and overtopping are responsible for most of the damages from floods (U.S. Army Corps of Engineers 1999). As part of the analysis of the benefits of setback levees, we examined the potential benefits due to decreased damages.

Although both the existing system and the setback levees will protect up to the 500-year flood, setting back levees will increase the channel capacity of the river, which will result in a decrease in stress on the levees. This decrease in stress is due to a decreased velocity of the flow when it is in contact with the levees, as well as decreased water height and a decrease in the amount of time that the levees would be exposed to the channel flow. Less stress on the levee would maintain the integrity of the levee and decrease the likelihood of a levee breach.

The combined damages for the floods of 1983, 1986, and 1997 are in excess of $1.6 billion, with the 1997 flood causing $524 million of damages in the Central Valley alone. Table 5.11 shows the damages associated with the last 4 major floods for the counties in our study reach converted to 1999 dollars.

	1983		1986		1995		1997	
County	Private	Public	Private	Public	Private	Public	Private	Public
Colusa	$2.0	$3.8	$3.8	$3.3	$12.3	$1.2	$0.8	$0.6
Sutter	$16.8	$1.2	$25.4	$4.9	$15.5	$11.6	$25.2	$17.0
Yolo	$43.5	$0.3	ND	$0.4	$5.0	$7.0	$2.0	$0.4
Total	$62.2	$5.3	$29.2	$8.5	$32.7	$20.0	$28.0	$18.0

Table 5.11: Past Damages for Selected Counties – in millions of 1999 dollars. ND – No data (U.S. Army Corps of Engineers 1999)

The total average damage for the three counties within our study reach is $51 million consisting of $38 million average damage to private land, and $13 million to public lands. The existing data on the cause of the damages conflicts. The Army Corps of Engineers reports that the flooding during these times was a result of levee failures on tributaries of the Sacramento River and private levee overtopping, not project levee failures on the main channel (U.S. Army Corps of Engineers 1999). The Sacramento River West Side Levee District (responsible for the maintenance of most of the levees along the west side of the river in our study reach) and the Colusa Basin Drainage District report that project levee failures did occur on the main channel during the 1986, 1995, and 1997 floods (Jenness 2000). Due to this discrepancy in the data, we were not able to quantify the damages caused by levee breaks within our study reach for past floods. In addition, it is beyond the scope of this study to attempt to predict where and how often the levees in our scenarios would break. As a result, we were not able to quantify the benefits of decreased flood risk, though we believe such benefits exist due to the increased channel capacity that the setback levees would create and the decrease in shear stress on those levees.

Market Value of Salmon Fisheries

As was will be discussed in detail in the ecology results, it is likely that setback levees will provide benefits to the rearing habitat salmon. Salmon not only have value as a commodity, but they likely have an environmental non-market value. As discussed in the willingness to pay section in this chapter, we were unable to quantify the environmental value of improving salmon habitat.

Improving salmon habitat would likely have economic values (large commercial and recreational fishery), but these were also quantified for several reasons.

- 1983 stock estimates vary from 154,500 (Yoshiyama, Fisher et al. 1998) to 381,000 (Meyer Resources Inc. 1985). This level in uncertainty would likely lead to little credibility in an attempt to quantify the benefits to the stock from setback levees
- We were unable to predict changes in stock size due to setback levees. Although salmon are like to benefit from reduced flow velocity, creation of oxbows, and woody debris accumulation, assigning number of fish to these benefits would be speculative.

Maintenance and Operation Costs

Maintenance costs generally include vegetation management, control of animals that burrow in to the levees, upkeep of recreational areas, and levee repair (Army Corps of Engineers 1989). We assume that the costs for vegetation management will not increase because we do not propose any additional management (such as the planting of native species). It was assumed that the habitat types discussed in the Riparian Ecology background will establish without human assistance. Although Shasta Dam and various bypasses have heavily regulated flows, the Sacramento River still maintains high enough flows to maintain successional processes [Council, 1998 #10]. The results from our study (see Results) indicate that most of the sections of our reach will have overbank flows, which flood the area between the setback levees and the channel, on average every 2 years. In addition, analysis of 1997 aerial photographs of a bend cut off in 1976 on the Sacramento River shows extensive riparian forest regeneration (Greco 1999).

The control of animals that burrow into levees will not be effected by setback levees, nor will the upkeep costs of recreational areas (we are not considering increasing recreational areas, only natural riparian habitat). It is likely that the levee repair costs decrease with setback levees. This decrease would be due to a decrease in stress on the setback levees caused by decreased flow velocities, decreased water height, and decreased time in contact with the water.

Maintenance costs vary between reaches of the river and between levee districts. Some discrepancies in cost range from just over $1000 to approximately $10,000 per mile per year (Hammond 2000; Jenness 2000). The actual costs per mile of levee maintenance within a reach of the Feather river does not vary significantly between levees at different distances from the river (0.25 and 0.5 mile) (Hammond 2000). Because the data varied considerably, we did not attempt to quantify decreased maintenance costs for our setback scenarios.

Improved System Reliability

In conjunction with the benefits from reduced flood risk and maintenance costs, overall system reliability should be improved by setback levees. Increased channel capacity and reduced stress on the levees will lead to more dependability in the event of a major flood. We do not propose that current bypass systems or Shasta Dam function be altered in any way, but further study may find this is possible due to the increased channel capacity created by setback levees

Results

Scenario One

Description of scenario

The following are the results from the ecology, hydrology, and economic analysis for scenario 1. The scenario 1 levees have an average inter-levee distance of 3000 feet. Inter-levee widths under scenario 1 are close together or “pinch” in some places due to economic constrains (see preliminary economic analysis). Inter levee widths are pinched close together at the following locations in the project reach (RM 143-84) for scenario 1: RM 91-90, RM 100-98.5, and at RM 135-133.

Hydrology

The discharge for particular intervals was used to calculate the water depth at several cross sections (Table 6.1). Calculated inundation depths that were less than one foot, for any given flow, are not reported here. Due to a lack of topographic resolution and the error involved in visually estimating an average floodplain height, such depths were considered to be negligible. For cross sections at which all flows resulted in an inundation depth of less than one foot, the channel was assumed to contain the entire range of flows.

At three cross sections, RM 134.2, RM 99.1, and RM 90.2, levees were not setback due to infrastructure or urbanization. As calculated, these cross sections contain up to 500-year flood, and the results were thus the same for all scenarios.

River Mile	Return Interval	Discharge	Water Depth (Left Floodplain)	Water Depth (Right Floodplain)
	(yrs)	(cfs)	(ft)	(ft)
137	2	39,250	2.4	2.4
	5	46,620	3.8	3.8
	10	49,830	4.4	4.4
	25	52,690	4.9	4.9
	50	54,220	5.1	5.1
	100	55,390	5.3	5.3
	500	57,200	5.6	5.6
135.4	2	39,250	4.9	1.9
	5	46,620	6.5	3.5
	10	49,830	7.2	4.2
	25	52,690	7.7	4.7
	50	54,220	8	5
	100	55,390	8.2	5.2
	500	57,200	8.5	5.5
135.1	2	39,250		3.5
	5	46,620	1.2	5.2
	10	49,830	1.9	5.9
	25	52,690	2.4	6.4
	50	54,220	2.7	6.7
	100	55,390	2.9	6.9
	500	57,200	3.2	7.2
134.2			flow contained	
131.1	2	39,250	0.4	0.4
	5	46,620	1.9	1.9
	10	49,830	2.5	2.5
	25	52,690	2.9	2.9
	50	54,220	3.2	3.2
	100	55,390	3.4	3.4
	500	57,200	3.6	3.6
127.3	10	49,830		1.1
	25	52,690		1.7
	50	54,220	1	2
	100	55,390	1.2	2.2
	500	57,200	1.6	2.6
125.5	2	39,250	3.8	2.8
	5	46,620	5	4
	10	49,830	5.5	4.5
	25	52,690	5.9	4.9
	50	54,220	6.1	5.1
	100	55,390	6.2	5.2
	500	57,200	6.5	5.5
122.8	2	39,250	2.6	1.6
	5	46,620	4.1	3.1
	10	49,830	4.6	3.6
	25	52,690	5.1	4.1
	50	54,220	5.4	4.4

	100	55,390	5.6	4.6
	500	57,200	5.8	4.8
120.5	2	39,250		3.4
	5	46,620	1.7	4.7
	10	49,830	2.2	5.2
	25	52,690	2.6	5.6
	50	54,220	2.8	5.8
	100	55,390	3	6
	500	57,200	3.2	6.2
117.7	2	26,610	1.1	
	5	29,730	2	1
	10	31,030	2.4	1.4
	25	32,170	2.7	1.7
	50	32,770	2.8	1.8
	100	33,220	2.9	1.9
	500	33,920	3.1	2.1
115.7			flow contained	
113.7	2	26,610	2.7	1.7
	5	29,730	3.5	2.5
	10	31,030	3.8	2.8
	25	32,170	4	3
	50	32,770	4.2	3.2
	100	33,220	4.3	3.3
	500	33,920	4.4	3.4
110.3	2	26,610		2.4
	5	29,730	1.2	3.2
	10	31,030	1.5	3.5
	25	32,170	1.7	3.7
	50	32,770	1.8	3.8
	100	33,220	1.9	3.9
	500	33,920	2.1	4.1
108.2	2	26,610	2.8	2.8
	5	29,730	3.6	3.6
	10	31,030	3.9	3.9
	25	32,170	4.2	4.2
	50	32,770	4.3	4.3
	100	33,220	4.4	4.4
	500	33,920	4.5	4.5
101.8	5	29,730		1.2
	10	31,030		1.5
	25	32,170		1.8
	50	32,770	1	2
	100	33,220	1.1	2.1
	500	33,920	1.3	2.3
99.1			flow contained	
97.8	2	26,610	2	
	5	29,730	2.9	0.9
	10	31,030	3.2	1.2
	25	32,170	3.5	1.5
	50	32,770	3.7	1.7

	100	33,220	3.8	1.8
	500	33,920	3.9	1.9
94.4	25	32,170		1.1
	50	32,770		1.2
	100	33,220		1.3
	500	33,920		1.5
91.3	5	29,730	1.8	
	10	31,030	2.1	
	25	32,170	2.4	
	50	32,770	2.5	
	100	33,220	2.7	
	500	33,920	2.8	
90.2			flow contained	
88.6	2	26,320		2.9
	5	29,850		4
	10	31,390		4.4
	25	32,790		4.8
	50	33,550	1	5
	100	34,150	1.1	5.1
	500	35,110	1.3	5.3
88	5	29,850		1.7
	10	31,390		2.1
	25	32,790	1	2.5
	50	33,550	1.2	2.7
	100	34,150	1.3	2.8
	500	35,110	1.6	3.1
86.5	2	26,320		1.6
	5	29,850		2.7
	10	31,390		3.1
	25	32,790		3.5
	50	33,550		3.7
	100	34,150		3.9
	500	35,110	1.1	4.1

Table 6.1: Discharge and Water Depth for Scenario 1.

Return Interval	Scenario 1	Scenario 2	Scenario 3
2	65	30	10
5	20	30	30
10	5	0	15
25	5	5	0
50	0	5	0
100	0	0	5
500	0	0	5
no overbank	5	30	35

Table 6.2: % Overbank Flow at Given Return Intervals

Ecology

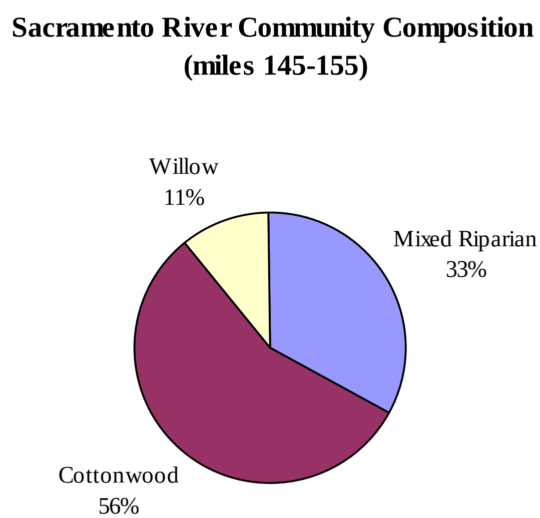


Figure 6.1: Predicted % Cover (RM 145-155)

Terrestrial Ecosystem Results

Vegetation Analysis, Predicted Acreage of Habitat Created

The total acreage created by setting back the levees to the specifications of scenario 1 is approximately 9800 acres. Using the predicted percent cover for each habitat type, the acreage of each habitat was predicted for this scenario.

Scenario 1: 3000 feet	Willow	Cottonwood	Mixed Riparian
Approximate % Coverage	11%	56%	33%
Total Habitat Created (Acreage)	1078	5488	3234

Table 6.3: Acreage of Habitat Types (Scenario 1)

Avian Analysis

Scenario 1 will benefit the following bird species

- Bank Swallow
- Black Grosbeak
- Common Yellowthroat

Aquatic Analysis

Stream Side Vegetation Results

From RM 126-131 the levees are not directly adjacent to the river

Streamside coverage or conditions	Miles	% Coverage
Willow	2.06	24%
Cottonwood	2.09	24%
Mixed Riparian	2.22	25%
Valley Oak	0	0%
Gravel	0.55	6%
Other	1.83	21%
Total Coverage	8.75	100%

Total Vegetated % Cover	**73%**
Total Non-Vegetated % Cover	**27%**

Table 6.4: Streamside Vegetation (RM 126-131)

The following are the overall results obtained for streamside vegetation analysis of the project reach (RM 84-144) and the open reach (RM 145-175). See appendix G finer detail of results for 10-mile subsections of these reaches.

Streamside coverage or conditions	Miles	% Coverage
Willow	9.51	14%
Cottonwood	11.68	18%
Mixed Riparian	20.66	31%
Valley Oak	0	0%
Gravel	13.94	21%
Other	10.55	16%
Total Coverage	66.34	100%

Total Vegetated % Cover	**63%**
Total Non-Vegetated % Cover	**37%**

Table 6.5: Streamside Vegetation (RM 145-175)

Streamside coverage or conditions	Miles	% Coverage
Willow	7.33	6%
Cottonwood	11.81	10%
Mixed Riparian	36.1	30%
Valley Oak	0	0%
Gravel	1.12	1%
Other	62.59	53%
Total Coverage	118.95	100%

Total Vegetated % Cover	**46%**
Total Non-Vegetated % Cover	**54%**

Table 6.6: Streamside Vegetation (RM 84-144)

Comparing the overall vegetated percent cover of the project reach (RM 84-144) to the open section (RM 145-175) a 17 % increase in streamside vegetation is observed in areas where levees are further from the river. This translates to an increase of 20.2 miles in vegetated streamside habitat. Because the space needed to develop suitable good quality streamside vegetation for shaded riverine aquatic habitat should be well contained within 3000 feet, these results will apply to each scenario.

Thin Streamside Vegetation Results

Thin streamside vegetation are bands of vegetation along the bank 50-150ft wide (Department of Water Resources 1998). The percent of vegetated streamside with thin coverage from RM 126 to RM 131 is 14%.

RM	% of thin Vegetation Coverage
145-155	22%
155-165	8%
165-175	6%
overall	12%

Table 6.7: Thin Streamside Vegetation (RM 145-175)

RM	% of thin Vegetation Coverage
84-94	51%
94-104	17%*
104-114	69%
114-124	77%
124-134	34%*
134-144	88%
overall	58%

Table 6.8: Thin Streamside Vegetation (RM 84-144)
*Designates reaches with significant sections where levees are not directly constraining the river (inter-levee distance range from 1400-2250ft).

Comparing the overall percentage of thin vegetation cover of the project reach (RM 84-144) to the open section (RM 145-175) a 46 % decrease in thin streamside vegetation is seen in areas where the levees are further from the river. This translates into an increase of 25.4 of better quality vegetated streamside habitat. Because the space needed to develop suitable good quality streamside vegetation for shaded riverine aquatic habitat should be well contained within 3000 feet, these results will apply to each scenario.

Floodplain Aquatic Habitat Results

Under scenario 1 the levees would encompass 81 acres of lake habitat that are currently found outside the existing levees. See Meandering Section in this Chapter.

Economics

Costs

Land Acquisition

The table 6.7 illustrates the number of acres of each land use found between the existing levees and the proposed setback levees at this setback width.

Crop	Yolo (Acres)	Sutter (Acres)	Colusa (Acres)	total acres	Cost per acre	total cost per crop (millions)
Rice	771.6	0.0	829.5	1601.0	$2,560	$4.1
Vegetable Crops	1112.9	2861.0	1373.2	5347.1	$2,925	$15.6
Irrigated Fields	1694.3	3962.3	3771.1	9427.6	$2,780	$26.2
Almonds	0.0	0.0	0.0	0.0	$6,500	$0
Walnuts	219.7	2077.3	681.4	2978.3	$7,800	$23.2
Pasture	60.7	215.5	88.3	364.6	$1,050	$0.4
Prunes	273.7	198.2	347.2	819.1	$7,500	$6.1
Nuts and Fruits	179.7	0.0	4.9	184.6	$7,915	$1.5
					Total cost of Land	**$77.1**

Table 6.9: Land Acquisition Costs for Scenario 1

Removal of Roads

The total miles of road located between the existing levee and the proposed setback levee for this scenario is 17.4 miles. This was measured using the GIS basemap layer (REF), and is an estimate of the actual miles of road present. All roads were assumed to be 8 yards wide.

miles of road	Area of road (yards^2)	Cost per yard^2	Total Cost
17.4	244710	$4.00	**$978,842**

Table 6.10: Costs of Removing Roads (Scenario 1)

Building New Levee and Removing Current Levee

To calculate the costs of building the new levees and degrading the existing levees, the dimensions of the new levee were estimated. The new levees were assumed to have a crown width of 20feet. The slope on the water side was 3 to 1, and 2 to 1 on the land side. We assumed a slurry wall would not be necessary. The rock riprap on the water side is 15 inches thick, while the gravel for the maintenance road is 4 inches thick. The levees are 15 feet high, the average height of the current levees. Hydrological calculations show that a lower levee height may be feasible.

Feature	Volume of feature (yards^3)	Convert to tons	Cost per ton or per yard^3 or ton	Cost per foot of levee
Ditch	2.78		$6.00	$16.67
Levee	20.28		$5.00	$101.39
Rock Protection	1.39	2.50	$35.00	$87.50
Top Gravel	0.25	0.49	$12.00	$5.93
			Cost per foot of Levee	**$211**

Table 6.11: Cost of Building Levee (per foot)

The number of feet of levee required for this scenario, where the maximum distance between the current levee and the existing levee is approximately 3000 feet, was then multiplied by the cost per foot of levee. Costs estimates for the design and engineering of the levee, and the construction of the levee were added. 25% was added to the total to account for any unforeseen costs.

Length of levee (ft)	**Cost**	To account for any changes	Planning and engineering and design	Construction
327677	**$69,297,596.26**	25%	15%	10%

Total Cost
$103,946,394

Table 6.12: Cost for Building Scenario 1 Levees

Removing Vegetation

We assumed that vegetation removal would be required on all land between the existing and setback levees. We also assumed that burning vegetation would be allowed.

Acres of land	**Cost per acre**	**Total cost**
9800	$300	**$2,940,000**

Table 6.13: Vegetation Removal Cost (Scenario 1)

The total cost for setting back levees for this scenario, where the maximum distance between the setback scenario and the existing levees is ~3000ft, is **$185 million.**

Benefits

Willingness to pay

Table 6.14 shows the wetland benefits resulting from Scenario 1 strategies. We used the constant benefits per acre for California and the Sacramento basin counties and multiplied them by the wetland area created by Scenario 1.

Wetland Acreage Created	WTP benefits per acre	Total Wetland Benefits
9,800	$39,436	**$386,472,800**

Table 6.14: WTP for Scenario 1

Scenario 1 would create an additional 9,800 acres of riparian wetland habitat. Based on the WTP values derived in our analysis, the wetland benefits accrued would be approximately $386 million.

Scenario Two

Description of scenario

The following are the results from the ecology, hydrology, and economic analysis for scenario 2. The scenario 2 levees have an average inter-levee distance of 6000 feet. Inter-levee widths under scenario 2 are close together or "pinch" in some places due to economic constraints (see preliminary economic analysis). Inter levee widths are pinched close together at the following locations in the project reach (RM 84-143) for scenario 2: RM 90-91, RM 98.5-100, and at RM 133-135.

Hydrology

River Mile	Return Interval (yrs)	Discharge (cfs)	Water Depth Left Floodplain (ft)	Water Depth Right Floodplain (ft)
137	5	46,620	1.6	1.6
	10	49,830	2	2
	25	52,690	2.5	2.5
	50	54,220	2.7	2.7
	100	55,390	2.8	2.8
	500	57,200	3.1	3.1
135.4	2	39,250	3.2	
	5	46,620	4.7	1.7
	10	49,830	5.3	2.3
	25	52,690	5.7	2.7
	50	54,220	6	3
	100	55,390	6.2	3.2
	500	57,200	6.5	3.5
135.1	2	39,250		3.4
	5	46,620	1.1	5.1
	10	49,830	1.7	5.7
	25	52,690	2.3	6.3
	50	54,220	2.6	6.6
	100	55,390	2.8	6.8
	500	57,200	3.1	7.1
134.2			flow contained	
131.1	50	54,220	1.1	1.1
	100	55,390	1.3	1.3
	500	57,200	1.5	1.5
127.3			flow contained	
125.5	2	39,250	2.2	1.2
	5	46,620	3.2	2.2
	10	49,830	3.7	2.7
	25	52,690	4	3
	50	54,220	4.2	3.2

	100	55,390	4.3	3.3
	500	57,200	4.5	3.5
122.8	5	46,620	1.3	
	10	49,830	1.8	
	25	52,690	2.2	1.2
	50	54,220	2.4	1.4
	100	55,390	2.6	1.6
	500	57,200	2.8	1.8
120.5	2	39,250		1.6
	5	46,620		2.7
	10	49,830		3.2
	25	52,690		3.5
	50	54,220		3.7
	100	55,390		3.9
	500	57,200	1.1	4.1
117.7			flow contained	
115.7			flow contained	
113.7	2	26,610	1	
	5	29,730	1.7	
	10	31,030	1.9	
	25	32,170	2.1	1.1
	50	32,770	2.3	1.3
	100	33,220	2.4	1.4
	500	33,920	2.5	1.5
110.3	5	29,730	1.2	1.3
	10	31,030	1.5	1.6
	25	32,170	1.7	1.8
	50	32,770	1.8	1.9
	100	33,220	1.9	2
	500	33,920	2.0	2.1
108.2	2	26,610	1.2	1.2
	5	29,730	1.9	1.9
	10	31,030	2.2	2.2
	25	32,170	2.4	2.4
	50	32,770	2.5	2.5
	100	33,220	2.6	2.6
	500	33,920	2.7	2.7
101.8			flow contained	
99.1			flow contained	
97.8	5	29,730	1.2	
	10	31,030	1.5	
	25	32,170	1.8	
	50	32,770	1.9	
	100	33,220	2	
	500	33,920	2.1	
94.4			flow contained	
91.3	5	29,730	1.1	
	10	31,030	1.4	
	25	32,170	1.7	
	50	32,770	1.9	

	100	33,220	2	
	500	33,920	2.1	
90.2			flow contained	
88.6	5	29,850		1.8
	10	31,390		2.2
	25	32,790		2.5
	50	33,550		2.6
	100	34,150		2.8
	500	35,110		3
88			flow contained	
86.5	25	32,790		1.2
	50	33,550		1.4
	100	34,150		1.5
	500	35,110		1.7

Table 6.15: Discharge and Water Depth for Scenario 2.

Ecology

Terrestrial Ecosystem Results

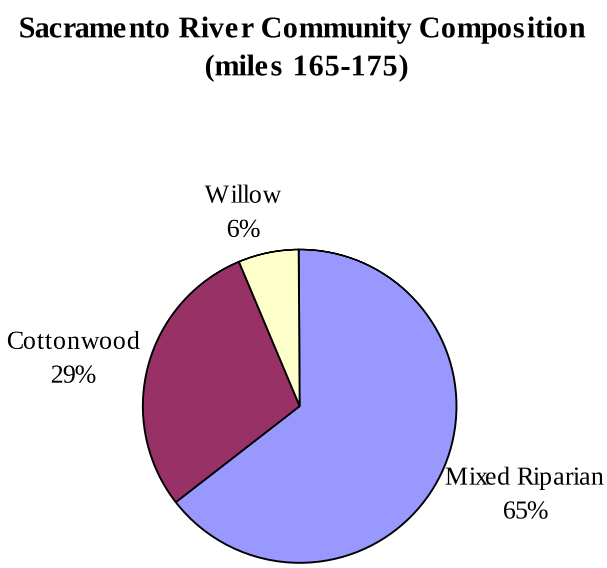


Figure 6.2: Predicted % Cover (RM 165-175)

Vegetation Analysis, Predicted Acreage of Habitat Created

The total acreage created by setting back the levees to the specifications of scenario 2 is 21,000 acres. Using the predicted percent cover for each habitat type, the acreage of each habitat was predicted for this scenario.

Scenario 2: 6000 feet	Willow	Cottonwood	Mixed Riparian
Approximate Percent Coverage	6.46%	29.19%	64.35%
Total Habitat Created (Acreage)	1357	6130	13514

Table 6.16: Acreage of Habitat Type (Scenario 2)

Avian Analysis

Scenario 2 will benefit the following bird species

- Bank Swallow
- Black Grosbeak
- Common Yellowthroat
- Song Sparrow
- Yellow Billed Cuckoo
- Yellow Breasted Chat

Aquatic Analysis

Stream Side Vegetation Results

The results do not change between scenarios. See scenario 1 for results.

Thin Streamside Vegetation Results

The results do not change between scenarios. See scenario 1 for results

Floodplain Aquatic Habitat

Scenario 2 levees would encompass an additional 34.6 acres of lake habitat to the 81 acres of lake habitat from scenario 1. Scenario 2 levees would also encompass 8.7 acres of ephemeral pool habitat on the floodplain. Therefore under scenario 2 there would be a total of 115.6 acres of lake habitat and 124.3 acres of total aquatic flood plain. See Meandering Section in this chapter.

Economics

Costs

Land Acquisition

Crop	Yolo (Acres)	Sutter (Acres)	Colusa (Acres)	total acres	Cost per acre	total cost per crop (millions)
Rice	1365.0	1492.9	2141.0	4998.9	$2,560	$12.8
Vegetable Crops	2072.9	3804.7	1745.9	7623.5	$2,925	$22.3
Irrigated Fields	1871.5	6805.6	5264.4	13941.5	$2,780	$38.8
Almonds	0.0	0.0	14.7	14.7	$6,500	$0.1
Walnuts	229.9	2606.3	802.4	3638.6	$7,800	$28.4
Pasture	167.3	273.7	118.2	559.3	$1,050	$0.59
Prunes	273.7	198.2	386.3	858.2	$7,500	$6.4
Nuts and Fruits	179.7	80.4	4.9	265.0	$7,915	$2.1
					Total cost of Land	**$111.5**

Table 6.17: Land Acquisition Costs for Scenario 2

Removal of Roads

Miles of road	Area of road (yards^2)	Cost per yard^2	Total Cost
51.4	723571	4.00	**2,894,284**

Table 6.18: Cost of Removing Roads (Scenario 2)

Building New Levee and Removing Current Levee

For a breakdown of costs, see economics results for scenario 1

Length of levee (ft)	**Cost**	To account for any changes	Planning and engineering and design	Construction
330528	**$69,900,551**	25%	15%	10%

Total Cost
$104,850,826

Table 6.19: Cost of Building Scenario 2 Levees

Vegetation Removal

Acres of land	Cost per acre	Total cost
21,000	$300	**$6,300,000**

Table 6.20: Vegetation Removal Cost for Scenario 2

The total cost for setting back levees for this scenario, where the maximum inter-levee distance is ~6000ft, is approximately **$225.5 million**.

Benefits

Willingness To Pay

Wetland Acreage Created	WTP benefits per acre	Total Wetland Benefits (millions)
21,000	$39,436	**$828.2**

Table 6.21: WTP for Scenario 2

Scenario 2 would create an additional 21,000 acres of riparian wetland habitat. Based on the WTP values derived in our analysis, the wetland benefits accrued would be approximately $828 million.

Scenario Three

Description of scenario

The following are the results from the ecology, hydrology, and economic analysis for scenario 3. The scenario 3 levees have an average inter-levee distance of 9000 feet. Inter-levee widths under scenario 3 are close together or "pinch" in some places due to economic constraints (see preliminary economic analysis). Inter levee widths are pinched close together at the following locations in the project reach (RM 84-143) for scenario 3: RM 90-91, RM 98.5-100, and at RM 133-135. Inter levees widths for scenario 3 narrow to 6000 feet for extended lengths at the following location in the project reach: RM 93-97, RM 101-103, and RM 109-113.

Hydrology

River Mile	Return Interval (yrs)	Discharge (cfs)	Water Depth Left Floodplain (ft)	Water Depth Right Floodplain (ft)
137	10	49,830	1	1
	25	52,690	1.4	1.4
	50	54,220	1.6	1.6
	100	55,390	1.7	1.7
	500	57,200	1.9	1.9
135.4	2	39,250	3.2	
	5	46,620	4.7	1.7
	10	49,830	5.3	2.3
	25	52,690	5.7	2.7
	50	54,220	6	3
	100	55,390	6.2	3.2
	500	57,200	6.5	3.5
135.1	2	39,250		3.1
	5	46,620		4.7
	10	49,830	1.4	5.4
	25	52,690	1.9	5.9
	50	54,220	2.2	6.2
	100	55,390	2.4	6.4
	500	57,200	2.7	6.7
134.2			flow contained	
131.1	500	57,200	1.2	1.2
127.3			flow contained	
125.5	5	46,620	1.9	
	10	49,830	2.3	1.3
	25	52,690	2.6	1.6
	50	54,220	2.8	1.8
	100	55,390	2.9	1.9
	500	57,200	3.1	2.1
122.8	100	55,390	1	

	500	57,200	1.2	
120.5	5	46,620		1.6
	10	49,830		2
	25	52,690		2.4
	50	54,220		2.5
	100	55,390		2.7
	500	57,200		2.9
117.7			flow contained	
115.7			flow contained	
113.7	10	31,030	1.2	
	25	32,170	1.4	
	50	32,770	1.5	
	100	33,220	1.6	
	500	33,920	1.7	
110.3	5	29,730		1.3
	10	31,030		1.5
	25	32,170		1.8
	50	32,770		1.9
	100	33,220		2
	500	33,920		2.1
108.2	5	29,730	1.2	1.2
	10	31,030	1.5	1.5
	25	32,170	1.7	1.7
	50	32,770	1.8	1.8
	100	33,220	1.9	1.9
	500	33,920	2	2
101.8			flow contained	
99.1			flow contained	
97.8	5	29,730	1.2	
	10	31,030	1.5	
	25	32,170	1.8	
	50	32,770	1.9	
	100	33,220	2	
	500	33,920	2.1	
94.4			flow contained	
91.3	5	29,730	1.1	
	10	31,030	1.4	
	25	32,170	1.7	
	50	32,770	1.9	
	100	33,220	2	
	500	33,920	2.1	
90.2			flow contained	

88.6	10	31,390		1.2
	25	32,790		1.5
	50	33,550		1.7
	100	34,150		1.8
	500	35,110		2
88			flow contained	
86.5			flow contained	

Table 6.22: Discharge and Water Depth for Scenario 3

Ecology

Terrestrial Ecosystem Results

Refer to Figure 6.2.

Vegetation Analysis, Predicted Acreage of Habitat Created
The total acreage created by setting back the levees to the specifications of scenario 2 is 28,300 acres. Using the predicted percent cover for each habitat type, the acreage of each habitat was predicted for this scenario.

Scenario 3: 9000 feet	Willow	Cottonwood	Mixed Riparian
Approximate Percent Coverage	6.46%	29.19%	64.35%
Total Habitat Created (Acreage)	1828	8261	18211

Table 6.23: Acreage of Habitat Type (Scenario 3)

Avian Analysis
Preferred Scenario for:
- Bank Swallow
- Black Grosbeak
- Common Yellowthroat
- Song Sparrow
- Swainson's Hawk
- Warbling Vireo
- Yellow Billed Cuckoo
- Yellow Breasted Chat

Aquatic Analysis

Stream Side Vegetation Results
The results do not change between scenarios. See scenario 1 for results.

Thin Streamside Vegetation Results

The results do not change between scenarios. See scenario 1 for results

Floodplain Aquatic Habitat

Scenario 3 levees would encompass no additional acres of aquatic floodplain. Therefore, scenario 3 would have a total of 115.6 acres of lake habitat, 8.7 acres of ephemeral pool habitat, and 124.3 acres of total aquatic flood plain habitat. See Meandering section in this chapter.

Economics

Costs

Land Acquisition

The following table illustrates the number of acres of each land use found between the existing levees and the proposed setback levees at this setback width.

Crop	Yolo (Acres)	Sutter (Acres)	Colusa (Acres)	total acres	Cost per acre	total cost per crop (millions)
Rice	1365.0	2369.7	2498.1	6232.8	$2,560	$16.0
Vegetable Crops	2815.1	4886.2	2229.3	9930.6	$2,925	$29.0
Irrigated Fields	1881.6	8812.5	5627.8	16322.0	$2,780	$45.4
Almonds	0.0	0.0	14.7	14.7	$6,500	$0.1
Walnuts	229.9	2692.7	873.6	3796.2	$7,800	$29.6
Pasture	167.3	273.7	118.2	559.3	$1,050	$0.59
Prunes	273.7	198.2	648.3	1120.2	$7,500	$8.4
Nuts and Fruits	179.7	132.5	4.9	317.1	$7,915	$2.5
					Total cost of Land	**$131.6**

Table 6.24: Land Acquisition Costs for Scenario 3

Removal of Roads

Miles of road	Area of road (yards^2)	Cost per yard^2	Total Cost
74.6	1050368	4.00	**4,201,472.00**

Table 6.25: Cost of Removing Roads (Scenario 3)

Building New Levee and Removing Current Levee

For a breakdown of costs, see economics results for scenario 1

Length of levee (ft)	**Cost**	To account for any changes	Planning and engineering and design	Construction
323664	**$68,448,942**	25%	15%	10%

Total Cost
$102,673,413

Table 6.26: Cost of Building Scenario 3 Levees

Vegetation Removal

Acres of land	**Cost per acre**	**Total cost**
28,300	$300	**$8,490,000**

Table 6.27: Vegetation Removal Cost (scenario 3)

The total cost for setting back levees for this scenario, where the maximum distance between the setback scenario and the existing levees is ~9000ft, is **$247.0 million**.

Benefits

Willingness to Pay

Wetland Acreage Created	WTP benefits per acre	Total Wetland Benefits (millions)
28,300	$39,436	**$1,116**

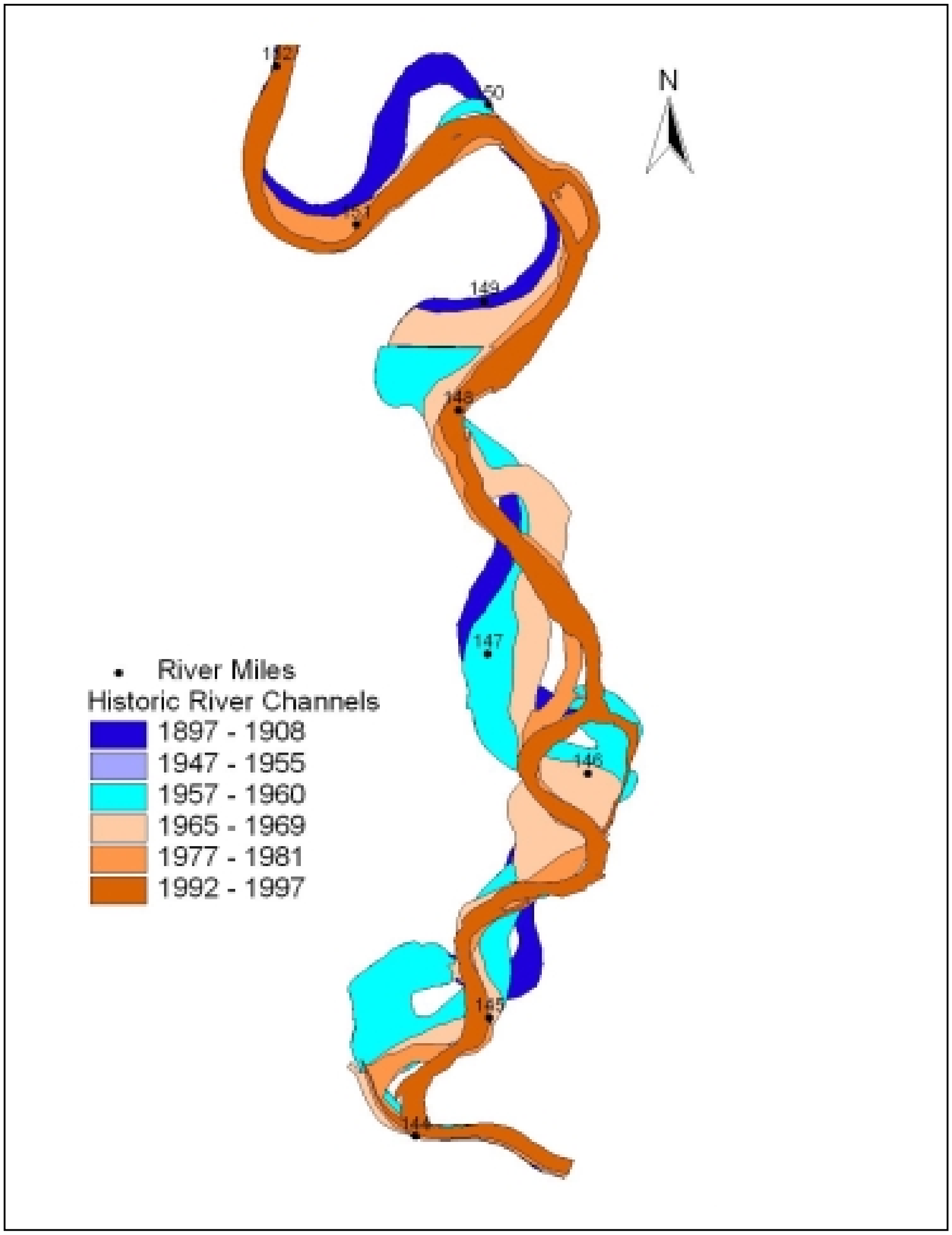
Table 6.28: WTP for Scenario 3

Scenario 3 would create an additional 28,300 acres of riparian wetland habitat. Based on the WTP values derived in our analysis, the wetland benefits accrued would be approximately $1.1 billion.

River Meandering

In addition to the small-scale hydraulic changes in channels, analyzed above, larger scale processes such as pool and riffle development, river bends, and the lateral and downstream migration of the channel develop over large spatial scales and longer time periods. We made a qualitative projection, based on the geomorphological literature, of the probable nature of channel migration that we expect to follow the setting back of levees. Rates of channel evolution and the specific shapes of bends and pools are beyond the scope of this study. Increasing the levee separation is likely to allow bank erosion on outer, concave banks and thus increase the meandering activity. Partial restoration of the natural flow regime to increase the frequency of moderately high flows would intensify the channel evolution. For example, in reaches where the inter-levee distance is approximately 6000ft., such as upstream from Colusa, the Sacramento River actively migrates in a lateral direction (Brice 1977) (Map 6.1).

Active meander bend development and migration are related to bank erosion and bar deposition (Figure 6.3). Deposition of sand or gravel in the form of a point bar deflects flow to the opposite bank, where shear stress, flow velocity, and erosion increase. Material eroded from the outer bank is deposited on the opposite side of the channel, adding to the point bar, which thus extends as the channel moves laterally (Mount 1995). Since bank erosion is most intense slightly downstream of the axis of the bend, the outside bank and the associated depositing of the point bar on the inside bank are translated downstream as well as across the floodplain. As the sinuosity of a bend increases, so does the depth of its pool and the complexity of its failing outer bank.



Map 6.1: Showing Sacramento River historic channels, located just above Colusa.

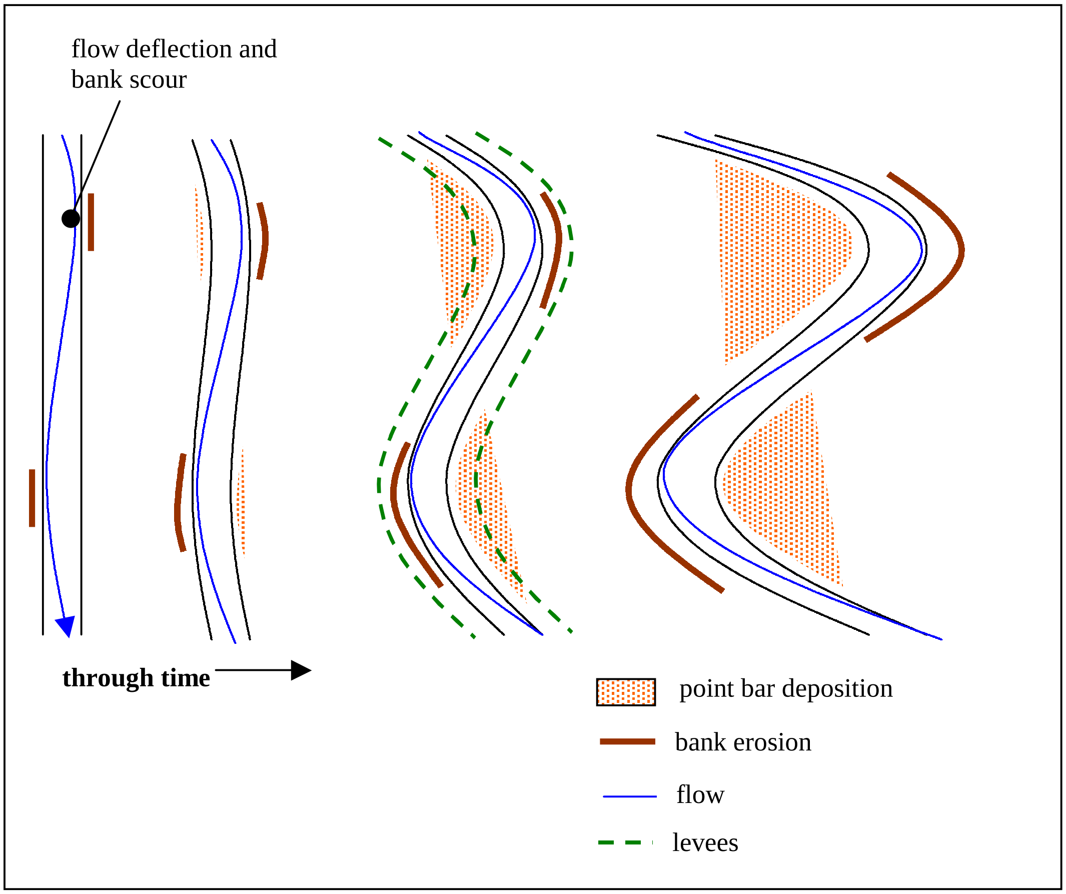


Figure 6.3: Active Meander Bends. Levees added to show how they may "freeze" the activity of meander bends. Modified from [Mount, 1995 #56].

Rivers migrate downstream, as well as laterally. Downstream migration causes meander bends to intersect or come very near one another. Where this occurs the channel has a tendency to bypass the meanders and significantly decrease its length. This process of bypassing meander bends is driven primarily by large, infrequent discharge events. There are two important types of bypasses (more commonly termed cut-offs): chute cut-offs and neck cut-offs (Figure 6.4). Chute cut-offs occur when the high flow of a river cuts through a portion of the point bar forming a new, shorter channel. Neck cut-offs occur at a higher sinuosity, when meander bends will pinch off rather than be cut through. These cut-off processes are important sources of key riverine habitats, such as backwater channels and oxbow lakes. Such features, evidence of historic or current migration, can be found at a number of places along the study reach (Figure 6.5).

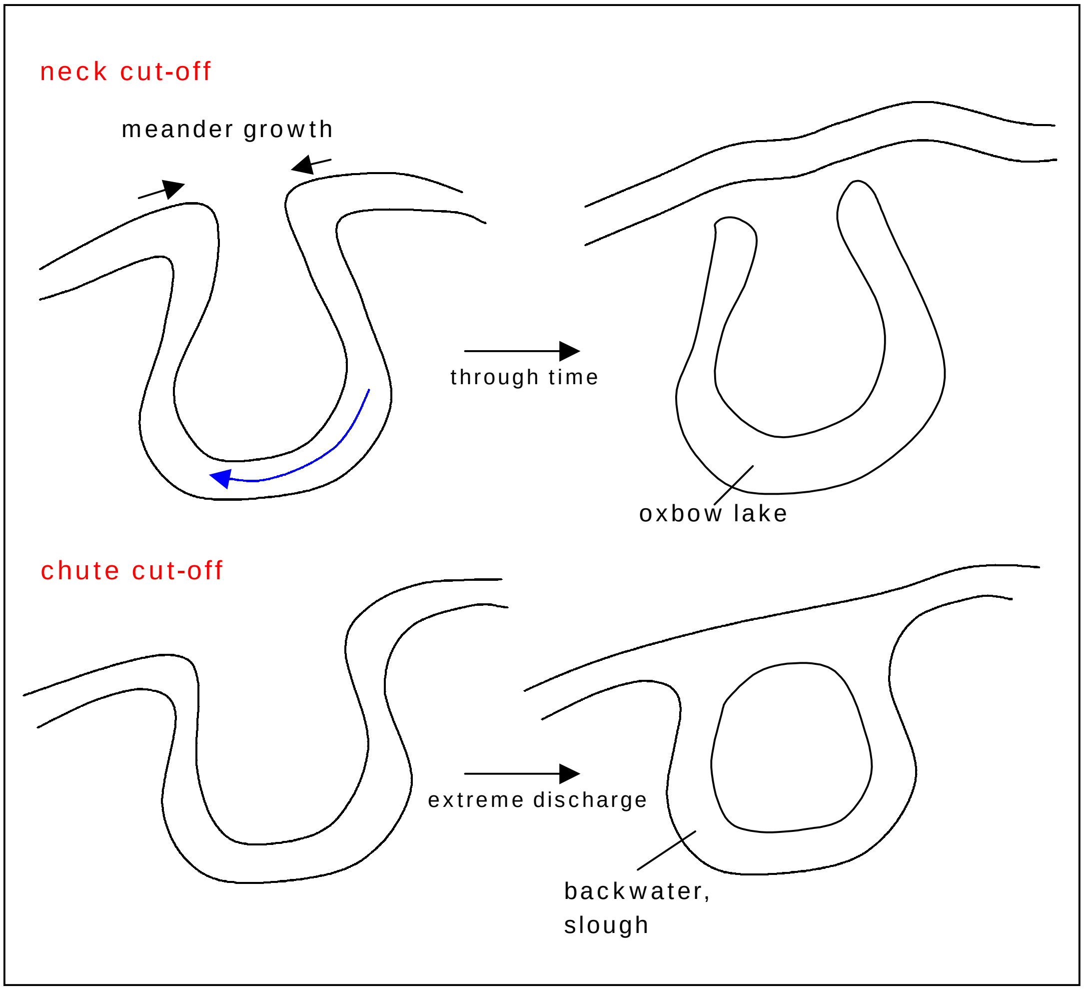


Figure 6.4: General mechanism of chute and neck cut-offs

A river may also move by displacing entire reaches, or portions of the channel. During extreme discharge events an entire reach of a river may be laterally displaced from the main channel, forming a new course across the floodplain. In large rivers, this displaced channel will usually reconnect with the original course somewhere downstream.

Both steady (erosion/deposition) and catastrophic processes are key for maintaining natural habitat diversity and quality. The regeneration of riparian habitat is controlled by lateral and downstream migration of a river. Point bars facilitate vegetative growth because their soils have high nutrient loads, nutrients are constantly supplied to them by the channel, and they are frequently inundated.

Sufficient periods of inundation is important to sustain the biota of a river (Bryan 1991). Channel cut-off is an important fluvial process that facilitates riparian vegetation succession (Greco 1999). The natural system, with its low and high probability events and subsequent dynamic interaction between the channel and floodplain, provides the spatial and temporal diversity necessary for maintaining quality riverine habitat.

The current levee system restricts the Sacramento River's natural tendency to meander by essentially "freezing" it in place (Figure 6.3). In turn, this prevents the continued propagation of riparian and aquatic habitat, resulting in habitat of lesser quantity and quality than that expected under natural conditions.

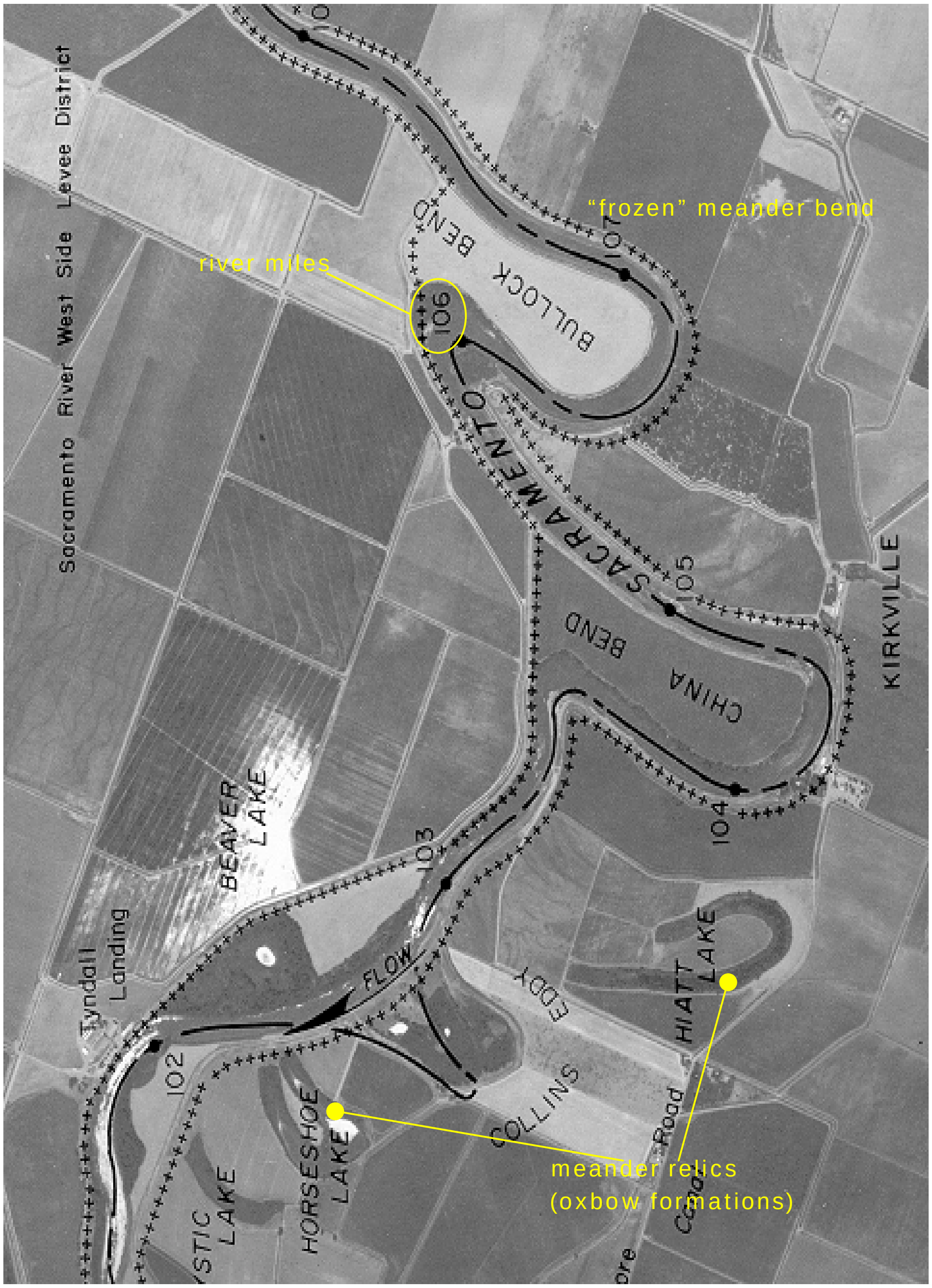


Figure 6.5: Section of Study Reach Aerial Photograph (RM 108-10)(USACE,1991)

Discussion

Each setback scenario was analyzed with respect to various hydraulic, ecological and economic parameters. The following is a discussion of the results that were presented for each setback scenario.

The hydrologic evaluation has shown that the majority of cross-sections in our reach (RM 84-143) will have over-bank flooding on the average of every two years, thus establishing a frequent flooding regime. Based on historical evidence, the river will begin to meander in our reach, instigating the disturbance regime needed for successional processes. Channel velocity will also decrease as setback widths increase. We have determined that a frequent disturbance regime is needed to create the required complex vegetation structure on the floodplain. Those plant species dependent on floodwaters for seed dispersal and nutrients will also benefit. This newly created riparian forest will be utilized by numerous avian species, and will become a source for allocthonous inputs (carbon derived from the terrestrial system) into the channel. The overall decrease in channel velocity, and increase in backwater habitat, will improve the productivity of the Chinook salmon.

We assumed that riparian forest habitat quality does not change between scenario, but the number of avian species that the habitat is capable of supporting will change as the habitat area increases. Unfortunately, this method may ignore patch dynamics of the populations.

The costs and benefits were quantified for each scenario. The major costs of this project were determined to be: (1) purchasing the land between the existing levee and the hypothetical width, (2) removing roads in these zones, and finally (3) the cost of removing the existing levee and building the new one. Benefits to setback levees were: (1) improving the riparian wetland habitat, (2) a decrease in flood damages, and (3) reduced levee maintenance costs. We were only able to quantify the benefits of riparian habitat on a per acreage value.

The use of different scenarios is appropriate for understanding and comparing how changing the setback width will affect the Sacramento system at different spatial and temporal scales. On long time scales we expect that increasing setback widths will support larger meander belts, thus creating a longer overall channel length. It will also give us an understanding of how costs and the willingness to pay benefits will vary between different setback widths. The discussion below will outline the terrestrial, aquatic and economic impacts associated with the inter-levee distance of 3000, 6000, and 9000 feet; termed Scenarios 1, 2 and 3 respectively.

Scenario One (inter-levee setback width of 3000 feet)

Aquatic System

Five important variables to the aquatic ecosystem emerged from this analysis. The variables that will benefit most from this scenario in the long-term are bolded.

- Channel Velocity - This scenario will produce the highest channel velocity, making it harder for aquatic organisms such as the chinook salmon to maintain their position in the channel.
- **Depth of Water on the Floodplain -** The depth of water will be higher on the floodplain for any given event in which the channel exceeds bankfull, thus giving fish seeking refuge from high velocity events more opportunities to escape to the floodplain.
- Allocthonous Inputs - This scenario creates the least acreage of habitat, and thus a smaller source of carbon into the channel to be utilized by aquatic organisms.
- Shaded Riverine Aquatic Habitat (SRA) - SRA provides cover for chinook. On a short-time scale, we would expect to see no difference between scenarios. On a longer time scale, due to potential for decreased channel length, this scenario would provide the least amount of streamside vegetation.
- Backwater Habitat - On a short time scale, we should see immediate benefits for it will reconnect the greatest percentage of depressions that are already established on the floodplain back to the channel. On longer time scales, however, this scenario is not as advantageous, larger setbacks will create a larger area of backwater habitat to form.

Terrestrial System

Scenario One will create a riparian forest system of approximately 10,000 acres, dominated by cottonwood forest. Willow will compromise about 10% or 1000 acres, and mixed riparian will be the smallest component. This regime is generally what is expected and is supported by the ecological analysis. Valley Oak is not likely to be established due to its moisture intolerance and high terrace requirements. This scenario will also eliminate low-quality thin vegetation that exists on the channel today. Reestablishment of riparian systems should happen fairly quickly. Willow and cottonwoods are characterized as extremely fast growing species, able to mature on a time scale of two years or less. Mixed riparian forest will take longer due to the slower growth rates, on the order of 5-10 years. The four vegetative communities and their expected relative abundance on the floodplain are denoted below. Communities in bold are thought to be those that create the most acreage, or are at least relatively comparable to other scenarios.

- **Willow Community -** There should be no significant difference in willow community between scenarios.
- Cottonwood Community - Although this scenario is dominated by cottonwood forest, we do not expect it to exceed the acreage's predicted by the wider scenarios.
- Mixed Riparian - As compared with the other scenarios, we should not expect as much mixed riparian forest in this scenario.
- Valley Oak - None expected in the short term.

Because the willow community should not significantly change per scenario, those birds that prefer willow habitat should have no preference between scenarios and include the Bank Swallow, Black Grosbeak, and Common Yellowthroat.

Costs and Benefits

The total cost of land acquisition in this scenario was approximately $77 million dollars, road removal was approximately $1 million, vegetation removal was $3 million, and the physical destroying and building of levees to be $200 a foot. Adding on additional costs for planning, engineering, construction, and a percentage error, the total cost for this scenario was estimated to be approximately $185 million dollars.

Economic benefits of the willingness to pay for riparian/wetland was approximately $39,000. The per acre value was based on WTP for an additional 40,000 acres of habitat in a similar study. The total wetland benefits for scenario 1 was calculated to be $387 million. The resulting Cost/Benefit Ratio is 0.48.

Scenario Two (inter-levee setback width of (6000 feet)

Aquatic System

Five different variables, important to the aquatic ecosystem emerged from this analysis. The variables that will benefit most from this scenario in the long-term are bolded.

- Channel Velocity - This scenario will produce intermediate channel velocities, making it harder for aquatic organisms such as the Chinook salmon to maintain their position in the channel as compared with scenario one.
- Depth of Water on the Floodplain - Compared with scenario one, the depth of water will be lower on the floodplain for any given event in which the channel exceeds bankfull, thus giving fish seeking refuge from high velocity events less opportunities to escape to the floodplain.
- Allocthonous Inputs - This scenario creates acreage of habitat between that of Scenarios one and three, thus creating a source of relative intermediate value to aquatic organisms.
- Shaded Riverine Aquatic Habitat (SRA) - SRA provides cover for Chinook. On a short-time scale, we would expect to see no difference between scenarios. On a longer time scale, due to potential for decreased channel length, this scenario would provide intermediate amounts of streamside vegetation.
- Backwater Habitat - On a short time scale, we should see immediate benefits for it will reconnect the greatest percentage of depressions that are already established on the floodplain back to the channel. On longer time scales however, this scenario is not as advantageous, larger setbacks will create a larger area of backwater habitat to form.

Terrestrial System

Scenario Two will create a riparian forest system twice the size of Scenario One, approximately 21,000 acres. Willow should occur in the same proportional density as Scenario One. Results show a slight increase to 1400 acres, but due to the large variance inherent in this analysis, this is probably not significant. Unlike the cottonwood forest that dominates Scenario One, mixed riparian cover should dominate this scenario. The cottonwood community should be slightly higher than scenario one. Again, valley oak is not likely to be established due to its moisture intolerance and high terrace requirements. Below denotes the four vegetative communities and their expected relative abundance on the floodplain. Communities in bold are thought to be those that create the most acreage, or are at least relatively comparable to other scenarios.

- **Willow Community -** There should be no significant difference in willow community between scenarios.
- **Cottonwood Community -** We expect this scenario to support cottonwood community equivalent to or greater than scenario one and approximately the same as scenario three. Our analysis does not support this supposition. It indicates that scenario three will have more acreage of cottonwood habitat. However, because we assumed the same community composition as scenario three, these numerical results are likely skewed.
- Mixed Riparian - As compared with the scenario one, we should expect more mixed riparian forest. Results support this assumption, mixed riparian forest quadrupled between scenarios.
- Valley Oak - None expected in the short term.

Because the willow community should not significantly change per scenario, those birds that prefer willow habitat should have no preference between scenarios. Additionally, those birds that prefer cottonwood forest are assumed to prefer this scenario. The total list of birds that will likely prefer this scenario are the Bank Swallow, Black Grosbeak, Common Yellowthroat, Song Sparrow, Yellow Billed Cuckoo, and the Yellow Breasted Chat.

<u>Costs/Benefits</u>

The total cost of land acquisition in this scenario was approximately $111 million dollars, road removal was approximately $3 million, vegetation removal was $6.3 million, and the physical destroying and building of levees to be $200 a foot. Adding on additional costs for planning, engineering, construction, and an percentage error, the total cost for this scenario was estimated to be approximately $225.5 million dollars.

Economic benefits of the willingness to pay for riparian/wetland habitat from our methodology section resulted in a per acre value of approximately $39,000. The per acre value was based on WTP for an additional 40,000 acres of habitat in a similar study. The total wetland benefits for scenario 2 was calculated to be $828 million. The resulting Cost/Benefit Ratio is 0.27.

Scenario Three (inter-levee setback width of 9000 feet)

<u>Aquatic System</u>

Five different variables, important to the aquatic ecosystem emerged from this analysis. The variables that will benefit most from this scenario in the long-term are bolded.

- **Channel Velocity -** This scenario will produce the lowest channel velocities and will help aquatic organisms such as the Chinook salmon to maintain their position in the channel as compared with both scenarios one and two.
- Depth of Water on the Floodplain **-** Compared with both scenario one and two, the depth of water will be lower on the floodplain for any given event in which the channel exceeds bankfull, thus giving fish seeking refuge from high velocity events the least opportunities to escape to the floodplain.
- **Allochthanous Inputs -** This scenario creates acreage of habitat greater than scenarios one and two, thus creating a source of relative high value to aquatic organisms.
- **Shaded Riverine Aquatic Habitat (SRA) -** SRA provides cover for Chinook. On a short-time scale, we would expect to see no difference between scenarios. On a longer time scale, due to potential for decreased channel length, this scenario would provide the largest amounts of streamside vegetation.
- **Backwater Habitat -** On short time scales, we should see the first scenario provide the most benefits. On longer time scales however, this scenario is the most advantageous, larger setbacks will create a larger area of backwater habitat to form.

<u>Terrestrial System</u>

Scenario Three will create a riparian forest system approximately three times the size of Scenario One, approximately 28,000 acres. Willow should occur in the same proportional density as Scenario One. Results show an increase to 1800 acres, but due to the large variance inherent in this analysis, this is probably not significant. This scenario is similar to Scenario Two, dominated by mixed riparian cover. The cottonwood community should be roughly equivalent to scenario two. Again, valley oak is not likely to be established. Below denotes the four vegetative communities and their expected relative abundance on the floodplain. Communities in bold are thought to be those that create the most acreage, or are at least relatively comparable to other scenarios.

- **Willow Community -** There should be no significant difference in willow community between scenarios.
- **Cottonwood Community -** We expect this scenario to support cottonwood community greater than scenario one and approximately the same as scenario two. Our analysis does not support this supposition. It indicates that scenario three will have more acreage of cottonwood habitat. However, because we assumed the same community composition as scenario three, these numerical results are likely skewed.
- **Mixed Riparian -** As compared with both scenarios one and two, we should expect more mixed riparian forest. Results support this assumption.
- Valley Oak - None expected in the short term.

The birds that prefer scenario three will include those that prefer willow, cottonwood, and mixed riparian habitat. This scenario encompasses the total list of birds that were classified as having high potential and include the Bank Swallow, Black Grosbeak, Common Yellowthroat, Song Sparrow, Swainson's Hawk, Warbling Vireo, Yellow Billed Cuckoo, and the Yellow Breasted Chat.

<u>Costs/Benefits</u>

The total cost of land acquisition in this scenario was approximately $132 million dollars, road removal was approximately $4.2 million, vegetation removal was $8.5 million, and the physical destroying and building of levees to be $200 a foot. Adding on additional costs for planning, engineering, construction, and an percentage error, the total cost for this scenario was estimated to be approximately $247.0 million dollars.

Economic benefits from Jones & Stokes of the willingness to pay per acre of wetland of $40,000, the total wetland benefits were calculated to be over $1.1 billion. The Cost/Benefit Ratio is 0.23.

Conclusions

Setback levees are part of a myriad of management options being considered in the restoration of the Sacramento River ecosystem. The major advantages of setback levees come through re-establishing a connection between the channel and its floodplain. In this project the hydraulic effects, the ecological significance, and the economic feasibility of setting back levees has been analyzed for a 60-mile long reach of the Sacramento River. The reach is fairly homogenous (small variance in slope and common hydraulic characteristics), it is bracketed by various constraints (wide levees to the north and major bypasses and urbanization to the south) and levees directly adjacent to the channel are characteristic throughout.

The purpose of this project was to allow recommendations concerning setback levees to emerge from the analysis of a range of options. These options are manifest in setback scenarios of varying width (ca. 3000ft., 6000ft. and 9000ft.). The objective was to predict the hydrological and ecological effects and the costs of setting back levees, given the physical, biological, and economic character of each reach.

The principal variable in this analysis was the floodplain area, or inter-levee distance. The hydraulic characteristics considered were floodplain inundation depth for various flood recurrence intervals, channel velocity and the potential for river meandering. The ecological parameters were aquatic (primarily in terms of fish) and terrestrial (primarily in terms of riparian vegetation and associated avian species) habitat. The economic parameters involved the value of land and associated infrastructure for the productive sector.

Scenario 3 (inter-levee distance of 9000 feet) appears to be the optimal scenario in terms of all parameters analyzed. For the aquatic ecosystem, this scenario establishes the most desirable conditions for improving habitat. It presents the most dramatic decrease in overall channel velocity, reducing the stress now placed on migrating fish (particularly Salmonids). Allocthonous inputs of organic material and nutrients are expected to be highest under scenario 3, given the increased area of floodplain being reconnected to the channel. Backwater habitat areas and shaded riverine aquatic habitat are also expected to develop most efficiently (over a long time scale) under this scenario. For the terrestrial ecosystem the most desirable conditions for improving riparian habitat were established under scenario 3, which of the three scenarios yields the largest area of willow, cottonwood and mixed riparian communities (the most common communities found in Sacramento Valley riparian habitat). This scenario also allows the most freedom for channel migration to occur over time, thus potentially establishing the most dynamic interactions between the floodplain and channel. These interactions may result in a more diverse range of aquatic and terrestrial habitats. Furthermore, economic analysis shows this scenario to be the most attractive, as the calculated cost/benefit ($247 million/$1.1 billion) ratio is at minimum (0.23) under this scenario.

Critical Uncertainties

The Sacramento River and its watershed is a large system. Consequently, any study attempting to analyze a river of this size would naturally entail some major assumptions. Therefore, our hydrological, ecological, and economic analyses, constrained by time and data availability, involve a significant number of important assumptions, or uncertainties.

The most important assumption related to hydrology is that the cross sections are independent of each other; which is to say that the hydraulic parameters at a given cross section have no effect on the parameters at upstream or downstream cross sections. Thus the depth and speed of flow calculations could be refined with a full step-backwater analysis. Another assumption relates to the potential for river meandering. We assume that the levee-to-levee distance defines the width of the meander belt. In other words, wider levees will eventually result in larger meander amplitudes and therefore a larger channel sinuosity, deeper pools, and more complex banks. In terms of setback levees, there is no consideration given to the change in flow characteristics associated with the "pinching" of the levee system near sections where setbacks cannot be implemented. Finally, the whole analysis assumes that the current flow regime will be maintained. We are not accounting for potential changes in flow control by dams, weirs, bypasses, and diversions. There would likely be a change in how these structures are operated if setback levees are implemented along the river.

For the ecological analysis, one major assumption is that the composition of riparian vegetation that will result under various setback widths will be similar to the composition currently found upstream of the project reach, where levees are already 3000 to 9000 feet apart in many places. Moreover, the quality of new habitat is assumed to remain the same from one scenario to another. It was also assumed that the various species of birds, and the Chinook salmon, will utilize new habitats in the capacity and forms that were discussed.

In the economic analysis there are two important assumptions related to the cost calculations. The first one is that average costs represent land purchases based on crop type and land use, and that land owners would be willing to sell their land at these costs. Secondly, Water Rights were not quantified for this analysis. For the

benefit calculations, willingness to pay estimates were assumed to be a viable measure of the social benefits resulting from increased riparian habitat.
It was assumed that the variables employed in the Jones and Stokes report for residents of the San Joaquin Valley were the same for the Sacramento Valley. Another assumption concerning that report is that its respondents were able to comprehend the 40,000 acre number posed to them and that their willingness to pay would reflect changes in acreage of habitat creation. Economic benefits were assumed to be the same per acre and to increase linearly with additional habitat created.

The above assumptions are inherent in the project and should be acknowledged when considering our conclusions.

Appendix A

Characterization of Reach

County	Colusa
Cities	Colusa at RM 144
Water Districts	Part of Reclamation District 2047 lies on the west side of the river. On the east side of the river, setback from the levees, is Reclamation District 1004.
Major Roads	The city of Colusa lies immediately to the west of the river. Roads within the city are located directly next to the levees and consist of both secondary highway's as well as small streets. South of RM 143 there are no major roads close to the levees, although there are some streets in place.
Current Land Use	East: Predominantly rice and irrigated field crops. Minor land uses include vegetable crops, and prune and walnut orchards. West: Predominantly prune orchards. Minor land uses include vegetable and irrigated field crops, and walnut, fruit and nuts, and almond orchards.
Levees	The levees north of RM 145 are set back an average of 0.4 mi. Levees turn in and by RM 143 are almost directly adjacent to the channel, leaving little room for the river to meander.
Surface Geology	The small amount of land between the channel and the current levee consists of stream channel deposits. Past the levees, the land consists mainly of basin or march deposits and undifferentiated stream alluvium. North of RM 143 the land inside the levees also contains 100 year meander belt deposits.
Soil Texture	Soil on both sides of the river consists of a combination of silt loam and loam soils.
Historical meanderbelt	North of RM 144 the historical meander belt is between 0.5 and 0.9mi wide. Between RM 143 and RM 140 the historical meanderbelt ranges between 0.1 and 0.3mi in width.
Riparian Habitat	Small patches of riparian scrub are found between RM 146 and 144, but not between RM 144-140. Great valley cottonwood riparian forest exists north of RM 144 inside the levees. This habitat is not found between RM 144 and 140, nor is it found outside the levees. Large areas of great valley mixed riparian forest are found between RM 146 and RM 144. The remainder of this section of river contains this habitat type along the river channel. There are also some small patches found outside the east levees at a distance of 0.3 to 0.5mi on. Within this section of the river there are a few small patches of valley oak habitat which are located outside the levees by approximately 0.3 to 0.4mi.

Table A.1: Characterization of RM 145-140

County	Colusa county on both sides of river until RM 138, after which Colusa county is only on the west side of the river. Sutter County on east side of river after RM 138.
Cities	No cities.
Water Districts	Reclamation District 1004 lies just to the north of this bend in the river.
Major Roads	There are minor streets running directly adjacent to the levees on either side of the river.
Current Land Use	East: Predominantly walnut and almond orchards, and rice, vegetable, and irrigated field crops. Minor land uses include fruit & nuts and prune orchards, and pasture. West: Predominantly rice and irrigated field crops. Minor land uses include vegetable crops and prune orchards.
Rivers and Diversions	Butte Creek meets the Sacramento River just north of RM 138.
Levees	The levees along this section allow the river to have approximately a 0.1mi width. One section at RM 138 has levees that are a bit further from the river with the two sides being approximately 0.3 to 0.4mi apart.
Surface Geology	Undifferentiated stream alluvium dominate this area near the river. There is an area of basin or march deposits on the west side of the river, but this is about one mile removed from the river.
Soil Texture	The land on the west side of the channel consists dominantly of silt loam. The land on the east side of the river consists of a combination of loam and silt loam.
Historical meanderbelt	The historical meanderbelt ranges in width from 0.9mi to 0.35mi. The widest area is around RM 138, and the remaining section has an average historical meandering belt of 0.12mi.
Riparian Habitat	No great valley riparian scrub is present. A small section of great valley cottonwood riparian forest is present at RM 138 where the levees are a not directly adjacent to the river. Thin sections of great valley mixed riparian forest are present along most of the river in this area, and larger areas exist near RM 138 where the levees provide more space. There is one small section of valley oak habitat just outside the levees at RM 136.

Table A.2: Characterization of RM 140-135

County	Colusa county on west side of river. Sutter county on east side of river.
Cities	Town of Meridian on east side of river.
Water Districts	Meridian Farms Water Company covers an area to the east side of the river, but this area does not run adjacent to the river.
Major Roads	Highway 45 is located on the west side of the river and comes to within 0.07mi of the west levee near RM 132. There is a cluster of streets near RM 134.
Current Land Use	East: Predominantly rice, walnut, vegetable, and irrigated field crops. Minor land uses include almonds, fruits and nuts, and pasture. West: Predominantly vegetable and irrigated field crops. Minor land uses include rice crops, and walnut, and fruit and nuts orchards.
Rivers and Diversions	None
Levees	The levees to RM 131 are close to the river and are an average of 0.1mi apart. At RM 131 the levees begin to widen and for the remainder of this section they range from 0.3 to 0.45mi apart.
Surface Geology	All land surrounding this section of the river was classified as undifferentiated stream alluvium.
Soil Texture	Most of the soil surrounding the river is loam. There are patches of fine sandy loam as well as silt loam.
Historical meanderbelt	The meander belt ranges from 0.1mi to 0.45mi in width. The average is 0.1mi until RM 131, after which it widens.
Riparian Habitat	There are only two very small sections of great valley riparian scrub located along this section of the river. Both are located where the distance between the levees increases. Several areas of great valley cottonwood riparian forest are present and located in areas where the levees are generally wider. Great valley mixed Riparian forest is located along the river in thin strips where the levees are close to the channel, but larger areas exist where the levees are further away from the channel.

Table A.3: Characterization of RM 135-130

County	Colusa County on west side of river. Sutter County on east side of river.
Cities	Grimes is located on the western side of RM 125
Water Districts	Meridian Farms Water Company covers an area to the east side of the river, but this area does not run adjacent to the river.
Major Roads	State Highway 45 is located on the east side of the river at a distance of 1 to 1.7 miles away from the west levee. There is a cluster of streets adjacent to the west levee between RM 126 and RM 125.
Current Land Use	East: Predominantly rice, vegetable and irrigated field crops. Minor land use includes pasture. West: Predominantly vegetable, rice, and irrigated field crops. Minor land uses include walnut and almond orchards.
Rivers and Diversions	None
Levees	The levees are from 0.3mi to 0.45mi apart until RM 126. There they narrow to ~0.15mi apart. The levees get a bit wider along RM 127 (0.35mi), and then again narrow down 0.1mi apart.
Surface Geology	All land surrounding this section of the river was classified as undifferentiated stream alluvium.
Soil Texture	The western side of the river is dominated by silt loam and loam soils. The eastern side of the river is combination of silty clay, silt loam, loam, silty clay loam, and fine sandy loam.
Historical meanderbelt	The historical meanderbelt ranges in width from 0.1mi to 0.4mi.
Riparian Habitat	There are significant areas of great valley cottonwood riparian forest and great valley mixed riparian forest where the levees are a bit further back from the channel. In areas where the levees are close to the channel, there are only small strips of great valley mixed riparian forest along the river banks. There are only very small areas of great valley riparian scrub and these are located where the levees are not directly adjacent to the channel. There are no areas of valley oaks.

Table A.4: Characterization of RM 130-125

County	Colusa County on west side of river. Sutter County on east side of river.
Cities	No cities
Water Districts	Meridian Farms Water Company and the Tisdale irrigation located to the east. Reclamation District 108 is located to the west.
Major Roads	State Highway 45 is within close proximity of the west levee starting at RM 125 and moving north. There are some small roads located near the levees.
Current Land Use	East: Predominantly rice, vegetable, and irrigated field crops. Minor land uses include walnut orchards and pasture. West: Predominantly irrigated field crops. Minor land uses include vegetable and rice crops, walnut and prune orchards, and pasture.
Rivers and Diversions	There is a small lake between RM 124 and RM 125.
Levees	The levees tightly constrain the river along this section.
Surface Geology	All land surrounding this section of the river was classified as undifferentiated stream alluvium
Soil Texture	The west side of the river is characterized by silt loam and loam soil with some areas of clay. The east side is a combination of silt loam, loam, silty clay and silty clay loam.
Historical meanderbelt	The historical meanderbelt along this section is narrow and averages ~0.1mi in width.
Riparian Habitat	There is no great valley riparian scrub habitat found within this section. There are some small sections of great valley cottonwood riparian forest present along the edges of the channel. Great valley mixed riparian forest is found in small areas along the channel, but the area covered appears to be less than in reaches north of this reach. There is no valley oak habitat present in this section.

Table A.5: Characterization of RM 125-120

County	Colusa County on west side of river Sutter County on east side of river
Cities	None
Water Districts	Tisdale Irrigation District, Reclamation District 1500, and Sutter Mutual Water District are located on the east side of the river. Reclamation District 108 is located on the west side of the river
Major Roads	There are some streets within close proximity of the levee, but no highways. Cranmore road and west side canal are connected to the Tisdale bypass and run south along the east side of the river.
Current Land Use	East: Predominantly rice, vegetable, and irrigated field crops. Minor land uses include walnut, prune, fruits and nuts, and peach orchards. West: Predominantly irrigated field crops. Minor land uses include vegetable and rice crops, walnut and fruits and nuts orchards, and pasture.
Rivers and Diversions	Just south of RM 119, Tisdale bypass connects to the east side of the river. Wilkiens Slough is located on the west side of the river just south of RM 118
Levees	The levees are tightly constraining the river along most of this reach with the exception of between RM 120 and RM 119 where the distance between the levees reaches 0.35mi.
Surface Geology	All land surrounding this section of the river was classified as undifferentiated stream alluvium.
Soil Texture	On the western side of the river the dominant soil type is loam and silty loam with some clay. On the eastern side of the river the main soil type is loam, fine sandy loam, and silty loam
Historical meanderbelt	The historical meander belt is between ~1.1mi except for between RM 120 and RM 119 where it reaches up to 0.36mi.
Riparian Habitat	There are areas of great valley riparian scrub located within the Tisdale bypass, but not along the main channel. Great valley cottonwood riparian forest is located within the areas where the levees are a bit further apart, as well as in the Tisdale bypass and in small sections along the main channel. Great valley mixed riparian forest is located along the main channel, and is present in larger areas where the distance between the levees is greater.

Table A.6: Characterization of RM 120-115

County	Colusa County on west side of river. Sutter County on east side of river.
Cities	No cities
Water Districts	Reclamation District 108 is on the west side of the river. Reclamation District 1500 as well as Sutter Mutual Water District are located on the east side of the river.
Major Roads	Highway 45 lies close to the levees at RM 111 Some small roads are located near the levees.
Current Land Use	East: Predominantly vegetable, rice, and irrigated field crops. Minor land uses include walnut orchards and pasture. West: Predominantly vegetable crops. Minor land uses include rice and irrigated field crops, walnut orchards, and pasture.
Rivers and Diversions	None
Levees	Levees tightly constrain the river in this section with distances between levees ranging from 0.1mi to 0.14mi.
Surface Geology	Undifferentiated stream alluvium is present adjacent to the river in this section, with basin and march deposits being 0.75mi to 1mi away from the channel location.
Soil Texture	The west side of the river is a mixture of loam, silt loam, and clay. The east side of the river is a mixture of clay, silty clay, silty loam, and silty clay loam.
Historical meanderbelt	The historical meander belt in this reach is narrow and ranges from 0.1mi to 0.13mi wide.
Riparian Habitat	No great valley riparian scrub present. Very small amounts of both great valley cottonwood riparian forest and great valley mixed riparian forest present along the channel, but within the levees. No valley oak present.

Table A.7: Characterization of RM 115-110

County	The west side of the river along this reach is Colusa County until between RM 109 and RM 108 where it moves into Yolo County. The east side of the river is in Sutter County.
Cities	No cities
Water Districts	Reclamation district 108 on the west side Reclamation district 1500 on the east side
Major Roads	Highway 45 reaches to within 0.25mi of the west levee near RM 109. Some streets present near the levees.
Current Land Use	East: Predominantly vegetable, rice, and irrigated field crops. Minor land use includes walnut orchards. West: Predominantly irrigated field crops. Minor land uses include vegetable crops and pasture.
Rivers and Diversions	None
Levees	Levees tightly constrain the river in this section, with distances between levees averaging 0.9mi. At RM 107 the channel curves to the east, and the east levee lies directly adjacent to the channel on that side. On the west side of this curve the levee does not follow the curve, but rather continues to go strait, and is once again directly next to the channel when the channel curves back.
Surface Geology	Undifferentiated stream alluvium is located next to the channel, and further away (0.5mi to 1.25mi) there are basin or march deposits present.
Soil Texture	The west side of the river is characterized by very fine sand loam, silty clay loam, loam, and clay. The east side of the river has a combination of loam, silty loam, silty clay loam, and clay.
Historical meanderbelt	The historical meander belt is narrow and ranges from 0.7mi to 1.2mi across.
Riparian Habitat	No great valley riparian scrub exists along this stretch. There is a small patch of great valley cottonwood riparian forest along RM 106 where the levees are not directly next to the channel. Very little great valley mixed riparian forest exists along this section of the river. Where it is present it is in very thin sections between the channel and the levees. No valley oak is present.

Table A.8: Characterization of RM 110-105

County	Yolo County is on the west side of the river. Sutter County is on the east side of the river.
Cities	No cities
Water Districts	Reclamation district 108 is located on the west side. Reclamation district 1500 is located on the east side.
Major Roads	There are a few streets which lie close to the levees, but no major roads.
Current Land Use	East: Predominantly vegetable, rice, and irrigated field crops. Minor land uses include walnut orchards and pasture. West: Predominantly rice, vegetable, and irrigated field crops. Minor land use includes pasture.
Rivers and Diversions	Hiatt Lake, Collins Eddy, Horseshoe Lake, and Mystic Lake are all located just to the east side of the east levees.
Levees	The river in this section has several curves. The levees at times follow these meanders closely, while in some curves the levees continue to go straight, and reach close proximity to the channel when the loop comes back around.
Surface Geology	The areas directly next to the river are undifferentiated stream alluvium. Basin or march deposits are present along both sides of the river, but the distance vary from 0.25mi from the channel on the west side, to over one mile away on the east side.
Soil Texture	On the west side of the river the soil is characterized by silt loam, silty clay loam, and very fine sandy loam close to the river. This changes to an area dominated by clay at ~0.3mi to 0.5mi away from the channel. The eastern soils are characterized by loam, silty clay loam, silt loam, and silty clay. The clay on this side is much further away from the channel (1-2mi).
Historical meanderbelt	The historical meander belt is approximately 0.1mi wide in most areas. There are some areas where it reaches up to 0.5mi wide
Riparian Habitat	There is an area of great valley riparian scrub present where the levee is not directly next to the river. There are areas of great valley cottonwood riparian forest present, particularly in the areas where the levees are not directly adjacent to the river. Great valley mixed riparian forest is also present in this section. In addition to being near the river, particularly when the levees provide room, there are also areas of this habitat formed around the lakes. No Valley Oak habitat is present.

Table A.9: Characterization of RM 105-100

County	Yolo County is on the west side of the river. Sutter County is on the east side of the river.
Cities	No cities
Water Districts	Reclamation districts 108 and 787 are located on the west side. Reclamation district 1500 and Sutter Mutual Water District are located on the east side of the river.
Major Roads	Highway 45 runs almost directly adjacent to the river from RM 98 to RM 100. There are some other streets that run close to the river.
Current Land Use	East: Predominantly rice, vegetable, and irrigated field crops. Minor land use includes walnut orchards. West: Predominantly rice and irrigated field crops. Minor land uses include vegetable crops, and walnut, and fruits and nuts orchards.
Rivers and Diversions	Sycamore slough and is located along the west side of the river, and connects south of RM 99.
Levees	The levees are tightly constraining throughout this section, except for at RM 97 where they are at a distance of ~.45mi apart in a bend.
Surface Geology	The areas directly next to the river are undifferentiated stream alluvium. Basin or march deposits are present along both sides of the river, but the distance vary from 0.25mi from the channel on the west side, to over one mile away on the east side.
Soil Texture	The dominant soil type on the west side of the river is clay, but there are also areas of silty clay loam and very fine sandy loam. The east side of the river is a combination of loam, silty clay loam, silty loam, and clay.
Historical meanderbelt	The width of the historical meander belt varies from 0.1mi to 0.3mi.
Riparian Habitat	There is a small area of great valley riparian scrub just above RM 100 where the levees are not directly adjacent to the river. There are two areas of great valley cottonwood riparian forest located in areas where the levees provide room next to the river. Small sections of great valley mixed riparian forest are present along the edges of the river. There are two areas of valley oak present along the outside edges of the levees. One area is 4 acres in size while the other is only one acre in area

Table A.10: Characterization of RM 100-95

County	Yolo County is on the west side of the river. Sutter County is on the east side of the river.
Cities	Knights Landing is located just south of RM 90
Water Districts	Reclamation district 787 is located on the west side. Reclamation district 1500 and Sutter Mutual Water District are located on the east side of the river.
Major Roads	Sate Highway 113 is located on the east side of the river and has a bridge crossing the river just below RM 90. There is a cluster of streets just below RM 90.
Current Land Use	East: Predominantly rice, vegetable, and irrigated field crops. Minor land use includes walnut orchards. West: Predominantly rice and irrigated field crops. Minor land uses include vegetable crops, and walnut, prune, and fruit and nuts orchards.
Rivers and Diversions	Colusa drainage canal connects with the main channel on the west side at RM 90. Sycamore slough is located on the west side of the river and connects with the Colusa drainage canal and the Sacramento river at RM 90 Knights Landing Ridge Cut connects with the Colusa Basin Drainage Canal at ~0.5mi from the Sacramento River.
Levees	Levees tightly constrain this segment of the river.
Surface Geology	Undifferentiated stream alluvium is found on both sides of the river. At approximately 0.3mi away from the western channel and 0.7mi away from the east there exist basin or march deposits.
Soil Texture	The west side of the river is characterized by a band of silty clay loam along the channel, followed by clay further out. The east side of the river consists of a band (though wider than that on the west side) of silt loam and silty clay loam, also followed by clay further away from the river
Historical meanderbelt	The historical meander belt is approximately 0.1mi wide through this section of the river.
Riparian Habitat	No great valley riparian scrub found. Only a very small section of great valley cottonwood riparian forest is found in this region. Great valley mixed riparian forest is found along the edges of the channel. No valley oaks found.

Table A.11: Characterization of RM 95-90

County	Yolo County is on the west side of the river. Sutter County is on the east side of the river.
Cities	No cities
Water Districts	Reclamation district 730 is located on the west side. Reclamation district 1500 and Sutter Mutual Water District are located on the east side of the river.
Major Roads	There are several streets which run close to the levees, but no major highways.
Current Land Use	East: Predominantly vegetable and irrigated field crops. Minor land uses include rice crops and walnut orchards. West: Predominantly vegetable and irrigated field crops. Minor land uses include walnut orchards and pasture.
Rivers and Diversions	Between RM 89 and RM 88 there are two lakes called the McGriff lakes, which are located outside of the levees on the eastern side of the river. Mary Lake is within the levees between RM 88 and RM 87 on the east side of the river. Horseshoe lake is located on the east side of the river between RM 86 and RM 85.
Levees	The levees in this section are tightly constraining except for between RM 88 and 87 where the distance between the levees reaches up to 0.5mi.
Surface Geology	Undifferentiated stream alluvium is found on both sides of the river. At approximately 0.15mi to 1.5mi away from the west side of the channel and 1.5mi to 2mi away from the east there exist basin or march deposits.
Soil Texture	The soil on the western side of the river is a mixture of very fine sandy loam, clay, silty clay loam, and silt loam. The eastern side of the river is dominated by silt loam and silty clay.
Historical meanderbelt	The historical meander belt is narrow and averages approximately 0.1mi in width.
Riparian Habitat	No great valley riparian scrub is found in this section Some small areas of great valley cottonwood riparian forest is located along the river, particularly in the area where the levees are not directly adjacent to the river. Great valley mixed riparian forest is located throughout this area along the river as well as around the lakes. No valley oaks found.

Table A.12: Characterization of RM 90-85

County	Yolo County is mostly on the west side of the river. Sutter County is mostly on the east side of the river.
Cities	No cities
Water Districts	Reclamation district 730 is located on the west side until RM 84. Sutter Mutual Water District is located on the east side of the river until RM 84.
Major Roads	There are several streets that are close to the levees, but no major highways.
Current Land Use	East: Predominantly irrigated field crops. Minor land uses include vegetable crops and walnut orchards. West: Predominantly irrigated field crops. Minor land uses include vegetable crops, walnut orchards, and pasture.
Rivers and Diversions	Sutter and Yolo bypass both connect with the main channel in this area. There are several lakes located near this area.
Levees	The levees move away from the river to form the levees along the Sutter and Yolo bypass on the east and west side of the river respectively at ~RM 84.
Surface Geology	The area surrounding the river is composed of undifferentiated stream alluvium with basin or march deposits located approximately 0.6mi to 0.75mi on the west side of the river.
Soil Texture	The west side of the river is a combination of clay, very fine sandy loam, silt loam, and silty clay loam complex. Silt loam and silty clay dominate the east side of the river.
Historical meanderbelt	The historical meander belt is narrow.
Riparian Habitat	No great valley riparian scrub is found in this area. Only a few small sections of great valley cottonwood riparian forest exist directly adjacent to the main channel. Great valley mixed riparian forest exists in areas next to the main channel, as well as near the lakes and within the bypass systems. A small area of valley oak is found along the Feather River just north of RM 80.

Table A.13: Characterization of RM 85-80

Appendix B

Agencies Involved

Flood control as well as conservation planning involves numerous agencies at the local, state and federal level. Although each agency has a designated role, these often overlap. This overlap, along with the great number of agencies involved, is often quite confusing. The reach is located within three counties and has numerous Levee Reclamation Districts, Irrigation Districts and Water Districts located within the area. This appendix describes some of these local agencies, as well as the state and federal agencies that play a role in Sacramento Valley flood protection.

Counties and Cities

The study reach is located within three counties: Colusa, Sutter, and Yolo. There are also several cities and communities located within this area (see map 3.1). Because these counties are located within the Sacramento River Conservation Area they are required to have a general plan that discusses open space, conservation, safety, and land use. The Sacramento River Conservation Area was established in accordance with the Senate Bill 1086, passed in 1986, which called for a management plan for the Sacramento River that would protect, restore, and enhance both fisheries and riparian habitat (Sacramento River Advisory Council 1998). The general plan of the counties and incorporated cities is required in order to help the counties develop goals for the future in terms of conservation.

Colusa County

The Colusa County general plan contains several elements that are designed to promote conservation efforts. The Resource Conservation Element of the plan encourages the conservation of fish and wildlife. The zoning, planning, and taxation policies should also preserve watershed areas and promote the preservation of rivers and streams. In addition, development in ecologically sensitive areas is discouraged (Sacramento River Advisory Council 1998).

Sutter County

The Natural Resources section of the Sutter county general plan encourages the preservation and protection of water resources. The county established a no net loss of wetlands policy in addition to discouraging the diversion of runoff from agriculture into wetland areas. The county also encourages the planting of native plants. A specific example of Sutter counties efforts is the Sutter County Zoning Code section 7910, which establishes a Flood Plain Combining Zoning District where development standards or use restrictions apply (Sacramento River Advisory Council 1998).

Yolo County

The Yolo county general plan is somewhat more specific than those of the other counties. It includes maps that highlight waterways and riverbank corridors that are part of its open space preservation program. All of the watersheds within the county are designated for conservation purposes. These areas are limited to grazing, wild hay production, soil conservation, water and wildlife conservation, and non-intensive recreation. The county is also currently working on a habitat management plan that encourages conservation easements and habitat protection zones within active agricultural fields and county sloughs (Sacramento River Advisory Council 1998).

City of Colusa

The general plan for the City of Colusa does not specifically state any goals or policies relate to the Sacramento River. Just outside the city limits there are 63 acres designated as the Colusa-Sacramento River State Recreation Area (Sacramento River Advisory Council 1998).

Resource Conservation Districts

Division IX of the Public Resources Code for the State of California calls for the establishment of Resource Conservation Districts (RCDs) which are responsible for addressing resource issues such as non-point source pollution, soil erosion, loss of prime and unique farmland, improvement of grazing, and the promotion of integrated pest management practices. The RCDs work closely with the USDA Natural Resources conservation Service (discussed later in this chapter) to address resource concerns. RCDs often make recommendations to county planning departments and the board of supervisors in regards to soil, habitat, and drainage related issues associated with building cite development. Members of the RCDs are elected locally or are appointed by the board of supervisors (Sacramento River Advisory Council 1998). Each county within our study reach has a Resource Conservation District associated with it.

Levee and Reclamation districts

The reclamation districts were first established in 1868 to facilitate reclamation of swamplands by building levees and drainage systems. On the eastern side of the river in our study reach Reclamation Districts 70, 1660 and 1500 are responsible for the maintenance of the Sacramento River Flood Control Project levees. On the western side of this section of the river the Sacramento River West Side Levee District is responsible for the maintenance of the levees. In the locations where there is no Reclamation District or Levee District present, the Department of Water Resources is responsible for levee maintenance (Sacramento River Advisory Council 1998).

State Agencies

Office of the Secretary for Resources

The secretary for resources directs the State Resources Agency, which sets major resource policy for the state and oversees programs of other agency departments including the Department of Water Resources (DWR), Department of Fish and Game (DFG), and the California Coastal Commission (CCC). State conservancies such as the California Coastal conservancy and the Tahoe Conservancy are also within the agency.

California Department of Fish and Game

The California Department of Fish and Game (DFG) coordinates the protection and management of fish and wildlife and the habitats upon which they depend. The DFG is a department within the State Resource Agency, and is governed by the Constitution and laws of the state, and policies of the Fish and Game Commission.

Some of the key programs and policies are: the Streambed Alteration Agreements, California Endangered Species Act, Native Plant Protection Act, Establishment of Ecological Reserves, Native Species Conservation and Enhancement Act, Sacramento-San Joaquin Wetlands Mitigation Back Act, Significant Natural Areas Program, Wildlife and Natural Areas Conservation Program, Keene-Nielsen Fisheries Restoration Act, California Wildlife Protection Action, Salmon, Steelhead Trout, and Anadromous Fisheries Restoration Program.

Fish and Game Commission

The Fish and Game Commission sets the policies for the DFG. Some of the policies set by the five members of the Fish and Game Commission who are appointed by the governor, include land use planning policy, Wetland Resources Policy, and the Joint Policy on Hardwoods. These policies are intended to: protect and restore fish and wildlife habitat through the purchase and maintenance and preservation of land, protect, restore and expand wetland habitat, and manage the hardwood rangelands.

Wildlife Conservation Board

The Sacramento River Wildlife Area was established by the Wildlife Conservation Board (WCB) which had the authority to purchase and restore fish and wildlife habitat. The board members include the President of the Fish and Game Commission, Director of DFG and the Director of the Department of Finance, in addition to six legislative advisory members. The WCB is also responsible for creating the Wildlife Conservation lay of 1947 which calls for the study and determination of which lands within the state are most suitable for habitat restoration. In addition the WCB participates in the California Riparian Habitat Conservation Program and the Inland Wetlands Conservation Program.

Department of Water Resources

The Department of Water Resources (DWR) coordinates the control, conservation, protection, and use of state water resources. Part of the mission of the DWR is to protect the public through flood control and dam protection. The Division of Flood Management is responsible for statewide flood protection. More specifically, the DWR is responsible for the maintenance of portions of the Sacramento River Flood Control Project.

Reclamation Board

The Reclamation Board was established by the legislature in 1911 and is currently the primary state agency that cooperates with the Army Corps of Engineers in flood control projects along the Sacramento River and its tributaries. It was initially established to oversee the construction of flood control levees and help Californians reclaim lands of the Central Valley, primarily for agriculture [Team, 1997 #65]. The Reclamation Board is staffed by DWR.

Department of Parks and Recreation

The goal of the Department of Parks and Recreation (DPR) is to protect the state's biological diversity and natural and cultural resources, and to provide the public with quality outdoor recreation. When state bond funds and Federal Land and Water Conservation Funds exists, it is the responsibility of the DPR to disperse these funds to local government park and recreation agencies that contribute to the resource management of rivers and streams.

Department of Boating and Waterways

The Department of Boating and Waterways (DBW) has programs to construct and improve small craft harbors in marinas in order to fulfil their responsibility of providing programs to develop recreational boating access and promote safety on California's waterways. In addition, the each Erosion Control Unit of the

DBW studies coastal sand supply and transport, which is related to the management of streams.

California Water Commission

The California Water Commission is composed of nine citizens who provide policy advice to the Director of Water Resources on all California water resource matters.

Office of Emergency Services

The Office of Emergency Services (OES) helps local governments prepare for emergencies such as flooding. As part of this responsibility the OES is the agency which gives Hazard Mitigation funds.

Department of Forestry and Fire Protection

The Department of Forestry and Fire Protection has several responsibilities, which include: preventing and suppressing fires occurring in forests (both state and privately owned), provide land management plans, enforce forest practice rules, participate in range improvement programs, and participate in fire research programs. The Department of Forestry and Fire Protection is an important agency in the fire protection of areas around the Sacramento River.

Regional Water Quality Control Board

The Regional Water Quality Control Board (Regional Board) is the local version of the State Water Quality Control Board. The Regional Board is responsible for developing planning that will ensure the water quality of the area. In addition, they are responsible for the issuing of waster discharge permits, and the enforcement of waste discharge requirements. The Regional Board administrates the Sacramento River Watershed Program, which aims to protect the current and potential uses of the Sacramento River watershed while promoting long term social and economic benefits of the region.

State Lands Commission

The Commission administers state-owned “sovereign lands.” Sovereign lands consist of those underlying tidal and navigable waterways and encompass almost 4 million acres of lakes, rivers, sloughs, bays, and state ocean waters. Under the Public Trust Doctrine, sovereign lands are to be held for the benefit of California citizens for a variety of purposes, including waterborne commerce, navigation, fisheries, open space, recreation, and habitat preservation. The Sacramento River, from Keswick Dam to the Feather River, is state-owned sovereign land. California holds a fee ownership in the bed of the river between the ordinary low water marks, however the entire river between the ordinary high water marks is subject to a Public Trust Easement. Both easement and fee-owned lands are under the jurisdiction of the Commission as landowner and manager. Commission authorization is normally needed for proposed development projects on state-owned lands or other projects seeking to occupy sovereign lands. The Commission seeks to balance resource management, revenue generation, environmental protection, and public enjoyment on sovereign state lands (Sacramento River Advisory Council 1998).

Sacramento River Bank Protection Project

The Sacramento River Bank Protection Project is a continuing construction project of the U.S. Army Corps of Engineers and the Reclamation Board. The goal of the Project is to preserve the integrity of the levee system of the Sacramento River Flood Control Project through environmentally sound bank protection, consistent with CALFED ecosystem restoration goals (Flood Emergency Action Team 1997).

Federal Agencies

United States Fish and Wildlife Service

The Fish and Wildlife Service (USFWS) is the primary agency through which the federal government implements conservation, protection, and enhancement of fish and wildlife habitats. It is a regulatory and land management agency most concerned with migratory birds, threatened, and endangered species. The USFWS provides technical and financial assistance for fish and wildlife management to the private sector, federal, state, and local agencies. This may include acquisition of areas for management and protection of wildlife, wetlands conservation, and wildlife-oriented recreation. Under the Fish and Wildlife Coordination Act, the USFWS reviews projects funded by the federal government or projects that require a federal permit. Under the Clean Water Act, the agency has the authority to review dredge and fill permits administered by the Army Corps of Engineers. The Federal Power Act empowers the USFWS to review hydroelectric power projects and the agency provides consultation on endangered species for the environmental review processes under the Endangered Species Act (ESA), National Environmental Policy Act (NEPA), and the California Environmental Quality Act (CEQA) (Sacramento River Advisory Council 1998).

United States Bureau of Reclamation

The Bureau of Reclamation (USBR) is the branch of the Department of Interior

(DOI) that is charged with the management, development, and protection of water (and water-related) resources in an economically and ecologically sound manner. The USBR is predominantly concerned with large river systems and can provide technical assistance for existing state water programs. The agency constructs and maintains federal water development and reclamation projects, including the Central Valley Project (CVP) in California. The USBR provides water for irrigation, commercial use, power generation, water quality, flood control, recreation, and habitat enhancement. The Central Valley Project Improvement Act (CVPIA) mandates that the USBR measure environmental water uses on par with urban and agricultural uses. The agency is a signatory to the Coordinated Operating Agreement between the CVP and the State Water Project (SWP), which specifies water quality standards and flow capture/export decisions (Sacramento River Advisory Council 1998).

United States Bureau of Land Management

The Bureau of Land Management (BLM) is the branch of the DOI that is charged with the management of public lands and resources. The BLM strives to balance the current needs for renewable and non-renewable resources with future needs. The Federal Land Policy & Management Act of 1976 requires the BLM to manage public lands for multiple uses including recreation, wilderness, species viability, and economic considerations. It also authorizes the use of Areas of Critical Environmental Concern to protect fish and wildlife resources, other natural systems, and human health and safety from natural hazards. The BLM's area of responsibility includes rivers and streams with substantial ecological value. The BLM takes part in restoring and enhancing wetland and riparian areas through consolidating public land parcels, cooperative agreements with ranchers and farmers, and other innovative restoration programs (Sacramento River Advisory Council 1998).

United States Geologic Survey

The United States Geologic Survey (USGS) provides geologic, topographic, and hydrologic information that assists in the management of resources. It collects data on the quality of surface and groundwater, and evaluates the consequences of alternative development plans on land and water resources. It also conducts research on hydrology and hydraulics, and coordinates all federal water data acquisition (Sacramento River Advisory Council 1998).

United States Army Corps of Engineers

The Army Corps of Engineers' mission is to provide engineering expertise and oversight for military and certain non-military construction and public works projects, and ensure the navigability and environmental protection of the waters of the U.S. (Sacramento River Advisory Council 1998). It is the principle federal agency involved in the regulation of wetlands (the EPA has oversight responsibilities) and has nationwide responsibility for flood control (Flood Emergency Action Team 1997). In California, flood control on the Sacramento River system are Corps projects (Flood Emergency Action Team 1997). The Corps' Water Management Section monitors the status of all reservoirs for which the Corps has issued a Water Control Plan for regulation of seasonally reserved flood storage purchased by the Corps. (Flood Emergency Action Team 1997). The Corps is authorized to perform immediate and long-term repairs to damaged project levees in partnership with local sponsors. (The local sponsor for the Sacramento River is the Reclamation Board). The Corps has two programs to provide assistance to State and local governments (Flood Emergency Action Team 1997).

Floodplain management Services Program

General Technical Services – develops or interprets site-specific data on obstructions to flood flows, flood routing and timing, flood depths or stages, floodwater velocities, and the extent, duration, and frequency of flooding. In addition, information on natural and cultural floodplain resources and flood loss potentials before and after the use of floodplain management measures can be provided. (Flood Emergency Action Team 1997). General Planning Guidance – provides assistance and guidance in the form of special studies on all aspects of floodplain management planning including the possible impacts of off-floodplain land use changes on the physical, socioeconomic, and environmental conditions of the floodplain. In addition, guidance and assistance for conducting workshops and seminars on nonstructural floodplain management measures can be provided (Flood Emergency Action Team 1997).

Planning Assistance to States Program

Provides assistance in the preparation of comprehensive plans for the development, utilization, and conservation of water and related land resources. The program can encompass water resource studies addressing water supply and demand, water quality, environmental conservation/restoration, wetland evaluations, dam safety/failure, flood damage reduction, floodplain management, and coastal zone management/protection, among other issues (Flood Emergency Action Team 1997).

United States Natural Resource Conservation Service
The Natural Resource Conservation Service (NRCS) is charged with providing national leadership in the areas of conservation, development, and productive use of soil, water, and related resources through a cooperative program that protects, restores, and improves these resources (Sacramento River Advisory Council 1998). Some NRCS activities include reparation of overtopped levees, dikes, and other flood retarding structures, while assisting other agencies with clearing waterways of sediment and debris. In 1996, the USDA was given the authority to purchase floodplain easements as an emergency measure. This gives the NRCS the flexibility to provide long-term, environmentally-responsible flood protection while respecting private property rights (Flood Emergency Action Team 1997).

National Marine Fisheries Service
The National Marine Fisheries Service (NMFS) is charged with conserving, managing, and developing living marine resource benefits. In addition to coastal zone management, the agency is concerned with the overall health of anadromous species of fishes, including salmon. It conducts scientific studies that are necessary to successful management decisions (Sacramento River Advisory Council 1998).

United States Environmental Protection Agency
The Environmental Protection Agency (EPA) was created to protect, maintain, and enhance environmental quality and human health through pollution prevention, reduction, remediation, and education. The Clean Water Act requires the EPA to establish regulations controlling effluent discharge and the discharge of dredged and fill material. The agency also provides technical assistance, pollution education, and funding for activities in the watershed (Sacramento River Advisory Council 1998).

Federal Emergency Management Agency
The Federal Emergency Management Agency (FEMA) is an independent agency of the federal government, reporting to the President. It provides flood insurance and administers emergency public assistance for natural disasters, including floods. The agency assists in improving floodplain management and reducing potential damages. FEMA's mission is to reduce loss of life and property and protect critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program of mitigation, preparedness, response and recovery (Federal Emergency Management Agency 2000). FEMA identifies flood-prone areas based on the 100-year floodplain. FEMA implements the National Flood Insurance Program (NFIP), which provides subsidized flood insurance for

flood-prone areas. The NFIP has two components, flood management assistance and flood insurance assistance.

Appendix C

Riparian Bird Species

Avian species that inhabit the riparian zone of the Sacramento River use different successional habitats created by the river. Some riparian songbirds (Song Sparrow, Yellow-billed Cuckoo, Bell's Vireo, Common Yellowthroat, Yellow Warbler, and Willow Flycatcher) are dependent on early successional riparian habitat for their survival. Other avian species depend on late successional oak woodland for nesting sites. Still others, like the Bank Swallow, are not dependent on riparian vegetation, but on consistently eroding banks characteristic of meander zones. Neotropical birds breeding in the riparian communities Sacramento River have low productivity. An increase in habitat will decrease likelihood of predators and parasites, and increase nesting sites and dispersal rates of adult and juvenile birds (Small 1998). Cottonwood-willow and the valley oak riparian forests are the most valuable nesting habitats in the Sacramento Valley (Small 1998).

We have researched the life histories of dependent and obligate riparian species, and the potential affects of setback levees to these species. Definitions by the United States Fish and Wildlife Service are as follows:

> **Dependent Riparian Species:** Species that place 60-90% of their nests in riparian vegetation or 60-90% of their abundance occurs in riparian vegetation during the breeding season. Riparian dependents might still occur in an area with degraded riparian vegetation, but their populations would be greatly reduced and not persist long-term.
>
> **Obligate Riparian Species:** These are species that place >90% of their nests in riparian vegetation or for which >90% of their abundance occurs in riparian vegetation during the breeding season. They may forage outside riparian vegetation, but without riparian vegetation in good ecological condition, these species will not occur in a given area. Some species may be classified as obligates in one geographic area but not in another.

Bank Swallow (*Riparia riparia*)

Dependent Riparian Species

Management Status- Threatened, California Department of Fish & Game

Historic and Current Range

The Bank Swallow spatial distribution is one of the largest in the world, largely Holartic, and with a winter range primarily in the Southern Hemisphere. In California, the Bank Swallow is found in approximately 100 colonies along the alluvial soils in the riparian zone. These colonies are capable of supporting thousands of birds (Garrison, 1999). They are open-cup nesters and burrow into the friable soils along the vertical banks of the river and are dependent on the erosive forces of the river to maintain those soils. The absence of erosion leads to gentler slopes and an unsuitable habitat.

The demographics of the Bank Swallow indicate declining populations. Between 1986 and 1987 the average number of pairs was 2082. From 1991-1997 the populations have become smaller and prone to greater fluctuation, causing the California population of this species to be listed as threatened.

Historical egg evidence indicates that the Bank Swallow was a localized breeder in the coastal zone of central and southern California (Laymon, Garrison et al. 1988). The Southern California populations from Santa Barbara to San Diego County are virtually extinct; only one population remains along the Santa Clara River in Ventura County (Laymon, personal communication). The extirpation of the Bank Swallow in the southern California area has been attributed to the channelization of rivers and streams (Garrison, 1999), and the development of the riparian zone.

Currently over 75% of the breeding area occurs along the Sacramento and the Feather rivers. The Sacramento population represents over 50% of the state's population in 1987, and occurs between Redding, Shasta County, and the Yolo Bypass (Laymon, Garrison et al. 1988).

Range Map: Currently unavailable

Seasonal Movements

Bank Swallows arrive at their breeding grounds from March-May and vacate their nests in June or July. During the fall, the Banks Swallow retreats south and is rarely found in California during the winter months (Garrison 1999). Prior to this fall migration, bank swallows roost on trees, roots, shrubs, and logs on sand and gravel bars.

Foraging and diet

The diet of the Bank Swallow is flying or jumping insects and/or larvae. Foraging occurs within 50-200 meters along the Sacramento River (Garrison 1999). They are primarily aerial feeders and only occasionally take prey from the surface of the river or the surface of the riparian forest.

Family Name	**Species**	**% Composition**
Hymenoptera	Ants	33.4
Formicidae	Ants	13.4
Diptera	Flies	26.6
Coleoptera	Beetles	17.9
Hemiptera	True Bugs	8.0
Odonata	Dragonflies	2.1
Lepidoptera	Butterflies	1.2
Other Insects	Mayflies	10.5

Table C.1: Foot items of Bank Swallow

Habitat

The Bank Swallow will colonize in the riparian forest dominated by willows and cottonwood. Colonies along the Sacramento River have been observed under cultivated land crops (Garrison 1999). Habitat suitability has yet to be determined. Researchers have found that the birds do not occupy all available sites and that they will only nest in 40-60% of the total number of banks that are available.

Fragmentation and Patch Size

Bank protection and flood control projects decrease the erodibility of the banks of the river and decrease the amount of available habitat for the bird (Garrison 1999). Bank Swallows nest in lengths of the river ranging from 10 to 2000 meters with a preference towards longer nesting sites which reduce the amount of predation proportionately (Garrison 1999).

The Effect of Setback Levees on Bank Swallows

Setting back levees on the Sacramento River should have a large positive impact on the Bank Swallow's population. Researchers have found that the limiting factor in bank swallow vitality is the lack of suitable habitat along the Sacramento River (Garrison 1999). Creating setback levees along the Sacramento will allow the creation of new nesting sites for the Bank Swallow and will likely lead to an increase in population. Limitations of benefits from setback levees:

- Only soils prone to erosion will benefit the Bank Swallow. Setback levees in erosion resistant soils will not benefit this species.
- Sections must be a minimum of 10 meters in length for the Bank Swallow to establish itself.

Pacific-coast Black-Headed Grosbeak (*Pheucticus melanocephalus maculatus)*

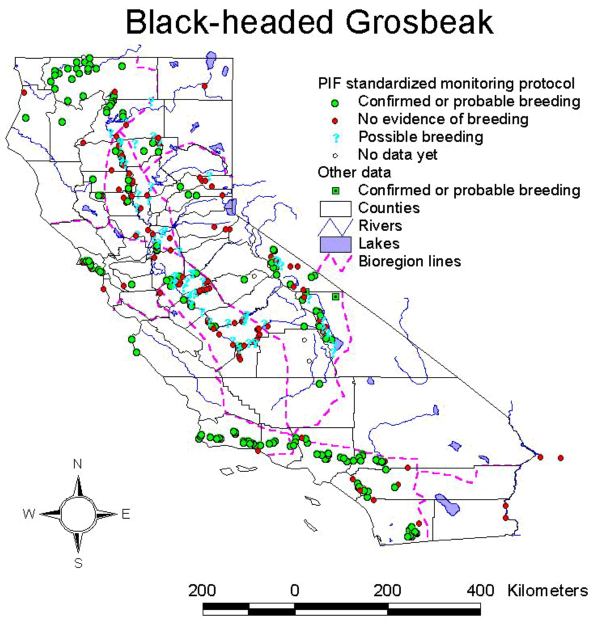
Dependent Riparian Species

Management Status: No special status.

Historical and Current Range in California

The Pacific-coast Black Headed Grosbeak is distributed in California west of both the eastern deserts and the Sierra mountain range (Grinnell, Miller et al. 1944). This species has a relatively stable populations in the California region, although, the Bay/Delta population may be decreasing. Banding in the Bay/Delta region from 1978-1997 has shown significant declines (Lynes 1998).

Range Map (http://www.prbo.org/CPIF/Riparian/curbhgr.gif)



Map C.1:
Range of Pacific Coast Black-headed Grosbeak

Seasonal Movements

The Black-Headed Grosbeak arrives in the Sacramento region in early to mid-April and departs their breeding grounds in late July (Weston 1947).

Foraging and Diet

The diet of the Black-Headed Grosbeak includes primarily insects, with a secondary diet of spiders, seeds, and fruits (Weston 1947)(Hill 1998). In Northern California, the species was noted to dine on California and Himalaya Blackberry during fruiting season (Lynes 1998). Their foraging habitat is diverse; they are able to scout for food in agricultural fields, weedy areas, and exotic thistle patches (Weston 1947; Shuford 1993)(Hill, 1995).

Habitat

Researchers in New Mexico noted that the diversity and vertical complexity of vegetation is highly correlated to Black-Headed Grosbeak populations (Hill 1988).

It was found that males produce more young in habitats that had multiple vertical vegetative structures. Nest sites are found in a variety of different places, ranging from orchards to oak-woodlands, and in the Sacramento region the species prefers early successional cottonwood-willow sites (Grinnell, Miller et al. 1944). Additionally, nest sites have been found along narrow strips of vegetation along levees. The nests in the Sacramento/San Joaquin region are largely made of Sandbar Willow, 23.7%, Arroyo Willow, 21.1%, Gooding's Black Willow, 15.8%, and Wild Grape, 10.5% (Lynes 1998). The height of the nest and height of the nest plant does not seem to affect breeding success. In the Cosumnes Preserve, nest sites were all within 50-300 meters of running water (Lynes 1998). Associated species include: Warbling Vireo, Western Tanager, Song Sparrow, Wrentit, Common Yellowthroat, and Lazuli Bunting. In the Cottonwood/Willow forest, it is associated with the Pacific-slope Flycatcher, Western Wood-Pewee, Spotted Towhee, and the Ash-throated Flycatcher (Lynes, M. (1998).

Fragmentation and Patch Size

The Black-Headed Grosbeak is not significantly affected by habitat fragmentation and has been observed in areas with "extensive edges" (Grinnell, Miller et al. 1944). Fragments as small as 200 m in length and 20-50 m in width will be utilized by the Grosbeak (Strong and Bock 1990). However, both Western Scrub-Jays and Steller's Jay's feast on the Grosbeak's eggs (Hill 1988). Areas with "extensive edges" would likely yield larger influx of Jay's, and negatively affect nesting success.

The Effect of Setback Levees on the Pacific Coast Black-Headed Grosbeak

This species is adapted to highly diversified conditions and is able to do well in fragmented environments. This is probably one of the reasons why the population remains stable. Setback levees will have a positive benefit if new successional habitat is formulated. Limitations on benefits are as follows:

- Setback lengths must be at least 200m in length and 20-50 meters in width.
- Will benefit from early and late successional vegetation stages.
- Will not likely benefit from setbacks larger than 300 meters (Nest distance to running water)

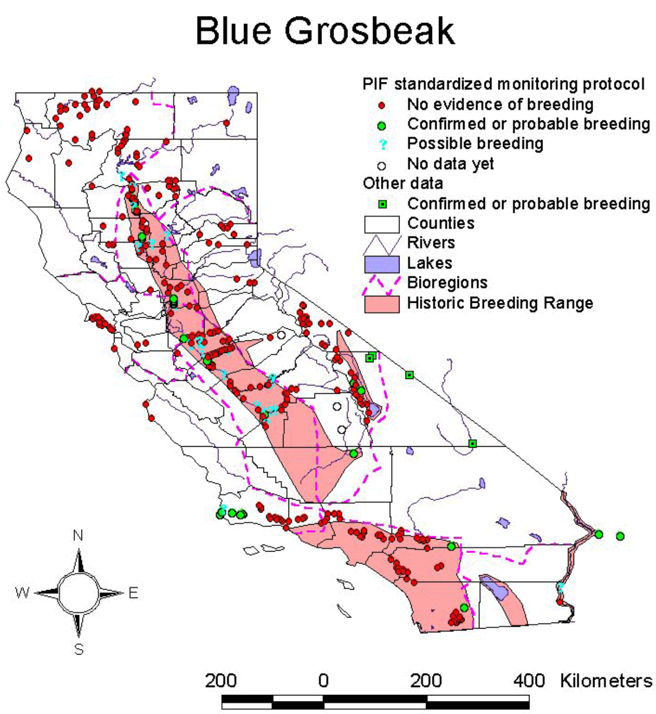
Blue Grosbeak (Guiraca caerulea)

Dependent Riparian Species

Management Status: California Species of Special Concern

Historical & Current Range

In the early 1900's The Blue Grosbeak primarily bred in Southern California (White 1999), but presently its range has moved northward. It occupies an average territory size of 5.2-6.2 hectares. It is relatively uncommon in the Sacramento Valley, and has been shown to occupy only 20-40% of suitable habitat (White 1999). Populations in California are relatively stable and data suggests a non-significant annual rate of increase of 2.5% (White 1999).



Map C.2: Range of Blue Grosbeak

Seasonal Movements

The birds arrive in California in early-mid April and depart in August and September (White 1999).

Foraging

The diet of the Blue Grosbeak primarily includes grasshoppers, mantids, and corn. Seeds of grains and rice, snails, fruits, and other invertebrates are consumed on a secondary basis (White 1999).

Habitat

The bird nests in a variety of habitats but in California are found mostly in riparian woodlands and fresh-water marshes. Nests are found in exotic trees such as the salt cedar (*Tamarix chinensis),* orchard trees, and native willow/cottonwood habitat (Grinnell, Miller et al. 1944). Their nests are generally low to the ground, with the mean height of the nest plant 131.32cm (White 1999).

Fragmentation and Patch Size

The Blue Grosbeak fairs well in a fragmented habitat and has been found to nest on the Cosumnes Preserve in narrow strips of vegetation (White 1999).

Effect of Setback Levees on the Blue Grosbeak

Because the Blue Grosbeak only occupies 20-40% of its eligible habitat in the Sacramento River region, setback levees should have a negligible affect on their populations in present conditions. If the breeding range tends to move further north however, the Sacramento River may provide suitable habitat from setback levees in areas of intermittent flooding, where the Blue Grosbeak's preferred habitat, riparian cottonwood forests, would establish.

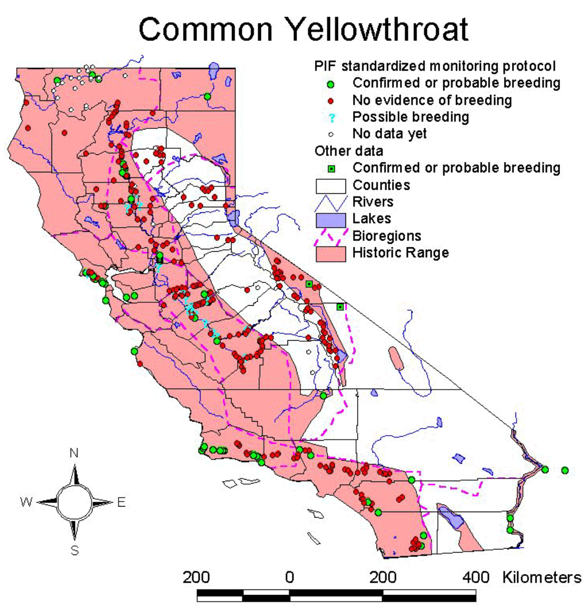
Common Yellowthroat (*Geothlypis trichas)*

Obligate Riparian Species

Management Status: California Species of Special Concern

Historic & Current Range

The Common Yellowthroat is a confirmed breeder in the Sacramento Valley showing a gradation pattern in densities along the river, increasing in the upper reaches and decreasing in the lower reaches. Population trends indicate an 8% annual increase in California (Menges 2000).



Map C.3:
Range of Common Yellowthroat

Seasonal Movements
The Common Yellowthroat is a summer resident in Northern California from spring until fall and a winter resident in central and southern California.

Foraging & Diet
The Common Yellowthroats diet includes insects, spiders, and caterpillars (Menges 2000).

Habitat
This species nests primarily in the tall emergent wetland plants found in either salt or freshwater marshes. It uses early successional stages associated with the shrubs blackberry, nettles, Juncus, and Grandelia.

Fragmentation & Patch size
Requires a minimum wetland size of 1-3 acres for breeding. The effect of fragmentation remains unstudied.

Effect of Setback levees on the Common Yellowthroat

Setback levees should have a large potential benefit on the Common Yellowthroat provided that setback levees create 1 to 3 acres of marshland/riparian habitat.

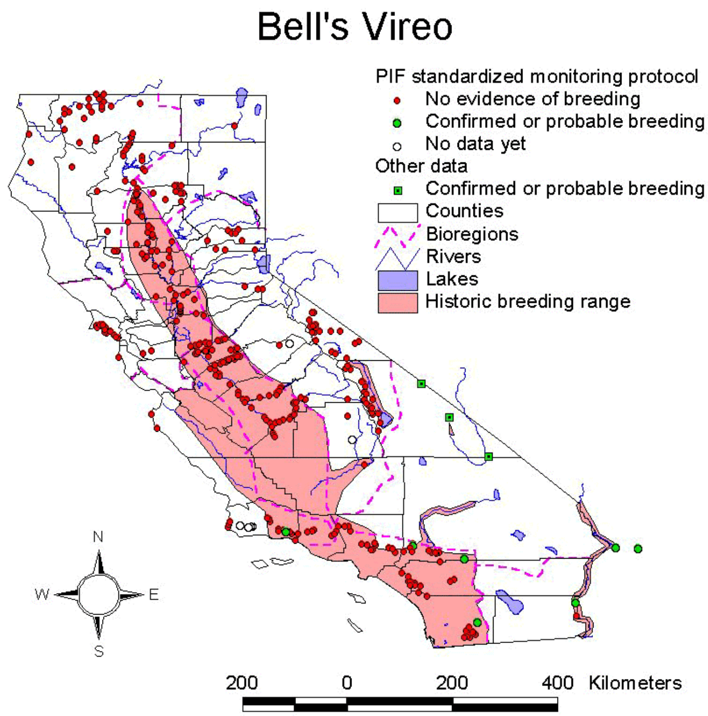
Least Bell's Vireo (*Vireo Bellii Pusillus*)

Obligate Riparian Species

Management Status: Federal & State Endangered

Historic and Current Range
Historically found in the Sacramento River South of Red Bluff, the population is now extirpated and limited to Southern California. They are currently in only a few

small areas in Southern California. Over 75% of the population is located in San Diego County (Kus 2000), and the northernmost colony is now found in Santa Barbara County.



Map C.4: Range of Least Bell's Vireo

Seasonal Movements

The Least Bell's Vireo migrates from Mexico to California between March and April to breed, and returns to Baja California in August (Thelander 1994).

Foraging & Diet

This species feed primarily on insects and pluck their prey from deciduous trees in the riparian zone.

Habitat

The Least Bell's Vireo breeds in willow thickets, wild rose, or other dense riparian forest cover. Historically in the Sacramento River Valley, the Least Bell's Vireo used early successional stage cottonwood willow riparian forest to nest.

Fragmentation & Patch Size

The Least Bell's is susceptible to brown-headed cowbirds and requires their removal for nesting success (Thelander 1994). Patch size must be a minimum of 1.5-3 acres to establish territory.

Effect of Setback Levees on Least Bell's Vireo

Presently, the Least Bell's Vireo does not breed in the Sacramento Valley, so the implementation of setback levees would have a minimal effect under current conditions. However, if the population did return to this region, breeding habitat would be created due to setback levees. Nesting success would require 1.5 – 3 acres of riparian habitat.

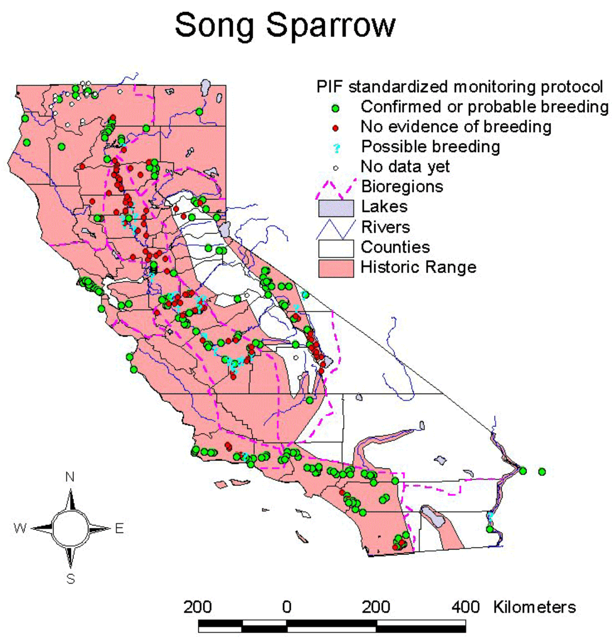
Song Sparrow (Melospiza melodia)

Obligate Riparian Species

Management Status: No special status

Historic & Current Range

Historically the Song Sparrow occupied a large portion of California's riparian zones. Currently, there is evidence of breeding in the Sacramento Valley.



Map C.5:
Range of
Song Sparrow

Seasonal Movements
No information available

Breeding Habitat:
The song sparrow's nest, composed of grasses and rootlets lined with fine grasses and long hair, is often placed on the ground. Most breed with 100 meters of riparian shrubs.

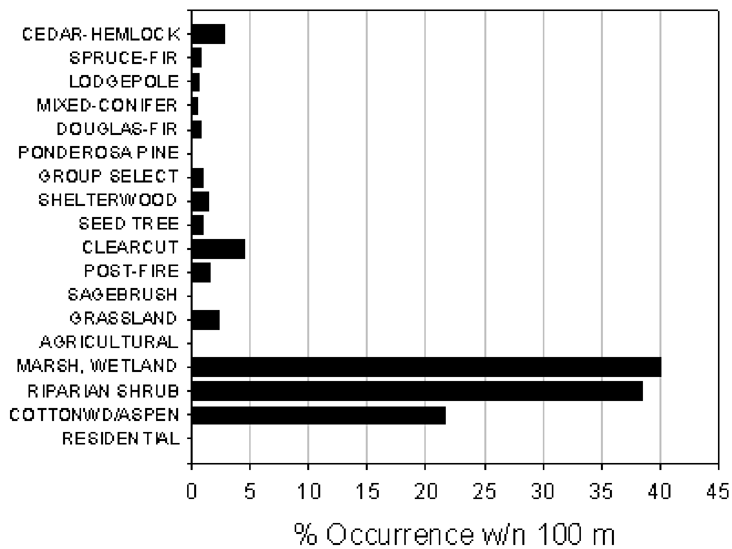


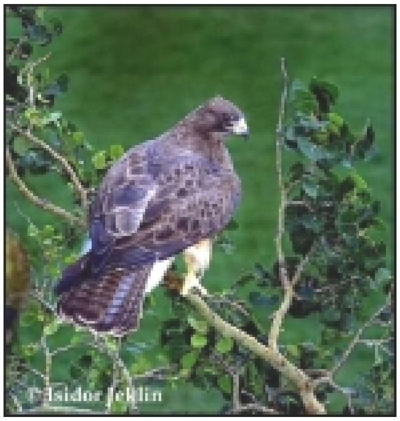
Table C.2: Breeding habitat of the Song Sparrow

Foraging and Diet:
The Song Sparrow primarily eats seeds and insects (http://www.kwic.com/~pagodavista/sngsprow.htm) .

Fragmentation and Patch Size
Their space requirements are small. A pair will live and nest in 1-1/2 acres or less. http://www.interbrief.com/fiftybirds/song.htm

Effect of setback levees on the Song Sparrow
Because this bird currently breeds in the riparian zone, the impact of setback levees on this species is likely to be significant with any creation of all habitat types. However, due to its love of water, the primary successional zones of willow and cottonwood forests will be most beneficial.

Swainson's Hawk (*Buteo swainsoni)*



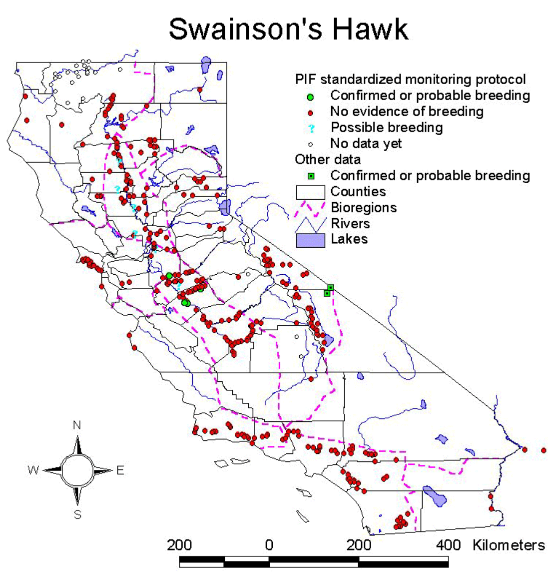
Dependent Riparian Species

Management Status: Threatened, California Department of Fish & Game

Historical & Current Range

Swainson's Hawk is associated with open habitat areas across the Western United States, Canada, and Northern Mexico. Historical records show that Swainson's Hawk occupied large portions of California, except the Sierra Nevada's. (Woodbride 1998). They reside in a variety of habitats, ranging from grasslands and shrubsteppe to valleys, canyons, and foothills of the mountainous areas.

Swainson's hawks currently breed only in the Central Valley and the Great Basin in California (Thelander 1994). Since the 1900's the population has declined 90% (Thelander 1994). Habitat destruction is considered to be the primary cause of this decline. The size of the current population in the Central Valley is approximately 1000 pairs (Woodbride 1998).



Map C.6:

Range of

Swainson's Hawk

Seasonal Movements

Swainson's Hawk arrives in California in the spring (March/April) and leave in the fall to migrate as far south as Argentina (Thelander 1994).

Foraging

Swainson's Hawk is dependent on large acreage of grassland and/or agricultural areas for foraging (Thelander 1994). They feed on voles, birds, ground squirrel's and insects (Woodbride 1998)(Thelander 1994).

Dependence on the Sacramento River

Swainson's Hawk is not necessarily dependent on the Sacramento River riparian habitat. However, the central valley contains some of the best remaining nesting trees to support populations of the hawk. They have been found to nest in oaks, cottonwoods, willows, and walnuts (Thelander 1994). Over 85% of Swainson Hawk in the Central Valley were found in riparian forests. The largest concern for the hawk is that the nesting area has access to an expansive foraging area (Woodbride 1998).

Fragmentation & Patch Size

Fragmentation of habitat does not seem to significantly affect the hawk. Nest sites are found to range from a single mature lone tree next to a agriculture field to a dense riparian forest.

The Effect of Setback Levees on Swainson's Hawk

The creation of riparian habitat associated with large trees will potentially have a large effect on the hawk population. They have been found to nest in trees associated with every successional stage at a mean density of 30.23 pairs/100 km^2 (Woodbride 1998). In addition, research from the Antelope and Owens valley has shown that birds will re-colonize areas in which habitat is recreated (Woodbride 1998). However there are areas in the central valley where suitable habitat exists, but it is not utilized; mature trees and open grasslands in Shasta and Tehama County have been shown to support very few hawks (Woodbride 1998**).**

Swainson's Thrush (*Catharus ustulatus)*

2 subspecies, Russet-backed and Olive-backed breeding in California.

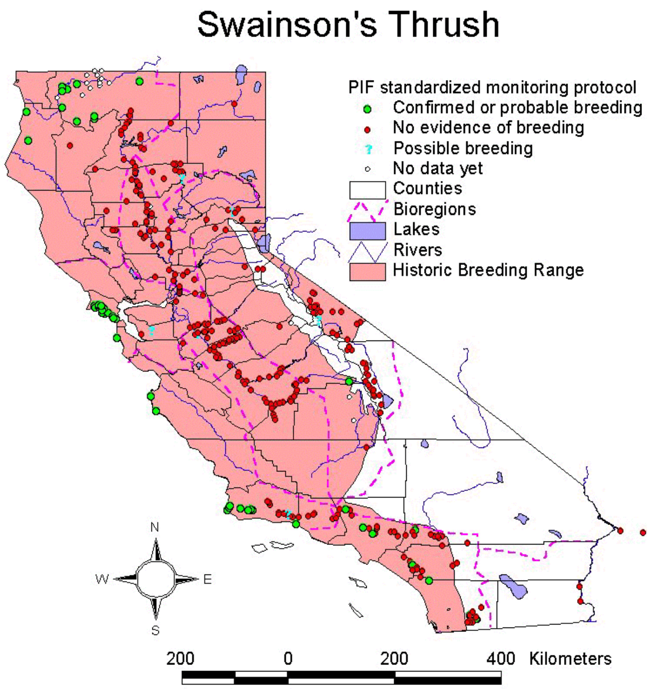
Dependent Riparian Species

Management Status: Proposed Species of Special Concern

Historical & Current Range

The russet-backed subspecies was historically found west of the Cascades and the Sierra Nevada, from Alaska to San Diego (Small 1998). The olive-backed subspecies was historically found in forested regions of Alaska south to Northern California, east of Cascades and Sierra Nevada, across Canada, Nevada, Utah, Colorado, northern Michigan, northern New England south to the mountains of West Virginia and Pennsylvania (Small 1998). There is currently no evidence of breeding anywhere along the Sacramento Valley.

Range Map (Point Reyes Bird Observatory 1999)



Map C.7:
Range of Swainson's Thrush

Seasonal Movements
No data available.

Habitat
During their spring migration this species utilizes a many habitat types – floodplain, willows, upland, swamp, and Oaks (Small, 1999). The existing breeding habitat data indicates that the thrush usually breeds in willow thickets in riparian zones (Small 1998).

Foraging and Diet
The thrush feeds on insects such caterpillars, beetles, ants, flies and berries (Small 1998).

Fragmentation and Patch Size
Swainson's Thrush has greater predation if their nests are located < 500 feet from an edge (Small 1998).

Effect of Setback Levees on Swainson's Thrush
Because Swainson's Thrush does not currently breed on any site in the Sacramento River, it is impossible to say whether or not the species will significantly benefit

from increased habitat from setback levees. However, potential benefits exist if populations return to the Sacramento River.

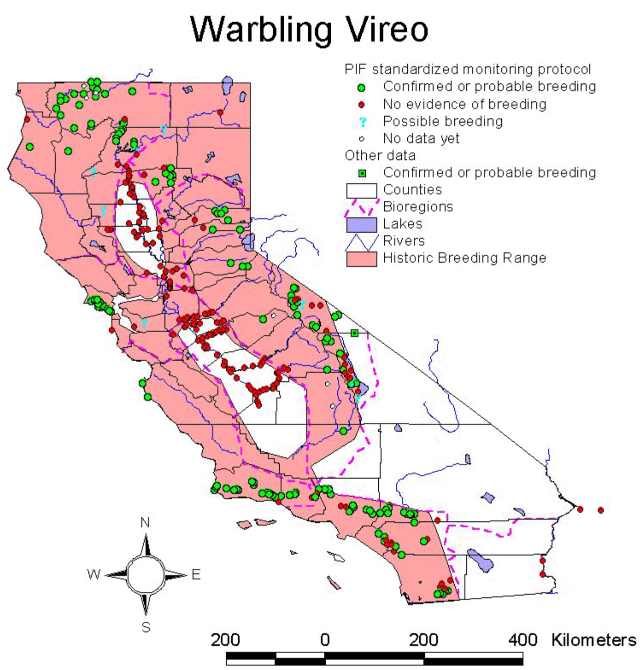
Warbling Vireo (*Vireo gilvus*)

Dependent Riparian Species

Management Status: No federal or state special status. California species of special concern.

Historical & Current Range

Historically, the Warbling Vireo bred throughout California west of the southeastern desert. Current range indicates a decrease in breeding in the Sacramento Valley and declines in populations from 0.4 – 8%.



Map C.8:
Range of Warbling Vireo

Seasonal Movements

The Warbling Vireo arrives on its breeding grounds in mid to late march, and in July or August.

Forgaing & Diet

The Warbling Vireo feeds on Lepidoptera, ladybugs, beetles, and insects in the riparian zone, making up 97% of its diet. The remaining 3% includes vegetative species such as elderberries and poison oak seeds.

Habitat

This species prefers to breed in large deciduous trees in the riparian zone, but will nest in shrubs if larger trees are not present. Dominant trees include willows and sycamore.

Fragmentation & Patch Size

Research indicates that Warbling Vireos are not affected by human presence and that high densities of this species in small patches do exist.

Effect of Setback Levees on the Warbling Vireo

The Warbling Vireo should significantly benefit from setback levees. It is a diverse species capable of breeding in primary successional riparian vegetation and is not significantly affected by fragmentation. Due to its preference for deciduous tress, this species should benefit most in mixed riparian forest.

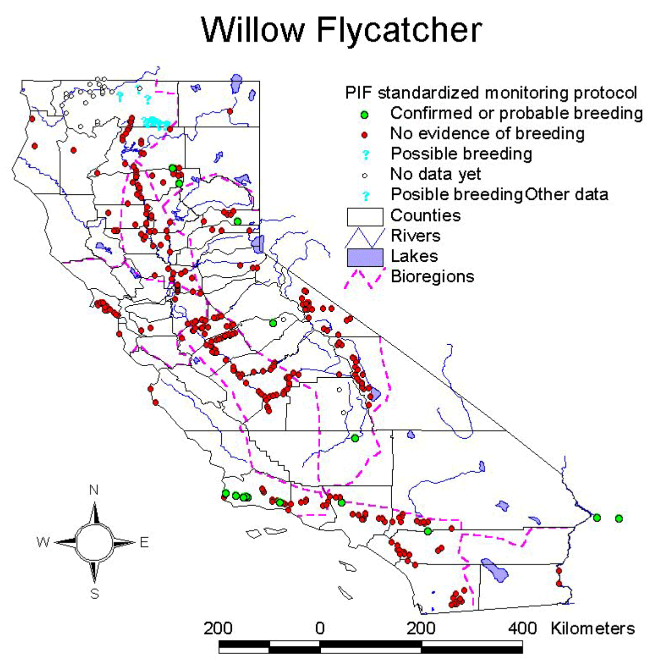
Willow Flycatcher (*Empidonax trailii*)

Obligate Riparian Species

Management Status: All three subspecies are listed as State Threatened and US Forest Service Region 5 Sensitive in California. The US Fish and Wildlife Service has designated the Willow Flycatcher a sensitive species in Region 1 (California).

Historic & Current Range

The Willow Flycatcher has one subspecies that was historically present in the Sacramento River ecosystem. *E.t. brewsteri* historically ranged and bred on the west side of the Sierra Nevada’s from Tulare county north; particularly common in the Sierras, but extending to the coast in Northern California. Historically they nested everywhere in California where willow thicket riparian habitat was found. Currently, there is no evidence that the bird still breeds in the Sacramento River valley. As of 1986 only 150 nesting pairs remained in California (Thelander 1994).



Map C.9: Range of Willow Flycatcher

Seasonal Movements

The Willow Flycatcher is a common in the spring and fall migrant at lower elevations, primarily in riparian habitats throughout the state exclusive of the Northern Coast. Most of the remaining breeding populations occur in isolated mountain meadows of he Sierra Nevada and Cascades.

Foraging and Diet

Commonly the diet was 96.05% animal food, and 3.95% vegetable food. *Hymenoptera (*mostly wasps and bees) made up 41% of their diet. *E.t. brewsteri* was reported as dieting on "wasps, bees, beetles, flies, caterpillars, moths, grasshoppers, and occasionally berries" (Sumner and Dixon 1953) in the Kings Canyon and Sequoia National Park.

Breeding Habitat

Historically they nested everywhere in California where willow thicket, riparian habitat was found. In the Sierra Nevada, nests are generally located in riparian deciduous shrubs with only scattered tall trees. In general, (Serena 1982) found that

Willow Flycatchers had a preference for tall clumps of shrubs separated by open areas. The critical factor was the availability of openings around the willow clumps (2-3 m in height); no territories were located in areas with a solid contiguous mass of willows (Sanders and Flett 1989).

Fragmentation and Patch Size

Much of the riparian deciduous shrub communities that historically provided habitat for Willow Flycatchers have all but disappeared in California, especially in the Central Valley and southern coastal zones. Existing Willow Flycatchers habitat is dispersed, mostly confined to small mountain meadows in the Sierra Nevada. Additionally, the *E.t. brewsteri* resides currently only in the geographic and altitudinal extremes of the Willow Flycatcher's historic range, where late spring storms, isolation, or other factors reduce the likelihood of successful breeding.

Willow Patch dynamics for Willow Flycatchers is still unknown, but various authors ascribe critical importance to openings in the willow stretches for nesting habitat. The smallest site documented for nesting is the 0.25 ha Poison Meadow habitat in south central Sierra Nevada, and surveys across California suggests this is the absolute minimum. The average breeding density ranged from 4 to 15 pairs per 40 ha.

Effects of Setback Levees on Willow Flycatchers

Willow Flycatchers will benefit from setback levees along the Sacramento River because of the increase in riparian willow forests and mixed riparian forests. There is no guarantee Willow Flycatchers will return to the Valley, but it may be an opportunity to provide breeding habitat in a previously central part of its range.

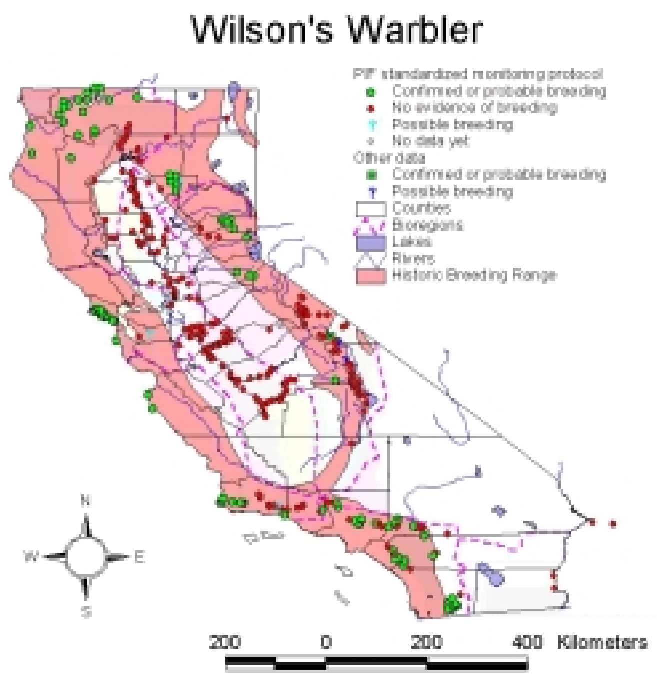
Wilson's Warbler (*Wilsonia pusilla*)

Obligate Riparian Species

Management Status**:** No special federal or state status.

Historic & Current Range

Wilson's Warbler has two subspecies inhabiting California: *W.p. pileolata and W. p.chryseola. W.p. chryseola* is the species that breeds west of the Sierra's and as far south as the transverse range. Population trends indicate a 1.6 % decline between 1966 and 1996. There is no information if this species has historically bred in the Sacramento Valley, and no evidence for current breeding within the area exists.



Map C.10: Range of Wilson's Warbler

Seasonal Movements

This species arrives in California from Mexico in late April or early May and leave in early August. Peak activity occurs in June.

Foraging & Diet

Wilson's Warler forages in the understory, usually within 2 meters of the ground and feeds on fruits, berries, seeds, and insects.

Breeding Habitat

This species prefers to nest in the understory near water, choosing blackberry as its preferred substrate for over 74% of its nests. Willows and alders complete the overstory for blackberry and are used as breeding cover.

Fragmentation & Patch size
Because the Wilson's Warbler prefers to nest on edges, it is susceptible to parasitism by the Brown-headed Cowbird. However, the presence of a shrub layer seems to be the most important characteristic associated with breeding species. Minimum recommended patch size is 1-3 acre's.

Effect of Setback levees on the Wilson's Warbler
Setback levees will have a minimal effect on the current status of Wilson's Warbler. They currently do not breed in the Sacramento Valley and it is impossible to foresee whether setback levees are the limiting variable to their establishment in the valley. However, if the Warbler chose to settle back in the valley, setback levees will benefit the Warbler by creating more habitat, specifically understory of blackberry with a cover of willows ranging from 1-3 acres.

Yellow Billed Cuckoo (*Coccyzus Americanus Occidentalis*)

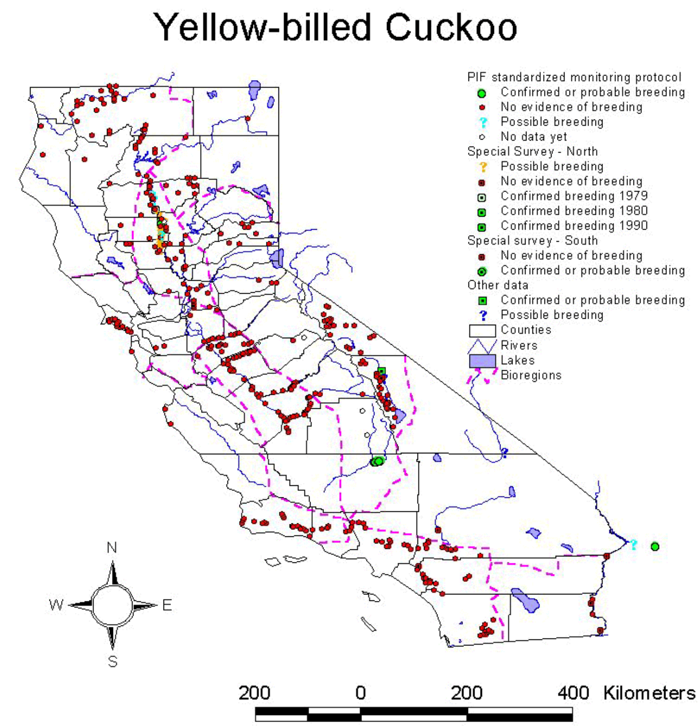
Obligate Riparian Species

Management Status: State: Endangered Species: 30-50 pairs left in California.

Historical & Current Range
This was once a wide-ranging species in California, with cuckoo populations in every riparian zone from Mexico to the Canadian Border, excluding the Sierra Nevada's (Thelander 1994). An estimated 15,000 pairs bred in California alone (Thelander 1994).

An estimated 30-50 pairs of Yellow Billed Cuckoo's now remain in California representing a decline of over 99% (Thelander 1994). There are two remaining populations greater than five pairs of the Yellow Billed Cuckoo left in

California. One is located in the Sacramento River between Red Bluff and Colusa, the other on the Kern River near Lake Isabella (Laymon 2000). Other locations (< 5 pairs) include the Santa Clara River in Ventura County, Owens River in Inyo County, Colorado River near Needles, and the Amargosa River in San Bernandino & Inyo counties.



Map C.11: Range of Yellow Billed Cuckoo

Seasonal Movements

The Yellow Billed Cuckoo arrives in California in early summer and depart from the riparian zone for South America in late fall. (Thelander 1994).

Diet & Foraging

Foraging occurs in cottonwood riparian forest. The diet of the Yellow Billed Cuckoo consists of caterpillars, grasshoppers, frogs, butterflies, and macro-insects.

Fragmentation and Patch Size

Extremely sensitive to patch size and fragmentation. Territory size ranges from 4 - 40 ha (Laymon 2000). Fragmentation was determined to be one of the more important variables in determining pair presence occupying 9.5% of 21 sites from

20-40 acres, 58.8% of 17 sites 41-80 acres, and 100% of 7 sites greater than 80 acres (Laymon 2000).

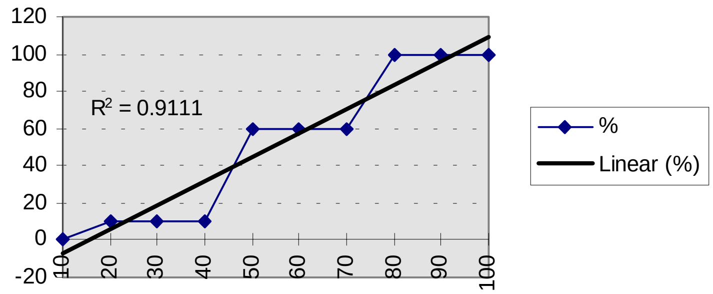


Figure C.1: Yellow Billed Cuckoo pair presence

Habitat
The Yellow Billed Cuckoo is an obligate riparian species, dependent on the riparian zone of rivers to survive. The bird forages in cottonwoods and exclusively nests in willows and English Walnuts. Humidity is also an important factor for the survivorship of the Yellow Billed Cuckoo, which nests in those zones along the river with decreased temperatures and increased humidity (Launer et al. 1990).

Yellow Billed Cuckoos utilize two different successional stages of the riparian zone, making this species very sensitive to patch size. An average of 50-60 acres of suitable habitat is needed for colonization. (Laymon 2000). Upland Cottonwood forest is used for nesting, while lowland willow scrub is used for foraging. Researchers have shown that the width of the riparian forest is important and must be at least 100 meters wide for the Yellow Billed Cuckoo to inhabit.

Effect of Setback Levees on the Yellow Billed Cuckoo
The creation of setback levees will only benefit the Yellow Billed Cuckoo if a large amount of cottonwood/willow habitat is formed. Because this species is very susceptible to patch size, it is important to create habitat areas at a minimum of 20 ha, ideally over 80 ha. In addition, setback width must be at least 100 meters wide and a minimum of 2000 m in length to benefit the Yellow Billed Cuckoo.

Yellow Breasted Chat (*Icteria virens*)

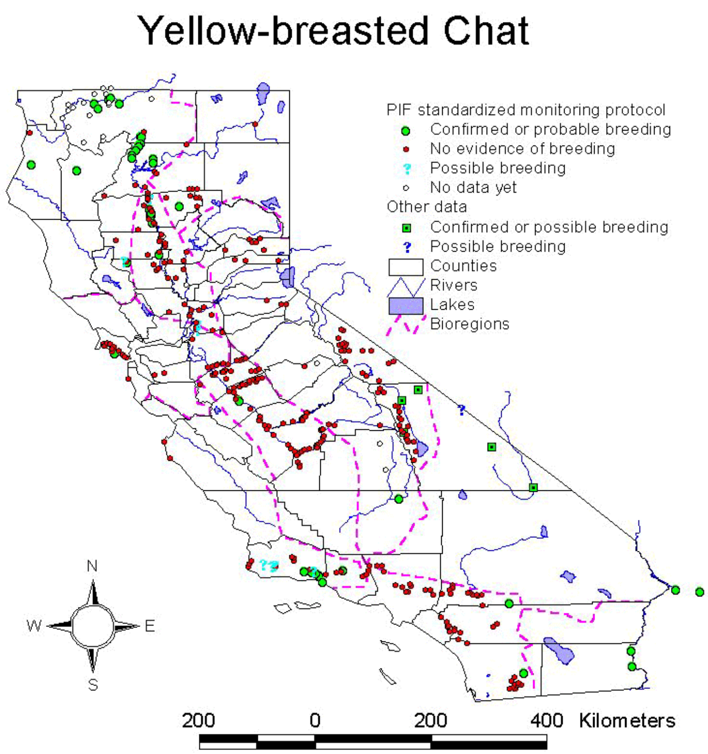
http://rbcm1.rbcm.gov.bc.ca/end_species/species/ybrchat.html

Management Status: No Special Status

Obligate Riparian Species

Historic & Current Range

In the United States, the Eastern Chat breeds in: North Dakota, southern Minnesota, southern Wisconsin, southern Michigan, central New York, southern Vermont, southern New Hampshire, south to south-central Baja California, Jalisco, the state of Mexico, southern Tamaulipas, the Gulf states and northern Florida. It winters from Mexico and southern Texas south to western Panama. There is evidence that the Yellow Breasted Chat presently breeds in the Sacramento River area.



Map C.12: Range of Yellow Breasted Chat

Breeding Habitat

The Yellow Breasted Chat favors woods, dense thickets and brambles in low wet places near streams, pond edges,swamps, and fields. It also nests in small trees such as trembling aspen, saplings or bushy tangles, favoring wild rose, hawthorn and snowberry thickets. Other shrub species commonly used include elderberry and saskatoon bushes. The most important variable for good chat habitat are areas of impenetrable thickets with few small trees. It is typically associated with the early successional stages of forest regeneration.

Seasonal Movements

The western Yellow Breasted Chat winters from southern Baja California, southern Sinaloa, southern Texas and southern Florida (casually from California, the Great Lakes region, New York and New England) south through Middle America to western Panama (western Bocas del Toro). There is little information regarding the species on its wintering grounds, and it is unknown whether it concentrates in any specific areas during the winter. They leave to return to breeding grounds about the middle of April.

Foraging and Diet

During the breeding season, the Yellow-breasted Chat's diet consists mainly of insects such as weevils, and beetles, ants, moths, bees, wasps, mayflies and caterpillars. Berries (including wild strawberries, grapes, blackberries, raspberries, whortleberries, and elderberries) make up a large portion of its diet in late summer. Young are apparently fed only insects. The main method of obtaining food during the breeding season is gleaning from plant foliage and occasionally from branches, and although both the male and female are foliage gleaners, the female tends to look for food lower in the shrubbery and on the ground.

Fragmentation and Patch Size

Data regarding patch size and fragmentation data is currently unavailable.

Effect of setback levees on the Yellow Breasted Chat

The Yellow Breasted Chat will likely benefit from setback levees. It is a current inhabitant of the Sacramento Valley, dependent on willow and cottonwood riparian forest for breeding.

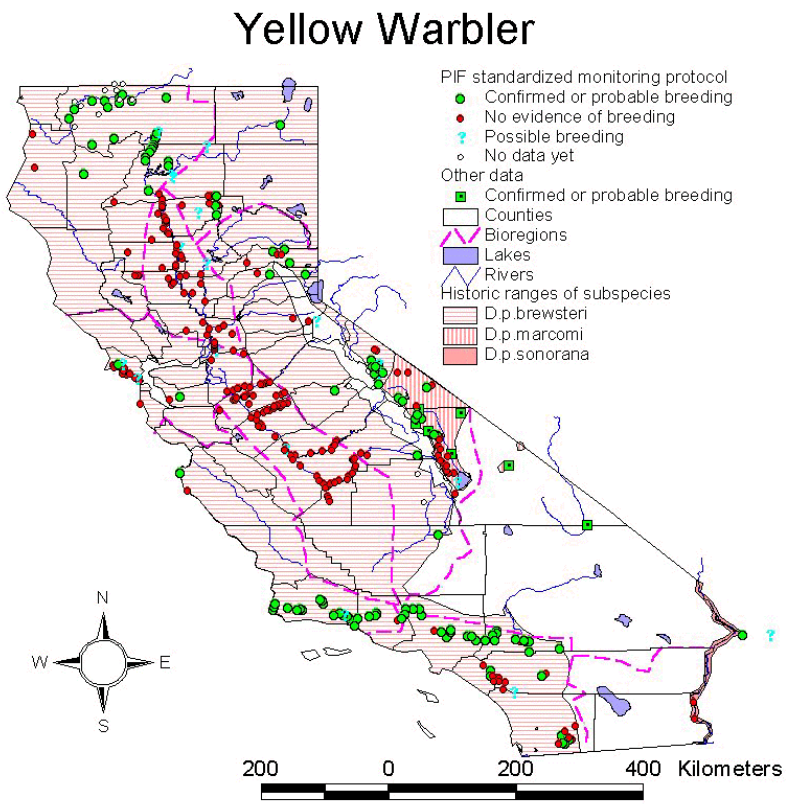
Yellow Warbler (Dendroica petechia aestiva)

Obligate Riparian Species

Management Status – California Species of Special Concern

Historical & Current Range

The yellow warbler was fairly common in the Sacramento Valley in the 1920's south of Red Bluff and Tehama County, nesting and foraging in the willow habitat (Heath 1999). In 1973, Yellow Warblers became uncommon, and between 1976 and 1979, only 3 pairs were found nesting along the river. current surveys along the Sacramento show no evidence of breeding. However, Yellow Warblers do use the area as a stopover during fall migration (Heath 1999). They were found utilizing overstory riparian area consisting of willow, black walnut, box elder, Oregon Ash, white alder, and Fremont cottonwood as well as the understory, comprised of blackberry, mugwort, and grasses (Heath 1999).



Map C.13: Range of Yellow Warbler

Seasonal Movements

The Sacramento River riparian zone is utilized by the Yellow Warbler during Fall Migration.

Foraging

Yellow Warblers forage in cottonwood/willow riparian forest in deciduous trees and shrubs. They feed on ants, bees, wasps, caterpillars, beetles, true bugs, flies, spiders, and other various insects. Fruit pulp and seeds were occasionally noticed (Heath 1999).

Habitat
The Yellow warblers will utilize the cottonwood/willow riparian forest of the riparian zone for breeding and/or foraging.

Fragmentation & Patch Size
Yellow Warblers are extremely susceptible to the Brown-Headed Cowbird brood parasitism and it has been suggested that this is the reason for declining populations in the Sacramento region (Heath 1999). This susceptibility has made the Yellow Warbler prone to edge effects. However one study in Alaska showed the absence of edge effects in a 300 ha riparian floodplain with a nesting success rate of 90% (Heath 1999).

Effect of Setback Levees on the Yellow Warbler
Because the Yellow Warbler is not currently using the Sacramento River region for breeding, it is impossible to foresee whether the addition of more habitat will positively benefit the breeding success of this species. However, because the Yellow Warbler uses the riparian zone during its fall migration, additional riparian zone habitat should be a benefit.

Appendix D

Chinook Salmon Species

Anadromous Fish

There are several types of anadromous fish that use the Sacramento River system some of which include: Green Sturgeon, White Sturgeon, Stripe Sass (non native), Shad (non native), River Lamprey, Delta Smelt, Longfin Smelt, Steelhead Trout, and Chinook salmon.

The term anadromous refers to an organism whose life history includes spending part of their life in the ocean and then migrating into freshwater to spawn (Fry 1979). There are varying degrees of anadromy among these species. Some species may travel only short distances from brackish to freshwater to spawn, while other species, like salmon, may travel thousands of miles through the course their life.

There are benefits and costs to this anadromous lifestyle (Fry 1979). Costs may include developing the physiology to survive in both saltwater and freshwater and the task of migrating long distances to spawning grounds. Benefits include a safer environment for egg/embryonic development and rearing and growth of young, the ability to colonize other freshwater streams through saltwater migration, and the ability to utilize a larger oceanic food base. By using the ocean and its food resources, species like Chinook salmon can grow to a larger size with higher fecundity. It also allows them to support a larger adult population than could otherwise be maintained within a freshwater stream system alone.

Chinook Salmon

General Description

Chinook salmon (*Oncorhynchus tshawytscha*) are anadromous fish of the family salmonidae. Chinook salmon range from 75-100 cm, and weigh 9-10 kg (Moyle, Yoshiyama et al. 1995). Adult fish are silver in color while in the ocean and turn olive-brown to dark maroon after they enter the river. Male salmon are often darker than females and develop a hooked jaw and snout and arched back prior to spawning. Chinook salmon are distinguished from other salmon by their body color including spots on the back and tail, and solid black coloration of the lower gum line.

Chinook salmon migrate from the ocean to spawn at 2-5 years of age, though the majority of the fish are 3 years old (Moyle, Yoshiyama et al. 1995). Adults live off stored fat reserves and do not feed during their upstream migration. Chinook salmon may travel thousands of before reaching upstream spawning grounds where they will deposit and fertilize their eggs in depressions they dig in the gravel (redds). Redds are usually constructed at the head of a riffle, at the tail end of a pool where there is a change in flow gradient (Moyle, Yoshiyama et al. 1995). Generally, Chinook salmon like to spawn in the higher reaches of the watershed and in gravel of 1-4 cm with less than 25% fines. The adult salmon die after spawning.

After hatching from eggs and emergence from gravel, juvenile Chinook salmon stay in the stream for 1-13 months, depending on the run type, before they smolt and begin their down stream migration to the ocean (Yoshiyama, Fisher et al. 1998). Juveniles feed on adult and larval forms of invertebrates such as chironomids (Chironomidae), stoneflies (Plecoptera), mayflies (Ephemeroptera) and caddisflies (Trichoptera) during their river stay (Boyles 1988).

Water temperatures are important to Chinook salmon at all life stages. A general range of 50-57 °F is the preferred temperature range over all life stages (Boyles 1988). Sustained water temperatures above 60 °F or below 38 °F result in increasing mortality or can result in poor development of pre-spawned, fertilized, and developing eggs or embryos.

Chinook salmon of the Sacramento River

Though five species of salmon are found within the Sacramento drainage on occasion, Chinook salmon are the only salmon species with major hatchery and naturally spawning stocks within this basin (Yoshiyama, Fisher et al. 1998; CALFED 1999). There are four runs of Chinook salmon that currently utilize the Sacramento River and several of its tributaries. The runs are named after the season that marks their upstream migration and are further defined by the timing of the following life history stages: spawning, juvenile residency, and smolt migration. The categories that comprise the Chinook salmon of the Sacramento River are as follows: fall run, late-fall run, winter run, and spring run Chinook salmon.

Run	Migration	Peak Migration	Spawning	Peak Spawning Period	Juvenile Emergence	Period of Juvenile Stream Residency (months)	Smolt Seaward Migration
Late-Fall	Oct-Apr	Dec	Early Jan-Apr	Feb-Mar	Apr-Jun	13-Jul	Nov-May
Winter	Dec-Jul	Mar	Late Apr-early Aug	May-Jun	Jul-Oct	10-May	Nov-May
Spring	Mar-Sep	May-Jun	Late Aug-Oct	mid-Sep	Nov-Mar	15-Mar	Mar-Jun and Nov-Apr
Fall	Jun-Dec	Sept-Oct	Late Sept-Dec	Oct-Nov	Dec-Mar	7-Jan	Mar-Jun

Table D.1: Life Histories of Chinook Salmon Runs

Typical Spawning Habitats of the Different runs

Fall

Fall run Chinook spawn soon after entering the river system (Yoshiyama, Fisher et al. 1998). They spawn in the lower rivers and tributaries of the valley floor and foothill reaches of the Sacramento River drainage up to an elevation of 1000 feet (Rutter 1902).

Late-Fall

Late-fall run Chinook also spawn shortly after entering the river system. They historically spawned on the upper main stem of the Sacramento River above the current location of Shasta Dam (Fisher 1994). Most late-fall run Chinook now spawn in the main stem of the Sacramento River below Keswick Dam.

Winter

Winter run Chinook reside in the river for a longer period of time to sexually develop before they are able to spawn (Yoshiyama, Fisher et al. 1998). Winter run Chinook have historically used cool headwater areas of the Sacramento basin such as the upper reaches of the McCloud and Pit rivers (tributaries to the Sacramento River). Dams currently block access to all historic spawning ground for winter run Chinook. The run is currently only maintained by cold water releases from Shasta and Keswick Dam that enable winter run fish to spawn in a section of river just below Keswick Dam.

Spring

Spring run Chinook stay in the river a long time before they spawn into higher cooler waters of the drainage. The preferred spawning grounds of spring run Chinook is in the upper drainage areas above 1500 ft in elevation (Yoshiyama, Fisher et al. 1998). Spring run Chinook have a small natural stock spawning in tributaries such as Deer and Mill creeks (Moyle, Yoshiyama et al. 1995). Dams and diversions also block much of the preferred spawning ground for spring run Chinook. Spring run Chinook are now forced to spawn in lower areas, resulting in overlapping use of spawning ground with fall run Chinook, and in some cases cross spawning and hybridization has occurred between the runs.

These differences in life histories are important to recognize as they give insight to the reason and extent of the decline among each of the four runs. All runs are important because their different life histories allow them to maximize their own productivity and use nearly all parts of the Sacramento river watershed nearly year round. Therefore, preservation of all runs is important to the genetic integrity and productivity of the Chinook salmon population as a whole.

General Habitat Requirements

There are many interrelated ecological processes and variables important for maintaining Chinook salmon populations. The following is a list of some of these processes as recognized by several sources (Cowx and Welcomme 1998; Yoshiyama, Fisher et al. 1998; CALFED 1999):

- Stream flow for upstream (adult) and downstream (juvenile) migrations.
- Sediment supply for spawning gravel and habitat formation processes.
- Stream meandering for habitat formation in stream and on the floodplain.
- Stream temperatures for daily living needs of aquatic organisms at all stages of life history.
- Floodplain processes and habitat formations.
- Bay-Delta Hydraulics affect passage through delta to the sea.
- Aquatic food web and influences on its diversity and productivity.

Life Stages	In-stream Habitat Needs
Adults	– Adequate flows and accessibility for migration to spawning grounds. – Adequate spawning gravel of appropriate size. – Adequate stream temperatures for in-stream survival and proper development of eggs.
Egg/Embryonic Development	– Adequate levels of inter-gravel flow and water quality for conveyance of dissolved oxygen to the egg and removal of generated wastes. – Water temperatures within range of optimal development.
Juveniles	– Adequate invertebrate food supply for growth before seaward migration. – Adequate flows for downstream migration and navigation of delta in seaward journey. – Adequate in-stream temperatures

Table D.2: Life Stages and Habitat Needs of Chinook Salmon

Ecological processes, and thus Chinook salmon, have been negatively affected by many different anthropogenically rooted variables. Many of these variables are large contributing factors to the degradation of the Sacramento River riparian basin and the decline of Chinook salmon and will be addressed in the following sections.

Historic Abundance and Range

The Central Valley was once one the most productive Chinook salmon fishery in the world (Yoshiyama, Fisher et al. 1998). Using early commercial fishing records, it is estimated that there were 1 to 2 million Chinook salmon spawning in the Central Valley Drainage. Commercial catch of 5-10 million lbs per year was common over years 1875-1910. Accurate historical abundance of individual run type is hard to estimate because fisherman did not often make the distinction between runs during the early years of the industry.

After the construction of Red Bluff Diversion Dam, more consistent and accurate estimates of each run type have been recorded (see Table D.3) (Yoshiyama, Fisher et al. 1998). Figure D.1 shows an alarming trend of significant decrease in Chinook salmon abundance over the past 30 years for late-fall, winter, and spring run salmon. The winter and the spring Chinook salmon runs have declined to dangerously low numbers in recent years. Fall run salmon are clearly the largest run of salmon and largely influence the numbers for total yearly abundance. This run is quite large relative to the other runs and has increased in abundance during recent years, in at least part due to heavy augmentation by hatchery produced fish. The observed differences between the fall run and the other runs is not surprising considering the traditional spawning ground of the late-fall, spring, and winter run Chinook are no longer accessible to them, while fall run Chinook evolved to spawn in lower warmer reaches of the Sacramento drainage.

Factors For the Decline of Chinook Salmon and Riparian Quality

The factors affecting the decline of Chinook salmon are important in order to evaluate the effects of setback levees. Attributing factors negatively affecting Chinook salmon are widely recognized (Nehlsen 1994; Moyle, Yoshiyama et al. 1995; Botsford and Brittnacher 1998; Cowx and Welcomme 1998; Yoshiyama, Fisher et al. 1998; CALFED 1999). The following is a list of factors recognized as influences in the decline of Chinook salmon and/or the quality and/or quantity of Chinook salmon habitat derived from the above listed references and organized into a category scheme based from Moyle (Moyle 1994).

- *Watershed Degradation.* Watershed degradation includes Influences of logging, road construction, overgrazing, and urbanization. Hydraulic gold mining during the late 1800's also negatively impacted salmon populations (Yoshiyama, Fisher et al. 1998).
- *Diversions and In-Channel Modifications*. Diversions are considered to be any factor that reduces or alters the flow of the stream and/or alters stream channel.
    - These factors are mainly attributable to dams, weirs, and irrigation diversions. Water diversions, Keswick Dam, and especially Shasta Dam present major issues for upstream migration of adults and downstream migration of juveniles (Moyle, Yoshiyama et al. 1995).
    - Construction of levees, bridges, and bank protection.
    - Removal of bed materials through: dredging and sediment disposal, and gravel mining.
- *Pollution.* Includes all toxic concentrations of substances. These substances enter the stream from a variety of sources and include contaminants in runoff from urbanized and agricultural areas.
- *Overfishing.* Overfishing refers to unsustainable harvest by:
    - Sport, commercial, and subsistence fisheries.
        - Illegal fishing and poaching.

- *Hatcheries.* Considers negative effects on native(wild) stocks by hatchery produced fish.
  - Loss of genetic diversity.
  - Competition for resources and even predation by hatchery fish.
- *Predation.* Predation on salmon by:
  - Marine mammals
  - Introduced (exotic) fish (striped bass) and native fish (Sacramento squaw fish)
- *Environmental Variability.* Environmental variability refers to negative effects of variations in natural occurrences like precipitation (drought) and events such as El Nino which reduces coastal productivity.

Watershed degradation and diversions are two of the most influential factors in the decline in Chinook salmon and the quantity and quality of their habitat (Moyle 1994). However, all these issues, alone or different levels of combination, have been responsible for the degradation of the Sacramento riparian corridor and Chinook salmon. The following is a list of some of the resulting habitat loss and ecosystem functionality due to the above factors of degradation:

1. Change in optimal temperature ranges.
2. Exclusion of adult salmon from historic spawning areas.
3. Increased complications and hardships for upstream migration of adults and downstream migration of smolts.
4. Degradation in rearing habitat for juveniles.
5. Increased susceptibility to predation.
6. Loss in habitat complexity.
7. Loss of much of the floodplain/channel interactions (meandering), functions, and backwater habitats

Conclusion

There are many variables that have influenced the degradation of the quality of the riparian corridor of Sacramento River basin, which have resulted in a loss of functionality of basic ecosystem processes and productivity and biodiversity of the system as a whole. Chinook salmon are a key indicator of these degrading influences. Better management and restoration of ecosystem functionality is necessary to increase viability and productivity of Chinook salmon which can in turn provide a valuable ecological, commercial, recreational, and aesthetic commodity in future years.

Year	Fall run	late-fall run	winter run	spring run	total
1967	157,600	37,200	57,300	23,800	275,900
1968	191,500	34,700	84,400	15,400	326,000
1969	268,200	38,800	117,800	27,400	452,200
1970	201,400	25,300	40,400	7,700	274,800
1971	193,400	16,700	63,100	9,300	282,500
1972	137,500	32,700	37,100	8,700	216,000
1973	262,800	23,000	24,100	12,000	321,900
1974	229,000	7,900	21,900	8,300	267,100
1975	187,100	19,700	23,400	24,000	254,200
1976	188,500	16,200	35,100	26,800	266,600
1977	185,100	10,600	17,200	14,000	226,900
1978	153,900	12,600	24,900	8,400	199,800
1979	221,000	10,400	2,400	3,000	236,800
1980	164,700	9,500	1,200	11,900	187,300
1981	230,100	6,800	20,000	21,800	278,700
1982	212,400	4,900	1,200	28,100	246,600
1983	154,500	15,200	1,800	6,200	177,700
1984	199,100	7,200	2,700	9,900	218,900
1985	283,500	8,400	4,000	13,100	309,000
1986	264,800	8,300	2,500	20,300	295,900
1987	244,700	16,000	2,000	12,700	275,400
1988	252,400	11,600	2,100	18,500	284,600
1989	174,000	11,600	500	12,300	198,400
1990	121,500	7,300	400	6,600	135,800
1991	125,500	7,100	200	5,900	138,700
1992	107,300	10,400	1,200	3,000	121,900
1993	147,200	6,000	400	9,200	162,800
1994	184,700	6,000	200	6,200	197,100
1995	285,700	ND	1,400	14,900	302,000
1996	278,000	ND	900	8,600	287,500
1997	381,000	ND	900	5,200	387,100

Table D.3: Chinook Salmon Abundance – For each run type from 1967-1997 (Yoshiyama 1998)

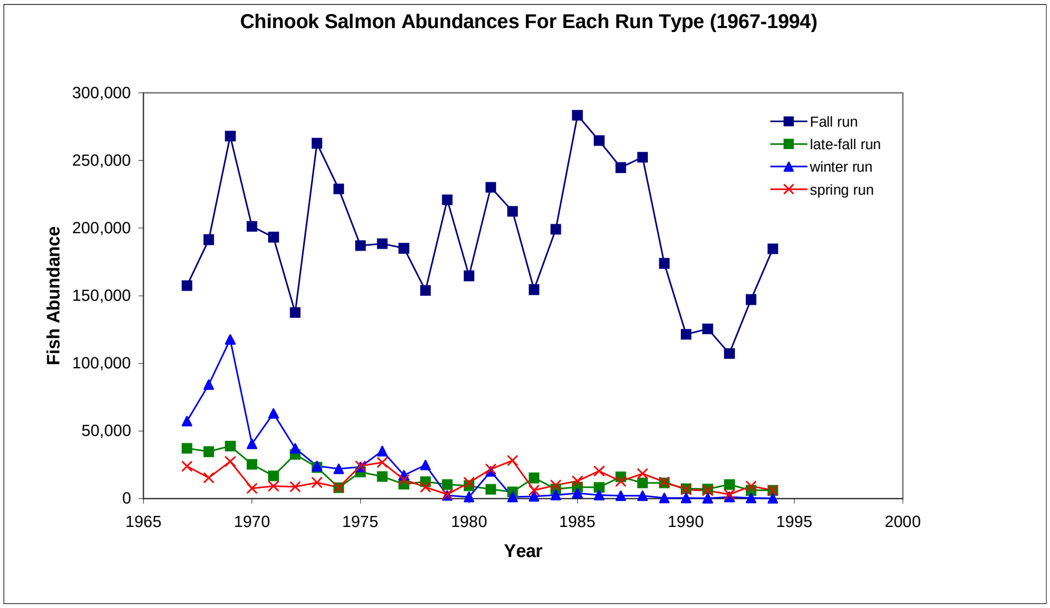


Figure D.1: Chinook Salmon Abundance – From 1967-1994

Appendix E

Riparian Plant Species

Common Name	**Latin Name**
California Box Elder	Acer negundo ssp. Californicum
Coyote brush	*Baccharis pilularis ssp. Consanquinea*
Mule fat	*Baccharis salicifolia*
Buttonbrush	*Cephalanthus occidentalis var. californicus*
Wild clematis	*Clematis ligusticifolia*
Oregon Ash	*Fraxinus latifolia*
California Sycamore	*Platanus racemosa*
Fremont Cottonwood	*Populus fremontii*
Valley oak	*Quercus lobata*
California Wild Rose	*Rosa californica*
Gooding's willow	*Salix gooddingii*
Sandbar willow	*Salix exigua*
Arroyo willow	*Salix lasiolepis*
Mexican elderberry	*Sambucus mexicana*

Table E.1: Most Common Riparian Tree and Shrub Species

Appendix F

Species of Special Status

Common Name	Scientific Name	California Status	Federal Status
Birds			
Cooper's hawk	*Accipiter cooperii*	SSC	none
sharp-shinned hawk	*Accipiter striatus*	SSC	none
tri-colored blackbird	*Agelaius tricolor*	SSC	none
golden eagle	*Aquila chrysaetos*	SSC	none
short-eared owl	*Asio flammeus*	SSC	none
long-eared owl	*Asio otus*	SSC	none
burrowing owl	*Athene cunicularia*	SSC	none
Barrow's goldeneye	*Buchephala islandica*	SSC	none
ferruginous hawk	*Bueto regalis*	SSC	none
northern harrier	*Circus cyaneus*	SSC	none
yellow warbler	*Dendroica petechia*	SSC	none
black-shouldered kite	*Elanus careruleus*	CFP	none
merlin	*Falco columbarius*	SSC	none
prairie falcon	*Falco mexicanus*	SSC	none
common loon	*Gavia immer*	SSC	none
yellow-breasted chat	*Icteria virens*	SSC	none
least bittern	*Ixobrychus exelis*	SSC	none
California gull	*Larus californicus*	SSC	none
long-billed curlew	*Numenius americanus*	SSC	none
osprey	*Pandeon haliaetus*	SSC	none
American white pelican	*Pelecanus erythrorhynchos*	SSC	none
double-crested cormorant	*Phalacroxorax auritus*	SSC	none
hepatic tanager	*Piranga flava*	SSC	none
summer tanager	*Piranga rubra*	SSC	none
white-faced ibis	*Plegadis chihi*	SSC	none
purple maritn	*Progne subis*	SSC	none
Fish			
Sacramento splittail	*Pogonichthys macrolepidotus*	SSC	none
Sacramento perch	*Archroplites interruptus*	SSC	none
green sturgeon	*Acipenser medirostris*	SSC	none
river lamprey	*Lampetra ayresi*	SSC	none
Mammals			
ringtail	*Bassaricus astutus*	SSC	none
Townsend's big-eared bat	*Plecotus townsednii*	SSC	none
badger	*Taxidea taxus*	SSC	none
Amphibians			
foothill yellow-legged frog	*Rana boylei*	SSC	none

Table F.1: Declining Species of the Sacramento Valley Ecosystem - SSC: Species of Special Concern. CFP: species that are California Fully-Protected. (Greco 1999).

Common Name	Scientific Name	California Status	Federal Status
Birds			
Aleutian Canada goose	*Branta caadensis leucopareia*	none	threatened
Swainson's hawk	*Buteo swainsoni*	threatened	none
western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	endangered	none
willow flycatcher	*Epidonax trailli*	endangered	none
peregrine falcon	*Falco perengrinus*	endangered	delist eval.
sandhill crane	*Grus canadensis*	threatened	none
bald eagle	*Haliaeetus leucocephalus*	endangered	delist eval
black rail	*Laterallus jamaicensis*	threatened	none
bank swallow	*Riparia riparia*	threatened	none
Bell's vireo	*Vireo bellii pusillus*	endangered	endangered
Fish			
thick-tailed chub	*Gila crassicauda*	extinct	extinct
delta smelt	*Hypomesus transpacificus*	threatened	threatened
coho salmon	*Hypomesus transpacificus*	endangered	threatened
winter-run Chinook salmon	*Oncorhynchus tshawytscha*	endangered	endangered
spring-run Chinook salmon	*Oncorhynchus tshawytscha*	endangered[2]	endangered[2]
fall-run Chinook salmon	*Oncorhynchus tshawytscha*	none	threatened[2]
steelhead trout	*Oncorhynchus mykiss*	none	threatened
Sacramento splittail	*Pogonichthys macrolepidotus*	threatened[2]	threatened[2]
Insects			
valley elderberry	*Desmocerus californicus*	none	threatened
long-horned beetle	*dimorphus*		
delta green ground beetle	*Elaphrus viridis*	none	threatened
Mammals			
proghorn	*Antilocapra americana*	extirpated[3]	none
tule elk	*Cervus elaphus*	extirpated[3]	none
riparian woodrat	*Neotoma fuscipes riparia*	SSC	endangered[2]
salt-marsh harvest mouse	*Reithrodontomys raviventris*	endangered	endangered
riparian brush rabbit	*Sylvilagus bachmani riparius*	endangered	endangered[2]
grizzly bear	*Ursus arctos spp.*	extirpated[3]	none
Reptiles			
giant garter snake	*Thamnothis couchi gigas*	threatened	threatened
Amphibians			
red-legged frog	*Rana aurora*	SSC	threatened
Crustaceans			
vernal pool fairy shrimp	*Branchinecta lynchi*	none	threatened
vernal pool tadpole shrimp	*Lepidurus packardi*	none	endangered

Table F.2: Endangered Species in the Sacramento Valley Ecosystem - SSC designates Species of Special Concern. [1] Listed in the Federal Register, 50 CFR 17.1. [2] Proposed listing (petition pending). [3] Nearly complete extirpation from Sacramento Valley, but is not listed under protected status. (Greco 1999)

Appendix G

Streamside Vegetation Analysis Results

Streamside vegetative analysis results for RM 126-131, a section of the study reach where the levees are not directly adjacent to the river.

Streamside coverage or conditions	Miles	% Coverage
Willow	2.06	24%
Cottonwood	2.09	24%
Mixed Riparian	2.22	25%
Valley Oak	0	0%
Gravel	0.55	6%
Other	1.83	21%
Total Coverage	8.75	100%

Total Vegetated % Cover	73%
Total Non-Vegetated % Cover	27%

Table G.1: Streamside Vegetation Analysis Results (RM 126-131)

Streamside vegetative analysis results for RM 145-175 reach above Colusa broken down into 10 mile segments.

Streamside coverage or conditions	Miles	% Coverage
Willow	2.36	11%
Cottonwood	4.08	18%
Mixed Riparian	8.29	37%
Valley Oak	0	0%
Gravel	4.72	21%
Other	2.68	12%
Total Coverage	22.13	100%

Total Vegetated % Cover	67%
Total Non-Vegetated % Cover	33%

Table G.2: Streamside Vegetation Analysis Results (RM 145-155)

Streamside coverage or conditions	Miles	% Coverage
Willow	4.71	21%
Cottonwood	4.75	21%
Mixed Riparian	6.89	30%
Valley Oak	0	0.00
Gravel	3.11	14%
Other	3.24	14%
Total Coverage	22.7	100%

Total Vegetated % Cover	72%
Total Non-Vegetated % Cover	28%

Table G.3: Streamside Vegetation Analysis Results (RM 155-165)

Streamside coverage or conditions	Miles	% Coverage
Willow	2.44	11%
Cottonwood	2.85	13%
Mixed Riparian	5.48	26%
Valley Oak	0	0%
Gravel	6.11	28%
Other	4.63	22%
Total Coverage	21.51	100%

Total Vegetated % Cover	51%
Total Non-Vegetated % Cover	50%

Table G.4: Streamside Vegetation Analysis Results (RM 165-175)

Summary for River Miles 145-175		
Streamside coverage or conditions	**Miles**	**% Coverage**
Willow	9.51	14%
Cottonwood	11.68	18%
Mixed Riparian	20.66	31%
Valley Oak	0	0%
Gravel	13.94	21%
Other	10.55	16%
Total Coverage	66.34	100%

Total Vegetated % Cover	63%
Total Non-Vegetated % Cover	37%

Table G.5: Overall Streamside Vegetation Analysis Results (RM 145-175)

Streamside vegetative analysis results for Project Reach (RM 84-144) broken down into 10 mile segment.

Streamside coverage or conditions	**Miles**	**% Coverage**
Willow	0.45	2%
Cottonwood	1.94	10%
Mixed Riparian	6.71	33%
Valley Oak	0	0%
Gravel	0.05	0%
Other	11.12	55%
Total Coverage	20.27	100%

Total Vegetated % Cover	45%
Total Non-Vegetated % Cover	55%

Table G.6: Streamside Vegetation Analysis Results (RM 84-94)

Streamside coverage or conditions	Miles	% Coverage
Willow	1.78	9%
Cottonwood	2.26	11%
Mixed Riparian	3.87	20%
Valley Oak	0	0%
Gravel	0.24	1%
Other	11.66	59%
Total Coverage	19.81	100%

Total Vegetated % Cover	40%
Total Non-Vegetated % Cover	60%

Table G.7: Streamside Vegetation Analysis Results (RM 94-104)

Streamside coverage or conditions	Miles	% Coverage
Willow	0.08	0%
Cottonwood	1.58	8%
Mixed Riparian	2.27	11%
Valley Oak	0	0%
Gravel	0.12	1%
Other	15.8	80%
Total Coverage	19.85	100%

Total Vegetated % Cover	20%
Total Non-Vegetated % Cover	80%

Table G.8: Streamside Vegetation Analysis Results (RM 104-114)

Streamside coverage or conditions	Miles	% Coverage
Willow	2.06	10%
Cottonwood	3	15%
Mixed Riparian	4.98	25%
Valley Oak	0	0%
Gravel	0.06	0%
Other	9.87	49%
Total Coverage	19.97	100%

Total Vegetated % Cover	50%
Total Non-Vegetated % Cover	50%

Table G.9: Streamside Vegetation Analysis Results (RM 114-124)

Streamside coverage or conditions	Miles	% Coverage
Willow	2.83	15%
Cottonwood	2.68	14%
Mixed Riparian	5.42	29%
Valley Oak	0	0%
Gravel	0.65	3%
Other	7.21	38%
Total Coverage	18.79	100%

Total Vegetated % Cover	58%
Total Non-Vegetated % Cover	42%

Table G.10: Streamside Vegetation Analysis Results (RM 124-134)

Streamside coverage or conditions	Miles	% Coverage
Willow	0.13	1%
Cottonwood	0.35	2%
Mixed Riparian	12.85	63%
Valley Oak	0	0%
Gravel	0	0%
Other	6.93	34%
Total Coverage	20.26	100%

Total Vegetated % Cover	66%
Total Non-Vegetated % Cover	34%

Table G.11: Streamside Vegetation Analysis Results (RM 134-144)

Overall streamside vegetative analysis results for Project Reach (RM 84-144)

Summary for River Miles 84-144		
Streamside coverage or conditions	**Miles**	**% Coverage**
Willow	7.33	6%
Cottonwood	11.81	10%
Mixed Riparian	36.1	30%
Valley Oak	0	0%
	0	
Gravel	1.12	1%
Other	62.59	53%
	0	
Total Coverage	118.95	100%

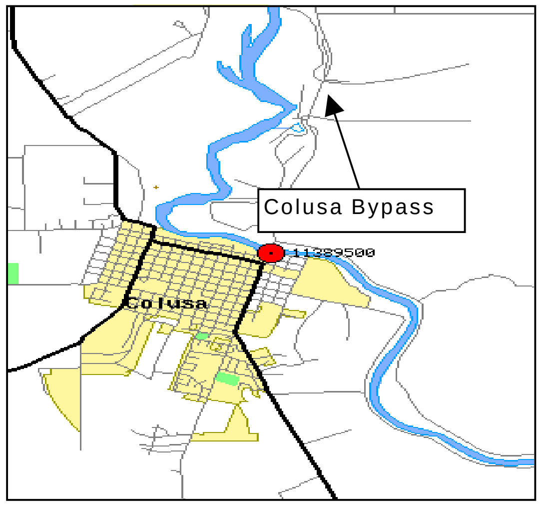
Total Vegetated % Cover	46%
Total Non-Vegetated % Cover	54%

Table G.12: Overall Streamside Vegetation Analysis Results (RM 84-144)

Appendix H

Gauging Station Data

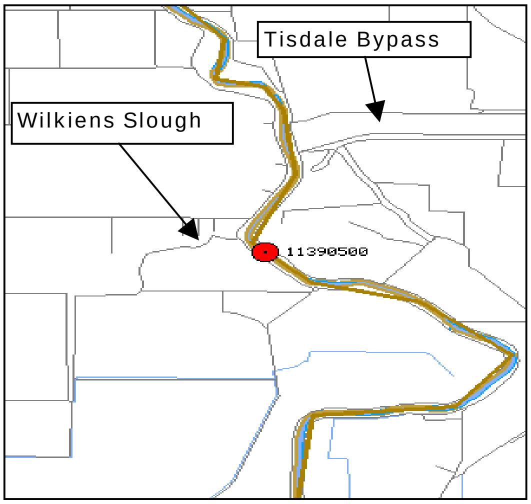
Station:	***Colusa***	11389500
RM	***143.4***	
lat	39.12' 51"	
lon	121.59' 57"	



Water Year	**peakQ (cfs)**		
1944	31200		
1945	34000		
1946	38100		
1947	32300		
1948	35800		
1949	35300		
1950	34200		
1951	37700		
1952	39700		
1953	40000		
1954	40000		
1955	30900	1977	10700
1956	43200	1978	45200
1957	36600	1979	37100
1958	45800	1980	45800
1959	39400	1981	41300
1960	38400	1982	44000
1961	35200	1983	51800
1962	38500	1984	49100
1963	39300	1985	34200
1964	33300	1986	50100
1965	43900	1987	36300
1966	40500	1988	36900
1967	39500	1989	37600
1968	39100	1990	24700
1969	42700	1991	27800
1970	48400	1992	35500
1971	41800	1993	46600
1972	24900	1994	22100
1973	42300	1995	48900
1974	48600	1996	37900
1975	41400	1997	48400
1976	23900	1998	50300

Table H.1: Colusa Gauging Station Data

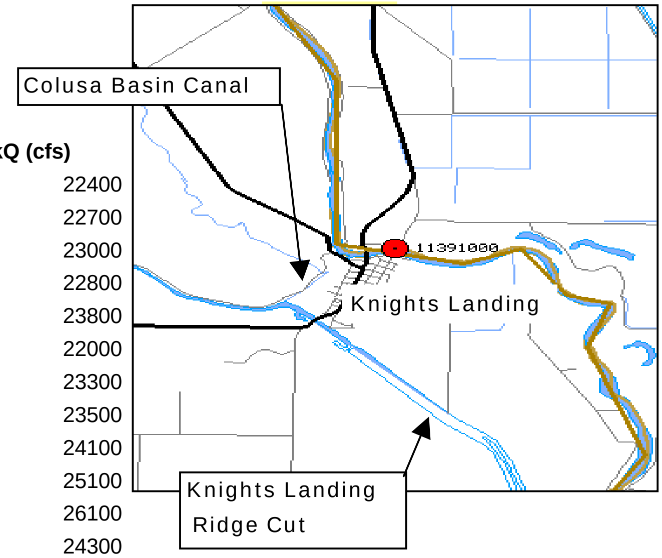
Station:	***Wilkiens Slough***	11390500
RM	***117.5***	
lat	39.00' 36"	
lon	121.49' 25"	



Water Year	**peakQ (cfs)**		
1944	20800		
1945	21700		
1946	22400		
1947	22400		
1948	23800		
1949	23200		
1950	22700		
1951	22500		
1952	23100		
1953	24700		
1954	25200		
1955	23400	1977	10900
1956	26300	1978	28600
1957	23900	1979	25500
1958	28900	1980	28600
1959	25100	1981	28400
1960	26700	1982	29300
1961	26200	1983	32300
1962	25700	1984	30400
1963	26000	1985	25900
1964	26000	1986	32700
1965	27500	1987	26100
1966	27100	1988	26700
1967	26400	1989	27300
1968	28400	1990	22400
1969	29000	1991	24300
1970	29300	1992	28700
1971	27500	1993	29500
1972	24700	1994	20600
1973	28000	1995	30700
1974	29400	1996	28800
1975	28000	1997	31600
1976	21200	1998	31100

Table H.2: Wilkiens Slough Gauging Station Data

Station:	*Knights Landing*	11391000
RM	***89.6***	
lat	38.48' 11"	
lon	121.42' 55"	



Water Year	peakQ (cfs)
1944	22400
1945	22700
1946	23000
1947	22800
1948	23800
1949	22000
1950	23300
1951	23500
1952	24100
1953	25100
1954	26100
1955	24300
1956	27800
1957	25200
1958	29600
1959	27000
1960	24900
1961	30000
1962	29100
1963	27600
1964	22800
1965	27300
1966	27500
1967	27900
1968	28100
1969	30600
1970	30800
1971	27800
1972	24500
1973	29700
1974	29800
1975	28600
1976	22000
1977	10600
1978	29700
1979	26900
1980	29400

Table H.3: Knights Landing Gauging Station Data

Appendix I

Velocity Calculations

Velocity Changes 100yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(1) - 7	137	base	0.0001	44.80	3.60
		1	0.0001	37.31	3.19
		2	0.0001	34.84	3.05
		3	0.0001	33.70	2.98
			change	**11.10**	**0.62**
			% change	**0.25**	**0.17**
3(1) - 11	135.4	base	0.0001	43.69	3.54
		1	0.0001	38.20	3.24
		2	0.0001	36.17	3.12
		3	0.0001	36.17	3.12
			change	**7.52**	**0.42**
			% change	**0.17**	**0.12**
3(1) - 12	135.1	base	0.0001	39.75	3.33
		1	0.0001	34.91	3.05
		2	0.0001	34.77	3.04
		3	0.0001	34.38	3.02
			change	**5.37**	**0.31**
			% change	**0.14**	**0.09**
3(1) - 25	131.1	base	0.0001	33.01	2.94
		1	0.0001	30.36	2.78
		2	0.0001	28.25	2.65
		3	0.0001	27.94	2.63
			change	**5.07**	**0.31**
			% change	**0.15**	**0.11**
3(1) - 31	127.3	base	0.0001	48.67	3.81
		1	0.0001	44.20	3.57
		2	0.0001	42.00	3.45
		3	0.0001	42.00	3.45
			change	**6.67**	**0.36**
			% change	**0.14**	**0.09**
3(1) - 37	125.5	base	0.0001	38.30	3.25
		1	0.0001	31.24	2.83
		2	0.0001	29.31	2.72
		3	0.0001	27.88	2.63
			change	**10.42**	**0.62**
			% change	**0.27**	**0.19**

avg. change in height (ft)	***7.69***
avg. change in velocity (ft/s)	***0.44***

Table I.1: Velocity for 100-year flood (RM 137-125.5)

Velocity Changes 100yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(2) - 9	122.8	base	0.00013	47.13	4.25
		1	0.00013	39.56	3.78
		2	0.00013	36.60	3.59
		3	0.00013	34.95	3.48
			change	**12.18**	**0.77**
			% change	**0.26**	**0.18**
3(2) - 15	120.5	base	0.00013	38.20	3.69
		1	0.00013	30.97	3.21
		2	0.00013	28.87	3.07
		3	0.00013	27.66	2.98
			change	**10.54**	**0.72**
			% change	**0.28**	**0.19**
3(2) - 27	117.7	base	0.00013	41.45	3.90
		1	0.00013	35.92	3.55
		2	0.00013	34.00	3.42
		3	0.00013	34.00	3.42
			change	**7.45**	**0.48**
			% change	**0.18**	**0.12**
3(2) - 32	115.7	base	0.00013	41.60	3.91
		1	0.00013	37.00	3.62
		2	0.00013	37.00	3.62
		3	0.00013	37.00	3.62
			change	**4.60**	**0.29**
			% change	**0.11**	**0.08**
3(2) - 38	113.7	base	0.00013	29.44	3.11
		1	0.00013	24.26	2.73
		2	0.00013	22.33	2.58
		3	0.00013	21.55	2.52
			change	**7.89**	**0.58**
			% change	**0.27**	**0.19**
3(2) - 50	110.3	base	0.00013	32.36	3.31
		1	0.00013	27.93	3.00
		2	0.00013	25.99	2.86
		3	0.00013	25.99	2.86
			change	**6.37**	**0.45**
			% change	**0.20**	**0.14**

avg. change in height (ft)	***8.17***
avg. change in velocity (ft/s)	***0.55***

Table I.2: Velocity for 100-year flood (RM 122.8-110.3)

Velocity Changes 100yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(3) - 8	108.2	base	0.0001	33.25	2.95
		1	0.0001	27.37	2.59
		2	0.0001	25.57	2.48
		3	0.0001	24.85	2.43
			change	**8.40**	**0.52**
			% change	**0.25**	**0.18**
3(3) - 22	101.8	base	0.0001	36.41	3.14
		1	0.0001	34.10	3.00
		2	0.0001	32.00	2.88
		3	0.0001	32.00	2.88
			change	**4.41**	**0.26**
			% change	**0.12**	**0.08**
3(3) - 33	97.8	base	0.0001	38.68	3.27
		1	0.0001	35.79	3.10
		2	0.0001	33.98	3.00
		3	0.0001	33.98	3.00
			change	**4.70**	**0.27**
			% change	**0.12**	**0.08**
3(3) - 40	94.4	base	0.0001	35.62	3.09
		1	0.0001	32.33	2.90
		2	0.0001	31.00	2.82
		3	0.0001	31.00	2.82
			change	**4.62**	**0.27**
			% change	**0.13**	**0.09**
3(3) - 47	91.3	base	0.0001	39.52	3.31
		1	0.0001	34.65	3.04
		2	0.0001	33.98	3.00
		3	0.0001	33.98	3.00
			change	**5.54**	**0.32**
			% change	**0.14**	**0.10**

avg. change in height (ft) ***5.53***
avg. change in velocity (ft/s) ***0.33***

Table I.3: Velocity for 100-year flood (RM 108.2-91.3)

Velocity Changes   100yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
1(1) - 8	88.6	base	0.00007	41.23	2.85
		1	0.00007	36.10	2.61
		2	0.00007	33.28	2.47
		3	0.00007	32.81	2.45
			change	**8.42**	**0.40**
			% change	**0.20**	**0.14**
1(1) - 11	88	base	0.00007	36.00	2.61
		1	0.00007	35.83	2.60
		2	0.00007	33.00	2.46
		3	0.00007	33.00	2.46
			change	**3.00**	**0.15**
			% change	**0.08**	**0.06**
1(1) - 16	86.5	base	0.00007	37.04	2.66
		1	0.00007	31.87	2.40
		2	0.00007	29.50	2.28
		3	0.00007	28.00	2.20
			change	**9.04**	**0.45**
			% change	**0.24**	**0.17**

avg. change in height (ft) ***6.82***
avg. change in velocity (ft/s) ***0.33***

Table I.4: Velocity for 100-year flood (RM 88.6-86.5)

Velocity Changes   2yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(1) - 7	137	base	0.0001	38.46	3.26
		1	0.0001	34.38	3.02
		2	0.0001	32.28	2.90
		3	0.0001	32.00	2.88
			change	**6.46**	**0.38**
			% change	**0.17**	**0.12**
3(1) - 11	135.4	base	0.0001	37.15	3.18
		1	0.0001	34.90	3.05
		2	0.0001	33.17	2.95
		3	0.0001	33.17	2.95
			change	**3.98**	**0.23**
			% change	**0.11**	**0.07**
3(1) - 12	135.1	base	0.0001	33.23	2.95
		1	0.0001	31.53	2.85
		2	0.0001	31.42	2.84
		3	0.0001	31.10	2.83
			change	**2.13**	**0.13**
			% change	**0.06**	**0.04**
3(1) - 25	131.1	base	0.0001	27.80	2.62
		1	0.0001	27.39	2.60
		2	0.0001	27.00	2.57
		3	0.0001	27.00	2.57
			change	**0.80**	**0.05**
			% change	**0.03**	**0.02**
3(1) - 31	127.3	base	0.0001	42.00	3.45
		1	0.0001	42.00	3.45
		2	0.0001	42.00	3.45
		3	0.0001	42.00	3.45
			change	**0.00**	**0.00**
			% change	**0.00**	**0.00**
3(1) - 37	125.5	base	0.0001	32.78	2.93
		1	0.0001	28.80	2.68
		2	0.0001	27.15	2.58
		3	0.0001	25.93	2.50
			change	**6.85**	**0.42**
			% change	**0.21**	**0.14**

avg. change in height (ft)	***3.37***
avg. change in velocity (ft/s)	***0.20***

Table I.5: Velocity for 2-year flood (RM 137-125.5)

Velocity Changes 2yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(2) - 9	122.8	base	0.00013	40.71	3.86
		1	0.00013	36.55	3.59
		2	0.00013	34.00	3.42
		3	0.00013	34.00	3.42
			change	**6.71**	**0.44**
			% change	**0.16**	**0.11**
3(2) - 15	120.5	base	0.00013	32.36	3.31
		1	0.00013	28.39	3.03
		2	0.00013	26.62	2.90
		3	0.00013	25.60	2.83
			change	**6.76**	**0.48**
			% change	**0.21**	**0.14**
3(2) - 27	117.7	base	0.00013	37.72	3.66
		1	0.00013	34.13	3.43
		2	0.00013	34.00	3.42
		3	0.00013	34.00	3.42
			change	**3.72**	**0.25**
			% change	**0.10**	**0.07**
3(2) - 32	115.7	base	0.00013	38.00	3.68
		1	0.00013	37.00	3.62
		2	0.00013	37.00	3.62
		3	0.00013	37.00	3.62
			change	**1.00**	**0.06**
			% change	**0.03**	**0.02**
3(2) - 38	113.7	base	0.00013	26.17	2.87
		1	0.00013	22.72	2.61
		2	0.00013	20.00	2.40
		3	0.00013	20.00	2.40
			change	**6.17**	**0.47**
			% change	**0.24**	**0.16**
3(2) - 50	110.3	base	0.00013	29.34	3.10
		1	0.00013	26.41	2.89
		2	0.00013	24.69	2.76
		3	0.00013	24.64	2.76
			change	**4.70**	**0.34**
			% change	**0.16**	**0.11**

avg. change in height (ft) ***4.84***
avg. change in velocity (ft/s) ***0.34***

Table I.6: Velocity for 2-year flood (RM 122.8-110.3)

Velocity Changes 2yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
3(3) - 8	108.2	base	0.0001	29.84	2.75
		1	0.0001	25.82	2.50
		2	0.0001	24.23	2.39
		3	0.0001	23.58	2.35
			change	**6.26**	**0.40**
			% change	**0.21**	**0.15**
3(3) - 22	101.8	base	0.0001	33.27	2.96
		1	0.0001	32.29	2.90
		2	0.0001	32.00	2.88
		3	0.0001	32.00	2.88
			change	**1.27**	**0.08**
			% change	**0.04**	**0.03**
3(3) - 33	97.8	base	0.0001	35.45	3.08
		1	0.0001	33.99	3.00
		2	0.0001	32.36	2.90
		3	0.0001	32.36	2.90
			change	**3.09**	**0.18**
			% change	**0.09**	**0.06**
3(3) - 40	94.4	base	0.0001	32.41	2.90
		1	0.0001	31.00	2.82
		2	0.0001	31.00	2.82
		3	0.0001	31.00	2.82
			change	**1.41**	**0.08**
			% change	**0.04**	**0.03**
3(3) - 47	91.3	base	0.0001	35.90	3.11
		1	0.0001	32.40	2.90
		2	0.0001	32.24	2.89
		3	0.0001	32.24	2.89
			change	**3.66**	**0.22**
			% change	**0.10**	**0.07**

avg. change in height (ft) ***3.14***
avg. change in velocity (ft/s) ***0.19***

Table I.7: Velocity for 2-year flood (RM 108.2-91.3)

Velocity Changes 2yr flood

x-section	RM	scenario	slope	height (ft)	channel vel. (ft/s)
1(1) - 8	88.6	base	0.00007	36.88	2.65
		1	0.00007	33.90	2.50
		2	0.00007	31.86	2.40
		3	0.00007	31.00	2.36
			change	**5.88**	**0.29**
			% change	**0.16**	**0.11**
1(1) - 11	88	base	0.00007	33.00	2.46
		1	0.00007	33.00	2.46
		2	0.00007	33.00	2.46
		3	0.00007	33.00	2.46
			change	**0.00**	**0.00**
			% change	**0.00**	**0.00**
1(1) - 16	86.5	base	0.00007	32.38	2.43
		1	0.00007	29.61	2.29
		2	0.00007	28.00	2.20
		3	0.00007	28.00	2.20
			change	**4.38**	**0.22**
			% change	**0.14**	**0.09**

avg. change in height (ft)	***3.42***
avg. change in velocity (ft/s)	***0.17***

Table I.8: Velocity for 2-year flood (RM 88.6-86.5)

Appendix J

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