Habitat Improvement for Native Fish in the Yolo Bypass

__A Project of__

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EXECUTIVE SUMMARY

This project entitled "Habitat Improvement for Native Fish in the Yolo Bypass" examines the feasibility of managing a portion of the Yolo Bypass to improve habitat for aquatic species, particularly native fishes such as Chinook salmon and splittail. The project's primary objective is to recommend a specific demonstration-scale managed floodplain inundation program in the Yolo Bypass that could be implemented over the next one to two years. However, this study also proposes possibilities for larger-scale, collaborative efforts that better address major habitat issues over the long term. It is envisioned that early results from the demonstration-scale project will inform these longer-term efforts.

The analysis was completed by a project team consisting of Natural Heritage Institute (NHI), California Department of Water Resources (DWR), California Department of Fish and Game (CDFG), and Yolo Basin Foundation, with assistance from consultants Northwest Hydraulic Consultants (NHC), Gus Yates (consulting hydrologist), Peter Kiel (legal analyst), and Jones and Stokes. The U.S. Army Corps of Engineers and the CALFED Ecosystem Restoration Program provided financial support.

The study area encompassed the entire 59,000-acre Yolo Bypass, a leveed floodplain engineered to convey floodwaters of the greater Sacramento Valley. Between floods, the Bypass primarily supports agriculture and managed habitat for waterfowl. As the largest contiguous floodplain of the lower Sacramento River, the Yolo Bypass is valuable to the flora, fauna, and people of the valley.

At the northern end of the Yolo Bypass, Fremont Weir conveys floodwaters from the Sacramento and Feather Rivers into the Bypass. Flow also enters the Yolo Bypass from several small west side streams: Knights Landing Ridge Cut, Cache Creek, Willow Slough Bypass and Putah Creek. After floodwaters recede, the basin empties through the Toe Drain, a perennial riparian channel on the eastern edge of the Bypass. During drier months the tidally influenced Toe Drain channel is the primary source of perennial water in the Yolo Bypass, feeding a complex network of canals and ditches.

In more than half of all water years, excess floodwaters enter the Yolo Bypass from the main channel of the Sacramento River, creating up to 60,000 acres of vital shallow water habitat for native fish and migratory and wintering shorebird populations (Sommer et al. 2002, Sommer et al. 2001a, Sommer et al. 2001b). Because much of the historical floodplain in the Sacramento Valley has been lost to development, river channelization and levee construction, the remnant floodplain habitat of the Yolo Bypass—the largest contiguous floodplain of the lower Sacramento River—has exceptional biological value for many native aquatic and wildlife species. However, the value of this habitat is compromised in below-normal to critically dry years, when there is little or no floodplain inundation and poor connectivity between the Yolo Bypass and the Sacramento River.

In order to adequately assess the feasibility of various management options in the Bypass, this project began with baseline ecological monitoring. In 2001–2002, DWR collected monitoring and experimental study data to help elucidate the floodplain processes that support aquatic species. These studies revealed the importance of Yolo Bypass floodplain inundation for native fish passage, spawning and rearing, as well as estuary food web processes. More specifically, the studies found that in drier years, when water does not flow over the Fremont Weir, adult fish migrating through the Yolo Bypass are unable to reach the Sacramento River to spawn (Harrell and Sommer, In prep). Additional passage problems exist in smaller tributaries to the Yolo Bypass, which have check dams and other structures that may impede upstream passage for migrating fish. These migration barriers are particularly detrimental to species like Chinook salmon, which have only one year to spawn. Data also suggested that the Yolo Bypass itself is important spawning habitat for species like Sacramento splittail, which spawn on flooded vegetation in relatively shallow areas. In years when the Bypass does not inundate, splittail production declines (Sommer et al. 1997).

In addition, monitoring studies showed that in wet years, the Yolo Bypass provides a major rearing area for juvenile fishes including Chinook salmon and Sacramento splittail (Sommer et al. 1997; Sommer et al. 2001b). In drier years, juvenile Chinook salmon and splittail are largely confined to the heavily channelized mainstem Sacramento River, where there is minimal cover, lower food supply, cooler winter water temperatures, higher water velocities, potentially greater diversion risk, and potentially higher predation rates.

Lastly, these initial studies conclude that when inundated, the Yolo Bypass serves the purpose of increasing organic carbon input to the Sacramento-San Joaquin Estuary, increasing the food base for the larger Delta ecosystem (Schemel et al. 1996). These ecosystem functions are greatly reduced in drier years.

To address the problems associated with reduced inundation of the Yolo Bypass since construction of the Fremont Weir and other flood control structures in the early 1900s, this project developed and analyzed alternative management scenarios to expand and enhance seasonal shallow water habitat in the Yolo Bypass. The specific goals of this project were to: 1) expand and improve spawning conditions for Sacramento splittail; 2) improve rearing conditions for juvenile salmonids; 3) enhance Delta food web productivity; and 4) reduce stranding and improve passage for native anadromous fish. Secondary goals included enhancing spring staging habitat for shorebirds and increasing knowledge about managing the Yolo Bypass floodplain for native species.

Public outreach and coordination with the stakeholders, including agencies, that have interests or jurisdiction in the Bypass was an important first step in this project. This consultative process continued throughout the life of the project. Through numerous meetings with the Yolo Bypass Working Group and representatives from state and federal agencies, we found that stakeholders were primarily concerned with the impacts that a floodplain inundation project might have on overall flood conveyance and capacity in the Bypass, the implications of introducing listed species on and near private lands, and the project's potential for increasing mosquito populations in the Bypass. These concerns were fully considered in the design and evaluation of managed floodplain inundation alternatives.

The next step in this project was to develop a long-term adaptive management plan for the Yolo Bypass, which included preliminary conceptual models and design hypotheses on how managed flooding of the Yolo Bypass in drier years can be used to increase production and survival of splittail, Chinook salmon and shorebird populations.

While these conceptual models were developed as part of the long-term adaptive management plan for the Yolo Bypass, they also informed the development of the short-term demonstration project that is the focus of this report.

The bulk of the analysis for this project involved detailed consideration of several major factors in assessing alternatives for the demonstration project, including suitable water for inundation, site topography and availability, and the opportunity to improve fish passage and hydrologic connectivity.

Initial analysis of suitable water sources for Yolo Bypass floodplain restoration identified two superior alternatives: Sacramento River and Putah Creek. The Sacramento River alternative had the greatest anticipated benefits. However, this water source would have greater potential effects on water projects, water users, and landowners and would require a lengthy planning and permitting process. It is unlikely that a restoration project using the Sacramento River water option could be implemented within the one- to two-year timeframe. In contrast, the Putah Creek alternative could likely be implemented relatively quickly as a demonstration project, a major goal of this project. As a consequence, the Putah Creek alternative was evaluated in the greatest detail.

The best approach identified for a demonstration-level project was to construct a managed floodplain along the South Fork of Putah Creek. Potential impacts to surrounding lands and private agricultural operation would be minimized by gravity delivery of seasonal creek water, and minimal land disturbance for channel construction. Because the creek would only inundate lands in the Yolo Bypass Wildlife Area, potential impacts of the presence of listed species on adjacent private landowners would be minimized.

Currently, the South Fork of Putah Creek flows from west to east, joining the Toe Drain about four miles south of I-80. From spring to fall, a check dam one mile upstream of the Toe Drain impounds water for agricultural and wildlife management use. Downstream of the check dam, the creek channel is a straight, deep ditch. Spring flows in Putah Creek are relatively reliable because natural runoff is supplemented by releases from Lake Berryessa in non-drought years, pursuant to the Lower Putah Creek Instream Flow Settlement Agreement.

The recent expansion of the Yolo Bypass Wildlife Area has created a broad range of restoration possibilities using source water from Putah Creek. Twelve combinations of creek path, capacity, and check dam operation or removal were considered, and three likely concepts were further developed, all of them supplied by water diverted from the existing channel upstream of the check dam: 1) a floodplain along the existing channel featuring a string of small ponds; 2) a new channel featuring a large pond with vegetated islands; and 3) a new four-mile long channel connecting existing marshes and sinks.

For each of the three alternatives, we assessed costs, potential adverse impacts, and ability to meet project design criteria. Our recommendation for a demonstration-scale managed floodplain inundation program in the Yolo Bypass is the third alternative (Alternative 3D), which would create a new alignment of Putah Creek through lowlands to the southeast.

This alternative has several advantages for project development. Because it inundates a substantial area of floodplain habitat (up to 1,100 acres), it best meets the project scale needed to detect changes in the responses of aquatic organisms to managed seasonal inundation. It also creates an excellent opportunity to improve fish passage for adult salmon to migrate up Putah Creek. And importantly, Alternative 3D works with existing topography to simulate the historical alignment and floodplain features of Putah Creek.

This report concludes with a detailed review of the universe of legal and regulatory compliance issues that may arise for the long- and short-term Yolo Bypass restoration strategies proposed in this feasibility study. There are three types of legal issues applicable to Yolo Bypass activities: 1) legal issues associated with acquisition of land and water rights; 2) environmental impact analyses; and 3) compliance with numerous state and federal environmental laws and regulations. The analysis describes the purpose and requirements of the laws and regulations applicable to various potential restoration strategies. It analyzes the unique legal issues associated with different strategies and discusses the consequences for project planning and implementation. Discussion of planning and implementation issues focuses on consequences specific to the recommended alternative from this feasibility study (Alternative 3D), but also briefly considers consequences for the Sacramento River alternatives, which hold much promise for long-term, large-scale floodplain restoration in the Yolo Bypass.

Additional analysis of legal issues, flood control, erosion and sediment deposition, and geomorphic stability will be required before the recommended Putah Creek project from this feasibility study can be implemented. We suggest that these issues be considered as part of California Department of Fish and Game’s planning effort with the expanded Yolo Bypass Wildlife Area.

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CHAPTER 1. INTRODUCTION

DOCUMENT ORGANIZATION

This document presents the results of a cooperative study to assess the feasibility of managing a portion of the Yolo Bypass floodplain to support aquatic species. The project was completed by a team consisting of Natural Heritage Institute (NHI), California Department of Water Resources (DWR), California Department of Fish and Game (CDFG), and Yolo Basin Foundation, with assistance from consultants Northwest Hydraulic Consultants (NHC), Gus Yates (consulting hydrologist), Peter Kiel (legal analyst), and Jones and Stokes. Although not formal project partners, the Yolo Basin Working Group (Working Group) provided substantial guidance. The project was funded by the U.S. Army Corps of Engineers through the CALFED Bay-Delta Program.

Each chapter in this report explores an aspect of project feasibility. Chapter 1 presents the history of the Bypass, its current function, and deficiencies of the present system for native aquatic species and wildlife. The chapter continues with the goals of this project for enhancing floodplain function, opportunities and constraints associated with habitat restoration in the Bypass, and a review of concurrent research efforts to restore and evaluate the floodplain. Chapter 2 describes stakeholder issues and involvement in this project.

Chapter 3 presents the Yolo Bypass long-term adaptive management plan, which was prepared as part of the March 2002 CALFED Adaptive Management Workshop. Two important elements of the adaptive management plan—monitoring efforts and conceptual models—are highlighted in this chapter. We discuss preliminary data collection and analysis conducted to inform this and future projects in the Bypass. The conceptual models that are presented support the hypothesis that intentional flooding of specific locations in the Yolo Bypass will enhance production and survivorship of aquatic species such as splittail and Chinook salmon.

The core of the project team's efforts is presented in Chapters 4 through 6. Chapter 4 provides an evaluation of the project site's suitability for various restoration alternatives. Chapter 5 presents a detailed analysis of three preferred restoration alternatives, based on the previous chapter's site evaluation, and recommends one alternative for a demonstration-scale managed floodplain inundation program in the Yolo Bypass. The report concludes with Chapter 6, a discussion of the various legal and regulatory issues associated with potential restoration efforts in the Bypass.

BACKGROUND

The Yolo Bypass is a leveed 59,000-acre floodplain engineered to convey Delta flood flows from the Sacramento, American, and Feather Rivers, and their tributary watersheds (Figure 1-1). This 3-mile-wide, 40-mile-long stretch of undeveloped (mostly agricultural) land extends from the junction of the Sacramento and Feather Rivers to just north of the city of Rio Vista, where it rejoins the Sacramento River. In more than half of all water years (October 1 to September 30),

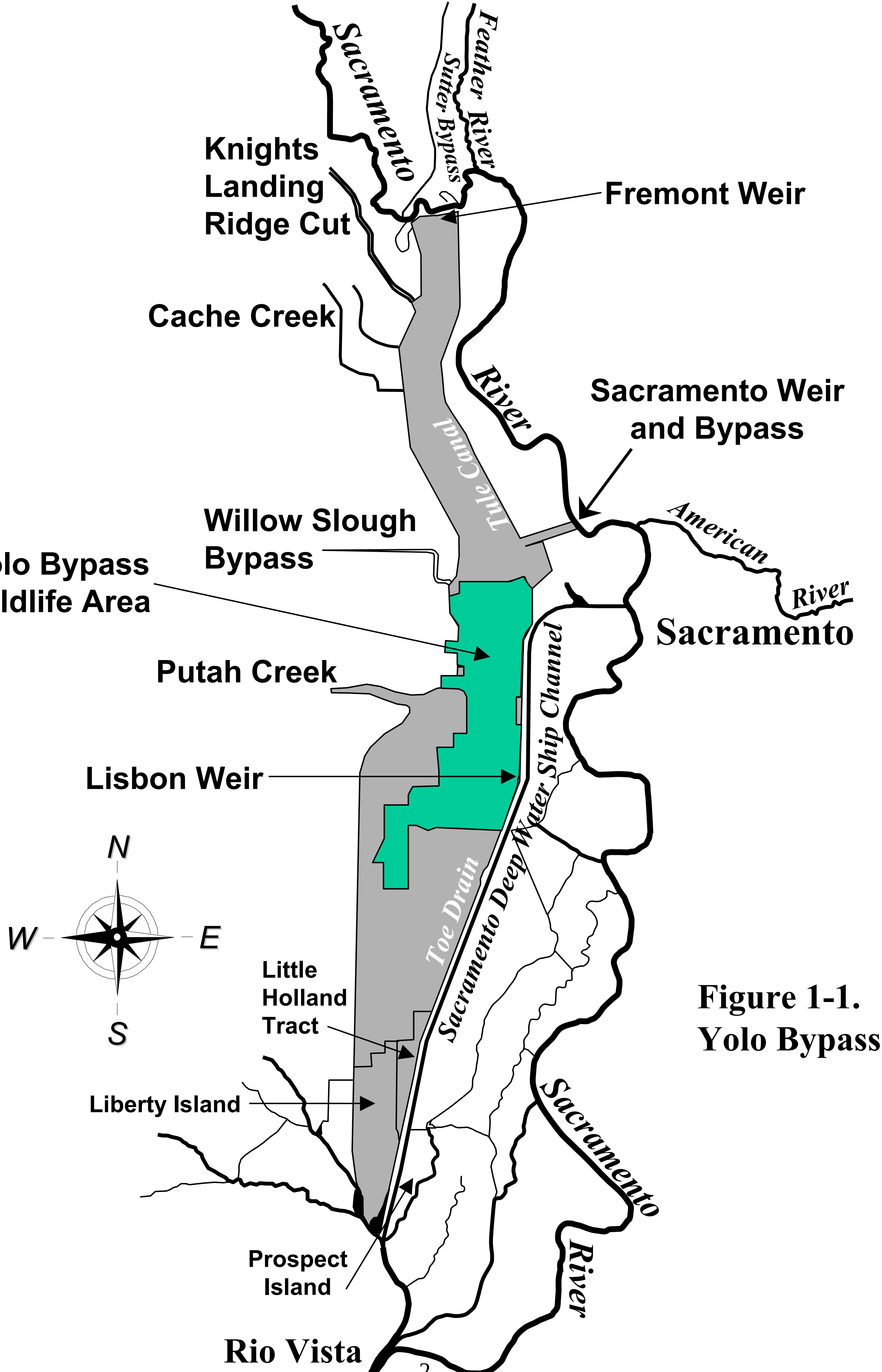


Figure 1-1. Yolo Bypass

excess floodwaters enter the Yolo Bypass from the main river channel, creating up to 60,000 acres of vital shallow water habitat for native fish and migratory and wintering shorebird populations (Sommer et al. 2002, Sommer et al. 2001a, Sommer et al. 2001b). In other (below-normal to critically dry) years, there is little or no floodplain inundation and poor connectivity between the Yolo Bypass and the Sacramento River. During these years, native fish production declines due to an inability to reach historical spawning and rearing habitat; and shorebird abundance decreases in correspondence with low availability of shallow water foraging habitat.

History of theYolo Bypass

Historically, the periodic floods from the Sacramento River filled a large part of the Sacramento Valley. One of the most dramatic of these events occurred in 1862, when the valley was essentially converted into an inland sea. This legendary event helped fuel a 50-year debate on the best flood control approach to protect the valley's rapidly growing communities (Kelley 1989). Initial recommendations in 1905 for high river levees were based on a relatively short hydrologic record. Coincidentally, the release of the flood engineering report was followed immediately by the extreme flood of 1907 in which an estimated 300,000 acres of the valley were inundated by Sacramento River flows of about 600,000 cfs.

An additional large flood in 1909 convinced flood managers that alternatives to levees were needed. The solution had its roots in a 1860s proposal by newspaper editor Will Green to construct a broad bypass system that would more closely mimic the Sacramento River's natural floodplain functions. Based in part on Green's concept, the U.S. Army Corps of Engineers (USACE) eventually developed a network of weirs and bypasses, which became the Sacramento Flood Control Project. Central features of the plan included the development of two engineered floodplains—the 59,000-acre Yolo Bypass and 18,000-acre Sutter Bypass—to safely convey floodwaters around Sacramento and other valley communities.

The USACE began levee construction along the east and most of the west side of the Yolo Bypass in 1917. The Sacramento and Fremont Weirs—the two spillways for flood overflow from the Sacramento River into the Bypass—were built in 1917 and 1924, respectively. Much of the system for the Sacramento Flood Control Project was in place by the early 1930s, although there were several additions over the next several decades, including the development of upstream reservoirs.

The concept of an engineered floodplain system like the Sacramento Flood Control Project is unique to this day. Conventional flood control practices frequently isolate rivers from ecologically essential floodplain habitat, eliminating the important ecosystem functions and processes of these increasingly scarce natural systems. The adverse environmental effects of conventional flood control techniques are well-documented (Bayley 1991; Toth et al. 1993; Galat et al. 1998). The Sacramento Flood Control Project, and the Yolo Bypass in particular, provides an excellent opportunity to evaluate how existing and future flood control projects can be designed and operated to minimize impacts on the floodplain processes needed to sustain healthy aquatic and wetlands systems.

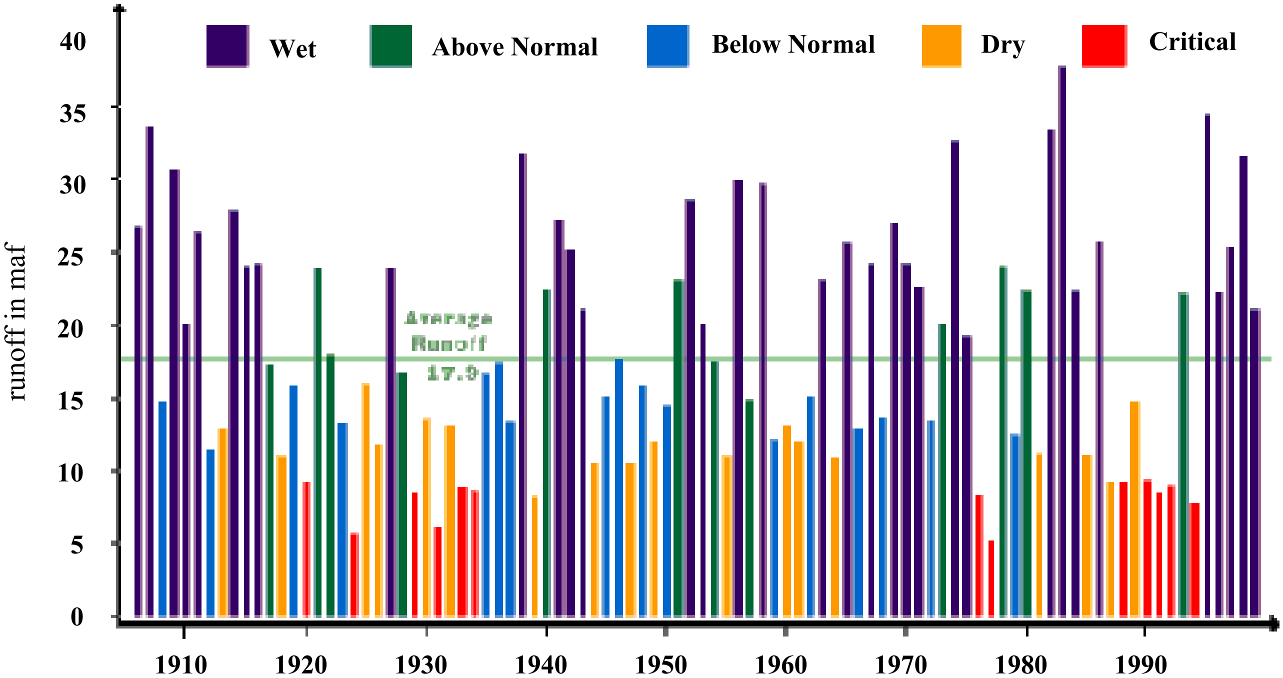
Hydrology of the Yolo Bypass

The Yolo Bypass is engineered to flood in above-normal and wet water years. Between 1956 and 1998, this occurred 58 percent of years, creating seasonal shallow water habitat for an array of fish and wildlife species (Figure 1-2). Three other water year types—below-normal, dry, and critically dry—complete the water year classification system for the Sacramento Valley. In these years, there is little or no inundation of the Yolo Bypass.

Figure 1-2. Flooding in the Yolo Bypass

Water years are classified based on current year's forecasted snowpack, precipitation, and reservoir storage, as well as previous year's index value. Historical water year classifications for the Sacramento Valley are shown in Figure 1-3.

In above-normal and wet water years, flooding of the Yolo Bypass has a major physical effect on the San Francisco Estuary and its two component regions: 1) the Sacramento-San Joaquin Delta, a network of channels bordered by the cities of Sacramento, Stockton and a point 20 km downstream of Rio Vista; and 2) the chain of downstream bays including Suisun, San Pablo and San Francisco Bays. When Yolo Bypass flows are greater than about 74,000 cfs, the partially leveed 59,000-acre floodplain is fully inundated; this level of inundation approximately doubles the wetted area of the delta and is equivalent to about one-third the area of San Francisco and San Pablo Bays. During major flood events, the Yolo Bypass can convey more than 75 percent of the total flow from the Sacramento, Feather and American Rivers. Besides Yolo Bypass, the only other Delta region with substantial connectivity to portions of the historical floodplain is Cosumnes River, a small undammed watershed. The floodplain has historically been inundated as early as October and as late as June, with a typical peak period of inundation during January through March.



Source: California Department of Water Resources, http://watersupplyconditions.water.ca.gov

Figure 1-3. Historical Water Year Classifications for Sacramento Valley, 1906–1999

The hydrology of the system is complex, with inundation possible from several different sources. The primary input to the Yolo Bypass is over Fremont Weir in the north (Figure 1-4), which conveys floodwaters from the Sacramento and Feather Rivers. The typical sequence of inundation is as follows. Flow pulses in the Sacramento River are first diverted into Sutter Bypass, an 18,000-acre agricultural floodplain with many similarities to Yolo Bypass. The Sacramento River immediately upstream of Fremont Weir has a relatively low channel capacity (28,300 cfs), so Sutter Bypass flooding is often initiated in modest flow pulses. When the combined flow of Sutter Bypass and Sacramento and Feather Rivers raises stage at Fremont Weir to a level of 29.7 feet (NGVD 1929), the weir is overtopped, and water enters Yolo Bypass.

The relative distribution of flow from different tributaries affects when this stage threshold is reached. However, Yolo Bypass flooding typically occurs when total flow from Sutter Bypass and the two rivers surpasses 56,500 cfs. Floodwater over Fremont Weir initially flows through the Tule Canal/Toe Drain (Figure 1-5), a perennial riparian channel on the eastern edge of the Bypass, before spilling onto the floodplain when discharge in this small channel exceeds 3,530 cfs. The floodplain is considered inundated when the stage of the Toe Drain at Lisbon Weir (Figure 1-5) exceeds 7.5 feet (NGVD 1929). In major storm events (e.g., >175,000 cfs), additional water from the American and Sacramento Rivers enters from the east via Sacramento Weir.

Figure 1-4. Fremont Weir

Flow also enters the Yolo Bypass from several small west side streams: Knights Landing Ridge Cut, Cache Creek, Willow Slough Bypass and Putah Creek. Depending on the distribution of precipitation, these tributaries can substantially augment the Sacramento basin floodwaters or cause localized floodplain inundation before Fremont Weir spills. The mean depth of the floodplain does not exceed 10 feet, except in the most extreme flood events.

After floodwaters recede, the basin empties through the Toe Drain. The floodplain is relatively well drained as a result of land-grading for agriculture. Other than agricultural berms, no major topographic features impede the drainage of flood flows to the lower Sacramento-San Joaquin Delta.

During drier months the tidally influenced Toe Drain channel is the primary source of perennial water in the Yolo Bypass, feeding a complex network of canals and ditches. Through tidal action, water flows into the Toe Drain from the base of the floodplain. Some of this water is impounded by Lisbon Weir for use in irrigation. Lisbon Weir straddles the Toe Drain about midway down the Bypass (Figure 1-1). During sufficiently high tides, upstream flow occurs over the top of the weir, and through three flapgates. The flapgates allow flow in the upstream direction, but close when water is higher upstream than downstream.

Figure 1-5. Toe Drain and Lisbon Weir

Current Function of the Yolo Bypass

As discussed in detail by the Yolo Bypass Working Group in their 2001 Yolo Bypass Management Strategy, the Bypass currently provides functions including:

- Flood conveyance for the Sacramento Valley;
- Agriculture;
- Waterfowl habitat, including duck hunting clubs;
- Wildlife habitat for shorebirds and other floodplain species; and
- Seasonal and perennial habitat for aquatic species.

Flood Conveyance: The primary purpose of the Bypass is to provide flood control, specifically the conveyance of floodwaters from the entire Sacramento River watershed. The maximum design flow for the Sacramento River channel below the Sacramento metropolitan area is 109,500 cfs. By contrast, the adjacent Yolo Bypass floodplain is engineered to convey approximately 495,000 cfs. The design capacity of the Yolo Bypass has not yet been exceeded, despite major floods such as 1997, estimated to be a 70-year recurrence interval event.

Land use within the Bypass is restricted by flood easements held by the Sacramento-San Joaquin Drainage District, as amended by the State of California Reclamation Board (Yolo Bypass Working Group et al. 2001). These easements do allow for the use of the land within the Bypass for duck clubs and agriculture.

Agriculture: For the past two decades, land use in the Yolo Bypass has been dominated by seasonal agriculture. The primary agricultural crops in Yolo Bypass are rice, wild rice, safflower, tomatoes, corn and other grains. Farming activity is concentrated in late spring and summer, when flooding is uncommon. However, spring planting can be delayed as a result of unusual late season storms. Crop yield data are not available specifically for the Yolo Bypass, but yields are generally lower than other nearby regions as a result of high clay content in the soils of the eastern half of the floodplain and occasional late-season flooding. Nonetheless, the Yolo Bypass remains a key crop production area for Yolo County, where agriculture is the major source of revenue.

Waterfowl: Although seasonal agriculture is the dominant land use on the floodplain, approximately one third of the Bypass is a mosaic of more “natural” habitat types on the floodplain including riparian, wetlands, upland and permanent (perennial) ponds. Many of these lands are managed for waterfowl. The best example is the Yolo Bypass Wildlife Area (Figure 1-1), one of the largest wetlands restoration projects in the western United States.

Land for the initial project was purchased in 1991 and wetlands were constructed through the cooperative efforts of the USACE, California Department of Fish and Game, Yolo Basin Foundation, U.S. Fish and Wildlife Service, California Department of Water Resources, Yolo County, the California Wildlife Conservation Board and Ducks Unlimited. During the past year, the project was expanded to more than 16,000 acres through the purchase of land by the State Wildlife Conservation Board.

Some privately owned lands, particularly in the southern Bypass, are also managed for waterfowl (duck hunting clubs). These are a mixture of irrigated pastures, seasonal wetlands, permanent wetlands and grain croplands that are typically flooded in October to attract waterfowl migrating along the Pacific Flyway. The Yolo Bypass is a critical link on this avian migration route, which is traveled by vast numbers of waterfowl. Duck clubs draw water down in late winter or early spring after the close of waterfowl hunting season in January.

Wildlife: The Yolo Bypass provides important staging and wintering habitat for shorebirds migrating along the Pacific Flyway. Shorebirds are primarily associated with shallow flooded fields, ponds, wetlands and mudflats. They are most abundant in the Yolo Bypass in fall and winter, when managed inundation for waterfowl increases the availability of habitat for shorebirds (Page et al. 1992).

The Yolo Bypass also supports numerous species of raptors (e.g., northern harriers, red-tailed hawks and kestrels), songbirds (e.g., orioles, towhees and bluebirds) and mammals (e.g., raccoons, skunks, beavers and gray foxes). The Yolo Bypass appears to be especially important to the Swainson's hawk, a state-listed threatened species that uses the floodplain as foraging habitat.

Aquatic Species: Because much of the historical floodplain in the Sacramento Valley has been lost to development, river channelization and levee construction, the remnant floodplain habitat of the Yolo Bypass has exceptional biological value for many native aquatic and wildlife species. Baseline data collection as part of this project indicates that the Bypass provides valuable aquatic habitat to at least 42 resident and seasonal fish species, 15 of which are native (Sommer et al. 2001a). It supports state and federally listed species (delta smelt, steelhead trout, spring-run and winter-run Chinook salmon) as well as game fish (white sturgeon and striped bass). Some of the observed benefits of the Yolo Bypass to aquatic species include:

- Increased spawning habitat (Sommer et al. 1997);
- Increased fish production (Sommer et al. 1997);
- Increased rearing habitat (Sommer et al. 1997; Sommer et al. 2001b);
- An enhanced food web within the floodplain (Sommer et al. 2001a; Mueller-Solger et al., In press); and
- Food web support to the downstream estuary (Schemel et al. 1996; Sommer et al. 2001a).

Problems with the Existing Bypass For Aquatic Species and Wildlife

Data collected over the past several years demonstrate that seasonal inundation of the Yolo Bypass is particularly important for native aquatic species (Sommer et al. 2001a). The typical winter- and spring-run spawning and rearing period for native delta fish coincides with the timing of the winter flood pulse (Moyle 2002). Thus, when the Bypass floods, it serves as an important migration corridor, spawning ground, and rearing nursery for these floodplain-dependent species. Seasonal inundation is less important for exotic fish species, which generally utilize the deeper perennial waters of the Bypass (e.g., Toe Drain channel) and spawn in late spring or summer after the floodplain is drained.

In below-normal to critically dry water years, river and tributary flows are generally insufficient to overtop the Bypass weirs and inundate the floodplain. Major problems ensue for native delta fish in these years, including the following:

Migration Barriers**:** Adult fish, including salmon, steelhead trout, splittail and sturgeon, migrate through the Yolo Bypass Toe Drain in all water years (DWR, unpublished data). Unless water is flowing over Fremont Weir, there is no possibility of upstream passage to the Sacramento River (Harrell and Sommer, In prep). While steelhead trout, splittail and sturgeon may survive to spawn another year by returning to the San Francisco Estuary, Chinook salmon cannot. Moreover, there are apparently passage problems for sturgeon even when Fremont Weir flows. During moderate flow events (e.g., <50,000 cfs in the Yolo Bypass), Fremont Weir functions like a low head dam. Unlike salmon, sturgeon do not jump well and cannot pass the weir during these conditions. Additional passage problems exist in smaller tributaries to the Yolo Bypass. For example, Putah Creek has a seasonal check dam in its lower reaches that typically blocks upstream salmon migration until it is removed in late autumn.

Spawning Habitat**:** Splittail do not produce strong year classes unless they have access to spawning habitat in the Yolo Bypass and other floodplain areas (Sommer et al. 1997). Splittail spawn on flooded vegetation in relatively shallow areas, e.g., <6 feet deep (Moyle et al., In prep). During flood events, the Yolo Bypass provides large areas of this type of habitat.

Juvenile Rearing: In wet years, the Yolo Bypass provides a major rearing area for juvenile fishes including Chinook salmon and splittail. In drier years, juvenile Chinook salmon and splittail are largely confined to the heavily channelized mainstem Sacramento River, where there is minimal cover, lower food supply, cooler winter water temperatures, higher water velocities, possibly higher diversion risk and potentially higher predation rates (Sommer et al. 2001b).

In addition to impacts on native fish populations, the loss of shallow water habitat in below-normal to critically dry years reduces the Yolo Bypass' ability to support declining populations of migratory and wintering shorebird species. In 1993, a 30 percent increase in shorebird abundance in the Yolo Bypass from the previous year was attributed largely to an experimental flooding of 4,300 acres in the Bypass, as part of a groundwater recharge study. The shallowly flooded fields provided optimal foraging opportunities for several thousand shorebirds that congregated in the area (Jones & Stokes 1992).

PROJECT GOALS

In concert with the opportunities identified in the CALFED Strategic Plan for Ecosystem Restoration, this project developed and analyzed alternative management scenarios to enhance northern California's native fish populations through expansion and enhancement of seasonal shallow water habitat in the productive Yolo Bypass floodplain. The project's primary objective was to recommend a specific demonstration-scale managed floodplain inundation program in the Yolo Bypass that could be implemented over the next one to two years. However, this study also lays the groundwork for larger-scale, collaborative efforts that more adequately address the major issues over the long term.

The study area encompassed the entire 59,000-acre Yolo Bypass, as shown in Figure 1-1. Emphasis was placed on management alternatives that discouraged exotic fish species such as centrarchids and carp, and did not compromise existing water and land uses in the Bypass. The specific goals of this project were as follows:

- Expand and improve spawning conditions for Sacramento splittail
- Improve rearing conditions for juvenile salmonids
- Enhance Delta food web productivity
- Reduce stranding and improve passage for native anadromous fish

Secondary goals included enhancing spring staging habitat for shorebirds and increasing knowledge about managing the Yolo Bypass floodplain for native species.

Expand and Improve Spawning Conditions for Sacramento Splittail: Sommer et al. (1997) found that splittail abundance correlates strongly with the annual duration of flooding in the Yolo Bypass. In years when the Bypass floods for an adequate duration, splittail populations can increase by one to two orders of magnitude. Inundation of the Bypass in below-normal and dry years should thus help to improve spawning success for splittail and possibly other species.

Improve Rearing Conditions for Juvenile Salmonids: Data from 1998 and 1999 (Sommer et al. 2001b) show that juvenile salmon grow up to twice as fast in the Bypass floodplain as in the mainstem rivers due to warmer water temperatures and an abundant food supply. Initial results from these studies also indicate that survival rates for salmon reared in the Bypass are over two times higher than for individuals from the adjacent Sacramento River.

Enhance Delta Food Web Productivity: There is a growing recognition that detritus is a major input to the food chain in the Sacramento-San Joaquin Delta, and the Bypass is a primary source of the organic carbon to the estuary (Schemel et al. 1996). As evidence, a 1998 study showed that chlorophyll *a* (an indicator of phytoplankton biomass) trends downstream of the Yolo Bypass closely followed the floodplain hydrograph. The peak in chlorophyll *a* that corresponded to receding floodwaters was presumably caused by shallower water, increased residence time and warmer temperatures in the floodplain (Sommer et al. 2001a). More frequent and greater duration flooding of the Bypass floodplain should therefore increase the food base for the larger Delta ecosystem.

Reduce Stranding and Improve Passage for Native Anadromous Fish: Both Fremont and Sacramento Weirs are migration barriers for upstream migrating adult fish, and surveys from 1996–1999 show that fish stranding rates at the barriers are relatively high. Modification of one or both of these structures and improved drainage of isolated ponds could reduce juvenile stranding and improve adult fish passage. Additional fish passage issues exist in the tributaries, including Putah and Cache Creeks.

Enhance Spring Staging Habitat for Shorebirds: The Yolo Bypass is in the direct route of vast numbers of shorebirds migrating every fall and spring. During this time, shallowly flooded sections of the Bypass are abundant with sandpipers, curlews, avocets and other species feeding on its bounty of invertebrates. Surveys from 1991 and 1992 show that approximately six times as many shorebirds use the Bypass during fall migration as use it during spring migration (Page et al. 1992). Since early fall flooding of seasonal wetlands by duck clubs greatly increases the acreage of wetlands and mudflats during fall migration, habitat availability likely contributes to this disparity. Maintaining these wetlands through the spring migration period would be a valuable asset for California shorebird populations.

Increase Knowledge about Managing the Yolo Bypass Floodplain for Native Species: A primary objective for Yolo Bypass restoration is to inventory and describe existing hydrologic conditions in the Bypass. Most of the compilation of such hydrologic data was completed for the 2001 Yolo Bypass Management Strategy (Yolo Bypass Working Group et al. 2001), which preceded this project. This project expanded on that base of information, with updated stage-frequency information for the Sacramento River at Fremont Weir, improved estimation of Yolo tributary flows, and analysis of inundation patterns near the Tule Canal/Toe Drain. This information is necessary both to understand how current management practices impact native and exotic species, and to better identify opportunities and constraints for enhancing native populations.

OPPORTUNITIES AND CONSTRAINTS

Opportunities

The Yolo Bypass is well suited for habitat restoration projects. It is a large, highly visible project near a metropolitan center, close to agency and university support, with a high potential for habitat enhancement with minimal alterations. The opportunities include:

Availability of Land: Through recent acquisitions, over 16,000 acres are now available for habitat restoration on publicly owned land. Additional areas could be included through coordination with local landowners and wildlife organizations. The area of floodplain that can be inundated is large enough to incorporate multiple habitat types.

Public Support: There is already a great deal of public support for restoration in this area. Through the establishment of the Yolo Bypass Wildlife Area and its associated stakeholder group the Yolo Bypass Working Group (Working Group), public, agency and private entities have worked cooperatively to establish management principles for the area. Actions taken would require coordination with the Working Group, but the proposed pilot scale effort appears to conform to its established management principles (Yolo Bypass Working Group et al. 2001).

CALFED continues to support and fund research in the Yolo Bypass (including this project), as an essential component for the restoration of native delta fish. In 2002, CALFED also sponsored a workshop to develop long-term adaptive management plans for key areas including Yolo Bypass, which has become a key focus of the CALFED Science Program. Scientists from UC Davis played an important role in this effort. The proximity of the university to the Bypass allows for their continued assistance and expertise.

Land Use Compatibility: Management of Bypass lands for aquatic species is reasonably consistent with existing land uses, particularly government lands purchased for habitat restoration. Besides the CDFG land in the Yolo Bypass Wildlife Area, substantial areas have recently been purchased in the southern Bypass at Liberty Island (USFWS) and Little Holland

Tract (Audubon Society). Large areas are also managed for other wildlife, principally waterfowl, in a 2,500-acre property located near Sacramento Bypass**.** Other tracts are farmed for annual crops (rice, corn, wild rice) that have existing flood easements in place. Pilot-scale inundation of habitat for aquatic species would generally occur in winter and early spring before farming actitivies begin.

Water Rights Acquisition: Procuring increased flows through dam releases for floodplain inundation on Sacramento and San Joaquin River tributaries is typically a major constraint to floodplain restoration. However, most of the water that would be used for a planned inundation project in the Yolo Bypass is returned to the river as it enters the Delta, so there is little net consumptive loss. Since water flowing through the Bypass is returned to the Delta before the major diversions, water rights may be less of an issue in the Bypass compared to other floodplain areas on the Sacramento and San Joaquin Rivers (see Chapter 6).

Flexibility: Ideally, implementation of the restoration project should include the ability to make adjustments to the project as the study progresses. Minor modifications to the Fremont Weir or changes in operation of the Sacramento Weir would not drastically alter periods of inundation in the Bypass. Modifications to Lisbon Weir, Fremont Weir, Tule Canal and the Toe Drain would affect fish passage to varying degrees. Most of these changes would be done incrementally and would be reversible if adverse effects are detected.

Cost of Error: The actions to be taken will involve changes in seasonal floodplain inundation and will not result in the permanent loss of resources or land. Since almost all the actions being considered are easily reversed, any adverse effects such as mercury methylation or organic carbon production detected through monitoring could be addressed.

Availability of Baseline Data: Pre-project data is available through recent studies on Yolo Bypass, including the Monitoring element of the present effort (see Chapter 3). Long-term monitoring of the Delta by the Interagency Ecological Program and its agencies will also provide a good baseline to examine system-wide responses and background variability of the biota.

Monitoring Opportunities: The Yolo Bypass was engineered as a virtually closed floodplain system, with few points of inflow and outflow. Such a design allows monitoring stations to be established at key locations in the Bypass to comprehensively track changes in fish survival, growth rates, water quality and other factors between the inlets and outlet.

Time Scale: Previous research on Yolo Bypass and Cosumnes River suggests that lower trophic levels respond to floodplain inundation on the scale of weeks. Higher trophic levels such as fish or macroinvertebrates respond on the order of months. These time scales provide the opportunity to make adjustments between years or even within the seasons, facilitating management experiments.

Signal-to-Noise Ratio: From baseline studies, it is apparent that experimental floodplain restoration projects will yield useful data (Sommer et al. 2001a,b). Statistically significant differences between the aquatic biota of river channel and floodplain habitats have been observed. Changes in lower trophic level biomass between the inlet and outlet of the floodplain has also been detected.

Compare/Contrast With Other Sites: The results of new projects in Yolo Bypass could easily be compared with those taking place on other sites, especially the Cosumnes River. The Cosumnes River floodplain can serve as a control of sorts because it floods naturally on an annual basis and, like Yolo Bypass, has a high residency time of the water.

Constraints

Existing Land Use: Management of Bypass lands for aquatic biota needs to be compatible with existing land uses such as wildlife management, duck clubs and farming. As a result of recent land acquisition by the Yolo Bypass Wildlife Area, several thousand acres of potential habitat are available for restoration. The northern portion of the Yolo Bypass Wildlife Area, however, has already been successfully developed for wildlife habitat; a major re-engineering of this area for aquatic species is therefore unlikely.

Regulatory Issues: Aquatic habitat restoration could be constrained by government regulations such as the Federal Endangered Species Act, water rights (SWRCB), California Endangered Species Act and the Clean Water Act. Perhaps the major issue is flood control, which is under the state jurisdiction of the Board of Reclamation. Floodplain restoration activities must be compatible with flood management in the Central Valley. Restoration activities cannot significantly reduce flood conveyance capacity, which is usually evaluated using hydrologic modeling. While increasing floodplain connectivity itself may be flood neutral (or even beneficial), allowing the development of substantial riparian or marsh vegetation could reduce flood conveyance. These issues are described in greater detail in Chapter 6.

Water Availability: Relatively little water is available within the Yolo Bypass for managed floodplain inundation. Local tributaries such as Putah Creek or Cache Creek could support modest floodplain projects, but landscape-scale efforts ultimately depend on the availability of water from the Sacramento River. These issues are described in detail in Chapter 5.

Topographic Considerations: Some project configurations may not be feasible based on geomorphic considerations. For some areas, existing topography and hydrology could make experimental floodplain restoration designs infeasible without structural changes. Site-specific topographic and water surface elevation data are needed to address this issue.

Water Quality: Although CALFED seeks to improve both water and habitat quality, some activities may involve tradeoffs. There is a reasonable expectation that floodplain restoration could result in at least slight increases in the loading of organic carbon and methylation of mercury, each a concern for municipal water quality. Pesticide loading could also be an issue if Knights Landing Ridge Cut (which receives water from Colusa Drain) is a major hydrologic input to the floodplain restoration project.

Introduced Species/Biological Factors: Benefits of floodplain restoration could be partially or completely offset by introduced species. For example, our ability to maintain or manipulate experimental floodplain habitats could be lost if there is a proliferation of invasive plants. On relatively small streams such as Putah Creek, beaver activity could make it difficult to maintain the desired hydrologic characteristics.

Control Structures: Because of topographic or hydrologic constraints, control structures may be needed to emulate historical floodplain hydrology at some sites. Gates, weirs or partial levees have been used in other locations to regulate or enhance inundation of restoration sites. However, the use of control structures is often considered less desirable to fisheries management agencies since they can sometimes limit fish passage.

Species Benefits: Evidence to date suggests that floodplain restoration will have the greatest benefits to shorebirds and to a few native fish species (e.g., splittail and salmon) that seasonally migrate into the Bypass. While some primary and secondary production from the floodplain may reach the estuary, it is uncertain whether there would be substantial benefits to other fish such as delta or longfin smelt.

CONCURRENT INITIATIVES

This project consulted with the other three major concurrent projects in the Yolo Bypass to determine areas of overlap and opportunities for coordination. The USACE Sacramento and San Joaquin River Basins Comprehensive Study (Comprehensive Study) and the plan of the Sacramento Area Flood Control Agency (SAFCA) focus primarily on flood control. The third effort, led by the U.S. Fish and Wildlife Service, targets floodplain habitat improvement at the proposed North Delta National Wildlife Refuge (NDNWR).

USACE Comprehensive Study

The Comprehensive Study (http://www.spk.usace.army.mil/civ/ssj/genInfo/index.htm) was initiated in response to the Central Valley flooding of January 1997, one of the worst flood disasters in the state's history (USACE and Rec Board 1999). The USACE and California Reclamation Board are jointly leading this effort to develop and begin implementation of flood management master plans for the Sacramento and San Joaquin River Basins. While the primary focus of the Comprehensive Study is to reduce future flood damage, high priority is also being given to the integration of measures that benefit ecosystem restoration.

Phase I of the study concluded in April 1999, with the completion of several reports that are now available on the study's website: the Post-Flood Assessment, Phase I Documentation Report, and a summary Interim Report. Phase I activities identified flood management and associated environmental problems in the Central Valley. It began development of hydrologic and hydraulic models for the Sacramento and San Joaquin Rivers, developed a conceptual Ecosystems Function Model relating physical and biological processes in the system, and began assembly and development of spatial information for a Geographic Information System (GIS) resource database for the study area.

Phase II activities include soliciting public input on measures for flood damage reduction and ecosystem restoration, and evaluating these measures using the project's hydrologic/hydraulic and ecosystem function models. The reach of the Yolo Bypass under consideration in the Comprehensive Study extends from Fremont Weir to the mouth of Cache Slough. Potential Bypass flood control measures include lengthening Fremont Weir to increase flows into Yolo Bypass, modifying Bypass levees, constructing an overflow weir connecting Yolo Bypass and the Deep Water Ship Channel, and reducing the height of some levees downstream of the Bypass.

Phase II deliverables include Comprehensive Master Plans for flood management and ecosystem restoration for the Sacramento and San Joaquin River basins. The expected completion date for this project is 2003.

Sacramento Area Flood Control Agency

SAFCA (http://www.safca.org/), a "joint powers agency" of City of Sacramento, County of Sacramento, County of Sutter, American River Flood District, and Reclamation District 1000, has been coordinating regional flood control since its creation in 1989. In addition to modifications to Yolo Bypass listed for the Comprehensive Study above, SAFCA is interested in extending the Tule Canal to Fremont Weir and restoring habitat along the Tule Canal/Toe Drain.

In March 2002, SAFCA entered into a Memorandum of Understanding with the State Reclamation Board, the Department of Water Resources, the Cities of Sacramento and West Sacramento and the Counties of Sacramento, Yolo and Sutter to form the Sacramento River Corridor Planning Forum (Forum). Membership on the Forum is open to the public. Over the next three years, the Forum's mission is to develop a Sacramento River Corridor Floodway Management Plan containing recommendations on flood management goals and policies, with guidelines for riparian habitat protection, public access and recreation, and riverfront development. The plan will also include recommendations for assessing and mitigating impacts of proposed projects. The Forum is looking at the Yolo Bypass with respect to proposals and studies to enhance the flood control system through its study area reach, which comprises the Sacramento River corridor from Fremont Weir south to the town of Courtland. Representatives from organizations and agencies working in the Yolo Bypass participate in the Forum's bi-monthly meetings, which are also open to the public.

North Delta National Wildlife Refuge

The North Delta National Wildlife Refuge, proposed by USFWS in 1998, is intended to conserve, restore and perpetuate the habitats of diverse native fish, wildlife and plants representative of the Sacramento-San Joaquin Delta ecosystem. The environmental assessment (EA) prepared considered a range of resources to protect, within geographical extents of 9,000 to 49,200 acres. The EA has not been completed, but initial review has narrowed the site to 12,300 acres on Liberty, Prospect and Little Holland Tract Islands in the southern portion of the Bypass. The habitats would likely be protected through a combination of fee title acquisition, federal land transfer, conservation and agricultural easements, cooperative agreements, memoranda of understanding and technical assistance. The need to limit or eliminate impacts to flood control, water rights, local endangered species liability, prime agricultural land base and the local tax base are persistent concerns with moving ahead with the NDNWR.

CHAPTER 2. PUBLIC OUTREACH AND AGENCY COORDINATION

Public outreach and coordination with the numerous stakeholders, including agencies, that have interests or jurisdiction in the Bypass was the first step of this project. The public outreach element entailed meetings with the Yolo Bypass Working Group to refine project objectives, identify opportunities and constraints, evaluate alternative designs and develop implementation strategies.

The Yolo Bypass Working Group is a collection of landowners, water users, and public agencies (collectively defined as "stakeholders") that have ownership of or responsibility for property and flood conveyance functions in the Bypass. The Working Group has been meeting regularly since fall 1999 to advance consensus-based development of a long-range management strategy for the Yolo Bypass. Approximately thirty stakeholders participate at each of the bimonthly Working Group meetings. While the meetings are open to any stakeholders, the inclusion of the landowners and water users is a priority.

The Yolo Basin Foundation (www.yolobasin.org) facilitated communication of the Working Group with the project team that produced this document. The Foundation's credibility with the Bypass community and other stakeholders has been an asset to this project.

In addition to the Working Group meetings, the project team convened three agency coordination meetings with representatives from state and federal agencies, including State Reclamation Board, U.S. Army Corps of Engineers (USACE), Sacramento Area Flood Control Agency (SAFCA), and California Department of Water Resources (DWR). The purpose of these meetings was to discuss constraints between habitat restoration and flooding, and to identify approaches for modeling and permitting restoration projects that could affect flood levels. Stakeholder participation throughout the project development process provided team members an opportunity to address stakeholder concerns and to obtain feedback on proposed strategies, as described below.

PROJECT TEAM PRESENTATIONS

The project team participated actively with the Working Group, presenting and learning about other members' technical information and perspectives. Through the efforts of the Yolo Basin Foundation, a consistent link has been maintained between technical restoration efforts of the project team and the stewardship, outreach and education goals of the Working Group.

Beginning in early fall 2000, the project team met to determine the most appropriate public outreach strategy. It was decided that in keeping with the existing format of the Working Group process, the initial efforts of the project team would focus on stakeholder education. Representatives from the team (Ted Sommer, Gus Yates and NHC) initiated a series of discussions at successive Working Group meetings. These educational presentations began in late fall 2000 and extended on a periodic basis through late spring of 2001.

Early educational presentations focused on ecological/biological discussions about fisheries in the Bypass with an emphasis on state and federally listed species. More specific discussions then took place regarding the ecology of delta smelt and splittail and, to a lesser extent, salmonids. These discussions included information about lifecycles, habitat requirements (refugia, food and seasonal requirements), preferred hydrologic regime and similar information.

Following these presentations, the engineering and hydrology specialists on the team led discussions on current hydrologic and hydraulic conditions in the Bypass with an emphasis on where favorable splittail and smelt habitats exist in the Bypass and the role these areas play in flood conveyance and capacity in the Bypass. Following these presentations of "baseline" conditions, subsequent presentations identified preliminary habitat enhancement ideas in the Bypass.

HABITAT OPPORTUNITIES DISCUSSED

Habitat enhancement discussions with the Working Group began with a restatement of favorable habitat conditions. The Working Group was then asked to provide feedback regarding possible locations for habitat enhancement in the Bypass. Stakeholder discussions focused on comparing shallow flooding requirements for spawning and rearing habitat, with agricultural and duck club operations. Agriculturalists identified certain windows of opportunity between the end of the flood/wet season and the beginning of field operations during which fish habitat management activities could potentially occur without impacting their operations, and duck club operators provided similar feedback.

CONCERNS IDENTIFIED

Concerns identified by the landowner/land manager stakeholders were consistent with the broader set of concerns described in the Working Group's subsequent document *A Framework for the Future: The Yolo Bypass Management Strategy,* available at www.yolobasin.org. The greatest concerns voiced by stakeholders are described below.

Presence of Special Status Species: Stakeholders expressed concern about the implications of introducing listed species on and near private lands. They feared the presence of listed species would impact their water diversion, water management and water quality as it relates to agricultural practices.

Hydraulic Impacts: Stakeholders are concerned that any new habitat projects could adversely affect the overall flood carrying capacity of the Yolo Bypass. Stakeholders identified that earthen features constructed to detain shallow floodwater could influence flood conveyance and capacity. Changes in the conveyance of floodwaters could have an adverse effect on stakeholder lands in the areas adjacent to the project by affecting their abilities to farm or hunt.

Mosquito Control: Lastly, mosquito vector control was raised as an issue. As proposed shallow flooded habitat enhancements are implemented, repeated hatchings of a variety of mosquito species would probably increase. There was concern that additional larvicides or pesticides would be needed for management, but possibly prohibited on flooded habitat created to enhance fish populations.

As a follow-up to these vector control issues, the Working Group is engaged in continuing collaborative dialogue with the Sacramento Yolo Mosquito Vector Control District. These discussions focus on the interface of district activities and land/water management for duck clubs. The goal of these discussions is to establish preliminary water use protocols to achieve mutually beneficial results for waterfowl habitat management and vector control. Actions identified in these discussions may also be applicable to future fish habitat efforts.

IDENTIFICATION OF POTENTIAL SITES

Following feedback discussions with the stakeholders, the technical team focused on identifying possible sites within the Bypass for implementing a short-term pilot restoration project. After continued meetings with the Working Group, the technical team identified the existing Yolo Bypass Wildlife Area adjacent to Putah Creek as the most logical site for habitat restoration efforts. Utilizing this site, which will be included in the Yolo Bypass Wildlife Area Expansion Management Plan currently being prepared by the Department of Fish and Game, reduces many of the issues associated with the five variables listed above.

FUTURE INVOLVEMENT OF THE YOLO BYPASS WORKING GROUP

The project team is committed to continuing its relationship with the Working Group. The Working Group is currently funded through spring 2004 by CALFED. The Yolo Basin Foundation anticipates sponsoring bimonthly general Working Group meetings over the next two years. Additional meetings will take place regarding the proposed management plan for the Yolo Bypass Wildlife Area Expansion. Future restoration efforts may also benefit from interaction at Working Group meetings to keep stakeholders informed on project goals and status.

CHAPTER 3. LONG-TERM ADAPTIVE MANAGEMENT

Public input on the adaptive management component of this project was garnered through the project team's participation in the March 2002 CALFED Adaptive Management Workshop, which led to development of a preliminary long-term adaptive management plan for the Yolo Bypass. The workshop was organized by the CALFED Science Program as a showcase for adaptive management in the region. The workshop included the CALFED Science Board, and scientists and managers from agencies throughout the state, as well as invited experts from Washington, Louisiana, Florida and Colorado. Floodplain restoration was one of three feature topics at the workshop. The workshop included a technical discussion of potential sites for restoration, including floodplains along the lower Cosumnes River, newly constructed floodplains on the Tuolumne and Merced Rivers, and floodplains in the Yolo Bypass.

The Yolo Bypass was chosen for development of a long-term adaptive management plan because it best fits the principles of adaptive management elucidated in the workshop (see below). The following Yolo Bypass adaptive management plan was prepared by project staff (Drs. Ted Sommer and Elizabeth Soderstrom) and university scientists (Drs. Peter Moyle and Jeff Mount, UC Davis), with extensive input and review by workshop participants. Because of this high degree of oversight and peer review, we believe that the adaptive management plan is robust and scientifically defensible.

Note that the plan focuses on long-term adaptive management objectives such as the acquisition of more reliable water sources for restoration; such features are beyond the scope of a short-term demonstration project like the Putah Creek project identified in Chapter 5 of this report. However, the conceptual models and other important elements of the adaptive management plan generated through this workshop were used in identifying and designing the short-term demonstration project that is the primary focus of this report.

PRINCIPLES FOR ADAPTIVE MANAGEMENT

In preparing the adaptive management plan, project staff and workshop participants relied on the following criteria for successful adaptive management identified by the CALFED Science Board.

Concepts Must be Scale-Dependent: While small-scale study systems can be a useful source of information about the basic biology of some of the target species, evaluation of floodplain restoration ultimately requires large-scale efforts to adequately address the major issues. The Yolo Bypass has the advantage of a large area (59,000 acres) with relatively long inundation periods and thus is appropriate for reducing key uncertainties associated with floodplain restoration. An added advantage is that most of the available floodplain is currently under management for habitat preservation or wetlands protection by either private organizations or federal and state agencies.

High Signal-to-Noise Ratio: Any action taken must have a sufficient signal-to-noise ratio to allow a reasonable probability that the anticipated system response can be detected. Observational studies of the Yolo Bypass have already shown statistically significant differences in the aquatic biota of river channel versus floodplain habitat. Changes in lower trophic level biomass between the inlet and outlet of the floodplain has also been detected. Therefore, we can reasonably expect that floodplain restoration projects in the Yolo Bypass should yield statistically useful data.

Implementation of Experiments Should Result in Ecosystem Restoration: A guiding principle of the proposed adaptive management approach is that the project should restore habitat in addition to increasing system understanding. The Yolo Bypass represents a vast area of floodplain, the restoration of which could yield ecosystem-level benefits.

Acceptable Risk of Structural Change: In the Yolo Bypass, floodplain restoration actions and hypothesis testing would generally require minimal structural changes and those changes made would have a high degree of reversibility. Relatively minor structural changes could easily be returned to their original state if necessary.

Actions Can Take Place at Different Scales: Projects within the Yolo Bypass could be either pilot projects or full-scale restoration projects. Due to the high degree of reversibility, actions that produce positive benefits could be easily replicated over time or expanded in their scope.

YOLO BYPASS ADAPTIVE MANAGEMENT GOALS

The restoration measures considered for the Yolo Bypass are primarily oriented toward enhancing native fish populations, especially salmon and splittail, while discouraging exotic species such as centrarchids and carp. The actions being considered will also increase Delta food web productivity and improve conditions for shorebirds and other non-target species by increasing habitat diversity, terrestrial material input, primary production and invertebrate production.

These restoration goals are embedded within an adaptive management protocol described below with the intent of reducing key uncertainties associated with restoration of floodplain habitat for native species. At the 2002 CALFED workshop, participants identified two key uncertainties that a long-term Yolo Bypass adaptive management program should be designed to address: hydrologic regime and habitat/topographic diversity.

Hydrologic Regime

Annual inundation is the principal force determining productivity and biotic interactions in river-floodplain systems (Junk et al. 1989). The Yolo Bypass adaptive management plan proposes a combination of natural flows and manipulated flows to determine the optimum frequency and duration of floodplain inundation for productivity of native fish. The Bypass presently floods in approximately 60 percent of years during winter or spring for an average of about 20 days. The adaptive management plan proposes four levels of flow augmentation based on hydrologic condition, as summarized below and in Figure 3-1:

- No flow augmentation (in "Critically Dry" water years).
- Fully controlled flow (in "Dry" and "Below-Normal" water years). All water for flooding within the project area would originate from new intake structures at

Fremont or Sacramento Weirs, or from smaller tributaries such as Putah Creek or Knights Landing Ridge Cut.

- Partially controlled flow (in "Below-Normal" and "Above-Normal" water years). The magnitude and duration of uncontrolled flood events would be extended within the project area using control structures or new intake structures.
- Uncontrolled flow (in "Wet" water years). Complete inundation of the Bypass in extreme wet years would provide a high flow reference for the other hydrologic levels.

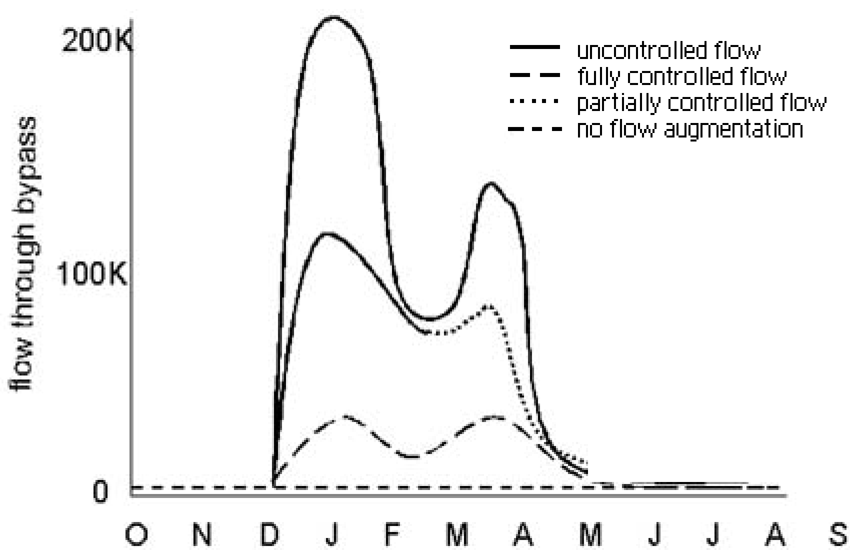


Figure 3-1. Yolo Bypass Adaptive Management Flow Augmentation

Under this proposed flow augmentation scheme, the Yolo Bypass would be flooded in January or February in all but the driest of water years. Water would be kept on the project area floodplain through mid-April with a second pulse in April to aid emigration of salmon. Water would be drained off the floodplain by early May except in extremely wet springs. The response of aquatic species would be compared for each of the hydrographs, helping to inform future actions through adaptive management.

To implement this long-term adaptive management program as designed, possible modifications to the existing Bypass system include:

- A low-flow notch in Fremont Weir allowing diversion of water from the Sacramento River (see Appendix G). This would presumably require modifications to allow fish passage through the weir during low flows. Capacity of the Tule Canal/Toe Drain might also need to be increased.

- Operational changes in the Sacramento Weir that would allow inundation of the project area in the southern Bypass without flooding the northern section. Landowner issues could be greatly simplified by this approach.
- Conservation easements or other agreements with area landowners to allow increased flow through the Tule Canal/Toe Drain.
- Alterations to Lisbon Weir to allow greater control of flooding and to improve upstream fish passage through the Tule Canal/Toe Drain.

Habitat/Topographic Diversity

Although ponds were a major feature of historical floodplains, recent surveys indicate that these habitats are often dominated by non-native species (Feyrer et al., In prep). These concerns led Sommer et al. (2001a) to hypothesize that floodplain habitats that seasonally dewater might offer greater benefits to native fish. This hypothesis is somewhat contrary to the conventional ecological thinking that increased habitat and topographic diversity is preferable for restoration. To resolve this issue, the workshop participants recommended that the adaptive management project include a mosaic of habitat types that could be compared. Habitats would range from well-drained, relatively homogenous areas (e.g., agricultural fields or grasslands) to topographically complex areas that include perennial ponds.

MONITORING AND EXPERIMENTAL STUDIES

Unlike much of the San Francisco Estuary, there is no long-term database of Yolo Bypass water quality, lower trophic levels, and fish abundance. Therefore, the first component of developing the adaptive management plan for the Bypass included collection of data to help us understand the processes that support aquatic species.

This information was then used to generate hypotheses and conceptual models on how managed flooding can enhance floodplain habitat and productivity—a necessary early step in designing an adaptive management study. The data will also provide a baseline reference for assessing and informing management activities to meet specific restoration goals.

Monitoring and Baseline Data

In 2001, DWR developed a peer-reviewed aquatic monitoring plan for the Yolo Bypass that expanded previous sampling efforts. The major field protocols, sample frequency and duration, personnel, agency coordination and locations for sampling are discussed in detail in Appendices A and B. The data collected included juvenile fish species composition and density, juvenile fish growth and survival, adult fish species diversity and abundance, and environmental conditions in the Yolo Bypass. Data are available on the Interagency Ecological Program website at www.iep.ca.gov. They were used as the basis for several analyses that were supported by this project and written up as scientific papers, attached in Appendix D.

Our monitoring effort also included collection of land use data for the Yolo Bypass. Aerial photographs were taken of the Bypass from the Fremont Weir to the Liberty Island/Holland tract during 5 flights over 4 years. DWR extracted a database of georeferenced landscape attributes from the aerial photos. Attributes are represented by ArcView shape files and include land use (e.g., irrigated fields, crops, and urban developments), ponding extent following flood events, and drainages. The aerial photographs and landscape attributes are referenced to the UTM Zone 10 NAD 27 projection, rendering the files applicable for land use planning and monitoring projects. The aerial photographs and georeferenced landscape files are described further in Appendix C and included on the accompanying CD-ROMs.

Experimental Studies

There is a shortage of data on the importance of floodplain habitat for aquatic species in drier years, when many Yolo Bypass restoration actions are proposed. In 2000–2001, DWR conducted a small-scale, single-year study to test the hypothesis that managed inundation of floodplain can be used to support splittail reproduction in dry years, when this habitat type is not readily available. Adult splittail were captured during upstream spawning migration and transferred to a model floodplain wetland at the Yolo Bypass Wildlife Area headquarters. Researchers collected data on splittail spawning success, and juvenile splittail habitat use and distribution. A detailed review of this project can be found in Appendix E.

Summary of Findings

A major finding from monitoring studies was that the Yolo Bypass appears to be particularly valuable spawning and rearing habitat for the splittail and for young Chinook salmon, which use the Bypass as a nursery area. Juvenile salmon have higher apparent growth rates in the floodplain compared to the Sacramento River, likely due to the greater availability of drift invertebrates. Data suggest the Yolo Bypass floodplain also functions as an important migration corridor for Chinook salmon and other delta fish; however, lack of fish passage to upstream spawning habitat appears to be a problem during low flow periods.

At a more general level, field studies demonstrated that the Bypass provides widespread benefits to a high diversity of aquatic species at various trophic levels. The Bypass seasonally supports 42 fish species, 15 of which are native. The system may also be an important source of organic carbon to the downstream food web of the San Francisco Estuary as a result of enhanced production of phytoplankton and detrital material. Results from the experimental study suggest that adult splittail will successfully spawn if they are provided access to floodplain habitat in dry years and that young splittail show a strong association with shallow water areas. These observations have potential implications for the design of habitat restoration projects for splittail.

Preliminary Conceptual Models and Design Hypotheses

The preliminary studies described above substantiate that intentional flooding of specific locations in the Yolo Bypass could greatly benefit native aquatic species. These studies were the basis for the following preliminary conceptual models on how managed flooding of the Yolo Bypass in drier years can be used to increase production and survival of splittail and Chinook salmon populations.

The preliminary conceptual models reflect our current level of understanding about the system, and were subsequently used to generate hypotheses for designing a large-scale floodplain inundation project. While these conceptual models were developed as part of the long-term adaptive management plan for the Yolo Bypass, they also informed the development of the short-term demonstration project described in detail in Chapter 5. Enhancement of spring staging habitat for shorebirds was a secondary goal of the demonstration project; therefore, we also include a shorebirds conceptual model in this section.

Splittail Conceptual Model

Background Information

The Sacramento splittail (*Pogonichthys macrolepidotus*), a large native minnow, was listed as threatened under the Federal Endangered Species Act in 1999. Reduced abundance levels during the 1987–1992 drought was the primary rationale for listing. Although the threatened status of splittail is presently under legal review, splittail remain a target species for CALFED actions.

The life cycle of splittail is described in detail in Sommer et al. (1997) and in the CALFED Splittail White Paper (Moyle et al., In prep). An illustration of the lifecycle is presented in Figure 3-2. Adult splittail reside in the lower parts of the Sacramento and San Joaquin Rivers, the Delta, and the Suisun Bay region. Small numbers are found in the Petaluma River and the marsh system of San Pablo Bay.

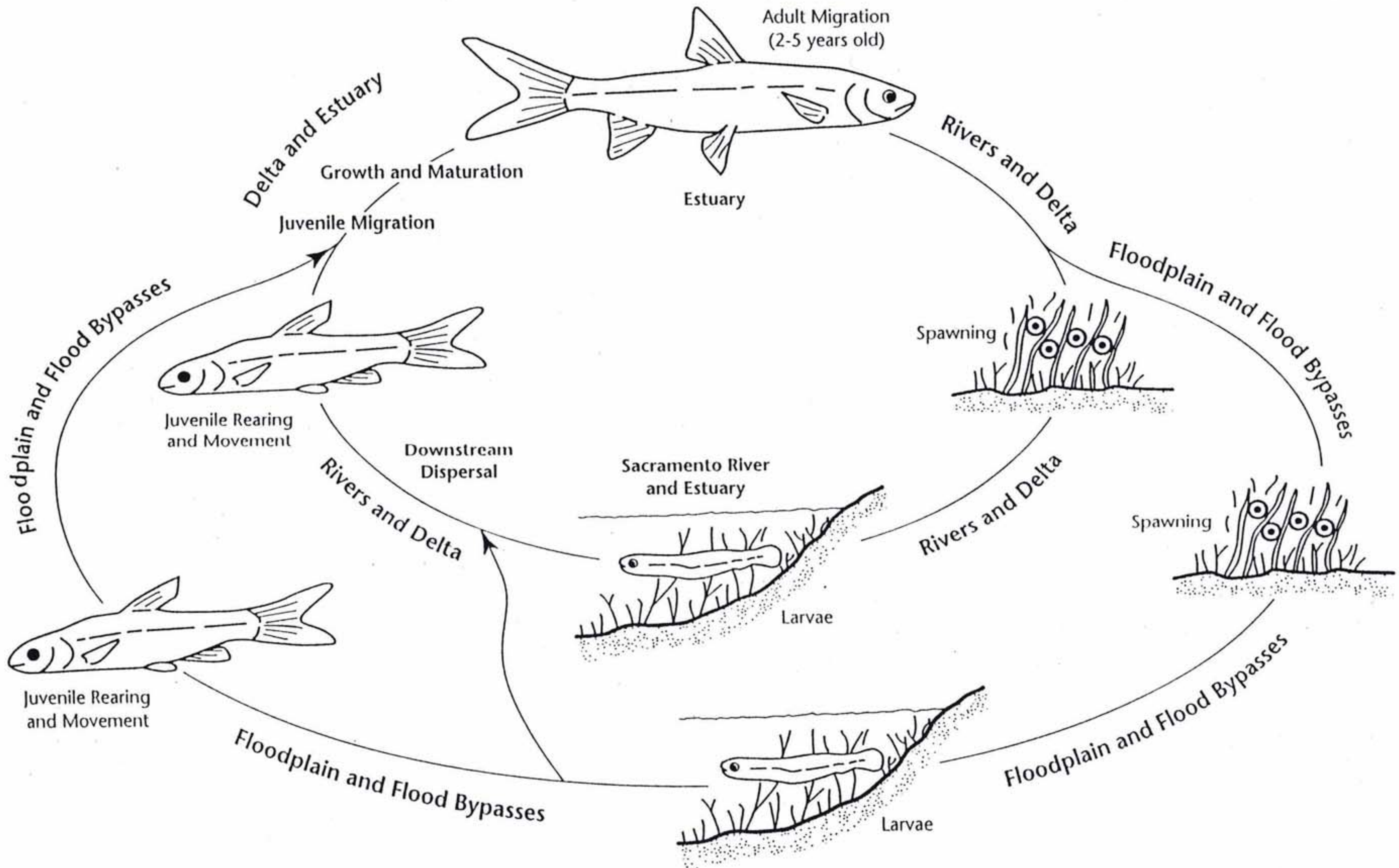
Splittail migrate upstream during the winter and spring months to forage and spawn. Small pre-spawning aggregations have been observed over submerged vegetation in inundated areas of the Yolo and Sutter Bypasses (Sommer et al. 1997). The peak spawning months appear to be February through April. Eggs are adhesive and deposited on submerged vegetation (Wang 1986). Young-of-year hatch and rear in shallow water areas. The majority of young splittail eventually move downstream to the Delta and Bays from April to August. Some year-round rearing has been observed in Delta tributaries (Randy Baxter, CDFG, unpublished data). Most splittail spend the summer and fall in the Delta and the Suisun Bay region. A few males may reach sexual maturity by the end of their first year. Females reach sexual maturity in their second and third year.

Evidence for the Importance of Floodplain Habitat to Splittail

Floodplain inundation appears to be a primary factor controlling splittail abundance (Sommer et al. 1997). Optimal spawning and rearing habitat for native fish such as splittail includes low-velocity refuges, diverse habitats, and high food supplies. The floodplains of the Yolo Bypass provide these requirements better than the main channel of the Sacramento River. Relative to the deep, channelized, rip rapped Sacramento River, Yolo Bypass floodplains provide a mosaic of low-flow habitats. The low velocity areas provide a refuge for adult and juvenile fish (Childs et al. 1998).

In addition to providing low-velocity areas, the Yolo Bypass offers diverse habitat types that attract and support a variety of species and life stages (Sommer et al. 1997; Sommer et al. 2001a; Sommer et al. 2002). For example, different life stages of splittail prefer different habitat throughout the day. Juveniles in a wetland pond preferred shallow areas with emergent vegetation during daytime, and deeper, open water with submergent vegetation during nighttime, whereas adults preferred the open water throughout the entire day (Sommer et al. 2002).

Additional benefits of floodplain rearing include the enhanced availability of invertebrate prey relative to that in adjacent river channels (Junk et al. 1989; Sommer et al. 2001b; Sommer et al.



Jones & Stokes

Figure 3-2. Sacramento Splittail Life Cycle

2001a). A 1999 study of zooplankton and dipterans (food sources for fish) identified an order of magnitude more dipterans in the Yolo Bypass than in the main channel due to high densities of chironomids. The study concluded that food resources for many native fish species were substantially better in the Yolo Bypass (Sommer et al. 2001b).

The importance of floodplain to splittail is evinced by the observations that:

1) a strong statistical relationship exists between splittail young-of-year abundance and the duration of flooding in the Yolo Bypass,
2) significantly higher densities of splittail have been sampled from the floodplain than from river channels,
3) adult splittail move onto the floodplain during high flow events, and
4) splittail were induced to spawn in a dry year by providing them access to a small-scale floodplain wetland (Sommer et al. 2002).

Observations of adult splittail migration to floodplain areas during the spawning period have been recently confirmed by DWR fyke trap sampling (Appendix D). The samples showed peaks in catch during increasing flow in the Yolo Bypass. Randy Baxter of the Department of Fish and Game also observed splittail migrating onto the floodplain of the Sutter Bypass in the winter of 1998 and 1999 (unpublished data). In addition, screw traps captured young-of-year splittail in the Yolo Bypass (DWR 1999; DWR, unpublished data) and Sutter Bypass (CDFG, unpublished data), confirming successful splittail reproduction.

Problem Statement

Perhaps the major reason that splittail abundance is reduced in dry years is that the frequency and duration of floodplain inundation is not sufficient to support high levels of foraging, spawning, and rearing. For example, Sacramento River flow must exceed approximately 56,000 cfs at Verona before the Fremont Weir spills into the Yolo Bypass, where substantial floodplain would be inundated. A related problem in dry years is that adult splittail migrate up the Toe Drain in the Yolo Bypass. Passage out of the Yolo Bypass and migration to upstream spawning habitat in other areas would be unlikely because in dry years the Sacramento River does not spill over the Fremont Weir, the primary “exit” for adult migrants at the top of the floodplain.

Project Design Hypotheses

Under our conceptual model, we propose that specific locations in the Yolo Bypass can be purposely inundated to support floodplain production of splittail in drier years. We present the following hypotheses for designing a Yolo Bypass floodplain inundation project as a tool to enhance splittail production.

<u>*Attraction Flow*</u>

- **Source:** Any source of winter flow may attract splittail into the Yolo Bypass, but water originating from the Sacramento River will be most effective.

  Rationale: Fyke trap sampling in 2000–2001 showed that modest flow pulses from Cache and Putah Creeks were sufficient to induce upstream migration of splittail. However, water originating from the Sacramento River may be more effective because the river is a major migration corridor (Sommer et al. 1997), whereas the tributaries are not known to be spawning areas for this species.

- **Magnitude of Flow Pulse:** An initial flow pulse of at least 1,000 cfs will attract spawners.

  Rationale: Approximately 1,000 cfs was the flow associated with upstream migration of splittail in the Yolo Bypass during the winter of 2000. Smaller flow pulses may attract splittail adults if associated with floodplain inundation. The 1,000 cfs pulse in 2000 remained within the Toe Drain channel and did not inundate the floodplain (Harrell and Sommer, In prep).

- **Inundation of Terrestrial Vegetation:** The initial attraction flow will be more effective if some terrestrial vegetation is inundated by the pulse.

  Rationale: Attraction of spawners by relatively small flow pulses suggests a strong olfactory cue. Terrestrial organic matter mobilized by a flow pulse may provide the cue (Moyle et al., In prep.).

- **Timing:** Upstream migration and spawning will be greatest when flow pulse is initiated in the winter months and, depending on flow availability, focused on the February–March period.

  Rationale: Peak upstream migration and spawning occurs in the winter. The peak spawning months appear to be February through April (Moyle et al, In prep).

<u>*Intentional Floodplain Inundation*</u>

- **Project Location:** Splittail migration success will be directly related to proximity of managed floodplain habitat to the Toe Drain. A project site upstream of Lisbon Weir will result in lower egg and larval mortality due to desiccation. A project site upstream of Cache Creek will lower egg and larval mortality due to mercury poisoning.

  Rationale: Proximity to the Toe Drain will facilitate filling and draining and provide the "shortest path" for splittail migration to spawning and rearing habitat. Siting the project upstream of Lisbon Weir will minimize tidal variation in stage and rapid changes in depth of water over the floodplain project site. Minimizing changes in depth over the floodplain caused by tides will minimize potential drying of spawning habitat and the subsequent mortality of egg and larval splittail. Sediments in the Yolo Bypass downstream of Cache Creek have elevated levels of mercury relative to sediments upstream of Cache Creek. Location of the project area upstream of Cache Creek could minimize mercury contamination and potential methylation during managed flooding. Low contaminant loads minimize egg mortality, larval mortality and food web effects.

- **Area:** A demonstration project area of 100 to 1,000 acres will produce a measurable change in splittail productivity.

  Rationale: The total area of shallow water habitat <6 feet deep may be as little as 600 acres in the mainstem Sacramento River between Fremont Weir and Isleton (Sommer et al., In prep). Inundation of 100 to 1,000 acres of floodplain habitat during dry years would represent a substantial increase in shallow water area, potentially causing a measurable change in splittail production.

- **Flow Distribution:** Continuous gravity flows, rather than pumping, will facilitate splittail migration on and off the floodplain.

  Rationale: Gravity flows are probably more consistent with the natural flow regimes that splittail are adapted to (Moyle et al, In prep). Moreover, pumping has the potential to entrain fish, resulting in fish mortality (Nobriga and Matica, In review), or confuse upstream adult migrants.

- **Water Depth:** A mean water depth less than 6 feet will maximize spawning success.

  Rationale: Sampling to date suggests that splittail spawning and rearing occurs in vegetated shallow water areas (Sommer et al. 2002). Water deeper than 6 feet may not provide suitable spawning conditions (Moyle et al, In prep).

- **Habitat Characteristics:** Topographic variation and a mix of vegetated and open water areas will produce greatest spawning and rearing success on a managed floodplain.

  Rationale: Sampling to date suggests that splittail spawn and rear in vegetated and shallow areas (Sommer et al. 2002). Variable topography and vegetation is desirable because we do not fully understand conditions needed for successful spawning and rearing.

- **Inundation Timing and Duration:** Inundation of at least 30 consecutive days during the February–May period will produce strongest year classes. If the duration of floodplain inundation is less than 45 days, inundation during March and April will produce stronger year classes.

  Rationale: Strong year classes of splittail are associated with at least 30 days of flooding (Sommer et al. 1997). The March–April period was the peak for splittail spawning and rearing in the Yolo Bypass during 2000–2001 (DWR, unpublished data).

- **Flow Variability:** Flow variability during initial inundation of the managed floodplain will trigger greater splittail spawning.

  Rationale: UC Davis lab studies found that flow variability triggered splittail spawning.

<u>*Controlled Drainage*</u>

- **Drainage:** To minimize juvenile stranding and splittail predation by exotic fish species, the managed area should drain to the Toe Drain; isolated ponds should be minimized when drainage is complete.

  Rationale: Efficient drainage will promote juvenile movement to the Toe Drain. Temporary ponds strand juvenile fish that eventually die or are eaten by predators as the ponds dry. Permanent ponds may promote development of exotic predatory fish communities, increasing predation on splittail and reducing the value of contiguous inundated floodplain as splittail spawning and rearing habitat.

- **Timing:** For greatest rearing success, the managed floodplain area should be drained during April–June. To minimize resource competition and predation effects from exotic species, the timing of floodplain drainage should occur after observed completion of early larval development for splittail, and before observation of significant spawning in floodplain habitat by less desirable exotics.

Rationale: April–June corresponds to the time period when large-scale movement of juveniles has been observed in screw traps and at the CVP and SWP salvage facilities. The movement may be at least partially attributable to increasing water temperature or emigration of splittail from inundated floodplain. Inundation through May or June maximizes habitat availability to juvenile splittail. Observation of a reasonably strong year class of splittail produced in 2000, however, indicates that floodplain drained as early as mid-March may produce substantial numbers of juveniles (DWR, unpublished data).

Salmon Conceptual Model

Background Information

There are four races of Chinook salmon in the Sacramento Valley: winter-, spring-, late fall- and the numerically dominant fall-run (Yoshiyama et al. 2000). Historical data indicates that all races have decreased in abundance since the 1950s, but the spring-, winter- and late fall-run have shown the most pronounced declines. There are multiple proposed causes for these long-term reductions including habitat loss, habitat degradation, water diversions, harvest and oceanic conditions.

Adult Chinook salmon migrate from the ocean to spawn in the gravels of creeks and rivers. After the fry emerge from the gravels, the young fish rear in fresh water before returning to the ocean as adults. In the Sacramento Valley, the salmon typically emerge from their gravel nests within 2 to 3 months and will spend the better part of the next 4 to 6 months rearing and migrating to the ocean. For most Chinook salmon in the valley, downstream migration occurs during winter and spring (Fisher 1994). In low flow periods, the Sacramento River and similar delta channels are the only migratory paths, but during flood pulses the Yolo Bypass floodplain provides an alternative migration corridor. Figure 3-3 illustrates the life cycle of the Chinook salmon.

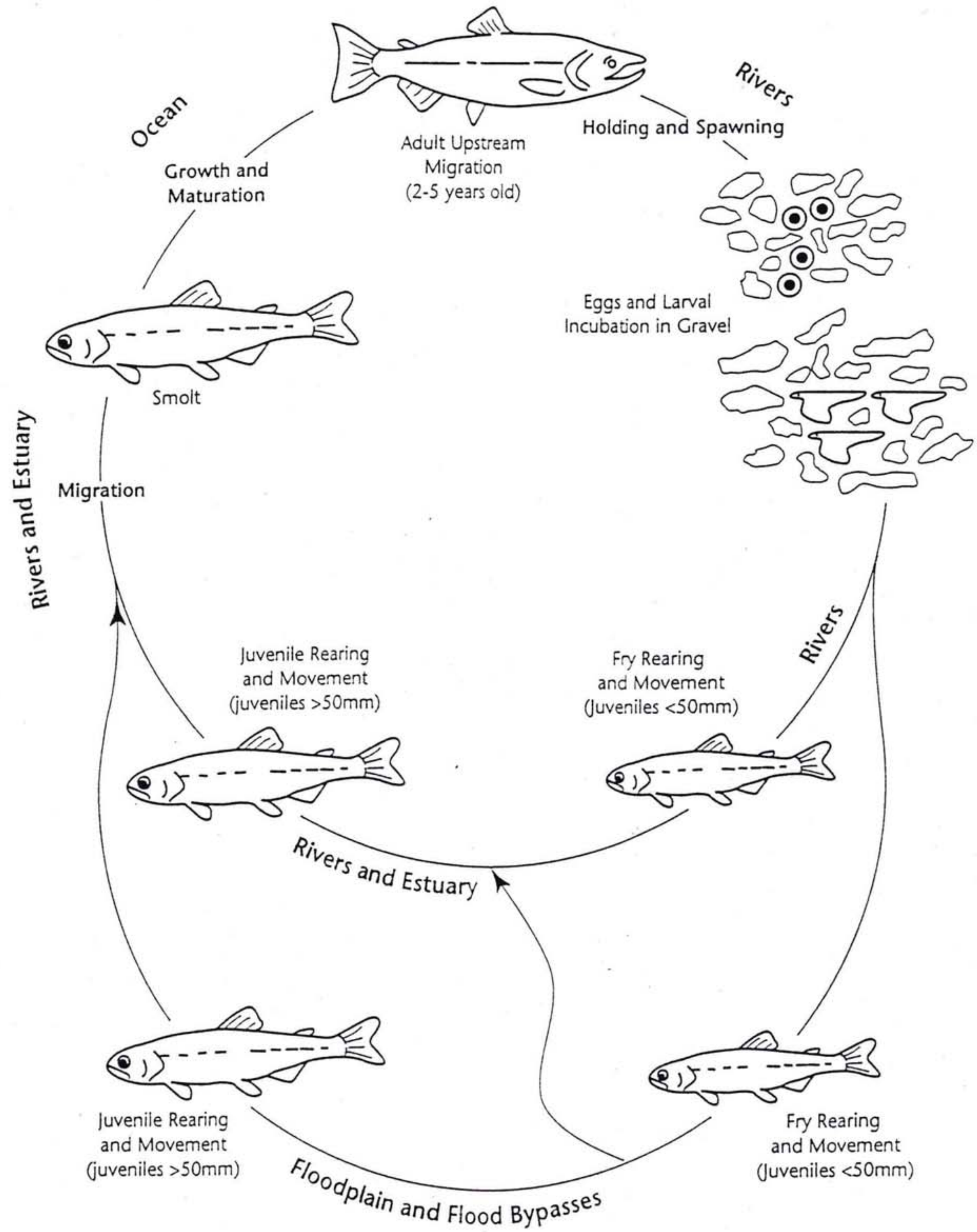
Evidence For the Importance of Floodplain Habitat to Salmon

Production and survival of Chinook salmon are enhanced in years of high flow (Jassby et al. 1995, Kjelsen et al. 1982). The specific mechanisms for this have not been established; however, the area of inundated floodplain in the Sacramento Valley increases dramatically during wet years, coinciding with increased downstream presence of juvenile Chinook salmon (Brandes and McLain 2001). The Yolo Bypass can convey more than 75 percent of the total flow from the Sacramento, Feather, and American Rivers during major flood events and is also likely to convey a significant proportion of the juvenile Chinook salmon production during these same years.

Floodplain in the Yolo Bypass has recently been demonstrated to be important habitat for juvenile Chinook salmon in the Sacramento River basin (Sommer et al. 2001b). Chinook salmon rearing on the floodplain have higher growth rates, and perhaps survival rates, than fish that migrate down the Sacramento River channel. The higher growth and survival is attributed to 1) higher densities of invertebrate prey, 2) warmer winter water temperatures, 3) larger areas of suitable rearing habitat, 4) lower diversion effects, and 5) potentially less predation.

Problem Statement

In drier years, juvenile Chinook salmon downstream of Chico Landing are confined to the heavily channelized mainstem Sacramento River, where there is minimal cover, lower food



Jones & Stokes

Figure 3-3.
Chinook Salmon Life Cycle

supply, cooler winter water temperatures, higher water velocities, possibly greater diversion risk, and potentially higher predation rates.

A related problem in dry years is that adult salmon migrate up the Toe Drain in the Yolo Bypass. Passage out of the Yolo Bypass and migration to upstream spawning areas would be unlikely when the Sacramento River does not spill over the Fremont Weir. Harrell and Sommer (In prep.; see Appendix D) documented the occurrence of spring-run, winter-run and fall-run adults in fyke trap sampling of the Toe Drain during the winter of 2000, prior to spill of Sacramento River flow over the Fremont Weir.

Project Design Hypotheses

Under our conceptual model, we propose that managed inundation of the Yolo Bypass can support rearing of juvenile Chinook salmon and migration of adult Chinook salmon. Because splittail and Chinook salmon populations evolved under the same historic valley conditions, many of the design hypotheses we presented for enhancing splittail production also hold true for Chinook salmon.

One important difference is that splittail may use Yolo Bypass floodplains for both spawning and rearing, whereas Chinook salmon may primarily use the Bypass for passage (between the Delta and upstream spawning grounds) and rearing. Therefore, for Chinook salmon, flow connection between the Bypass and upstream spawning habitat is critical for the benefits of floodplain inundation to be realized; without such connection, outmigrating young will not have access to Yolo Bypass floodplains. Below we present hypotheses for designing a Yolo Bypass floodplain inundation project as a tool to promote adult salmon migration and juvenile rearing. Similarities with those presented for splittail are emphasized.

Passage Flow

- **Source:** Water originating from the Sacramento River would most effectively facilitate upstream adult passage and provide juvenile Chinook salmon access to the floodplain.

  Rationale: The Sacramento River corridor is the major salmon producer in the region (Yoshiyama et al. 2000), so using that water source for restoration projects would benefit the largest number of fish. However, tributary flows such as Putah Creek could also benefit local salmon populations.

- **Timing:** Juvenile rearing success will be greatest when passage flow over the Fremont Weir occurs during December–April. Passage flow over the Fremont Weir will benefit adult salmon migration in all months.

  Rationale: Winter-early spring is the peak period for movement and rearing of juvenile Chinook salmon. Considering the four runs of salmon present, adult migration may occur in any month.

- **Facility Design:** Bifurcation of flow off the Sacramento River with a gradual elevation drop will best promote salmon passage through the Yolo Bypass in a range of flow conditions.

  Rationale: Ladders or other heavily engineered systems potentially impede passage and are complex to design for the range of flow conditions in the Sacramento River (Ken Bates and Chris Katopodis, consulting engineers, pers. comm.).

Intentional Floodplain Inundation

Our hypotheses for optimal project location, area, flow distribution, water depth, and habitat characteristics to benefit salmon are the same as those proposed for splittail. The rationale behind them differ slightly because Chinook salmon do not spawn in the Yolo Bypass. To give an example, our rationale for locating the project upstream of Lisbon Weir is to minimize tidal variation in stage and changes in depth that might cause juvenile stranding for salmon (as compared to egg and larval desiccation for splittail). Our hypothesis for inundation timing does differ somewhat from that presented for splittail (see below).

- **Inundation Timing and Duration:** Inundation of at least 30 consecutive days during January–March will maximize rearing success.

  Rationale: Peak migration of salmon fry occurs during January–March. Sommer et al. (2001b) observed high growth rates for juvenile Chinook salmon rearing in the Yolo Bypass floodplain for at least 30 days.

Controlled Drainage

Similar to the splittail model, we hypothesize that Chinook salmon will benefit most from drainage to the Toe Drain with no remaining isolated ponds. Our hypothesis for drainage timing, however, differs somewhat from that presented for splittail (see below).

- **Timing:** For greatest rearing success, the managed floodplain area should be drained during March–April. To minimize resource competition and predation effects from exotic species, the timing of floodplain drainage should occur after the majority of young salmon on the floodplain are smolt-sized, and before observation of significant spawning in floodplain habitat by less desirable exotics.

  Rationale: March–April corresponds to the time period when large-scale movement of smolts has been observed in screw traps and at the CVP and SWP salvage facilities. Depending on growth rates, juvenile Chinook salmon may leave inundated floodplain before the end of April. Inundation through April maximizes habitat availability to juvenile Chinook salmon (Ted Sommer, DWR, unpublished data). By late April many exotic species begin to spawn in the Delta (Moyle 2002).

Shorebirds Conceptual Model

Background Information

Located along the Pacific Flyway, California's Central Valley has been documented as one of the most important regions in western North America for both migratory and wintering shorebirds. Although long-term population data for shorebirds in the Central Valley are not available, in the past century populations have suffered extensive habitat loss. Approximately 90 percent of valley wetlands have been converted for agriculture and urban development (Page and Shuford 2000).

Shorebird populations in the Central Valley peak in spring from mid-March to mid-May, and in autumn from mid-August to early November, coinciding with migration. In the Yolo Bypass, the most common shorebirds during these periods are western sandpipers, black-bellied plovers, American avocets, long-billed curlews, least sandpipers, and dowitchers. Common winter residents include western sandpipers, least sandpipers, and dunlins. Populations of American avocets, black-necked stilts, and killdeer nest in the Bypass between April and June each year (Beedy 1993).

In the Yolo Bypass, shorebirds are primarily associated with shallow ponds, managed wetlands, mudflats (which are exposed as floodwaters recede), and flooded agricultural lands (Jones & Stokes 1993). These habitats are rich in invertebrates, which the shorebirds glean from shallow water columns and mud bottoms. At night, shorebirds roost above the tide line, in surrounding barren or sparsely vegetated areas where predators such as red foxes can be easily seen.

Evidence for the Importance of Floodplain Habitat to Shorebirds

Periods of peak abundance of shorebirds in the Yolo Bypass may be related to the availability of shallowly flooded wetlands. In 1990 and 1991, partial surveys in the Bypass recorded approximately six times as many shorebirds during fall migration than spring migration (Page et al. 1992). Habitat availability has been suggested as an important factor contributing to this disparity given that early fall flooding of seasonal wetlands by duck clubs greatly increases the acreage of wetlands and mudflats during fall migration. These wetlands are usually maintained only through the end of waterfowl season in January, reducing habitat for spring migrants during dry years.

Yearly differences in winter shorebird abundance have also been attributed to habitat availability. In January 1993, shorebird counts revealed almost 30 percent more shorebirds in the Bypass than in the previous January. A large percentage of these shorebirds were observed in the flooded rice and fallow fields of Conaway Ranch (Page et al. 1992). Increased acreage flooded by Conaway Ranch, in conjunction with natural flooding in the Bypass that year, was cited for the larger shorebird numbers.

Problem Statement

The Central Valley provides critical wintering and staging habitat for the hundreds of thousands of shorebirds that migrate along the Pacific Flyway each year. Although long-term data are not available, high levels of historical and continuing habitat loss in the valley may threaten the viability of numerous shorebird populations, particularly those such as killdeer, long-billed dowitchers, and greater yellowlegs, for which the region is considered of primary importance (Page and Shuford 2000).

Although habitat loss is the primary threat to shorebird populations, secondary concerns include poor water quality due to pesticides and other toxins, invasive exotic plants that degrade wetland habitats, and disturbance from human recreation activities (Page and Shuford 2000).

Project Design Hypotheses

As one of the largest contiguous floodplain remnants in the Bay-Delta system, the Yolo Bypass represents a unique opportunity to conserve shorebird populations in the Central Valley through managed flooding, particularly during drier years. Shorebird habitat in the Bypass can be enhanced in a variety of ways, from promoting the annual winter inundation of rice fields after harvest to redirecting natural floodwaters through large sections of the Bypass. We present the following hypotheses for designing a Yolo Bypass floodplain inundation project to benefit shorebirds.

Intentional Floodplain Inundation

- **Source:** To minimize mortality due to pesticides, major hydrologic inputs for floodplain inundation should not come from sources, such as Knights Landing Ridge Cut, with potentially high pesticide loads.

  Rationale: Agricultural pesticides are known to cause limited direct mortality of shorebirds and are believed to reduce abundance of their invertebrate prey (Page and Shuford 2000).

- **Project Location:** Shallowly inundated rice fields may afford foraging shorebirds greater protection from predators than semi-natural wetlands.

  Rationale: In a study of habitat use by shorebirds and other waterbirds in California's Central Valley, Elphick (1998) found that rice fields flooded one to five inches may provide equivalent foraging habitat to semi-natural wetlands and, because of reduced predation threat, may be safer habitat for waterbirds.

- **Water Depth:** Water depth should range from mudflats to six inches to maximize shorebird use of floodplains.

  Rationale: Shorebird habitat use is more constrained by water depth than is habitat use for waterfowl (Isola 1998). Williams (1996) found that winter densities of large shorebirds such as black-necked stilts, American avocets, and dowitchers correlated with the availability of water depths from two to six inches. Densities of the smaller sandpipers correlated with availability of water depths less than two inches. Winter studies in rice fields by Elphick and Oring (1998) similarly found that shorebirds were most abundant in median depths of one to five inches, which was lower than median water depth in most rice fields in early winter.

- **Habitat Characteristics:** Managed floodplains and wetlands with topographic variation and little or no vegetation will support the greatest diversity of shorebirds. Shorebird nesting success will increase with greater availability of open upland habitats adjacent to these wetlands.

  Rationale: Topographic complexity provides habitat for a greater diversity of shorebirds by presenting varying water depths for shorebirds of all sizes. Features such as undulating pond bottoms, gentle levee slopes, and underwater berms have been shown to enhance shorebird habitats (Page and Shuford 2000). Shorebirds are most commonly found in habitats with less than 25 percent vegetative cover (Shorebird Management Manual). Resident shorebird species, such as black-necked stilts and American avocets require nesting habitat between April and June. These species construct their nests on bare or sparsely vegetated ground, such as drier portions of receding seasonal wetlands, near wetland foraging areas.

- **Inundation Timing and Duration:** Floodplain inundation during winter months and through the month of April will significantly increase shorebird abundance in the Yolo Bypass for those periods.

  Rationale: The timing of this flooding would provide for the needs of wintering shorebird populations, spring migrants (abundance peaks in April), and early nesting populations. The provision of rich feeding grounds for spring migrants would assist shorebirds in building critical fat layers for them to reach their northern breeding grounds. Early fall flooding by duck clubs already greatly increases available habitat for fall migrants, but the lack of wetland foraging habitat in winter and spring is believed to limit Yolo Bypass shorebird populations during those periods (Page et al. 1992).

Controlled Drainage

- **Drainage:** The provision of isolated ponds through the summer season will increase shorebird nesting success.

  Rationale: Semi-permanent and permanent wetlands, such as isolated ponds, would provide foraging habitat for resident shorebirds through the summer nesting season (Page and Shuford 2000).

- **Timing:** Staggering drawdowns through the month of April will increase Yolo Bypass shorebird diversity over a longer period of time.

  Rationale: Slow (approximately 2 weeks) and staggered drawdowns of water would provide mudflats and fields with varying water depths over a longer period of time, to benefit a greater diversity of shorebirds, which arrive in staggered, overlapping groups according to the timing and distribution of their migrations (Page and Shuford 2000). Abundance of spring shorebird migrants peaks in April.

Summary of Project Design Hypotheses

The hypotheses generated from these preliminary conceptual models provide guidelines for designing a long-term adaptive management study in the Yolo Bypass to benefit splittail, Chinook salmon, and shorebird populations. The hypotheses are based on our current understanding of how floodplain functions influence various stages in the life history of these species.

There are many notable similarities in how floodplain inundation can be managed to increase production and survival of splittail and Chinook salmon. It may be difficult, however, to design a project that will simultaneously and significantly enhance shorebird populations. The greatest discrepancy is that shorebirds forage in much shallower waters (up to 6 inches) than ideal for splittail and salmon (typically 1 to 6 feet). Nevertheless, shorebirds will derive some benefit from a floodplain inundation project designed for fish. Shorebirds will be able to utilize shallower parts of the managed floodplain, and more frequent inundation of the Bypass may increase density of the shorebirds' invertebrate prey. In addition, many projects specifically targeting shorebird recovery (e.g., post-harvest inundation of rice fields) can be implemented in the Yolo Bypass with little or no conflict with concurrent splittail and salmon recovery efforts.

The primary goal of the Yolo Bypass long-term adaptive management plan, as identified in the CALFED Adaptive Management Workshop, is to enhance native fish populations, especially salmon and splittail. Based on the preliminary conceptual models presented above, the following managed inundation design characteristics are most likely to increase production and survival of these two species in the Yolo Bypass:

- Source of hydrologic input—Sacramento River, over the Fremont Weir
- Facility design—bifurcation of flow off the Sacramento River with a gradual elevation drop

- Initial flow pulse—a target level of up to 1,000 cfs in January, with inundation of some terrestrial vegetation
- Period of flow—January through April (especially February/March)
- Project location—near the Toe Drain
- Project area—100 to 1,000 acres inundated
- Period of inundation—minimum 30 days, January through April (especially March)
- Flow variability—yes, during initial inundation
- Flow distribution—continuous gravity flow
- Inundation depth—average less than 6 feet
- Habitat characteristics—topographic variation, mix of vegetated and open waters
- Drainage—drainage to Toe Drain in April

NEXT STEPS

Design. A more detailed and comprehensive conceptual model for the Yolo Bypass is needed that articulates the uncertainties associated with the system in relation to a range of management actions. The conceptual model should also identify more fully a suite of testable hypotheses about ecological responses to the restoration program. We expect that many of the design criteria discussed in Chapters 4 and 5 of this report will be incorporated.

Coordination. Coordination is needed between the Yolo Bypass adaptive management program and other efforts to develop the region for habitat restoration and flood control. The project must continue to maintain close contact with groups such as USACE, CDFG, USFWS and the Working Group.

Implementation. Major steps for project implementation will include preparing environmental documentation and obtaining necessary permits and approval. The legal and regulatory issues associated with various proposed long- and short-term restoration strategies are discussed in detail in Chapter 6. Other tasks will include securing funds for construction, selecting contractors, and overseeing project activities.

Monitoring and Evaluation. Adaptive management relies upon a science-driven, sustainable research, monitoring, and evaluation plan. Monitoring elements described in this chapter provide a good foundation for this work. Additional elements will likely be added as a result of collaborative efforts. Project partners should develop a detailed evaluation procedure for peer review prior to incorporation into the adaptive management plan. The ultimate plan is expected to include establishment of a close linkage between the Yolo Bypass and Cosumnes restoration projects, likely through the UC Davis Center for Watershed Science.

PROPOSED ADAPTIVE MANAGEMENT PARTNERS

The California Department of Fish and Game (CDFG) is the lead agency for the development of the Yolo Bypass Wildlife Area and will provide oversight for restoration efforts in the Yolo Bypass on CDFG land. Since 2000, DWR, the Yolo Basin Foundation, and NHI have been developing some of the aquatic restoration concepts for a long-term adaptive management program for the Yolo Bypass. These activities and their products were described in this chapter and are detailed in associated report appendices. USFWS is also presently developing plans for a refuge that would include the southern portion of the Yolo Bypass. We therefore propose that these groups, in conjunction with CALFED staff, continue to form the core of a long-term project planning effort.

DWR has staff funds for planning-level work on the Yolo Bypass through the CALFED Ecosystem Restoration Program; however, additional resources may be needed for the other partners. The major avenue for stakeholder input will be the Working Group, funded by CALFED since 2000. Both U.S. Army Corps of Engineers and Sacramento Area Flood Control Agency are presently working on flood management plans that include the Yolo Bypass. Thus, both agencies should also be closely involved in a long-term adaptive management effort for the Bypass.

Research and monitoring would continue to be coordinated by DWR personnel, which has been collecting Yolo Bypass data since the mid-1990s (see below). As in previous years, this work would be conducted in partnership with U.S. Geological Survey, USFWS, UC Davis, and CDFG. A major recommendation of the workshop participants was that the partnership with UC Davis should be expanded to include better coordination with the university's Cosumnes River floodplain restoration investigations. As a result, this project may eventually be associated with the UC Davis Center for Watershed Science.

CHAPTER 4. SITE SCREENING

A major focus of the Yolo Bypass project was to evaluate prospective sites for a demonstration-scale floodplain restoration project. Suitable water for inundation, site topography and availability, and the opportunity to improve fish passage and hydrologic connectivity are the major demonstration project considerations. Each of these three requirements is evaluated below. In this analysis, vertical elevations above sea level are referenced. Historically, three different datums have been used for elevation measurements. The applicable datum is indicated wherever elevations are mentioned, and a datum conversion table is provided in Appendix F.

Combinations of water source and site characteristics are evaluated in Chapter 4, and the most favorable alternative is developed further in Chapter 5.The most feasible alternative appears to be inundating a floodplain along the South Fork of Putah Creek with water from the creek. Compared to other alternatives, this project has relatively few complications, and could be rapidly implemented for a demonstration and pilot study. Modifying Fremont Weir or Sacramento Weir to obtain a more reliable source of water for floodplain restoration is also an attractive alternative; however, substantial technical and stakeholder concerns make this a less suitable option for a pilot-scale project.

SUITABILITY OF WATER SOURCES

The lack of water for inundation and fish passage in dry years is a major constraint to floodplain habitat restoration. The potential water sources can be grouped into three categories: the Sacramento River, the west side Yolo Bypass tributaries, and tidal inflow from the Delta. Only a few of these sources appear adequate to supply a floodplain inundation project.

Sacramento River

Water from the Sacramento River offers three distinct advantages over water from any of the other sources. First, flow passing from the river through the Fremont or Sacramento Weirs would provide a migration pathway for anadromous fish. Presently, the Yolo Bypass is a dead-end for fish that migrate upstream during periods when the weirs are not overtopped, because the weirs are not passable. Fish trapped in the resulting cul-de-sac likely fail to reproduce for lack of suitable spawning habitat within the Bypass, although some species such as salmon may still be able to reproduce in Putah Creek. In the case of sturgeon, the weirs may be impassable even when overtopped.

The second reason that Sacramento River water may be successfully used as a water source is that environmental water may be available through the Central Valley Project Improvement Act (CVPIA) and CALFED's Environmental Water Account (EWA). These programs presently allocate water for environmental needs with emphasis on listed species such as Chinook salmon, delta smelt, splittail and steelhead trout. A major advantage of using a portion of this water for fish habitat in the Yolo Bypass is that there would be little consumptive use in the floodplain, so the water would still be available for downstream environmental (or other) uses. Flows in the Sacramento River at Fremont Weir are mostly already allocated or consist of carefully managed reservoir releases destined for existing users, especially in normal and dry years. Some of the water is destined for the western part of the Delta to maintain fisheries and manage salinity, and that water could arrive equally well via the Tule Canal and Toe Drain as via the Sacramento River channel. Flows remaining in the river would in most cases be more than ample to meet the needs of local diverters, wastewater dilution, and exports routed through the Delta Cross Channel. Consumptive losses of water to seepage and evaporation along the Tule Canal/Toe Drain would be slightly higher than if the water remained in the river channel, but probably not by more than a few tens of cubic feet per second.

The third advantage of the Sacramento River as a source of flow for inundation is the reliability of its flows compared to those in the west side Yolo Bypass tributaries during the splittail spawning and juvenile rearing season. To quantify and illustrate this difference, the variability of daily flows in the Sacramento River and the west side tributaries from February 15 to May 15 of each year was evaluated. Details of the calculations and the results for all of the waterways are presented in Appendix F.

Figure 4-1 shows graphs of two normalized variability measures for predevelopment flows in the Sacramento River. Predevelopment flows are the natural flow regime to which native fishes are adapted. Data for the gage near Red Bluff during water years 1903–1934 (upstream of the flood bypass system and prior to the construction of Shasta Dam) were selected to represent this condition. The upper graph shows that the ratio of the standard deviation of daily flows to the average flow is small and fairly constant—between 0.3 and 1.0—indicating relatively steady flow conditions. The 10 years of normalized daily flows in the lower graph show some storm-related upward spikes during February and March, but daily flows never fall below 50 percent of the average. The present-day flow regime in the Sacramento River at Verona (near the upstream end of the Yolo Bypass) is only slightly less variable than the predevelopment flow regime, making it fairly ideal as a source of water for floodplain habitat restoration.

The physical availability of Sacramento River water via a notch in the Fremont Weir depends on the bottom elevation of the notch and connecting channels. For example, the design concept described in Appendix G involves a notch with a low-flow invert elevation of 13 feet (NGVD 1929). River stage exceeds this elevation about 65 percent of the time during February–May when all years are averaged. Even during the 1987–1992 drought, the median monthly stage exceeded 13 feet in 1–2 months during the February–May spawning season in every year.

Using the hypothetical weir notch design described in Appendix G as an example, flows through the notch would be less than 100 cfs when river stage is between 13 and 18 feet (NGVD 1929). This stage range corresponds to a Sacramento River flow range of 13,000–23,000 cfs, which means less than 1 percent of the river's flow would be rerouted down the Yolo Bypass. The hypothetical notch widens above an elevation of 16 feet, and flow through the notch would increase to approximately 3,000 cfs at a river stage of 29 feet. This stage corresponds to a river flow of 54,000 cfs and is also the elevation at which water begins spilling over the entire length of Fremont Weir. Thus, at most 5 percent of the river's flow would be diverted through the notch. Alternative designs could be formulated to decrease the maximum flow rate through the notch, but careful consideration would be needed of velocities through the notch to allow upstream fish passage. The maximum design flow rate through the notch also needs to consider increased frequency of inundation along the Tule Canal/Toe Drain. All of these legal,

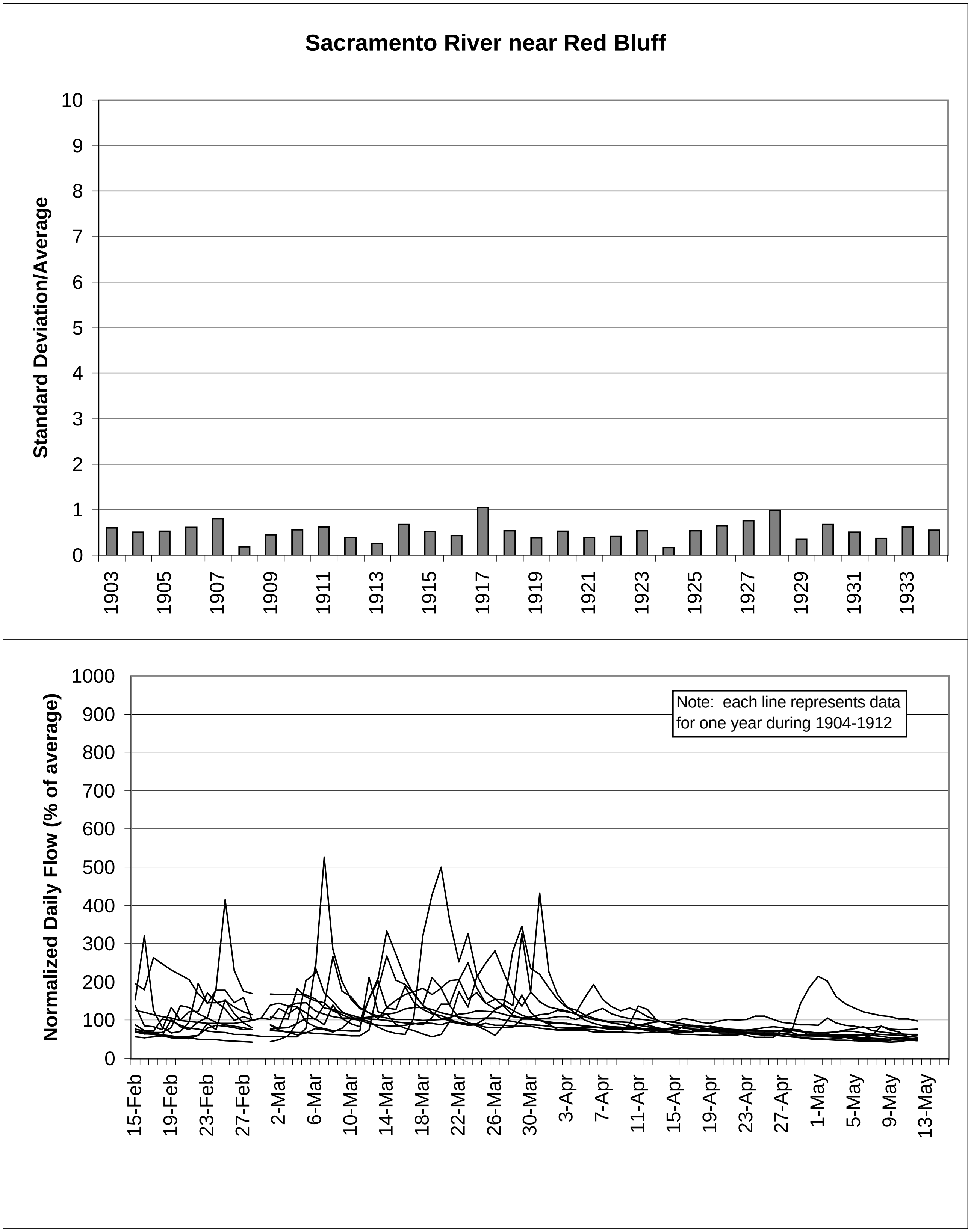


Figure 4-1. Variability of Pre-Shasta Daily Flows in the Sacramento River during the Splittail Spawning/Rearing Season

institutional and operational issues appear to be solvable, but working through the details would require a significant effort for operations modeling, hydraulics modeling and negotiations with landowners, water rights holders and water projects operators. Such an effort was beyond the scope of the present project.

Yolo Bypass Tributaries

The flow regimes of the tributaries along the west side of the Yolo Bypass are all considerably more variable than the flow regime of the Sacramento River. Knights Landing Ridge Cut has the greatest variability, as shown in Figure 4-2. Both of the variability measures show extremely high values. In this case, the high degree of variability is largely attributable to the operation of the gated outflow structure at the lower end of the Colusa Basin Drain near Knights Landing. The structure normally passes the Colusa Basin Drain flow into the Sacramento River but shunts it into the Ridge Cut when river stage is high, resulting in large erratic flow fluctuations in the Ridge Cut.

Flow variability in the other west side Yolo Bypass tributaries is intermediate between the Sacramento River and Knights Landing Ridge Cut (see Appendix F). However, all of the tributary streams typically have periods when flow drops to zero in late winter and spring. These large fluctuations could adversely affect the reproductive success of splittail and rearing conditions for juvenile salmon, especially since their target window is February 15 to May 15.

Putah Creek has the most stable flow regime of all of the tributaries, as illustrated by the flow variability graphs in Figure 4-3. A unique characteristic of the Putah Creek flow regime is the regular occurrence of sustained moderate flows released from Putah Diversion Dam pursuant to terms and conditions in the Solano Project's water rights (described in Chapters 5 and 6). The sustained flows are not large but are steadier and more reliable than moderate flows in the other west side Yolo Bypass tributaries. The instream flow criteria are reduced in dry years, which are expected to occur approximately 1 year in 4 on average. However, dry years in this case are defined by reservoir storage in Lake Berryessa and would tend to coincide with climatologically dry years only toward the end of a prolonged drought. The relatively high availability of flow in spring combined with the availability of public land managed for habitat purposes along the creek channel prompted a more in-depth investigation of Putah Creek as a potential site for a floodplain restoration project (see "Prospective Floodplain Inundation Sites" below).

Tidal Water

Toward the southern end of the Yolo Bypass (from approximately Lisbon Weir to the tip of Liberty Island) water levels in the Toe Drain and other channels are influenced by tides. During new and full moons, the tidal range at the Lisbon Gage just south of the Lisbon Weir is typically 0.5 to 4.5 feet above sea level (NGVD 1929). Some lands adjacent to the Toe Drain would be inundated by tides if they were not isolated by levees. However, diurnal tidal inundation creates a different habitat than seasonal inundation by floodwaters; there is good evidence that seasonal inundation is particularly valuable for native fishes such as splittail and juvenile salmon (Sommer et al. 2001a), but no comparable evidence that tidally inundated habitat offers special advantages.

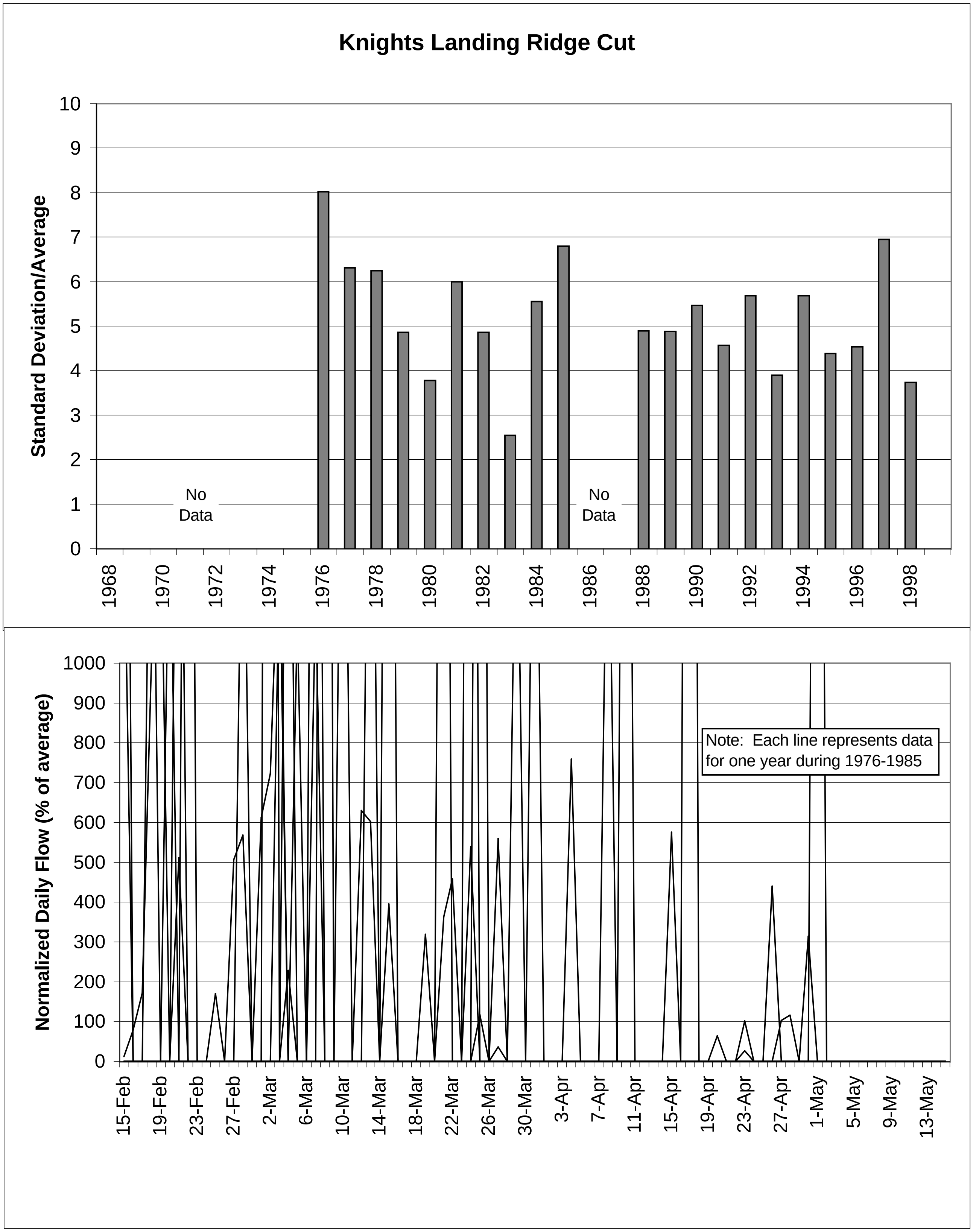


Figure 4-2. Variability of Daily Flows Entering the Yolo Bypass from Knights Landing Ridge Cut during the Splittail Spawning/Rearing Season

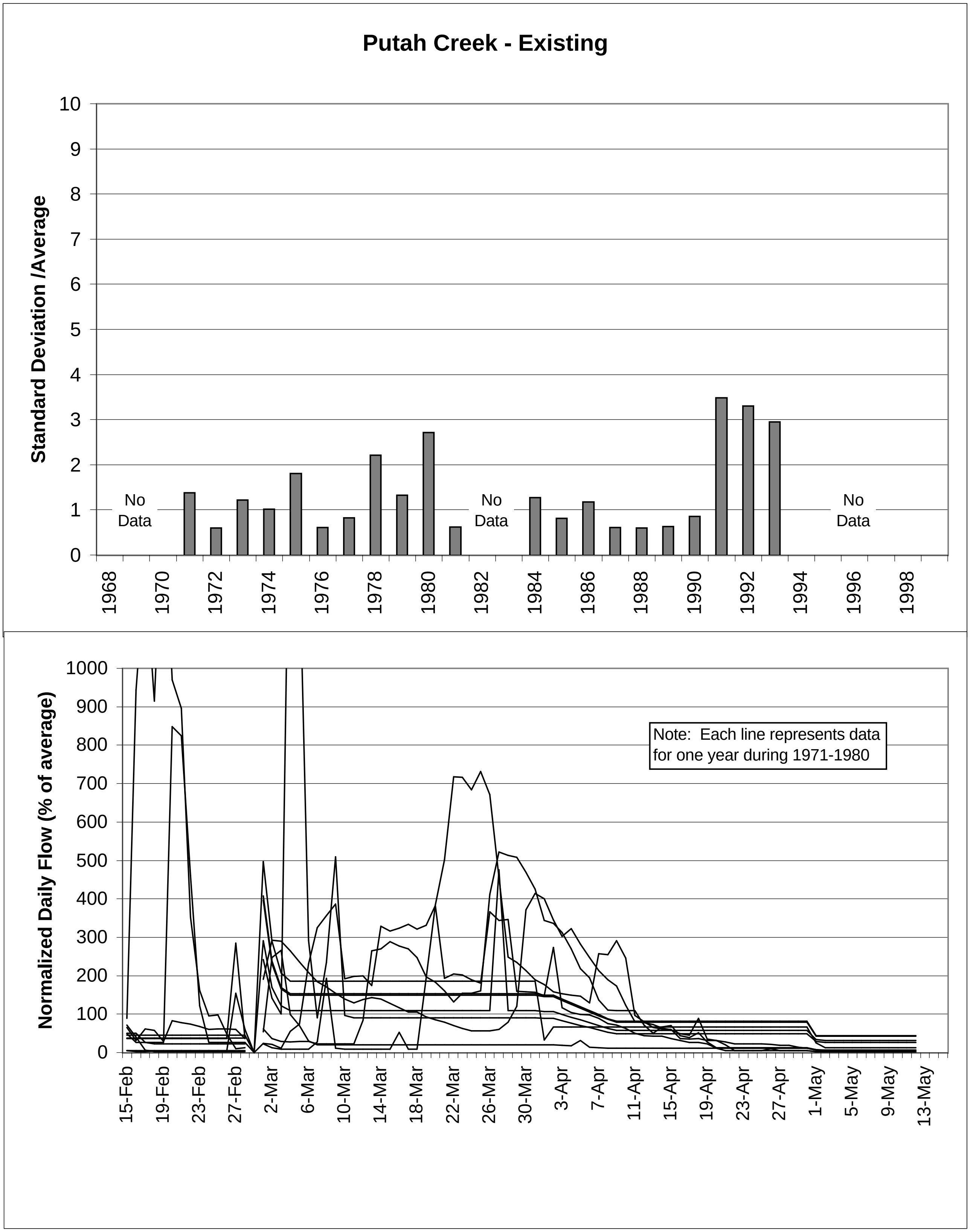


Figure 4-3. Expected Variability of Existing Putah Creek Flows during the Splittail Spawning/Rearing Season, Pursuant to Settlement Agreement

Tidal water could be used to prolong seasonal inundation on a leveed floodplain cell adjacent to the Toe Drain. With water control structures similar to the flap-gates of Lisbon Weir, one-way gravity flow of tidal water through the cell could be achieved. This flow would be intermittent (pulses possible at 12-hour intervals). Structures would need to be designed to allow fish passage and maintain function for agricultural diversions.

Water Quality

Water quality is another factor potentially affecting the suitability of source waters for floodplain habitat restoration. The Sacramento River has the freshest water (specific conductance of 80–150 µS/cm compared to 200–1,000 µS/cm for the other waterways) and has comparably low levels of pesticide residues. Cache Creek water would be of concern because of the large amount of mercury in the watershed. Some of the highest concentrations of mercury in fish tissue ever recorded in California were in fish in the Cache Creek watershed. Mercury does not appear to adversely affect fish, but it is toxic to birds and mammals that eat the fish. Sampling of fish and invertebrate tissue in existing floodplain habitat areas along lower Cache Creek (such as the Moore Wildlife Sanctuary, Cache Creek Nature Preserve at Road 94b, or the Cache Creek Settling Basin) might be warranted prior to construction of a floodplain restoration project in the Yolo Bypass reach of the creek (i.e., below the Settling Basin). The quality of Putah Creek water is also generally good. Specific conductance has a very wide range (200–800 μS/cm) at low flows but does not exceed 400 μS/cm when flow is more than about 1,000 cfs. Because the land next to the channel slopes away from the creek along most of lower Putah Creek, relatively little agricultural runoff enters the creek. Sampling for priority pollutants in recent years has not revealed problematic levels of agricultural chemicals.

Summary of Alternative Water Sources

The most suitable water sources for floodplain habitat restoration were identified based on an overall consideration of the availability of water in dry years, the variability of flow during the spawning/rearing season, and water quality. The most suitable sources appear to be:

- Sacramento River water routed through the Fremont Weir into the Tule Canal for inundation along the Tule Canal/Toe Drain,
- Sacramento River water routed through the Sacramento Weir into the Tule Canal for inundation along the Tule Canal/Toe Drain, and
- Putah Creek water for inundation along the existing channel or a new channel alignment.

SITE SUITABILITY

Site Criteria

The entire length of the Yolo Bypass was evaluated for potential project sites. Site suitability was determined based on the potential to meet the following goals at a site:

- Enhance the protection and restoration of native fish and wildlife habitat, especially for listed species.

- For fish passage projects, create unrestricted year-round passage.
- Work with existing topography and structures as much as possible so that the project is reversible.
- Give preference to floodplain locations that are immediately adjacent to the waterway supplying them.
- Minimize obstructions to fish movement between the channel and the floodplain.
- Avoid or minimize impacts on agricultural and other land uses in and near the Bypass.
- Minimize impacts on operations for waterfowl habitat.
- Avoid infringement on property or water rights.
- Avoid or minimize adverse impacts on water quality.
- Maintain the flood conveyance capacity of the Yolo Bypass.
- Avoid obstructing navigational waterways.
- Maximize the amount of habitat benefit achieved relative to the construction cost.
- Minimize ongoing operating costs by using gravity flow and passive operation wherever feasible.
- Manage mosquitoes and other pests in coordination with the mosquito abatement district and other local agencies.

The above water source suitability analysis narrowed sites to those that could be readily inundated from the two most suitable water sources, the Sacramento River and Putah Creek.

Prospective Floodplain Inundation Sites along the Tule Canal/Toe Drain

When the Sacramento River spills across Fremont Weir or Sacramento Weir, flow typically concentrates in the Tule Canal/Toe Drain along the eastern edge of the Bypass. A two-step topographic screening analysis was completed to identify feasible inundation sites along the Tule Canal/Toe Drain. The first step was to identify and map the first agricultural field berm or upland west of the channel. Because the terrain in the Bypass is flat, these features could bound a planned inundation area, with little or no modification to limit the extent of inundation. The second step in the topographic screening process was to generate profiles along the length of the Tule Canal/Toe Drain indicating the elevation and width of the adjoining floodplain strip.

Raised features to the west of the channel are generally discernible on USGS 7.5-minute quadrangle maps and on the 1,000-foot-interval cross-sections USACE used to construct the UNET flood hydraulics model for the Comprehensive Study. In the few areas where the appropriate western limit of potential inundation was not obvious, judgment was exercised. The strip of land between the Tule Canal/Toe Drain and the first berm or upland to the west is shown on Figure 4-4. The Sacramento Bypass and a parcel immediately south of it are also low enough to be included in the floodplain project. The total area of the potential floodplain strip along the west side of the Tule Canal/Toe Drain (excluding Liberty Island and Little Holland Tract) is 11,400 acres. The area of the Sacramento Bypass and adjoining parcel to the south is 890 acres.

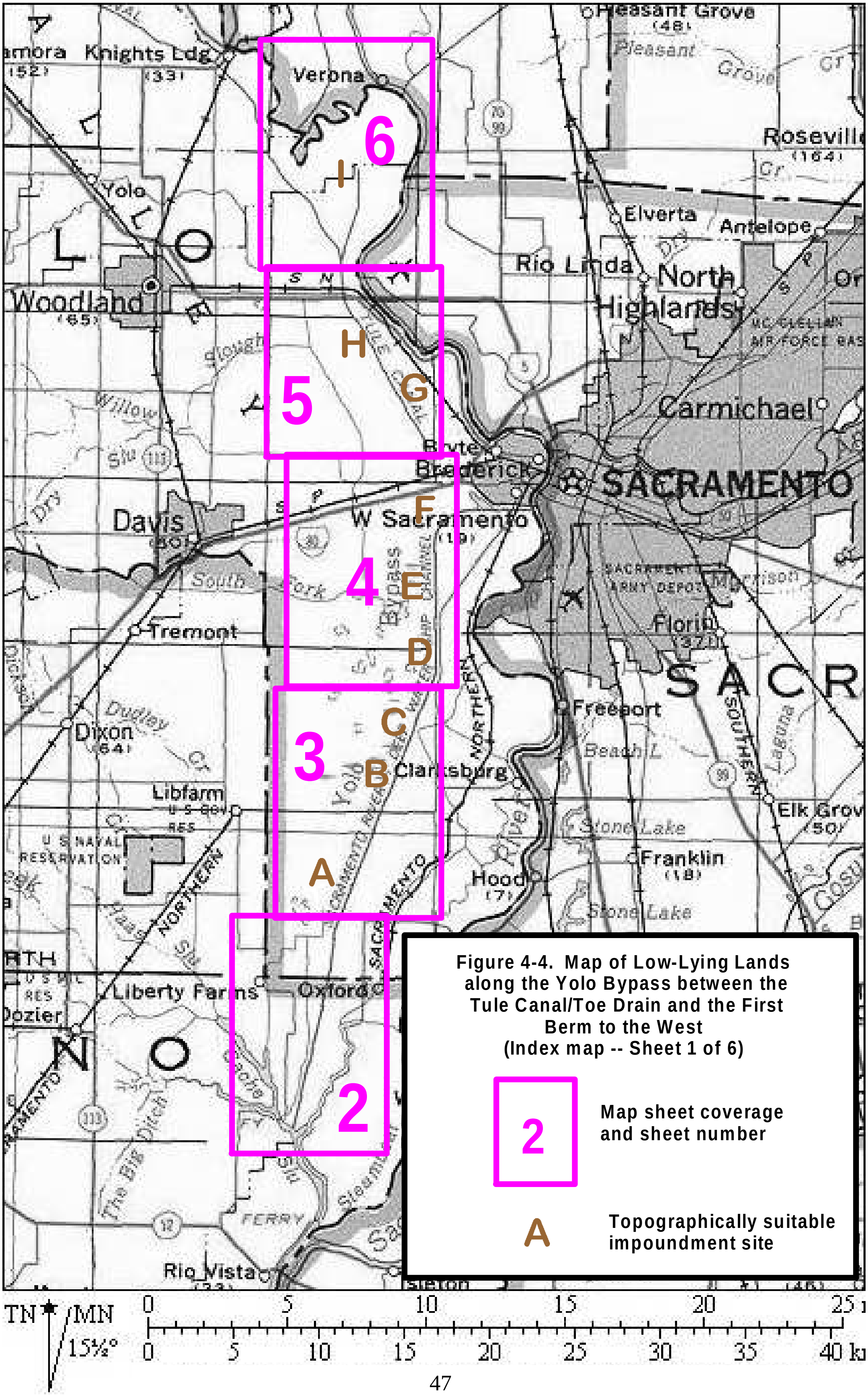
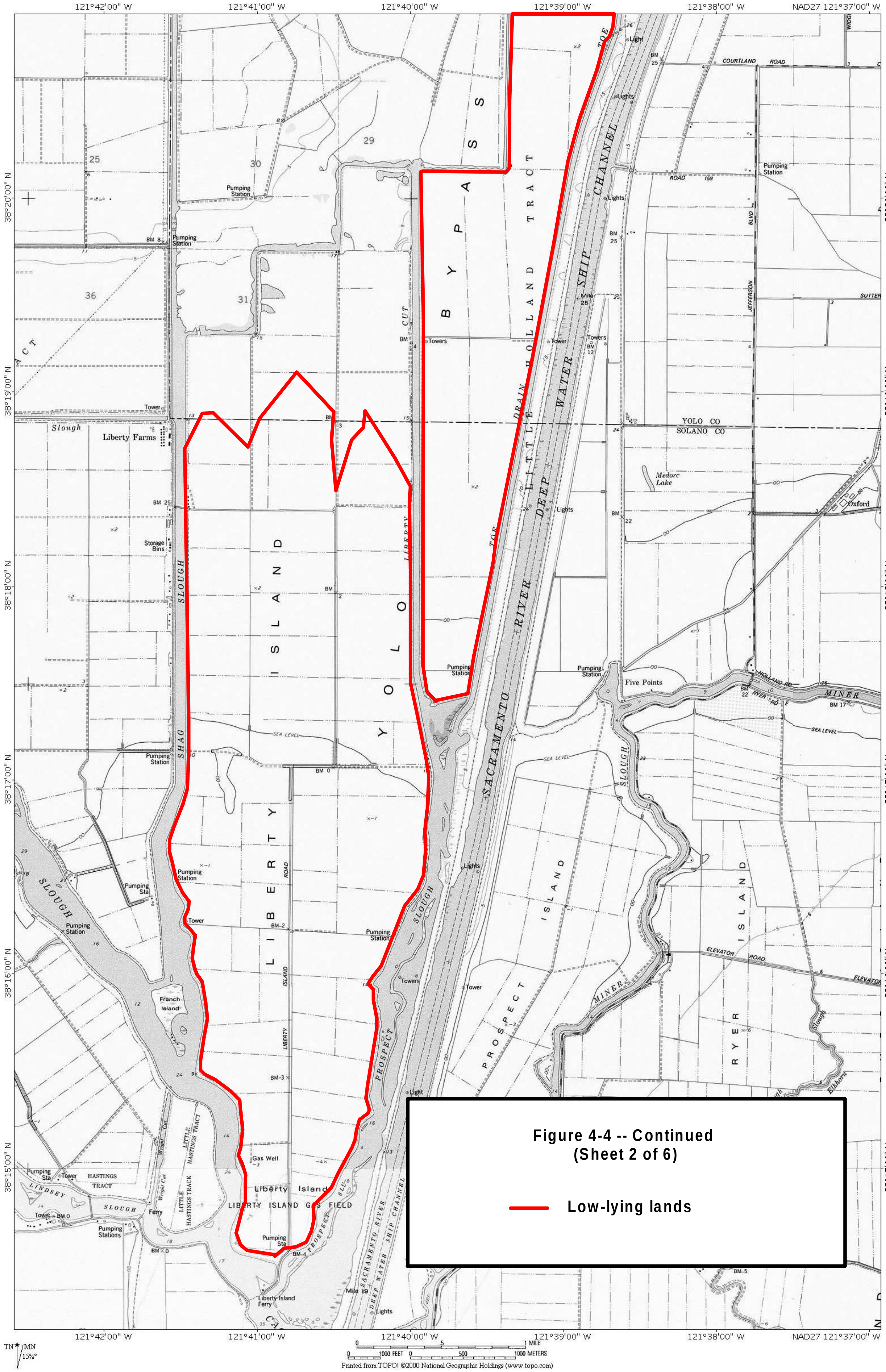


Figure 4-4. Map of Low-Lying Lands along the Yolo Bypass between the Tule Canal/Toe Drain and the First Berm to the West (Index map -- Sheet 1 of 6)



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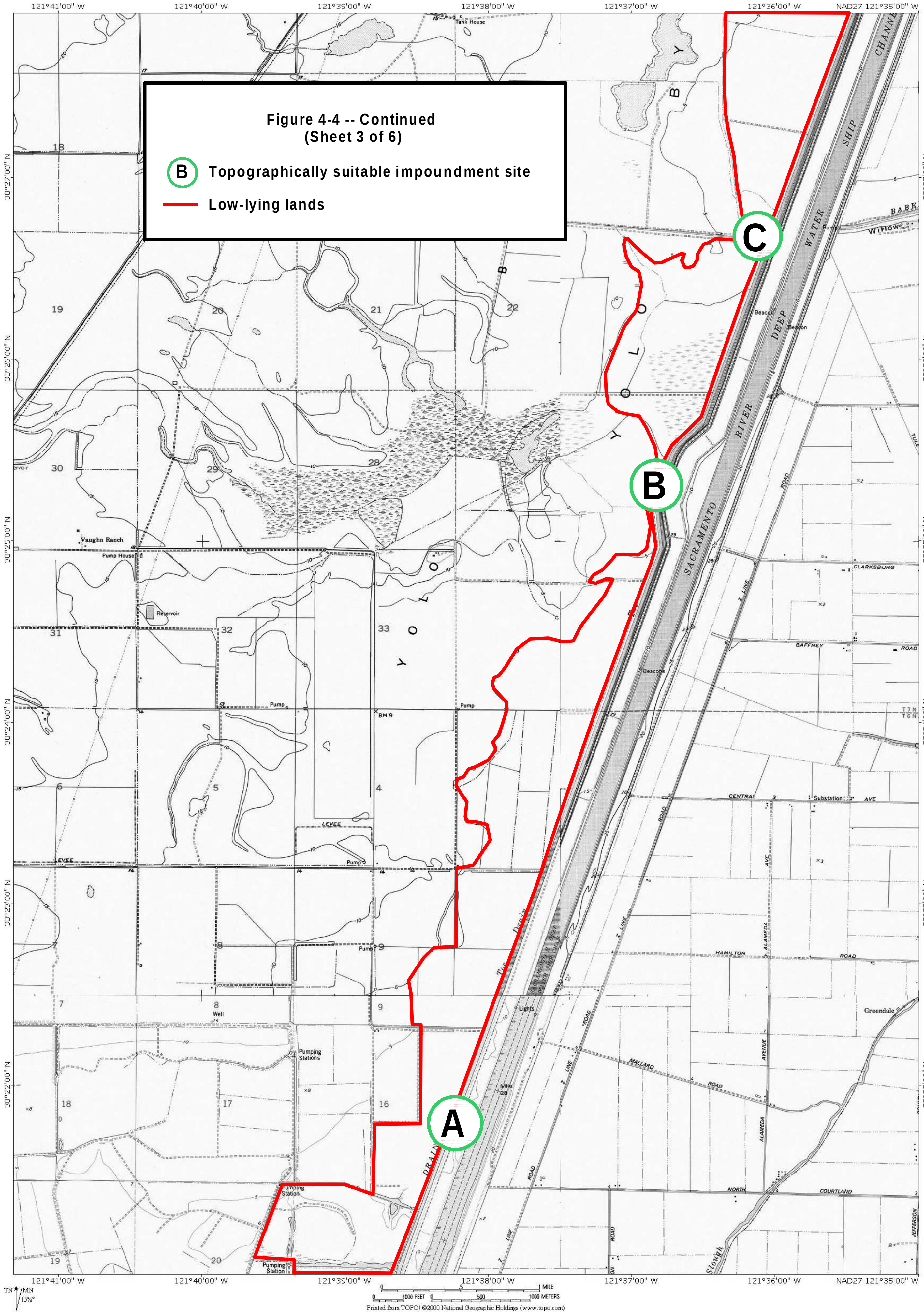
Figure 4-4 -- Continued
(Sheet 3 of 6)
B Topographically suitable impoundment site
Low-lying lands
A
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C
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121°38'00" W
121°37'00" W
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NAD27 121°35'00" W
38°27'00" N
38°26'00" N
38°25'00" N
38°24'00" N
38°23'00" N
38°22'00" N
SACRAMENTO RIVER DEEP WATER SHIP CHANNEL
YOLO BYPASS
Tank House
Vaughn Ranch
Pump House
Reservoir
Pump
BM 9
LEVEE
Beacon
Beacons
Lights
Pumping Stations
Pumping Station
Well
Mile 28
Toe Drain
CLARKSBURG
GAFFNEY ROAD
CENTRAL AVE
Substation
HAMILTON ROAD
ALAMEDA AVE
MALLARD ROAD
NORTH COURTLAND
Greendale
Willow
Z LINE ROAD
Slough
JEFFERSON
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1 MILE
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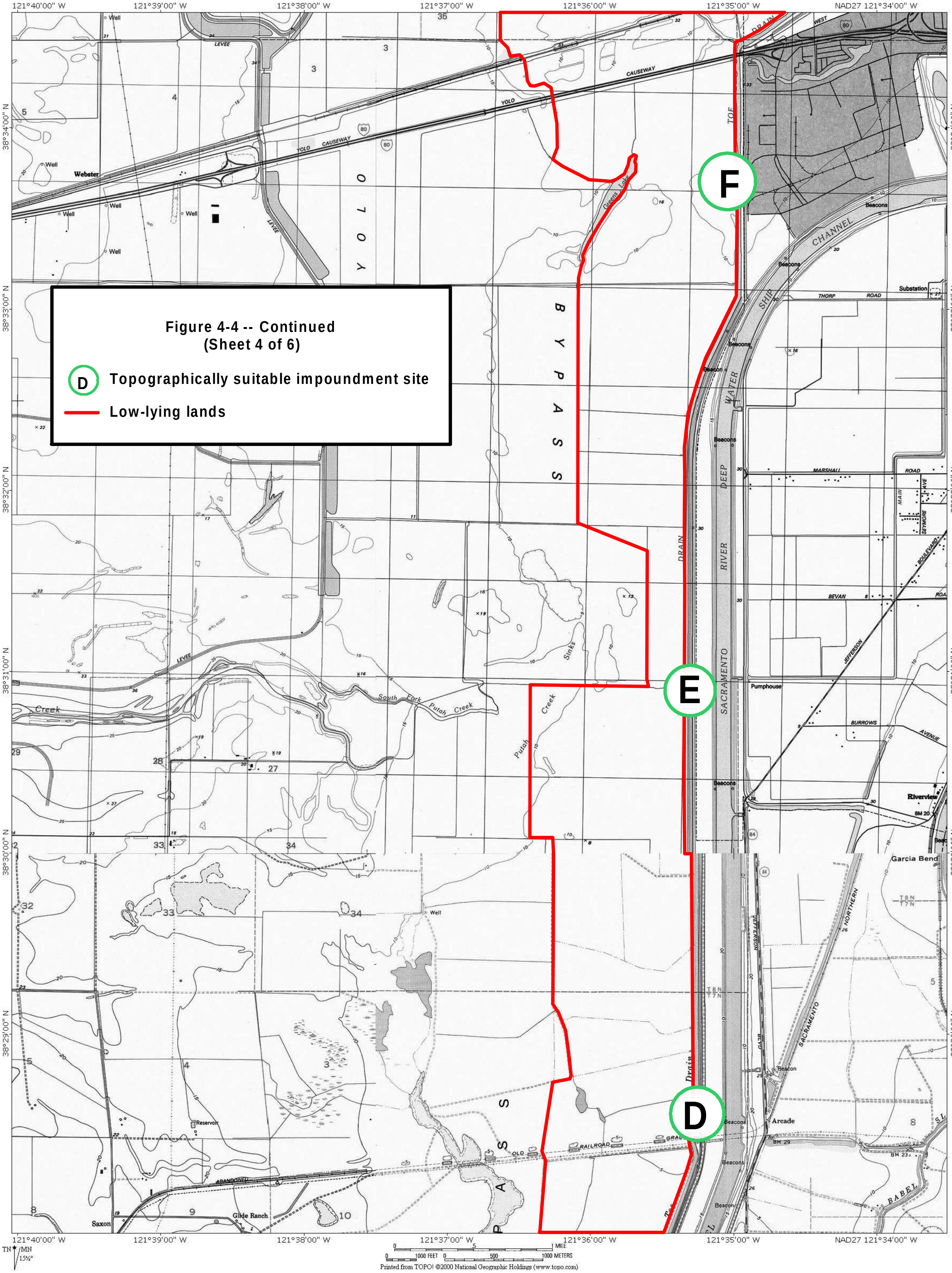
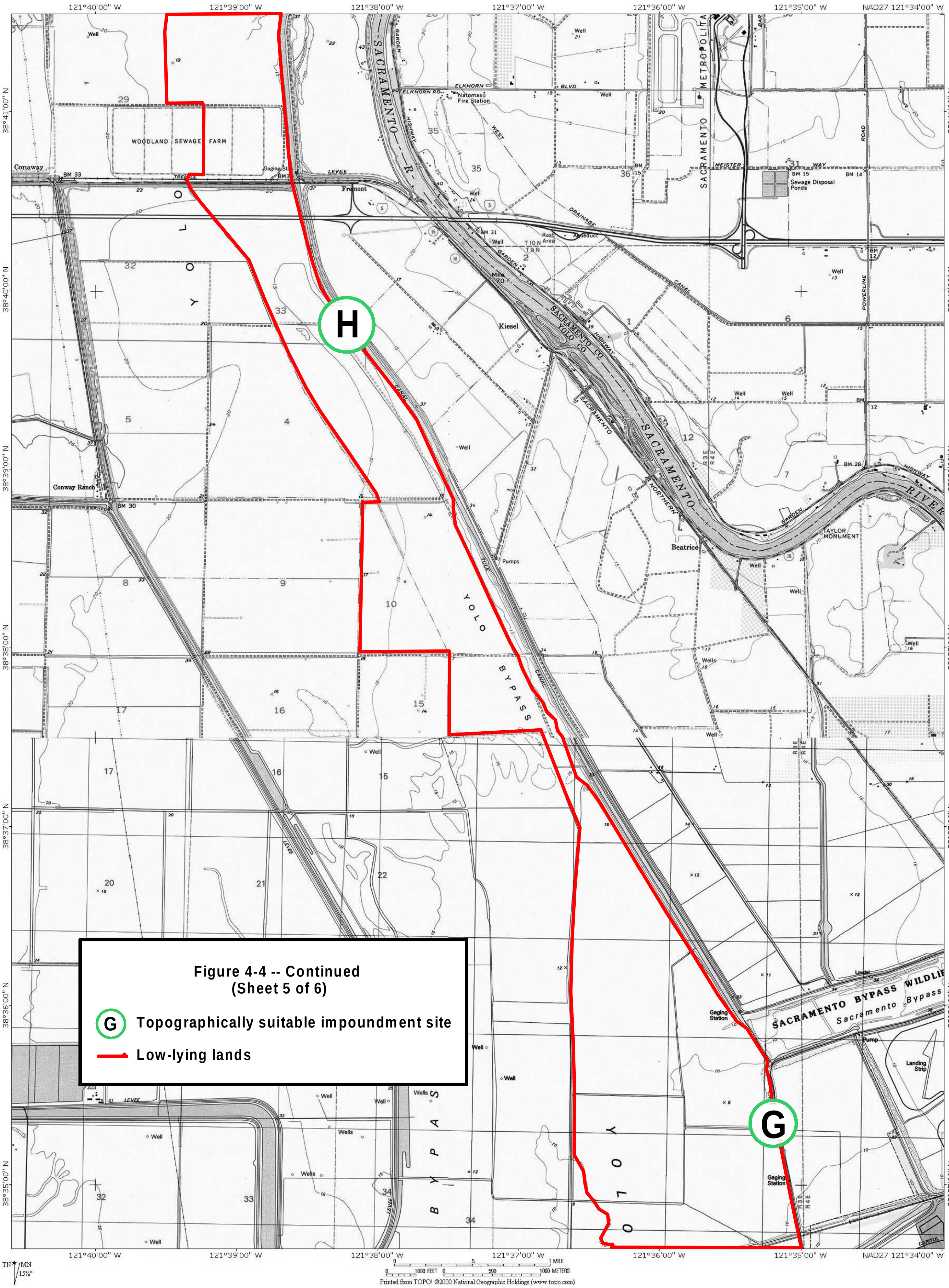


Figure 4-4 -- Continued
(Sheet 4 of 6)



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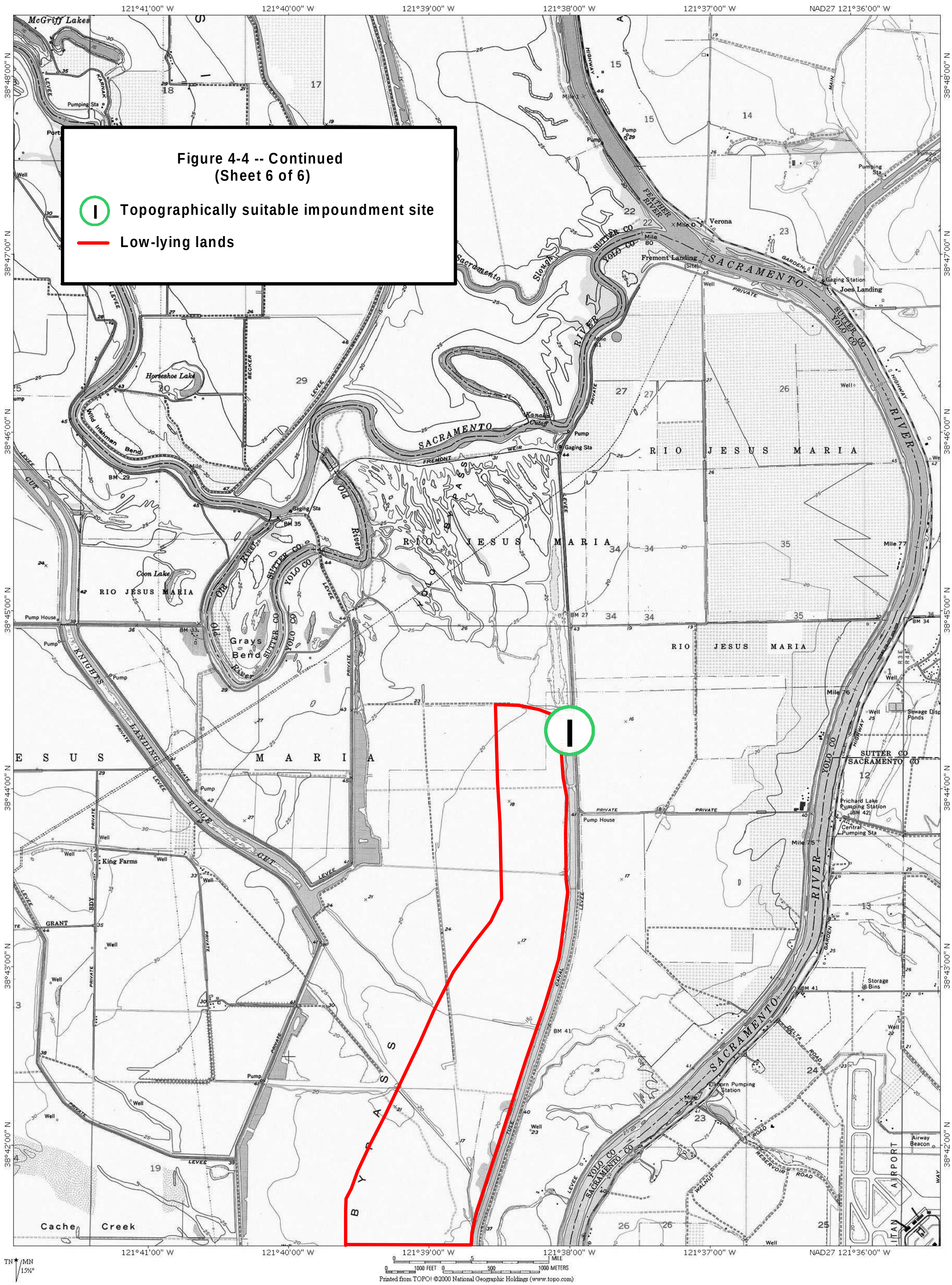
Figure 4-4 -- Continued
(Sheet 6 of 6)
I Topographically suitable impoundment site
Low-lying lands
121°41'00" W
121°40'00" W
121°39'00" W
121°38'00" W
121°37'00" W
NAD27 121°36'00" W
38°48'00" N
38°47'00" N
38°46'00" N
38°45'00" N
38°44'00" N
38°43'00" N
38°42'00" N
McGriff Lakes
SACRAMENTO
RIVER
FEATHER RIVER
Verona
Fremont Landing
Joes Landing
Horseshoe Lake
Wild Irishman Bend
Coon Lake
Grays Bend
RIO JESUS MARIA
FREMONT WEIR
KNIGHTS LANDING RIDGE CUT
King Farms
Cache Creek
YOLO BYPASS
TULE CANAL
SUTTER CO
YOLO CO
SACRAMENTO CO
Prichard Lake Pumping Station
Elkhorn Pumping Station
AIRPORT
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Profiles of the potential floodplain along the length of the Tule Canal/Toe Drain are shown in Figure 4-5. Nine locations were identified where local high spots along the length of the floodplain strip would facilitate water impoundment. The profiles show the elevation of the west side floodplain adjacent to the Tule Canal/Toe Drain, the elevation at the first berm west of the Tule Canal/Toe Drain, the width of the west side floodplain strip, and the low-flow water surface elevation in the channel. In the vicinity of the Sacramento Bypass, the elevations and width of the east side floodplain are included. The width of the floodplain strip in this area is reasonably large.

Potential impoundment locations are labeled A through I on the map and profiles (Figures 4-4 and 4-5). Sites A, B and C are in the tidal zone downstream of Lisbon Weir and consequently are not as desirable as the upstream sites for seasonal inundation projects; tides could make water management more complicated. Sites D, E and F would all inundate substantial floodplain width. The land adjacent to site D is within the Yolo Bypass Wildlife Area, but some of it is already managed for permanent rather than seasonal wetlands. Some of the west side floodplain upstream of site F (and upstream of I-80) has already been converted to wetlands. Site G is promising because it would inundate the western part of the Sacramento Bypass, which is already in public ownership, naturally vegetated, and only slightly higher than the water surface elevation in the Tule Canal. Finally, site I near the northern end of the Tule Canal would not encompass a large area, but the ground elevation is only slightly higher than the water surface elevation in the Tule Canal.

The floodplain width above site H is relatively narrow, but it includes a strip of land along the west side of the Tule Canal that is particularly promising because it is not farmed and its elevation is not much higher than the low-flow water surface in the Tule Canal. The site is an approximately 1,200-foot-wide strip of land about 2 miles long, beginning about 0.5 mile downstream of the Interstate 5 (I-5) causeway and ending 2 miles upstream of the Sacramento Bypass. The site is separated from the agricultural fields to the west by a large berm constructed in October 1962 in an attempt to protect crops during an exceptionally early-season flood. Accordingly, it is referred to in this report as the "1962 flood strip". The strip is separated from the Tule Canal by a small berm (Figure 4-6).

The basic design concept would be similar for most of the potential sites along the Tule Canal/Toe Drain, and site H is described here in moderate detail to illustrate the concept. The shallow berm between the strip and the Tule Canal would be removed at the upstream and downstream ends of the site, creating a shallow channel parallel to the Tule Canal during high water months, similar to a natural floodplain.

On the basis of several cross sections along site H surveyed for the USACE's Comprehensive Study UNET model and inspection of conditions at the site, it does not appear that the site is usually inundated for at least four consecutive weeks in the late winter and early spring. Increased and prolonged inundation of the floodplain strip could be achieved by increasing the flow in the Tule Canal or by constructing an adjustable weir just downstream of the site inlet. The weir height could be adjusted to achieve the desired depth and duration of inundation along the floodplain. Fish migrating up or down the Tule Canal could probably travel via the floodplain strip. If water depths are too shallow there, however, it might be necessary to provide a fish ladder at the weir whenever the weir is in operation. Additional details regarding the design concept are provided in Appendix H.

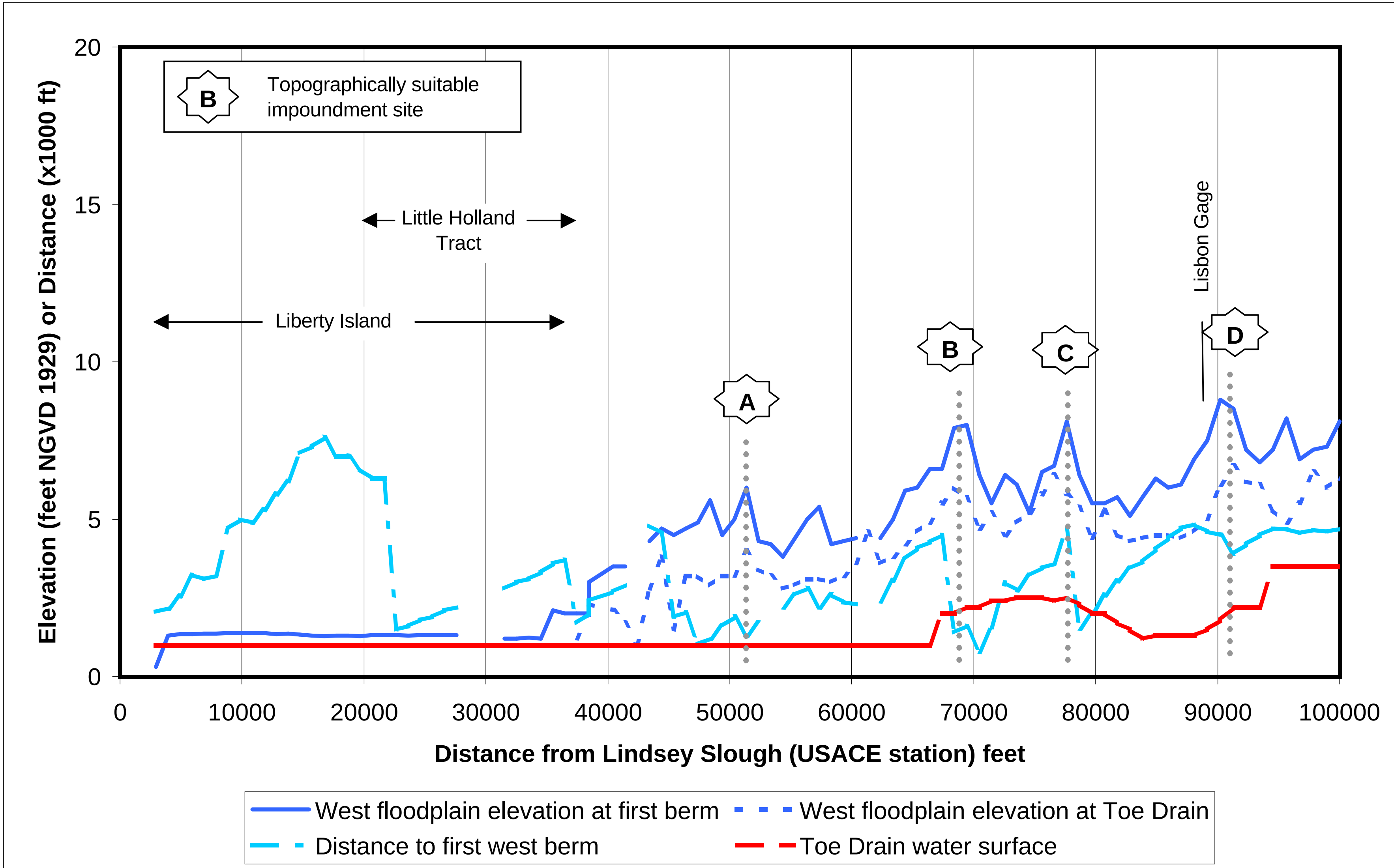


Figure 4-5. Longitudinal Profiles of Floodplain Elevation and Inundatable Width along the Tule Canal and Toe Drain

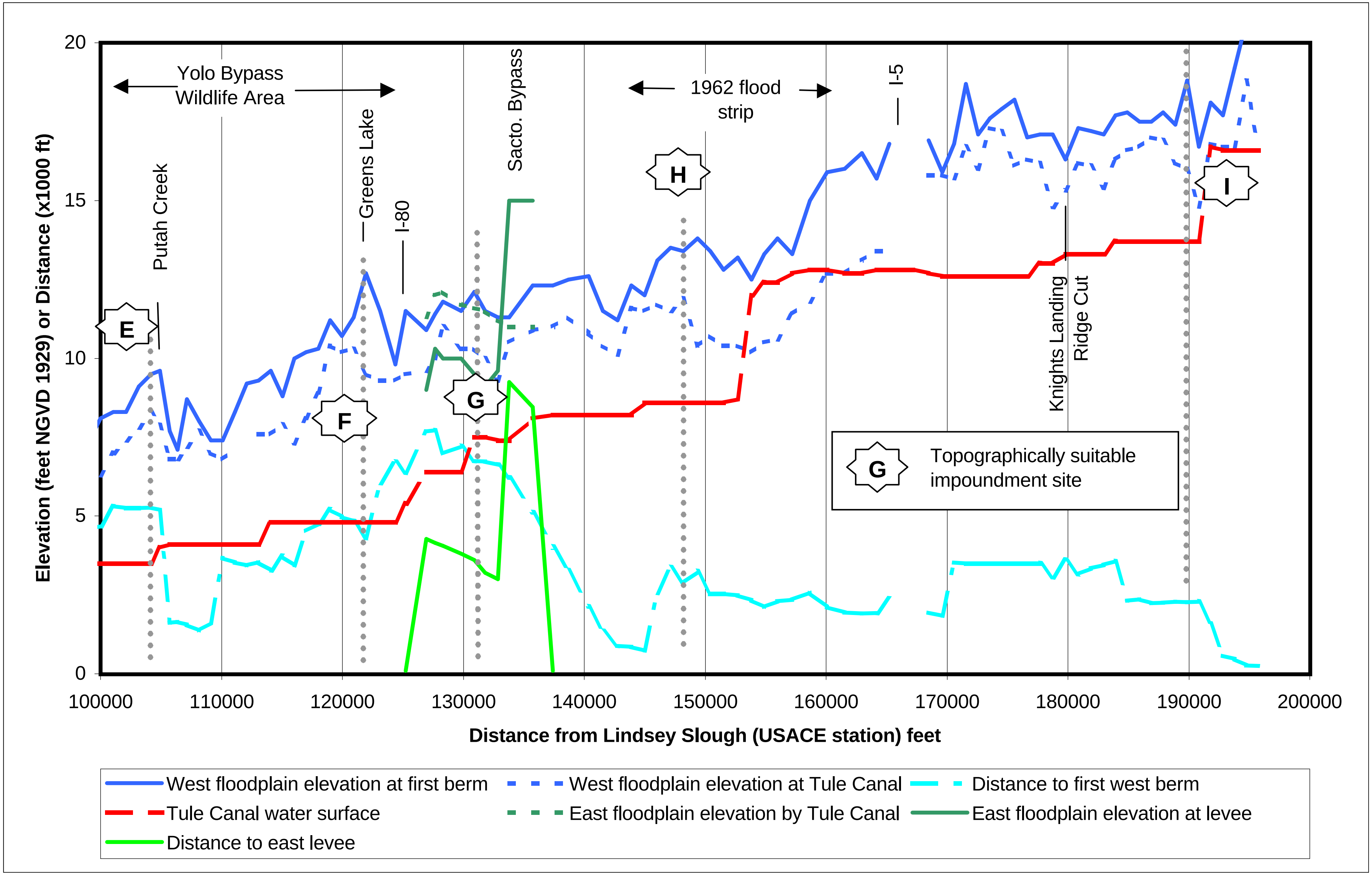


Figure 4-5 -- Continued

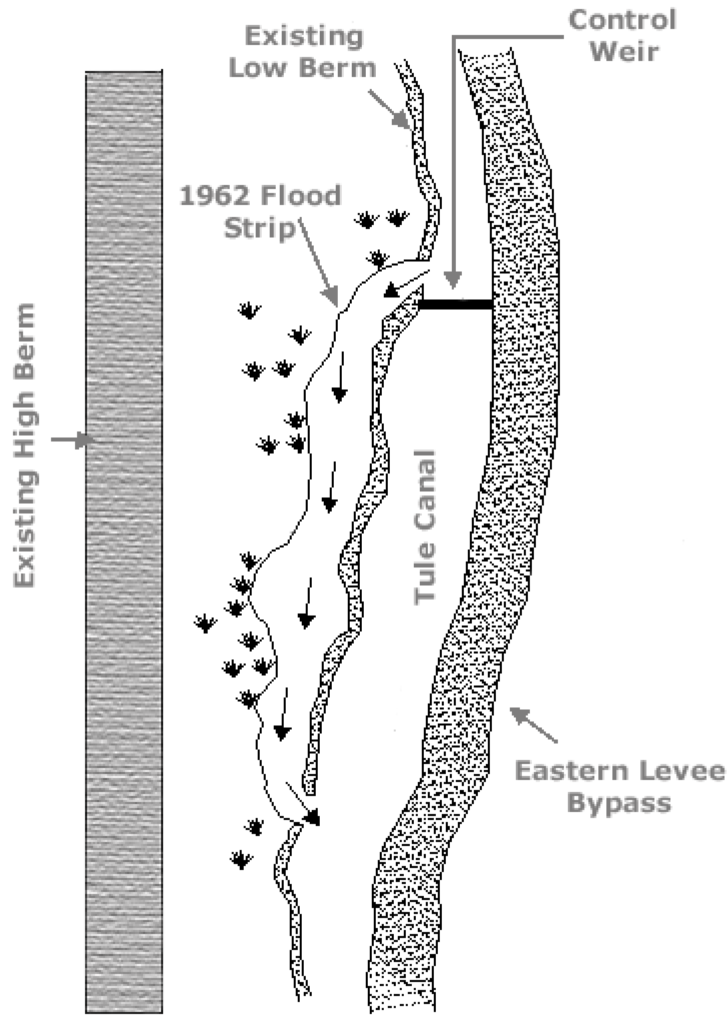


Figure 4-6. Schematic of 1962 Flood Strip Site Concept

Prospective Floodplain Inundation Sites along Putah Creek

The South Fork of Putah Creek crosses the Yolo Bypass approximately 4 miles south of I-80. Lowlands along the creek are particularly promising for floodplain habitat restoration because: 1) sustained moderate flows occur in spring in most years, 2) an existing adjustable check dam could potentially be reoperated to facilitate inundation, and 3) land along both sides of the creek is part of the Yolo Bypass Wildlife Area. The California Department of Fish and Game (CDFG) is in the process of designing a management plan for the wildlife area, and is amenable to the inclusion of seasonal inundation of appropriate portions of the wildlife area. At this site, Los Rios Farms and CDFG jointly operate a check dam to raise water levels for irrigation. The creek is channelized straight east from the check dam, for about 1 mile to the Toe Drain. The terrain south of the present channel includes areas of natural topography and marshes. If the creek were realigned to flow southeast and pass through some of these features on the way to the Toe Drain, the topography along the new alignment would be highly suitable for floodplain restoration.

Figures showing the present alignment of Putah Creek and potential locations for floodplain restoration along the existing channel or a realigned channel are provided in Chapter 5, where those opportunities are discussed in detail.

OPPORTUNITY TO IMPROVE FISH PASSAGE AND HYDROLOGIC CONNECTIVITY

Opportunities to improve fish passage and hydrologic connectivity exist at each of the three best locations of flow introduction, Fremont Weir, Sacramento Weir, and the check dam on the South Fork of Putah Creek. Fremont Weir is a better site than Sacramento Weir to pass Sacramento River flow because it could reinstate hydrologic connectivity over the full length of the Bypass and would create a less circuitous migration path for fish. Improving fish passage at Sacramento Weir is, thus, not discussed further.

Fish Passage at Fremont Weir

The crest elevation of the Freemont Weir is at about at 29 feet (NGVD 1929), while the invert of the Tule Canal one mile downstream of the weir is at about 12 to 13 feet (NGVD 1929). Appendix F provides stage-frequency analyses of historic water levels recorded on the Sacramento River at Fremont Weir. Due to the short historic period available, analyses were limited to one exceptionally wet period (1997–99) and one exceptionally dry period (1989–91).

A variety of structural modifications might successfully pass water from the Sacramento River over the Fremont Weir and into the Yolo Bypass for floodplain inundation. However, pumps, siphons or gated conduits only provide flow—not fish passage. An opening in the weir would connect the Tule Canal to the Sacramento River, providing both fish passage and flow for floodplain inundation.

The potential to provide continuous fish passage and water for floodplain inundation through the Fremont Weir under wet and dry periods in the Sacramento River is discussed in more detail in Appendix G. The analysis in Appendix G suggests that a shallow notch could improve fish passage during wet years. The notch would need to extend to the invert of the Tule Canal in order to provide fish passage and inflows to the Tule Canal in typical years. In dry years, even such a deep notch would be of little benefit to continuous fish passage and inflows. Further analysis of the timing of fish movements relative to stages in the Sacramento River would be required to select an appropriate design for an opening through the Fremont Weir.

Creating a notch in Fremont Weir could potentially provide fish passage as well as water for floodplain inundation during typical and wet years, but such a modification to the weir would also raise complex issues regarding water rights and flood protection along the Sacramento River and the Yolo Bypass (Chapter 6). In addition, modification of the weir would require engineering studies to ensure that the structure remains stable and numerical or physical modeling studies to ensure that it functions as designed for flood control. The engineering feasibility studies, environmental compliance and permitting for such a project would likely require several years to complete and is beyond the scope of this study.

Fish Passage on South Fork Putah Creek

Fish passage improvements to the South Fork of Putah Creek are both technically feasible, and readily implementable. The lowermost barrier to fish is a seasonal check dam, described in detail in Chapter 5. The dam is jointly operated by CDFG and Los Rios Farms. The check dam blocks upstream migrants during part of the spring, summer and fall. When installed, the flashboards at the check dam impound a pool that is about 8 feet deep. The pool behind the check dam maintains upstream water levels on Putah Creek for irrigation. Gravity diversion enables irrigation of fields by Los Rios Farms and filling of wetland cells by the Department of Fish and Game. The check dam has no fish ladder or any other means of providing upstream fish passage.

The flashboards are installed in spring (typically early to mid-April, depending on weather and irrigation requirements) and removed in the fall when crop irrigation is no longer required and adult Chinooks enter the Yolo Bypass (typically in early November). The flashboards are removed to allow adult Chinook to pass up Putah Creek, with drainage of the headpond providing an attraction flow. The boards are left out over the winter to reduce water levels during winter floods on Putah Creek.

Putah Diversion Dam, located 22 miles upstream of the Bypass, is an impassable year-round barrier to fish migration in both directions. Providing fish passage at that structure would create access to 7 additional miles of high-quality habitat for salmon. However, modification of Putah Diversion Dam was considered beyond the scope of the present project.

Putah Creek flows are much smaller than existing or potential flows across Fremont Weir. They are also controlled by upstream storage and diversion facilities making it relatively easy to limit the extent of project inundation to designated areas within the Wildlife Area. Improvements to field berms along 1–2 miles of the low-flow channel upstream of the Wildlife Area might be necessary, however, to avoid increased inundation in that area.

Although fewer fish would likely benefit from Putah Creek improvements than from Fremont Weir improvements, improvements to fish passage on Putah Creek could be much more readily implemented in a demonstration project time frame.Alternatives for improved fish passage on Putah Creek are discussed further in Chapter 5.

Summary of Potential Sites for Floodplain Inundation or Fish Passage Projects

The analysis of alternative water sources limited potential floodplain inundation projects to sites along the Tule Canal/Toe Drain and Putah Creek. The best opportunities for local improvements to fish passage along those same waterways are to modify Fremont Weir or the Los Rios Farms/CDFG check dam.

Table 4-1 summarizes the advantages and disadvantages of the Yolo Bypass alternatives with respect to some of the key general screening criteria for fish passage and floodplain restoration projects. The rows in the table have been numbered to facilitate discussion of the results; the numbering has no further significance and is not used elsewhere in the text. The suitability of the sites is assessed based on their potential to meet the fourteen site selection criteria listed at the

Table 4-1. Summary and Screening of Alternatives for Floodplain Inundation and Fish Passage in the Yolo Bypass

Alt. #	Alt. Name	Description	Fish Passage	Floodplain Inundation	Flow Reliability	Land Ownership	Anticipated Controversy	Navigation Impacts	Passive / Active Operation	Other Considerations	Physical Suitability Ranking	Near-Term Implementability Ranking
1	Low-flow channel through Fremont Weir	A small open channel would allow up to about 1,000 cfs to flow by gravity from the Sacramento River to the north end of the Tule Canal at all but the lowest river stages	Year-round; would eliminate major obstacle of regional significance	None near the weir, but passed-through flows necessary for Tule Canal/Toe Drain alternatives	Steady spring base flow present in all years	Public	Very high	None -- the weir is not navigable except during large floods	Passive		High	Low
2	Low-flow channel through Sacramento Weir	A small open channel would allow up to about 1,000 cfs to flow by gravity from the Sacramento River to the Tule Canal near I-80 at all but the lowest river stages	Year-round; would eliminate major obstacle of regional significance; fish migration path more convoluted than for Fremont Weir alternative	None near the weir, but passed-through flows necessary for Tule Canal/Toe Drain alternatives	Steady spring base flow present in all years	Public	Very high	None -- the weir is not navigable	Probably passive; depends on design		Moderate-High	Low
3	Tule Canal/Toe Drain floodplain sites A and B	Low-lying floodplain strip adjacent to Toe Drain seasonally inundated by a lateral weir or an impoundment structure in the Toe Drain	Impoundment structure in Toe Drain, if needed, would need to allow year-round fish passage in both directions	Sites are in intertidal range -- difficult to achieve seasonal inundation	Tidal flows reliable, but difficult to use for seasonal inundation without pumping; otherwise depends on Sacramento River and Putah Creek flows	Private	Low unless Sacramento River water used; land acquisition or flood easement needed	Possibly none if lateral weir used to regulate flow from Toe Drain to floodplain	Passive for tidal-only flows; active for seasonal inundation		Low	Low-Moderate
4	Tule Canal/Toe Drain site C	Low-lying floodplain strip adjacent to Toe Drain seasonally inundated by a lateral weir or an impoundment structure in the Toe Drain	Impoundment structure in Toe Drain, if needed, would need to allow year-round fish passage in both directions	Sites are in intertidal range -- difficult to achieve seasonal inundation	Tidal flows reliable, but difficult to use for seasonal inundation without pumping; otherwise depends on Sacramento River and Putah Creek flows	Public (Yolo Bypass Wildlife Area)	Low unless Sacramento River water used	Possibly none if lateral weir used to regulate flow from Toe Drain to floodplain	Active seasonal adjustment of diversions into floodplain		Low	Low-High
5	Tule Canal/Toe Drain site D	Low-lying floodplain strip adjacent to Toe Drain seasonally inundated by an impoundment structure in the Toe Drain	Impoundment structure in Toe Drain would need to allow year-round fish passage in both directions	Several hundred acres of land slightly higher than Toe Drain elevation could be inundated	Low-flow connection from Sacramento River needed for flow reliability (via Fremont or Sacramento Weir)	Public (Yolo Bypass Wildlife Area)	Low for land use; high for Sacramento water use	Toe Drain impoundment structure would block watercraft	Active seasonal adjustment of diversions into floodplain	Floodplain area presently managed for perennial wetlands	Moderate	Low
6	Tule Canal/Toe Drain sites E and F	Low-lying floodplain strip adjacent to Toe Drain seasonally inundated by an impoundment structure in the Toe Drain	Impoundment structure in Toe Drain would need to allow year-round fish passage in both directions	Several hundred acres of land moderately higher than Toe Drain elevation could be inundated	Low-flow connection from Sacramento River needed for flow reliability (via Fremont or Sacramento Weir)	Largely or entirely private	Low for land use; high for Sacramento River water use; land acquisition or flood easement needed	Toe Drain impoundment structure would block watercraft	Active seasonal adjustment of diversions into floodplain	Much of the potential floodplain area at site F already managed for waterfowl habitat	Moderate	Low
7	Tule Canal/Toe Drain site G	West end of Sacramento Bypass seasonally inundated by an impoundment structure in Tule Canal	Impoundment structure in Tule Canal would need to allow year-round fish passage in both directions	Several hundred acres of land slightly higher than Tule Canal could be inundated	Low-flow connection from Sacramento River needed for flow reliability (via Fremont or Sacramento Weir)	Public	High (Sacramento River water use)	Toe Drain impoundment structure would block watercraft	Active seasonal adjustment of diversions into floodplain		High	Low
8	Tule Canal/Toe Drain site H	The "1962 flood strip" seasonally inundated by an impoundment structure in the Tule Canal	Impoundment structure in Tule Canal would need to allow year-round fish passage in both directions	Several hundred acres of land slightly higher than Tule Canal could be inundated	Low-flow connection from Sacramento River via Fremont Weir needed for flow reliability	Private	Low for land use; high for Sacramento River water use; land acquisition or flood easement needed	Toe Drain impoundment structure would block watercraft	Active seasonal adjustment of diversions into floodplain		High	Low
9	Tule Canal/Toe Drain site I	Low-lying floodplain strip adjacent to Tule Canal seasonally inundated by an impoundment structure in the Tule Canal	Impoundment structure in Tule Canal would need to allow year-round fish passage in both directions	100-200 acres of land slightly higher than Tule Canal could be inundated	Low-flow connection from Sacramento River via Fremont Weir needed for flow reliability	Private	Low for land use; high for Sacramento River water use; land acquisition or flood easement needed	Toe Drain impoundment structure would block watercraft	Active seasonal adjustment of diversions into floodplain		Moderate-High	Low
10	Lands along Knights Landing Ridge Cut, Cache Creek or Willow Slough	A managed, local floodplain would be created along the waterway where it crosses the Bypass	Any impoundment structures in the waterway would need to allow year-round fish passage in both directions	Up to several hundred acres, depending on design and location; more excavation and/or berms might be needed than for Tule Canal/Toe Drain options; splittail would need to ascend a greater distance and elevation to reach floodplain	Too variable to provide prolonged inundation in spring; inadequate quantity in dry years	Largely or entirely private	Low for land and water use; land acquisition or flood easement needed	Not presently very navigable; any new impoundments would further decrease navigability	Active seasonal adjustment of diversions into floodplain		Low	Moderate
11	Lands along Putah Creek	A managed, local floodplain would be created along the waterway where it crosses the Bypass	Any impoundment structures in the waterway would need to allow year-round fish passage in both directions	Up to 1,000 acres, depending on design and location; more excavation and/or berms might be needed than for Tule Canal/Toe Drain options; splittail would need to ascend a greater distance and elevation to reach floodplain	Adequately steady and reliable flow of about 40 cfs available in 3 out of 4 years	Public (Yolo Bypass Wildlife Area)	Low	Not presently very navigable due to check dam and low flows; little overall change expected	Active seasonal reoperation of check dam and/or wetland stage control structures	Needs to comply with Putah Creek Instream Flow Settlement Agreement	High	High

beginning of this section on "Site Suitability" for adult passage or floodplain inundation projects, based on a subjective balancing of their advantages and disadvantages. The potential for short-term implementation is largely dependent on potential impacts on landowners and water users, land ownership at the project site, environmental compliance and permitting, and anticipated public controversy.

Many of the sites rank more or less equally for some of the criteria because the criteria were the basis for selecting the sites in the first place. Criteria that are similarly met by most alternatives or that can only be evaluated in a general way at this stage of project planning are discussed in the following paragraphs and do not appear in Table 4-1. For example, all of the sites would enhance the protection and restoration of native fish and wildlife habitat, although fish passage projects enhance different habitat elements than floodplain restoration projects. Also, all of the potential inundation sites are immediately adjacent to the waterway that would supply the inundation water.

Many other criteria would be met for all of the sites during the design and operation phases. For example, all of the sites would maintain the present flood conveyance capacity of the Yolo Bypass because no high berms or tall vegetation are needed to meet project objectives. In addition, issues of particular concern to Yolo Bypass landowners and recommended approaches for addressing those issues were formulated through a stakeholder process and presented in the Yolo Bypass Management Strategy (Yolo Bypass Working Group et al. 2001). These issues will also be addressed during the design and operation phases. For example, it is assumed that property rights would not be infringed by any of the projects and increased inundation frequency would be limited to lands that are publicly owned or for which appropriate flood easements have been obtained. Similarly, potential impacts on nearby agricultural and wildlife refuge operations would be decreased to acceptable levels. Mosquito abatement would not likely be an issue for fish passage projects, and any planned inundation project would be designed and managed in coordination with the local mosquito abatement district.

Freedom of fish movement between the channel and floodplain depends on the method used to inundate the floodplain. There would be no obstruction if inundation were achieved simply by increasing flow in the waterway. This would be physically possible along the Tule Canal/Toe Drain if more than about 1,000 cfs were diverted into the channel from the Sacramento River. This approach is problematic because it would have potentially larger impacts on water rights and water operations along the Sacramento River, and because much more extensive earthwork would be needed along the Tule Canal/Toe Drain to limit inundation to designated areas and prevent unwanted inundation along the rest of the waterway. It is more likely that an in-channel impoundment would be used to divert water into an adjoining floodplain area, and fish access to the floodplain would be limited to short segments of connecting channel at the upstream and downstream ends of the floodplain. This also applies to floodplain sites along the tributary creeks.

With the possible exception of sites along Putah Creek, flow for all of the projects would be by gravity. On Putah Creek, supplemental flow amounting to a few cubic feet per second might be needed during 1–2 months each year to offset seepage and evaporation losses associated with the project. This would maintain compliance with instream flow criteria (see Chapter 5). If the supplemental water could not be obtained from an upstream user, it might be necessary to pump water into the creek from the Toe Drain (via an existing pumping station and irrigation canals) or from a well.

All of the projects would be reversible, but the reversal costs would be variable. In most cases, it would be relatively easy and inexpensive to discontinue the passage and inundation operations while leaving new structures in place. An exception would be a passively-operated notch through Fremont or Sacramento Weir, which would have to be filled with an engineered structure to restore the original weir function. Impoundments in the Tule Canal/Toe Drain or in one of the tributary creeks could be left in place with one or more gates completely open to restore existing flow and fish passage. Completely removing the structures would entail a cost, but a much smaller one than the original construction cost. Any field perimeter berms that were extended or raised to limit the extent of planned inundation could easily be bulldozed and graded into the surrounding soil. Any major excavation to create a low floodplain surface or to fill in unused segments of Putah Creek (see Chapter 5) would be approximately as expensive to reverse as to construct in the first place.

A comparison of the suitability rankings assigned to the sites suggests that the two best ones may be:

1. Modification of Fremont Weir to allow passage of fish and low flows, combined with floodplain inundation projects supported by those flows at Sites G, H or I along the Tule Canal.
2. Floodplain inundation along Putah Creek supported by flows from Putah Creek and with provision for unrestricted migration of anadromous fish up and down the creek.

Modifying the structure and operation of the Fremont Weir is not feasible in the near future and could affect several water projects, water users, and landowners and would undoubtedly require a lengthy planning and permitting process. Local landowners and farmers participating in the Yolo Bypass Working Group expressed concern over any proposal to modify the weir. In contrast, the majority of stakeholders in the Working Group felt that the Putah Creek site offered few complications. Potential impacts to surrounding lands and private agricultural operation would be minimized by gravity delivery of seasonal creek water, and limited land disturbance for channel construction. Because the floodplain would be surrounded by CDFG lands, potential impacts of the presence of listed species on adjacent private landowners and vice versa would be minimized. Based on these institutional considerations, the Putah Creek site is clearly superior for near term implementation of a demonstration project.

A major objective of this investigation is to identify a suitable demonstration project that could be implemented in the next 1– 2 years. Accordingly, the Putah Creek site was selected as the preferred one for further analysis. Project Alternatives and design concepts are evaluated in detail in Chapter 5.

CHAPTER 5. ANALYSIS OF PREFERRED SITE (PUTAH CREEK)

Putah Creek emerged from the screening process described in Chapter 4 as the most promising site for construction of a pilot scale floodplain restoration project. Chapter 5 characterizes the hydrology, topography, fisheries biology, and land use of Putah Creek and adjacent lands along the Yolo Bypass reach. Twelve alternative project concepts are identified involving various combinations of options for channel alignment, check dam operation, and floodplain excavation. These are evaluated with respect to objectives and constraints, resulting in three alternatives recommended for further design analysis.

PROJECT OBJECTIVES

The overall objectives are to provide spawning and rearing habitat for splittail during winter and spring months, downstream passage and rearing habitat for Chinook smolts, and upstream passage for adult Chinook salmon with water from Putah Creek. Chapter 3 provides biological design criteria for creating splittail spawning and rearing habitat and Chinook juvenile rearing habitat through managed inundation of floodplains. Several races of Chinook salmon are found in the Yolo Bypass; upstream fish passage focuses on fall run, the only race known to occur in Putah Creek. Timing requirements for water needs for life stages of splittail and other species and for other activities are shown on Table 5-1.

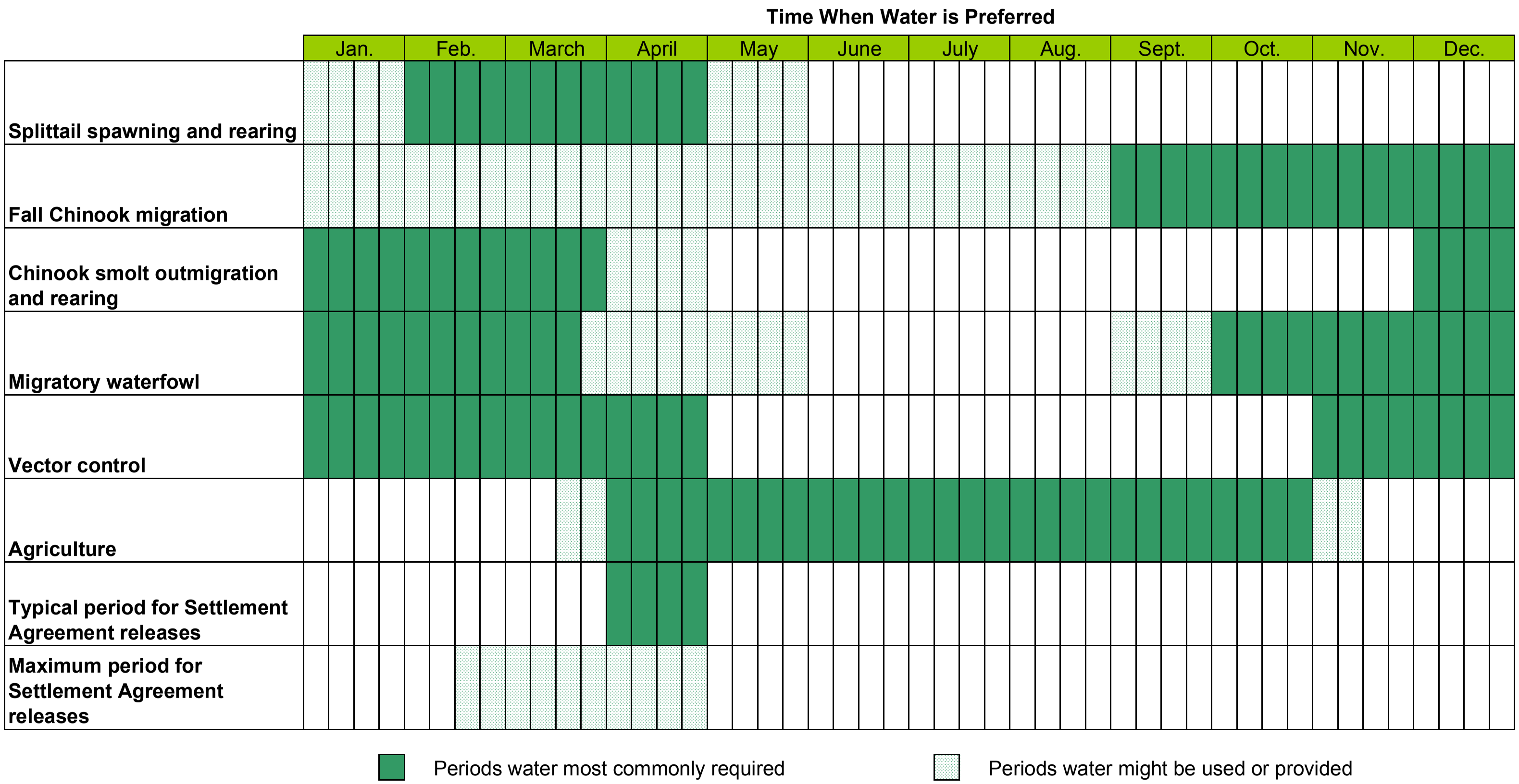
EXISTING CONDITIONS

The South Fork of Putah Creek flows across the Yolo Bypass from west to east, joining the Yolo Bypass Toe Drain about 4 miles south of I-80. Figure 5-1 shows the study area considered for the Putah Creek alternatives in relation to CDFG's Yolo Bypass Wildlife Area, including the recently acquired Tule Ranch (Glide Ranch).

The CDFG properties consist of existing wildlife areas, planned wildlife refuges, irrigation ditches, and fields. Some fields continue to be used for agriculture. "Sinks" or closed depressions are visible at various locations, and many of these fill during winter months and retain water into the spring. Investigation of cultural aspects of this area has not yet been completed.

Figure 5-2 shows the soils that lie in the study area. Most are floodplain soils formed from alluvial deposits in the Yolo Bypass and are characterized by relatively poor drainage resulting from high water tables and low infiltration capacity. Elevations in the study area range from about 18 feet near the northwest corner of the property to about 6 feet near the Toe Drain (Figure 5-3; elevations refer to the NAVD 1988 datum). The property slopes both to the east, towards the Toe Drain, and to the south, towards the Tule Ranch, from the northwest corner. Old channel alignments are visible on historic air photos. Putah Creek is typically incised about 8 feet below the nearby floodplain elevations. It flows on an artificial alignment for its last mile before entering the Toe Drain. A check dam operated jointly by Los Rios Farms and the California

Table 5-1. Timing Requirements for Flows for Native Fish, Wildlife and other Activities



The above rows show periods of the year when water is typically required for different species or provided for different uses. For instance, the first row shows that water for splittail minnow spawning and rearing is typically required from February through April and possibly from January through May.

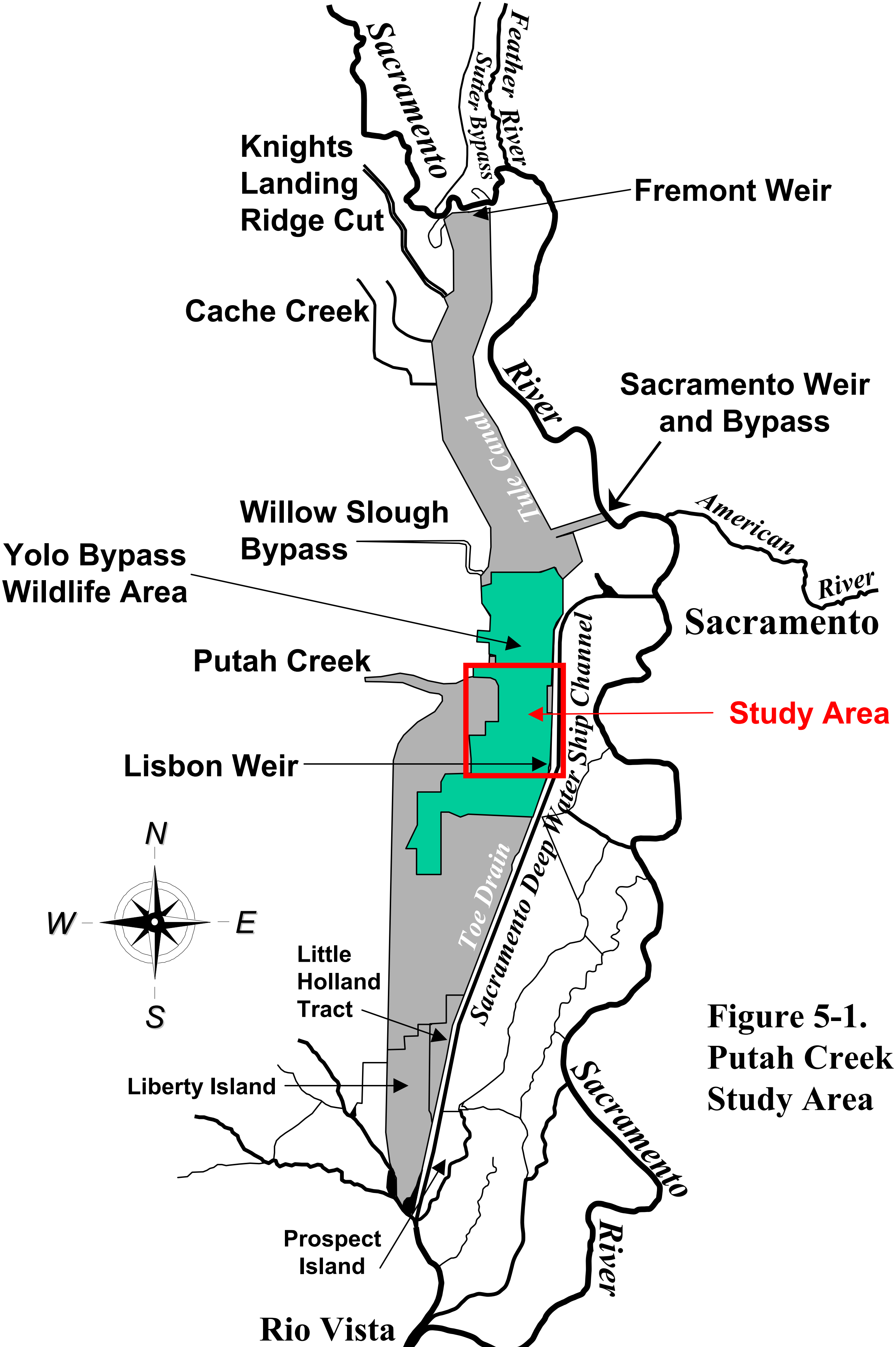


Figure 5-1. Putah Creek Study Area

Legend

BrA - Brentwood silty clay loam
Cc - Capay soils, flooded
Cn - Clear Lake soils, flooded
Ma - Made land
Pc - Pescadero soils
Rg - Rincon silty clay loam
Rh - Riverwash
Rn - Riz loam
Sg - Sacramento soils, flooded
Sp - Sycamore silt loam, drained
Sr - Sycamore silt loam, flooded
Sw - Sycamore complex, flooded
Wg - Willows soils, flooded

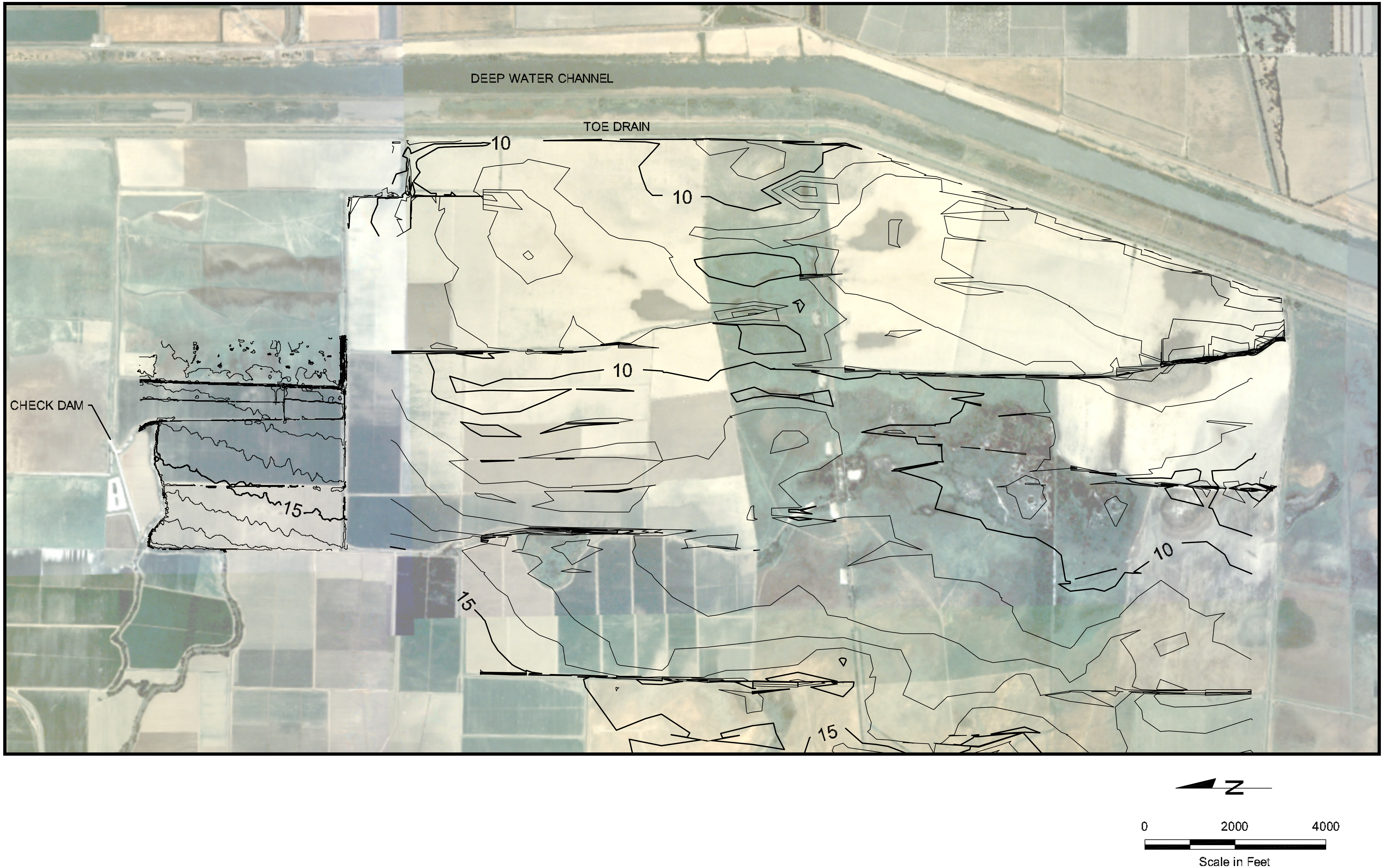
Permeability (in/hr)	
BrA :	0.20 - 0.63
Cc:	0.06 - 0.20
Cn:	0.06 - 0.20
Ma:	NA
Pc:	0.06 - 0.20
Rg:	0.06 - 0.63
Rh:	0.02 - 0.63
Rn:	0.02 - 0.63
Sg:	0.06 - 0.63
Sp:	0.20 - 2.00
Sr:	0.20 - 2.00
Sw:	0.06 - 2.00
Wg:	0.06 - 0.20

N

0 1000 2000
Scale in Feet

nhc
Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Figure 5-2
Soil Map of Study Area
SCS Soil Survey of Yolo County, June 1972
December 18, 2002



nhc

Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Figure 5-3
Topographic Map of Study Area
DWR Surveys completed Summer 2002, vertical datum = NAVD 88
December 18, 2002

Department of Fish and Game (Yolo Bypass Wildlife Area) sits about one mile upstream of the Toe Drain; downstream of this structure, Putah Creek flows in a straight, deep ditch. Upstream of the dam, Putah Creek splits into two channels along two reaches. The capacity of the right channel on Los Rios Farm is around 1,500–2,000 cfs and water overflows the right bank of this channel at several sites during larger floods, particularly near the apices of tight bends (Figure 5-3). The left channel sits considerably higher than the right channel and is not inundated very often (Appendix I). Upstream of the two split-channel reaches (near Road 106A), high flows also overtop the left bank and flow northeast across agricultural fields and into wetland cells in the Wildlife Area.

When installed, the flashboards at the check dam impound a pool that is about 8 feet deep at the dam and extends 1–2 miles upstream. A stage-volume curve developed from 17 cross sections surveyed by DWR in spring 2002 is shown in Figure 5-4. The normal water surface elevation with the flashboards up is about 16 feet above sea level (NAVD 1988), which corresponds to a pool volume of 123 acre-feet. The check dam has no fish ladder or any other means of providing upstream fish passage. Minor volumes of accumulated sediment are visible in the headpond when it is drawn down.

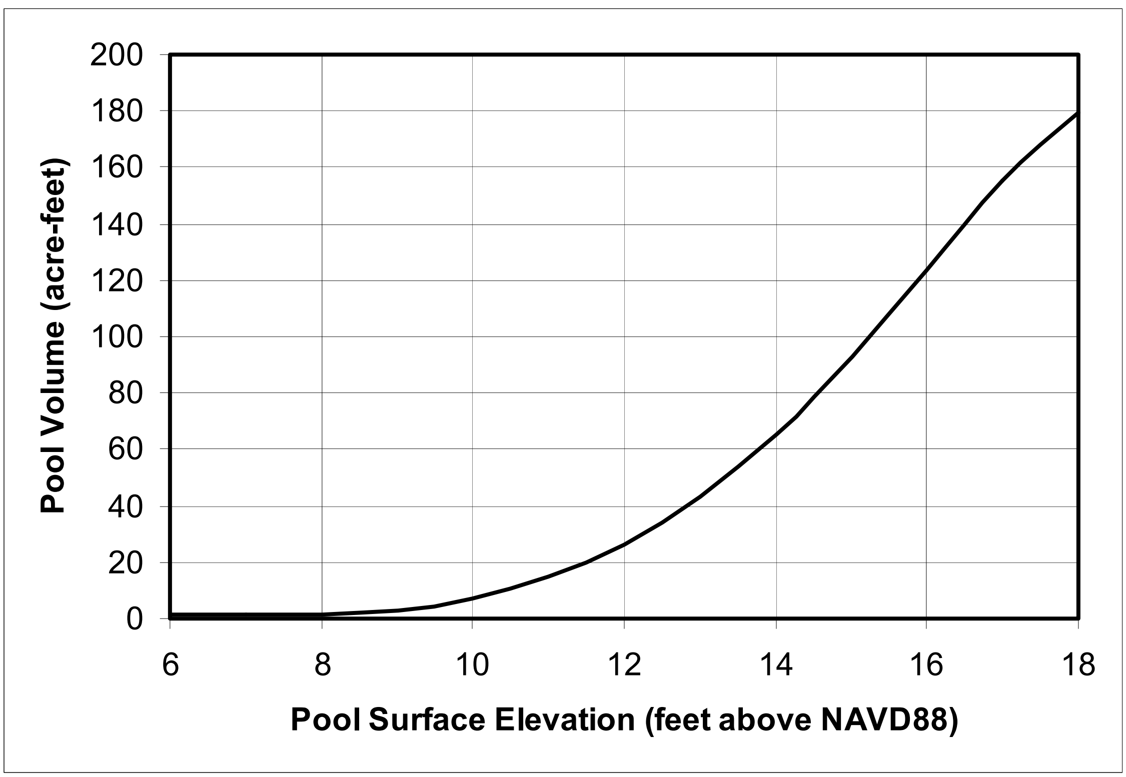


Figure 5-4. Stage-Volume Curve for Los Rios Farms/CDFG Check Dam Pool

The pool behind the check dam maintains upstream water levels on Putah Creek for gravity-fed diversions. Los Rios Farms irrigates fields and the Department of Fish and Game fills wetland cells with this diversion water. The pool is connected by a level canal extending 1 mile north to the Los Rios Farm pump station, which pumps water up from a Toe Drain lateral to the same elevation as the check dam pool. Water can flow in either direction through the canal.

The flashboards are installed in spring (typically early to mid-April, depending on weather and irrigation requirements) and removed in the fall when crop irrigation is no longer required and fall-run adult Chinooks enter the Yolo Bypass (typically in early November). The flashboards are removed to allow adult Chinook to pass up Putah Creek, with drainage of the headpond providing an attraction flow. The boards are left out over the winter to reduce water levels during winter floods on Putah Creek.

PROJECT HYDROLOGY

Putah Creek provides a fairly reliable source of water for local floodplain inundation in years when general flooding of the Yolo Bypass does not occur or is too intermittent to allow successful splittail spawning and juvenile rearing. Inundation of the Yolo Bypass, as defined by water stages at the Lisbon Weir greater than 11.5 feet above the U.S.E.D. datum, occurred in 23 of the 36 years since the second of the two major storage reservoirs upstream of the Yolo Bypass was completed (Oroville Dam, completed in 1964). However, continuous inundation of 25 days or more after February 15 occurred in only 9 of those 36 years. In the other years, managed floodplain inundation along Putah Creek might contribute significantly to the available splittail spawning and rearing habitat.

Spring flows in Putah Creek are relatively reliable because natural runoff is supplemented by releases from Lake Berryessa pursuant to the Lower Putah Creek Instream Flow Settlement Agreement (Settlement Agreement) adopted in 2000. The multi-party agreement resolved several years of litigation between various groups and agencies in Yolo and Solano Counties. Instream flows are governed by a fairly complex set of criteria applied to several compliance point locations. The criteria are summarized in Table 5-2.

The agreement groups the flow requirements into three categories, as indicated in the left-hand column of the table. Two categories are for spawning and rearing of resident native fish. The third category, "Supplemental Flows," are intended to meet instream flow needs related to migration of anadromous native fish. The flow requirements apply at a number of locations along the 26-mile reach of Putah Creek between Putah Diversion Dam and the Toe Drain (a few compliance points have been omitted from the table for simplicity). The Los Rios Farms/CDFG check dam is located at River Mile -2.0, slightly over 1 mile upstream of the Toe Drain.

The numbers in the table show the flow, in cubic feet per second, required at each location for each month of the year. Some of the required flows last for only a few days and/or have flexible timing within a specified date window, as indicated by shading and footnotes in the table. The elevated flows in spring consist of a pulse of high flows released from Putah Diversion Dam (150, 100 and 80 cfs on three consecutive days) followed by 30 continuous days of at least 50 cfs as far downstream as I-80. At the end of the 30 days, flows would be gradually ramped down

Table 5-2. Instream Flow Requirements for Lower Putah Creek in Non-Drought Years Pursuant to 2000 Settlement Agreement

Compliance Point and Flow Category	River Mile (1)	Required Instream Flow (cfs)											
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Putah Diversion Dam	22.6												
Rearing		20	25	25	25	16	26	46	43	43	43	34	20
Spawning						150-100-80 pulse(2)							
Supplemental													
I-80	8.1												
Rearing		5	10	10	15	15	25	30	20	15	15	10	5
Spawning						30 days at 50 (3)							
Supplemental				19 (4)	19	19	19						
River Mile 0.0	0												
Rearing		>0	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
Spawning													
Supplemental													
Toe Drain	-3.3												
Rearing													
Spawning													
Supplemental			|<----- 5 ------>|					5	5				
Supplemental			5-days at 50 (5)										

Notes:

(1) River mile 0.0 is where an imaginary line extending the west levee of the Yolo Bypass intersects the creek channel. Miles are positive in the upstream direction and measured along the low-flow channel.
(2) Daily releases of 150-100-80 cfs over 3 days, beginning sometime between February 15 and March 31
(3) Immediately following the 3-day pulse at PDD, 30 days at 50 cfs followed by gradual decrease over 7 days to applicable rearing flow
(4) Supplemental flow requirement at I-80 begins immediately following the 5-day pulse at the Toe Drain and continues through March 31
(5) Immediately following removal of Los Rios Farms/CDFG check dam flashboards, if possible; otherwise commence December 1

over 7 days to the applicable rearing flow at I-80 (20–30 cfs). This sequence of flow could be initiated anytime between February 15 and March 31 to take advantage of natural runoff events.

The instream flow criteria only require a flow greater than zero at River Mile 0.0, eight miles downstream of I-80, during the spring pulse and a flow of 5 cfs at the Toe Drain (3.3 miles downstream of River Mile 0.0) during April and May. Both of these flows are much smaller than the required flow at I-80, which means that the agreement provides little assurance that flows would not be diverted between I-80 and the Bypass.

Losses to seepage and evapotranspiration are usually less than about 5 cfs in spring, which would result in an estimated 45 cfs reaching the Bypass. However, some of this water is commonly diverted by riparian landowners for irrigation, generally beginning in early April. An inventory of riparian lands and existing diversion practices by Solano County Water Agency indicated that on the order of 1,500 acres between Old Davis Road and River Mile 0.0 are presently irrigated at least some of the time by Putah Creek diversions and that as many as 2,000 additional acres along that reach are "probable candidates" for future riparian water use (Sanford 1997).

If 0.5 feet of applied water were delivered to these lands from Putah Creek during the month of April, the average riparian diversion rate during that month would be between 13 and 35 cfs. Adding 5 cfs of seepage and evapotranspiration losses to this range of potential diversion losses would leave a flow of only 10–32 cfs arriving at River Mile 0.0. Diversions would be illegal to the extent that the flow in the creek exceeds that which would naturally occur in the absence of Lake Berryessa and to the extent that water is applied to parcels that are not adjacent to the creek.

The instream flow criteria apply only in non-drought years. Drought years are defined in the agreement as years when storage in Lake Berryessa is less than 750,000 acre-feet on April 1. During drought years—which are expected to occur on average about 25 percent of the time—the criteria are greatly reduced, and little or no water would reach the Yolo Bypass.

The instream flows specified by the Settlement Agreement represent the minimum flows thought to be necessary for maintaining resident native fish and anadromous salmonid populations in good condition. The deliberations that led to the agreement did not consider flow requirements for creating floodplain habitat for splittail along the Yolo Bypass reach of the creek.

The conceptual design process for the present floodplain inundation project attempted to fit the project within the existing flow regime. The flow regime in lower Putah Creek consists of storage releases from Lake Berryessa and natural runoff below Monticello Dam, as affected by seepage gains and losses, evapotranspiration, diversions, and channel storage along the creek. Statistical characteristics of the historical and existing flow regimes were developed by adjusting gaged or simulated peak and daily flows near Winters for various gains and losses along the lower reaches of the creek. A complete description of this analysis is presented in Appendix J.

Figure 5-5 summarizes characteristics of the present flow regime in lower Putah Creek that are particularly relevant to floodplain project design. The lower graph in the figure shows the flow duration characteristics of existing flows at the Toe Drain during January through April, a key period for native fishes including splittail and juvenile Chinook salmon (see Appendix J). It shows that 30-day-average flows may exceed 25 cfs about 80 percent of the time during those

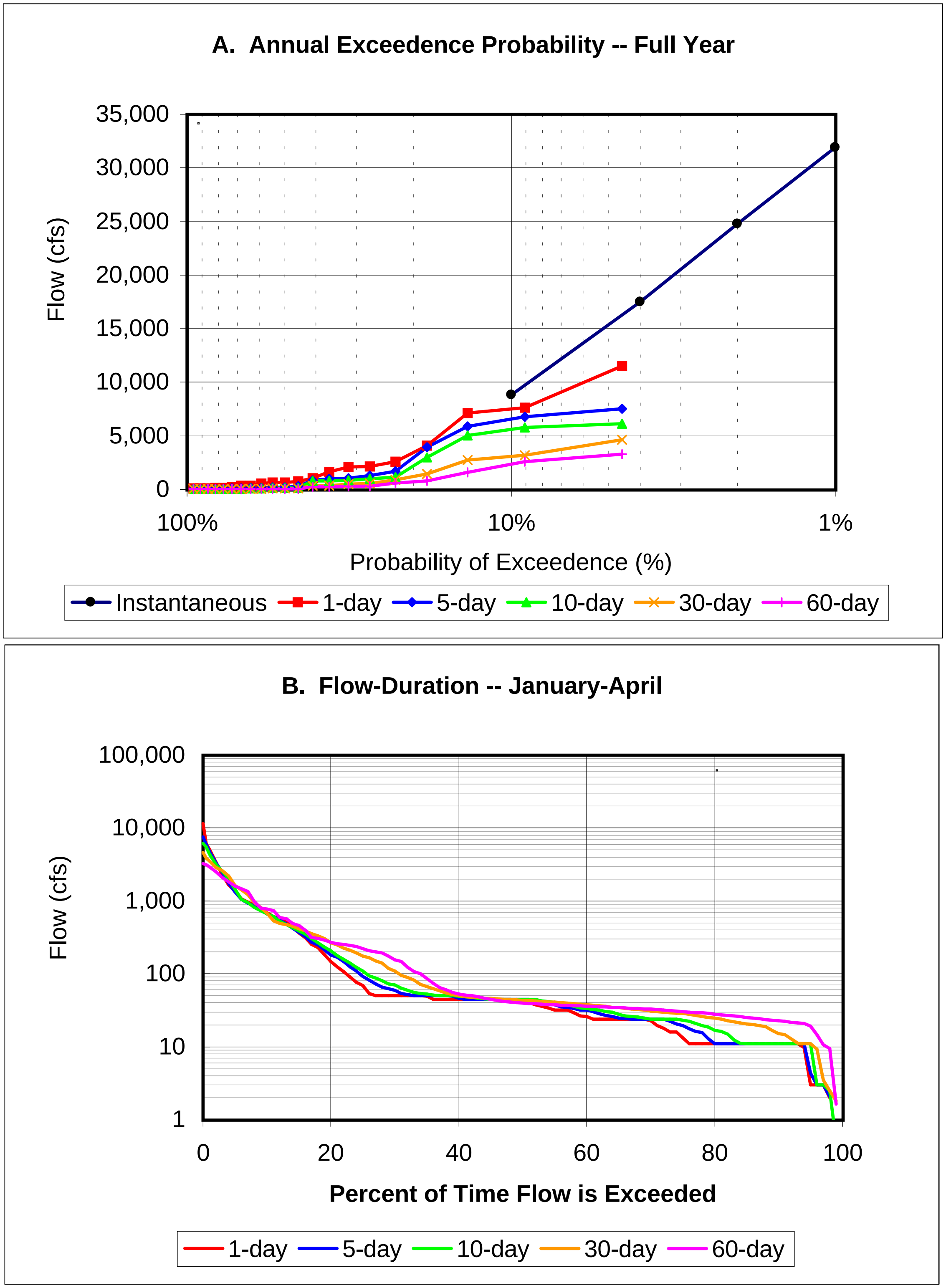


Figure 5-5. Statistical Characteristics of Putah Creek Flows Entering the Yolo Bypass

months and may exceed 50 cfs about 40 percent of the time. Note that these flows do not account for losses due to riparian diversions downstream of I-80, which are described in the following paragraphs.

For the purpose of developing a conceptual design for the floodplain inundation project, a Putah Creek flow of 40 cfs at the west edge of the Yolo Bypass (River Mile 0.0) was assumed for at least a 30-day period in spring. Although the designs will be capable of functioning at lower flows, it may be desirable under certain circumstances to supplement flows with water from other sources, such as groundwater or water pumped up from the Toe Drain and conveyed to the check dam pool via the existing pump station and canal north of Putah Creek.

Flows at other times of the year are important for fish passage, and the need to withstand flood flows influences the design of channels and water control structures. The upper graph in Figure 5-5 characterizes infrequent high-flow events using flood probability curves for maximum annual flows of various durations. The estimated 100-year peak flow of 31,900 cfs (obtained from USACE modeling) is dramatic but is expected to occur when the Yolo Bypass is already flooded. The probability of a maximum daily flow exceeding the capacity of the lower Putah Creek channel (1,000–2,000 cfs) is about 0.35, or one year in three. The maximum Putah Creek flow likely to occur in the absence of general flooding of the Yolo Bypass is 7,000–10,000 cfs (see Appendix J).

The capacity of Putah Creek upstream of the check dam is only 1,000–2,000 cfs, and the capacity downstream is only a few hundred cubic feet per second. Flows in excess of this amount spill out of the channel at several locations along the north and south banks of the creek downstream of Road 106A and spread out to the northeast and southeast as shallow overland flow. To maintain the present frequency of overbank flows, any realigned or modified Putah Creek channel constructed for the project will be designed to have a capacity of about 1,500 cfs. During detailed design, the maximum flow capacity of the channel might be altered to meet other land use objectives, either increasing or reducing the frequency of local floodplain inundation.

EXISTING PUTAH CREEK FISH HABITAT

Archeological evidence and historical accounts indicate that Putah Creek supported a modest run of fall-run Chinook salmon prior to development. Fish remains have been found in Patwin Indian middens near the present City of Davis, and fish surveys prior to construction of Monticello Dam reported salmon as far upstream as the Monticello Valley (Yoshiyama et al. 2001; Shapovalov 1947).

There is a wide range of temperatures along the creek, which now supports a remarkably diverse assemblage of fish including 11 native species and approximately 17 nonnative species (Jones & Stokes Associates, Inc. 1992; Trihey & Associates, Inc. 1996).The anadromous species that now visit the creek are Pacific lamprey, fall-run Chinook salmon, American shad, and possibly steelhead, none of which are presently abundant. During several years in the late 1990s, one or more salmon were seen spawning at various locations between Putah Diversion Dam and Pedrick Road (River Mile 10.2), and Pacific lamprey larvae have been seen in larger numbers emerging from a gravel road crossing near River Mile 17. Numerous anglers have reported catching steelhead, but these claims have not been verified. Because juvenile steelhead are visually indistinguishable from rainbow trout (which also inhabit the creek), biologists have not been able to conclusively demonstrate that steelhead use the creek.

Construction of Monticello Dam and Putah Diversion Dam greatly altered fish habitat along lower Putah Creek. Flood flows and gravel influx are substantially diminished, and releases from the reservoirs have created nearly-perennial flow in lower Putah Creek. Today, three dams create barriers to fish movement along Putah Creek, and the degree of obstruction increases in upstream order. The Los Rios Farms/CDFG check dam can block passage of upstream migrants early in the migration season for salmon and possibly steelhead. However, most of the migration season occurs after the flashboards have been removed. The dam probably has a bigger impact on smolt migration in spring, because the flashboards are typically installed while much of the smolting season remains. Putah Diversion Dam, which is approximately 14 feet high, forms an impassable barrier for upstream migration unless the sluice gate is open and the level of Lake Solano drawn down (one individual salmon slipped through during a 2-day window when the gate was open in fall 2000). A fish ladder or bypass channel would be feasible on the Putah Diversion Dam. Seven miles farther upstream, Monticello Dam is very high and completely impassable.

Floodplain habitat along Putah Creek consists only of small bars and low terraces within the main channel that are inundated during high-flow events. Except in years when Lake Berryessa spills, high flows last only a few days and would not support splittail reproduction, but could be useful for juvenile salmon rearing. The Yolo Bypass reach of Putah Creek—which is the most accessible to splittail—is too incised to be inundated for prolonged periods by Putah Creek flows alone. When lands along the creek are inundated by regional flooding in the Yolo Bypass, however, splittail readily spawn there.

HYDRAULIC REQUIREMENTS FOR HABITAT CREATION

Chapter 3 provides detailed criteria for floodplain inundation to create spawning and rearing habitat for splittail and juvenile Chinook. We have summarized the main hydraulic criteria to be incorporated in the conceptual design as follows:

- The test project should inundate from 100 to 1,000 acres.
- Continuous gravity flow, rather than pumping, is preferred as it better mimics natural flow regimes.
- Maximum swimming speeds for adult swimming splittail are not well known but are thought to be less than 6 feet/second; maximum velocities should be less than 3 feet/second for migration.
- Mean water depth should be less than 6 feet with considerable bottom variation and a mix of vegetated and open water areas.
- Rearing and spawning appear to occur in shallow vegetated water. Consequently, maximizing the perimeter relative to area may help maximize the available spawning habitat.
- Drainage of the project area should be as complete as possible in order to promote emigration, minimize stranding, and control predators.

The target attraction flow pulse needed to bring splittail spawners from the central part of the Delta up into the Yolo Bypass is estimated to be 1,000 cfs (see Chapter 3). Such a flow pulse cannot be provided from Putah Creek alone under the present flow regime. Fortunately, smaller pulses are likely to be adequate to attract splittail spawners from the Toe Drain up into Putah Creek if the flows are associated with inundation of the floodplain.

One of the major design challenges for the Putah Creek alternatives was to create as much habitat as possible within the range of appropriate channel and floodplain hydraulic conditions using the relatively limited amount of available flow. A discussion of the hydraulic performance of the three preferred alternatives is provided in subsequent sections.

OTHER MAJOR SYSTEM REOPERATION CONSIDERATIONS

Check Dam Operations and Channel Alignment

Withdrawals by Los Rio Farms and the California Department of Fish and Game that depend on water levels of about 15 feet (NAVD 1988) upstream of the check dam from April to November are one major constraint on project design. This requirement limits the options for treating the check dam to:

- Leave the check dam in place with the current seasonal flashboard operation.
- Leave the check dam in place with a modified operating regime to help meet project requirements for floodplain inundation or fish passage. The main modification might be to install flashboards earlier in the spring.
- Decommission the check dam by leaving the flashboards in place year-round or by removing the dam entirely and filling the downstream channel. Under these conditions, fish passage, attraction flows and flood flows would be conveyed through another channel but the existing channel would remain to deliver irrigation water to the headpond.

Modification of the check dam or check dam operation would require the agreement of Los Rios Farms, CDFG, and any other affected parties.

The floodplain project must provide for upstream passage of adult salmon in fall and winter and downstream passage of smolts in spring. The check dam presently does not have a fish ladder, and upstream fish passage is possible only when the flashboards are not in place. Consequently, the present flashboard season (early April to early November) may constrain adult migration for a couple of weeks in November. However, removal of the flashboards in the fall releases a pulse of water (approximately 90 acre-feet over the space of about 4 hours) that is thought to provide a beneficial attraction signal to upstream migrants. If the flash boards were left in place year-round or the check dam were decommissioned entirely and a new channel provided for upstream passage, an attraction flow would need to be generated from some other source of water such as new ponds.

Downstream smolt migration may now be constrained for several weeks in April, when flows do not pass over the flashboards under present operating conditions. Providing an unrestricted migration pathway for smolts was one of the design objectives for the Putah Creek project, and options that were considered included, a Bypass floodplain channel, reoperation of the check dam, and realignment of Putah Creek along a new route that has no barriers to fish migration.

Project design also requires a decision about passage of Putah Creek flood flows. One option is to divert only low flows (up to the maximum high flow pulse) from Putah Creek Diversion Dam to the new floodplain area and allow flood flows to continue down the existing Putah Creek channel. The other option is to convey flood flows through the floodplain inundation project, effectively creating a new Putah Creek channel. Such a project would provide environmental benefits but at a greater cost than for a channel that only accommodates relatively low flows. Realignment of lower Putah Creek or increased seepage and evapotranspiration losses along a new alignment might also require that the project assist Solano County Water Agency in meeting its instream flow obligations under the Settlement Agreement (see Chapter 6).

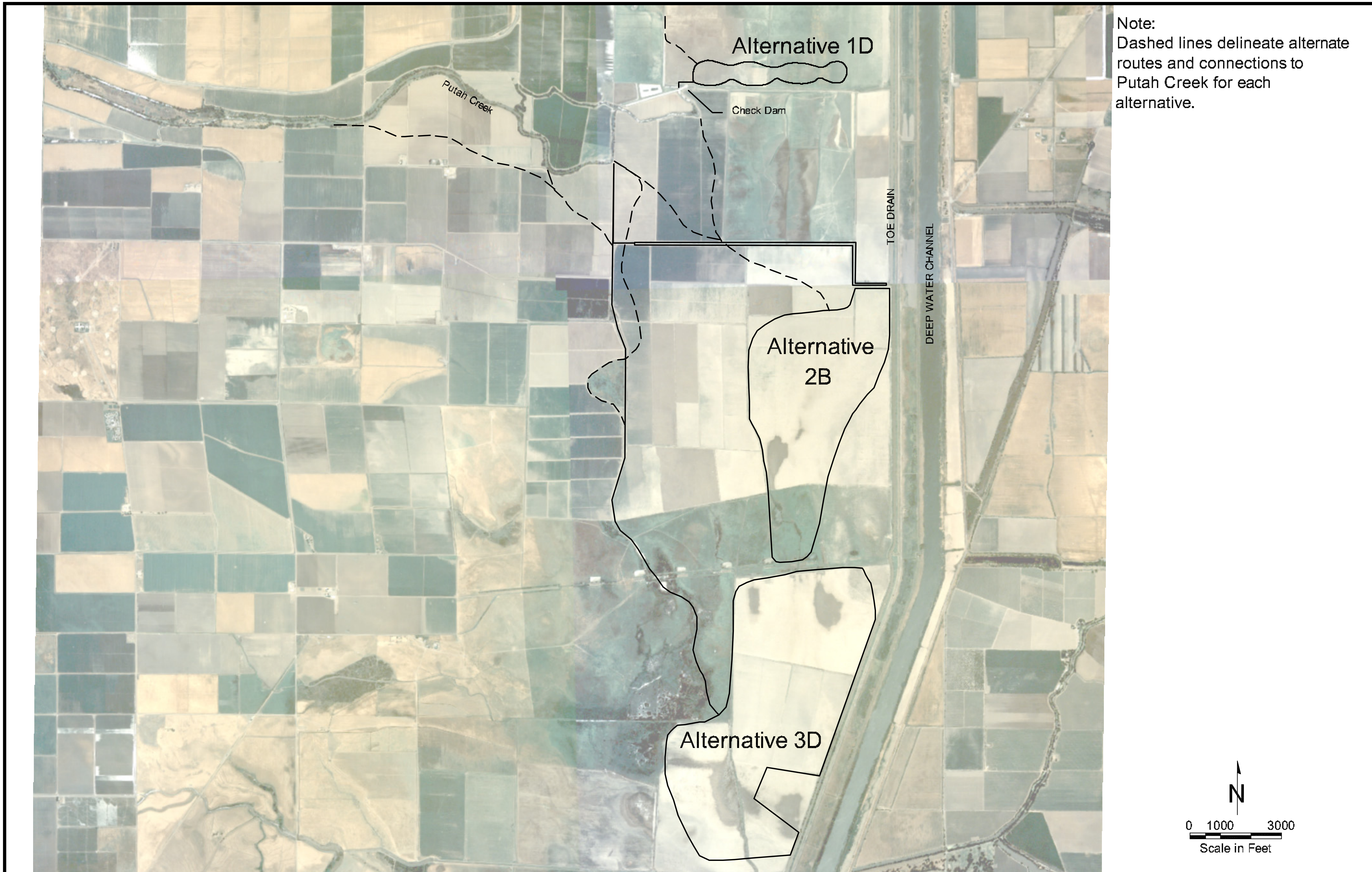
Realigning the channel of Putah Creek might improve year-round passage of adult and juvenile anadromous fish. The recent expansion of the Wildlife Area has created a broad range of potential channel alignments, of which three general alignments have been identified for a preliminary screening of alternatives. These are shown in Figure 5-6 and can be described as follows:

- Existing Putah Creek Channel: Floodplain inundation project could be developed either upstream or downstream of the existing check dam or on the nearby floodplain. This would be a simple alignment, as it does not require construction of a new channel to convey flood flows.
- Channel around South Wildlife Area: Under this option, flows would be diverted upstream of the check dam along either existing ditches or a newly constructed channel with a floodplain inundation project near the Toe Drain, where gradients are lower and depression storage can be converted to inundated floodplain. The steeper upper section might be enhanced to provide features for Chinook juveniles.
- Channel through Tule (Glide) Ranch: A long, low-gradient channel would be developed that connects existing sinks or marshes and re-joins the Toe Drain near the southern limit of the CDFG properties. Floodplain inundation habitat would be provided along the constructed channel and in marshes or sinks along the channel. Such a channel could be developed in conjunction with restoration of Putah Creek, and decommissioning of the check dam.

These alignments have not been surveyed or inspected in detail as part of fieldwork for this project. Consequently, some modifications to these layout concepts might be expected as part of detailed design.

Geomorphic Stability of Channels

Altering the alignment or shape of the lower end of Putah Creek could potentially initiate geomorphic processes that would adversely affect the project or nearby landowners, such as erosion, sediment deposition, channel meandering or channel avulsion (a spontaneous sudden change to a new alignment). These issues are explored at length in Appendix K "Putah Creek Geomorphology". Briefly, the investigation found that Putah Creek is an artificial channel with a



nhc

Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Figure 5-6
Alignment Options for Floodplain Inundation near Putah Creek
All Alternatives
December 18, 2002

flow regime and sediment supply that were greatly diminished by construction of the Solano Project (Monticello Dam and Putah Diversion Dam). The geomorphic characteristics of the creek channel (alignment, thalweg profile, width and depth) have barely changed at all during the last 50 years, suggesting that the lower-energy environment is less capable of causing geomorphic change.

Unconsolidated sediments are present along the length of lower Putah Creek, albeit only as patches on a dense clayey silt substrate in many places. These sediments are transported under the existing flow regime and would probably gradually fill any slack water areas created by the project, such as the pool impounded by the Los Rios Farms/CDFG check dam if the flashboards were left permanently up.

If a new channel is constructed at the approximate elevation of the floor of the Yolo Bypass (8 feet above the present creek thalweg), the creek may tend to scour around the intake structure to the new channel and along the new channel below the structure. The creek may tend to carve an incised rectangular low-flow channel along the new alignment, similar to the existing low-flow channel, if flow energy is not sufficiently dissipated. This could seriously impact the ability to inundate a floodplain along the new channel. Finally, if the check dam flashboards are left permanently in place to raise the hydraulic grade line of the creek to the elevation of the new channel, channel overflows along the reach between Road 106A and the check dam would be more frequent and would occur at lower flows. The risk that the entire creek would spontaneously change course to one of those overflow points would increase. Project design features that minimize this risk may be needed.

Increased Frequency of Channel Overflow Downstream of Road 106A

Some alternatives might include changing check dam operations, increasing channel overflows between Road 106A and the check dam. Under existing conditions, overflows from Putah Creek usually occur during or immediately before Yolo Bypass flood events that inundate those lands anyway. However, peak flows perhaps 7,000–10,000 cfs can occur when the Bypass is not flooded (see Appendix J "Putah Creek Hydrology" for details). If the base flow elevation of the creek were raised to facilitate gravity flow into a new channel alignment, upstream overflows would occur at much lower flows and more frequently. In general, increased overflow of Putah Creek onto surrounding lands within the Wildlife Area would be beneficial for habitat, provided significant erosion does not result. However, increased overflow onto agricultural lands would be an adverse impact that may require mitigation. The frequency and magnitude of overflows will be quantitatively evaluated using hydraulic models as design work for the floodplain project proceeds.

Fall Attraction Flows for Anadromous Fish

The present operation of the Los Rios Farms/CDFG check dam creates a flow pulse along the lowermost mile of Putah Creek when the flashboards are removed, which usually occurs in November. The timing of this pulse potentially attracts up-migrating fall run Chinook salmon, which commonly use flow pulses as a cue to begin migrating upstream. Under natural conditions, such pulses result from rainfall-runoff events early in the wet season.

The volume of water impounded by the check dam is approximately 90 acre-feet. This water is released over a period of about 4 hours as the flashboards are gradually removed, creating an average flow rate of approximately 270 cfs. Check dam operation is not regulated under the instream flow Settlement Agreement, although the pulse released from the dam may be used to meet the required attraction flow pulse. Although several parties to the Settlement Agreement have indicated that they consider the check dam flow pulse to be important for fisheries and that any modification of lower Putah Creek should continue to provide such a pulse (Marovich, Sanford and Krovoza pers. comm.), fish monitoring in the Toe Drain clearly demonstrates that flow pulses are not required for adult salmon to enter the system (Harrell and Sommer, In press).

ALTERNATIVES FOR FLOODPLAIN INUNDATION AND FISH PASSAGE

Twelve alternative conceptual designs for a Putah Creek floodplain inundation and fish passage project were developed by combining different options for channel alignment, check dam operation, fish passage, and routing of flood flows (Table 5-3). The other combinations of options were not included as alternatives because they were considered infeasible or impractical. For instance, removal of the check dam and excavation of a low floodplain along the existing Putah Creek alignment was not considered practical because it could require large volumes of excavation to create a floodplain, a siphon to convey irrigation water across the channel, and a pump station to lift water from the creek up to a new irrigation headpond. Some combinations of options are also illogical, such as combining existing check dam operations with routing of flood flows down a new channel.

Table 5-3 also provides a preliminary screening of the twelve alternatives based on the biological criteria in Chapter 3, the general site criteria discussed in Chapter 4, the hydraulic criteria summarized earlier in this chapter, the long-term geomorphic evolution of the modified channel and floodplain, and expected construction and operating costs. The success of the alternatives in meeting goals for project area, fish inundated habitat requirements, upstream adult passage and downstream migration and rearing were evaluated either by comparing project descriptions to the detailed criteria provided earlier in this chapter, or relative to existing conditions for adult Chinook passage. Potential impacts on surrounding lands are summarized under impacts on Wildlife Area, impacts on agriculture and impacts on frequency of flooding. These were assessed from the detailed project descriptions in this table and land use on nearby properties, based on discussions with representatives of CDFG and Los Rios Farms. The potential changes to Putah Creek from construction of the alternative are summarized in the Geomorphic Evolution column. These are based on the geomorphic description included in Appendix K and the detailed project descriptions in this table. The last two columns provide general comments on significant aspects of the project and a relative cost based on estimated volumes of grading and structures for control or management of flows.

An assessment of the overall ranking for each alternative is provided in the right-hand column of the table. For each of the three channel alignments, a preferred alternative was selected for the following reasons:

- Alignment A: Alternative 1D provided seasonal inundated floodplain habitat that was less than the minimum target area of about 100 acres, but met other biological criteria, was protected from damage by flood flows passing down Putah Creek, had minimal impact on other resources, and had relatively low construction costs.

Table 5-3. Summary and Screening of Alternatives for Floodplain Inundation and Fish Passage along Putah Creek

Description of Alternatives				
Alt. #	**Check Dam Operation**	**Flood Flows**	**Nature of Floodplain Inundation Construction**	**General Comments**
Channel Alignment A -- Floodplain Inundation and Passage along Existing Putah Creek Channel				
1A	Existing operations	Continue to be directed through present lower Putah Creek alignment	Excavate along island to create floodplain along right channel just upstream of the check dam	Potential fluctuating water levels upstream of dam, depending on flashboard installation
1B	Delay installation of flashboards some years to ensure flows for habitat	Continue to be directed through present lower Putah Creek alignment	Excavate along Putah channel to create floodplain downstream of the check dam	Excavation depths of about 8 feet to match channel invert
1C	Install flashboards earlier in March to raise upstream water levels	Continue to be directed through present lower Putah Creek alignment	Excavate floodplain habitat at a higher elevation along island upsteam of dam; fish passage structure for splittails	Much smaller excavation depths
1D	Install flashboards earlier in March to raise upstream water levels	Continue to be directed through present lower Putah Creek alignment	Divert spring releases onto left bank downstream of check dam with floodplain inundation and channel connecting to Toe Drain	Inundated area created by excavation and berms
Channel Alignment B -- Floodplain Inundation and Passage along Channel around South Wildlife Area				
2A	Existing operations	Continue to be directed through present lower Putah Creek alignment	Intake sized to spring releases upstream of check dam; floodplain inundation and connecting channel through low, flat area near Toe Drain	Intake required to function under wide range of water levels; deep excavation near intake; difficult design
2B	Install flashboards earlier in March to raise upstream water levels	Continue to be directed through present lower Putah Creek alignment	Intake sized to spring releases upstream of check dam; floodplain inundation and connecting channel through low, flat area near Toe Drain	Near constant water level simplifies intake design
2C	Check dam decommissioned; boards remain in place all year	Continue to be directed through present lower Putah Creek alignment	Floodplain inundation primarily near Toe Drain although some inundated floodplain created along new channel	Near constant water level simplifies intake design; damage to inundated areas during high flows
2D	Check dam decommissioned and removed but headpond and existing channel retained for irrigation	Pass flood flows down new constructed channel; may not be same as inundation habitat; Putah Creek filled	Floodplain inundation primarily near Toe Drain although some inundated floodplain created along new channel	Could fill existing channel; damage to inundated areas during high flows
Channel Alignment C -- Floodplain Inundation and Passage along Channel through Tule (Glide) Ranch				
3A	Existing operations	Continue to be directed through present lower Putah Creek alignment	Intake sized to Settlement releases; floodplain inundation by connecting existing channel and sinks or depressions with inundated pond on low, flat area near Toe Drain	Intake required to function under wide range of water levels; deep excavation near intake; difficult design; concerns that flows may not reach Toe Drain due to storage filling and transmission losses
3B	Install flashboards earlier in March to raise upstream water levels	Continue to be directed through present lower Putah Creek alignment	Intake sized to Settlement releases; floodplain inundation by connecting existing channel and sinks or depressions with inundated pond on low, flat area near Toe Drain	Near constant water level simplifies intake design; concern that water may not reach toe drain due to storage filling and transmission losses
3C	Boards remain in place all year	Pass flood flows down new constructed channel	Inundation along most of channel and in marshes; inundated pond near Toe Drain	Complex intake at headpond for low and flood flows and for upstream passage; berms along new channel and inundated floodplain
3D	Check dam decommissioned but headpond and existing channel maintained for irrigation	Pass flood flows down new constructed channel	Inundation along most of channel and in marshes; inundated pond near Toe Drain	Could fill existing channel; requirement for berms and erosion protection along new channel and inundated floodplain

Table 5-3--Continued

Assessment of Alternatives						
Alt. #	**Inundated Fish Habitat Requirements**	**Potential Area of Floodplain Inundation**	**Downstream Juvenile Chinook Passage and Rearing**	**Upstream Adult Passage**	**Potential Impacts on Wildlife Area**	**Potential Impacts on Agriculture or Private Lands**
Channel Alignment A -- Floodplain Inundation and Passage along Existing Putah Creek Channel						
1A	Difficult to maintain grass vegetation if inundated over the summer and fall; requires fish to migrate past check dam	likely less than 50 acres	No changes foreseen	No changes foreseen	None expected for current plans	Loss of land on Los Rios Farms
1B	Difficult to provide deep water without partial weirs along the channel; openings sized to meet swimming speed criteria	likely less than 100 acres	Improved, if flashboards are not installed	No changes foreseen	Loss of potential wildlife refuge area on left bank; reconstruction of ditches required	Later installation of flashboards may affect water rights and start of irrigation season
1C	Difficult to maintain grass vegetation when inundated over the summer and fall; requires fish passage structure for fish over check dam	likely less than 50 acres	Difficult passage over face of dam; if water available a pasage structure could be added to check dam	No changes foreseen	None expected for current plans	Loss of land on Los Rios Farms; flooding impacts (see next box)
1D	Upstream passage along connecting channel to reach inundated area; only seasonal flooding	about 70 acres	Improved passage and rearing through inundated area and channel	No changes foreseen	Seasonal flooding of potential wildlife refuge area	Flooding impacts (see next box)
Channel Alignment B -- Floodplain Inundation and Passage along Channel around South Wildlife Area						
2A	Meet depths with pond and connecting channel; grasses maintained by seasonal inundation	from 100 to 500 acres	Improved passage and rearing through inundated area and channel; rearing features added along upper channel	No changes foreseen	Potential impacts on ditches used for agriculture or to flood future refuge	Intake might be on Los Rios Farm property depending on the best location
2B	Meet depths with pond and connecting channel; grasses maintained by seasonal inundation	from 100 to 500 acres	Improved passage and rearing through inundated area and channel; rearing features added along upper channel	No changes foreseen	Potential impacts on ditches used for agriculture or to flood future refuge	Intake might be on Los Rios Farm property depending on the best location; flooding impacts (see next box)
2C	Meet depths with pond and connecting channel; grasses maintained by seasonal inundation; other species may replace grass along annually wetted channel	from 100 to 500 acres	Improved passage and rearing through inundated area and new channels; rearing features along constructed channel	Loss of attraction flow from headpond; compensate with improvements along new channel	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location; flooding impacts (see next box)
2D	Meet depths with pond and connecting channel; grasses maintained by seasonal inundation; other species may replace grass along annually wetted channel	from 100 to 500 acres	Improved passage and rearing through inundated area and new channels; rearing features along constructed channel	Loss of attraction flow from headpond; compensate with other ponds; improvements along new channel	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location; flooding impacts (see next box); new headponds
Channel Alignment C -- Floodplain Inundation and Passage along Channel through Tule (Glide) Ranch						
3A	Shallow slope allows creation of inundated habitat along alignment; potential seasonal ponding in sinks; attraction flows may be partly stored in ponds and marshes	up to 1,000 acres	Improved passage and rearing through inundated area and new channels; rearing features along constructed channel	No changes foreseen	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location
3B	Shallow slope allows creation of inundated habitat along alignment; potential seasonal ponding in sinks or marshes raises concerns for trapping and mosquito control; attraction flows may be partly stored in ponds and marshes	up to 1,000 acres	Improved passage and rearing through inundated area and new channels; rearing features along constructed channel	No changes foreseen	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location
3C	Shallow slope allows creation of inundated habitat along alignment; potential seasonal ponding in sinks or marshes raises concerns for trapping and mosquito control; attraction flows may be partly stored in ponds and marshes	up to 1,000 acres	Improved passage and rearing through new channel	Loss of attraction flow from draining headpond; improve passage with in-channel features; pumping or water purchase for attraction flows	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location
3D	Shallow slope allows creation of inundated habitat along alignment; potential seasonal ponding in sinks or marshes raises concerns for trapping and mosquito control; attraction flows may be partly stored in ponds and marshes	up to 1,100 acres	Improved passage and rearing through new channel	Loss of attraction flow from draining headpond; compensate with storage in other ponds; in-channel features along new channel; pumping or water purchase	Project occupies a larger area of wildlife refuge	Intake might be on Los Rios Farm property depending on the best location

Table 5-3--Continued

Assessment of Alternatives					
Alt. #	**Potential Impacts on Frequency of Inundation**	**Geomorphic Evolution**	**General Comments**	**Relative Cost**	**Overall Ranking**
Channel Alignment A -- Floodplain Inundation and Passage along Existing Putah Creek Channel					
1A	None	Potential sedimentation of constructed floodplain area when water levels are high; damage during floods	Large excavation volumes; not easily reversible	Moderate	Low; does not meet minimum area; vegetation may not survive summer inundation
1B	None; upstream water levels may be lowered by the large channel	Backwater sedimentation from Yolo Bypass; may require frequent maintenance; flood damage	Large excavation volumes; not easily reversible	Moderate	Moderate; maintenance and potential for damage from floods passing down Putah Creek reduce ranking
1C	Potential inundation from overbank flow upstream of dam from earlier installation of flashboards	Minor sedimentation in headpond from earlier installation of flashboards	Smalller excavation volumes; reversible	Low	Low; does not meet minimum area; requires fish passage structure for splittails
1D	Potential inundation from overbank flow upstream of dam from earlier installation of flashboards	Minor sedimentation in headpond from earlier installation of flashboards	Smalller excavation volumes; reversible	Low	Moderate; does not meet minimum area; protected from floods; relatively low costs; improvements for juvenile chinook
Channel Alignment B -- Floodplain Inundation and Passage along Channel around South Wildlife Area					
2A	None	No changes foreseen	Deep cut for intake to function under a range of water levels; pond created by excavation and berms	Moderate	Moderate; meets area and other criteria; relatively low cost; difficult intake design reduces ranking for this alternative
2B	Potential inundation from overbank flow upstream of dam from earlier installation of flashboards	Minor sedimentation in headpond from earlier installation of flashboards	Pond created by excavation and berms	Moderate	High; meets area and other criteria at relatively low cost
2C	Potential increases in inundation; new field berms along creek up to Rd 106A might be needed	Potential requirement for flushing of sediment from headpond down Putah Creek channel; sediment may be deposited in new channel	Large channel may interfere with ditches and other irrigation structures; large excavation volume	High	Moderate; meets area and other criteria but new channel would provide little inundated floodplain habitat for the increased cost
2D	Potential increases in inundation; new field berms along creek up to Rd 106A might be needed	Potential sedimentation along constructed channel and Putah Creek; no longer feasible to flush sediment from abandoned Putah Creek channel	Large excavation volumes; complex design and construction; may require initial maintenance and adjustment	High	Moderate; meets area and other criteria but new channel would provide little inundated floodplain habitat for the increased cost
Channel Alignment C -- Floodplain Inundation and Passage along Channel through Tule (Glide) Ranch					
3A	None	Little potential for sedimentation from diverted flows; no changes expected to Putah Creek or new channel	Deep cut for intake to function under a range of water levels; seepage losses a concern	Moderate	Moderate; meets area and other criteria but provides no benefit for adult passage; restores only low-flow floodplain function
3B	Potential inundation from overbank flow upstream of dam; new field berms along creek up to Rd 106A might be needed	Little potential for sedimentation from diverted flows; no changes expected to Putah Creek or new channel; minor sedimentation in headpond	Reversible; seepage losses a concern	Moderate	Moderate; meets area and other criteria but provides no benefit for adult passage; restores only low-flow floodplain function
3C	Potential inundation from overbank flow upstream of dam; new field berms along creek up to Rd 106A might be needed	Potential requirement for flushing of sediment from headpond down Putah Creek channel; sedimentation in new channel	Large excavation volumes; requires berms for flood protection; complex intake design for low, flood flows and fish passage; seepage and evaporation losses a concern; habitat features added; legal issues	High	Moderate; restores Putah Creek, meets maximum area and other criteria; full flow regime on floodplain; complex intake design reduces ranking for this alternative
3D	Potential inundation from overbank flow upstream of dam; new field berms along creek up to Rd 106A might be needed	Potential sedimentation along constructed channel; old Putah Creek will fill with sediment; new vegetation species along channel	Large excavation volumes; requires berms for flood protection; complex design to rejoin new channel to existing Putah Creek channel on Los Rios Farm; maintenance issues; seepage and evaporation losses a concern; habitat features added; legal issues	High to Very High	High; meets maximum area and other criteria; full flow regime on floodplain

- Alignment B: Alternative 2B provided seasonal inundated floodplain habitat that exceeded the minimum target area of 100 acres, met other biological criteria and had relatively low construction costs compared to the other alternatives for this alignment. Reconstruction of Putah Creek along this alignment was not favored because the alignment is relatively steep.
- Alignment C: Alternative 3D provided inundated floodplain habitat that met the target maximum area of about 1,000 acres as well as meeting other biological criteria. This alternative is relatively expensive but re-construction of a new Putah Creek channel provided better inundated floodplain habitat and fish passage than diversion of seasonal flows.

ADOPTED ALTERNATIVES FOR CONCEPT DESIGN

The three highest-ranking alternatives in Table 5-3 were selected for further conceptual design. These alternatives cover a broad range of project cost, technical and legal complexity and approaches to floodplain inundation. When comparing these three alternatives against project goals (Table 5-4) the following general results emerge:

- Alternative 1D provides less total area than the minimum target area;
- Alternatives 1D and 2B maintain existing upstream passage and improve smolt outmigration, whereas Alternative 3D improves both upstream and downstream passage, but requires storage to maintain fall attraction flows;
- All three alternatives meet the criteria for indundated floodplain along channels;
- All three alternatives meet the criteria for inundated floodplain through ponds;
- All three alternatives meet the criteria for velocities along the connecting channels; and
- Flow pulses needed to attract splittail spawners may be reduced by storage in Alternatives 2B and 3D.

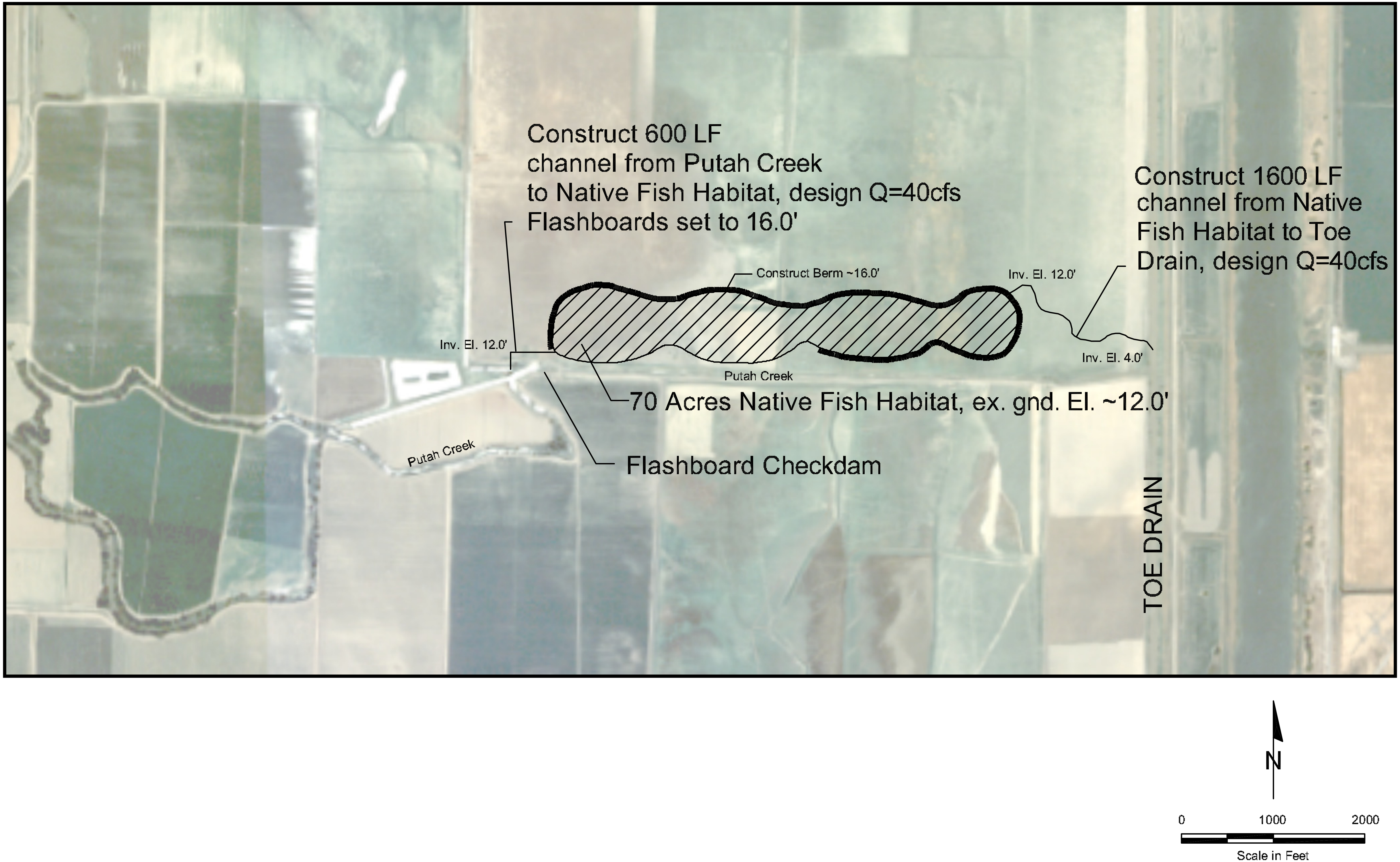
The sections following provide more detailed conceptual designs, hydraulic analyses, and geomorphic evolution and sediment analyses for the three alternatives.

Alternative 1D Concept Design

Alternative 1D would divert flows from Putah Creek— during time periods when splittail and other species would benefit—from the north side of the pool just upstream of the check dam (Figure 5-7). The intake would consist of a culvert, pipe, or channel with a gate or valve so that the diversion flows can be shut off to drain the inundated floodplain site after spawning, incubation and initial rearing. The flows for floodplain inundation would either be from Putah Creek Settlement Agreement flows, water pumped to the headpond of the check dam from the Toe Drain by the CDFG, nearby wells, Putah Creek water obtained by a water transfer agreement from a riparian user or a North Delta Canal water user, or from a combination of these sources. The intake capacity might be set to take advantage of flood flows that occasionally pass down Putah Creek in February and March, providing deeper and more extensive inundation for

Table 5-4. Characteristics of the Inundated Floodplain Area for Putah Creek Alternatives

	Description of Alternative				Fish Passage		Inundated Floodplain along Channel				Inundated Floodplain in Ponds				Channel to Toe Drain			Hydrology	
Alt. #	Intake	Operations and Maintenance	Nature of Floodplain Inundation	Approx. Total Area (ac)	Upstream Passage	Down-stream Smolt Migrants	Length (ft)	Area (ac)	Velocities	Depths	Area (ac)	Volume (ac-ft)	Depths (ft)	Residence Time (days)	Length (ft)	Average Velocities (ft/s)	Depth (ft)	Splittail Attraction Flows	General Comments
1D	Maximum capacity set to attraction flows released under Putah Creek Settlement flows.	Earlier installation of flashboards in some years to maintain water levels for intake. Operate diversion gate and arrange for pumping to supplement flows from Putah Creek as required.	Overbank flow in channel on left bank of Putah Creek. Constrictions in channel vary depths and water levels.	70	Along existing Putah Creek channel; conditions similar to those now occurring. Attraction flows from removal of flashboards.	Through inundated floodplain habitat when it operates.	6,000	70	Variable; may be up to 2 to 3 ft/sec through constrictions, depending on design.	Maximum of 3 feet along main channel; variable on floodplain.	N/A	N/A	N/A	About 2 days in main channel.	1,600	2.7	2	Part of attraction flows will fill channel storage. Floods may supplement attraction flows some years.	Channel will fill and drain over a period of a few days.
2B	Maximum capacity set to attraction flows released under Putah Creek Settlement flows.	Earlier installation of flashboards in some years to maintain water levels for intake. Operate diversion gate and arrange for pumping to supplement flows from Putah Creek as required. Maintenance and repair of south drain.	Inundation of low area in Yolo Bypass close to the Toe Drain. Water levels maintained by narrow outlet channel.	580	Along existing Putah Creek channel; conditions similar to those now occurring. Attraction flows from removal of flashboards.	Through inundated floodplain habitat when it operates.	N/A	N/A	N/A	N/A	580	1,160	Maximum depths over 2 feet; depths vary with local topography and constructed islands.	About 15 days in pond.	1,600	2 to 2.5	2.2	Attraction flows will fill storage in pond. Floods may fill storage and provide attraction flows some years. Potential to add outlet structure to release attraction flows.	Large storage volumes willl result in depths gradually increasing to maximum. Period of pond inundation will be greater than 30 days, with depths slowly declining after inflows stop.
3D	New channel joins Putah Creek upstream of check dam. Channel capacity set to design flow from Putah Creek, achieved before Yolo Bypass is inundated.	Either maintain check dam with boards up or remove dam and fill Putah Creek downstream of check dam. Part of existing Putah Creek maintained to supply head pond. Sediment, erosion and flooding management in new and existing channel. Development of storage for release of fall attraction flows from new facility.	Overbank flow along low flow channel in new Putah Creek and inundation of low area in Yolo Bypass close to Toe Drain.	1,100	Improved passage along the new Putah Creek channel. Attraction flows require development of new storage.	Along recon-structed Putah Creek channel.	20,000	150	1 to 1.5 ft/sec in main channel.	Maximum over 2 feet at low flows; over 5 feet at high flows; variable on floodplain.	950	1,900	Maximum depths over 2 feet; depths vary with local topography and constructed islands.	About 24 days in pond.	1,600	2 to 2.5	2.2	In dry years, attraction flows will fill storage along channel and in pond. Floods may fill ponds and provide attraction flows in some years. Potential to add outlet structure to pond to release attraction flows.	Large storage volumes willl result in gradually varying depths in inundated pond over the period of splittail spawning, incubation and rearing and an inundation period longer than 30 days.



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Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Figure 5-7

Alternative 1D, Floodplain Inundation Plan
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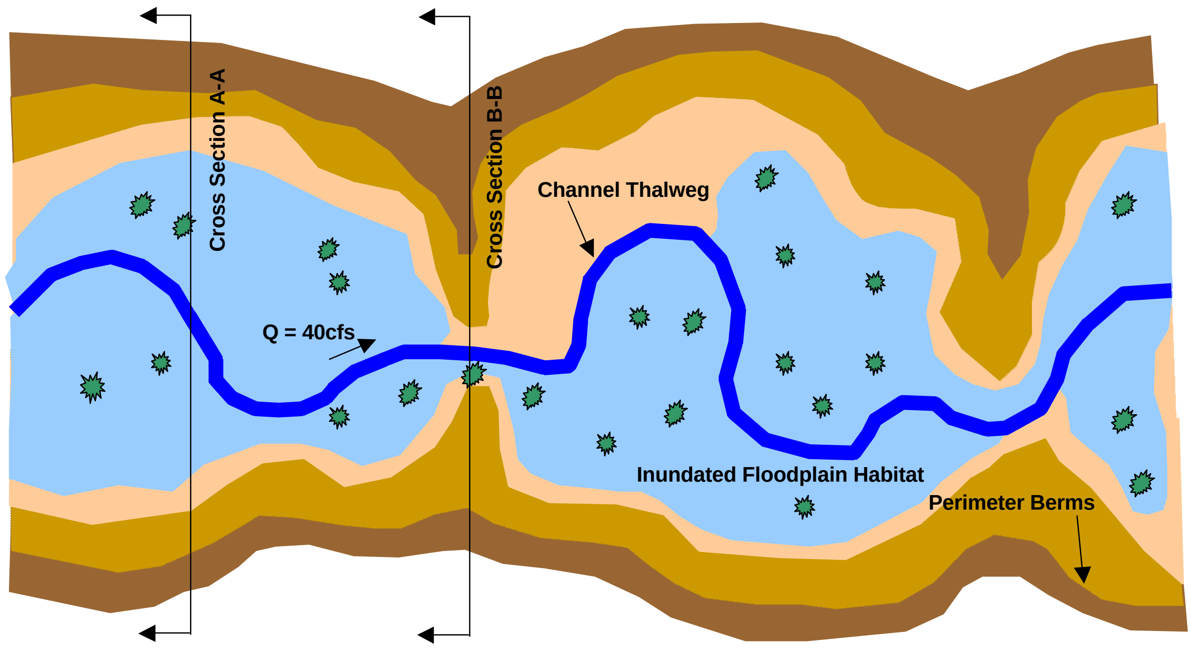
part of the spawning period or providing attraction flows. If the project is only to operate during dry years, then cost savings might be achieved by sizing the intake to the minimum flows required for its operation, which are currently the high flow pulse released from the Putah Creek Diversion Dam and the sustained flow of 40 cfs. It would be prudent to ensure that the project also functions at lower flows to maintain benefits if the minimum sustained flow are not available some years. Further hydrologic and biological benefit analysis during detailed design would be required as part of design.

The floodplain inundation site would be on the left bank of Putah Creek at elevations of approximately 12 to 14 feet (Figure 5-3). The project would consist of a low gradient channel on the upper bench that provides the spawning habitat, connected to the Toe Drain at elevation 4 feet by a narrow, steeper channel that maintains depths at the downstream end of the inundated area and provides upstream passage for migrating splittail adults (Figure 5-8). The bottom of the main channel would be set at a constant grade, without pools or other features, so that it drains completely to the Toe Drain when inflows are shut off.

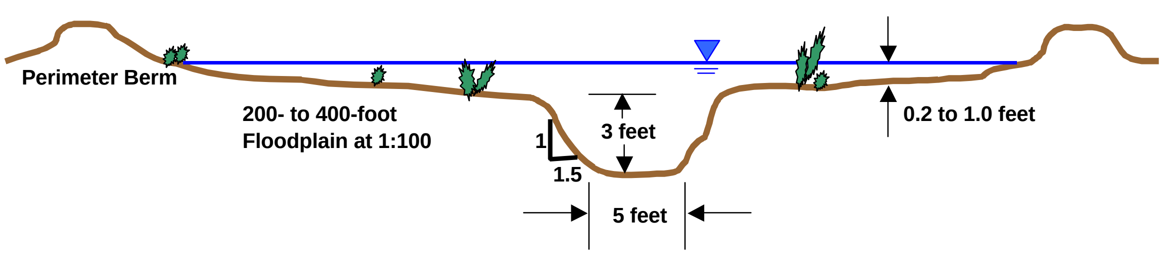
The basic concept for the floodplain inundation site is to provide a narrow, grassed main channel with maximum depths of about 3 feet or so, and a broad, low-slope, grassed floodplain graded so that it drains to the main channel (Figure 5-8). Waters would be contained by low berms, as required, constructed from the material excavated from the main channel. Constrictions across the floodplain would raise local water levels, varying the water surface profile and creating local deeper areas on the floodplain. The spacing and dimensions of these constricting berms would be set during detailed hydraulic design. The inundated area would appear to be a “string-of-beads” series of ponds.

When modeling Alternative 1D, the geometry of the downstream channel was assumed to be trapezoidal in shape with a bottom width of 5 feet and side slopes of 1.5 to 1. The energy slope was calculated assuming an upstream channel invert elevation of 12 feet (NAVD 1988) and a downstream invert elevation of 4 feet. For a 1,600-foot channel, this resulted in a channel slope of 0.005 feet per foot. The channel was assumed to be quite rough (n=0.045) due to thick vegetation that would likely grow there. For a 40 cfs discharge, the normal depth of the channel was calculated to be about 2 feet. Because the outlet channel would control the depth of the inundation site, and because the invert of the site cannot be lower than that of the channel in order to achieve full drainage, the downstream end of the site would be limited to the same 2-foot depth as calculated for the channel. However, deeper sections could be achieved further upstream by either restricting the channel or the installation of small weirs.

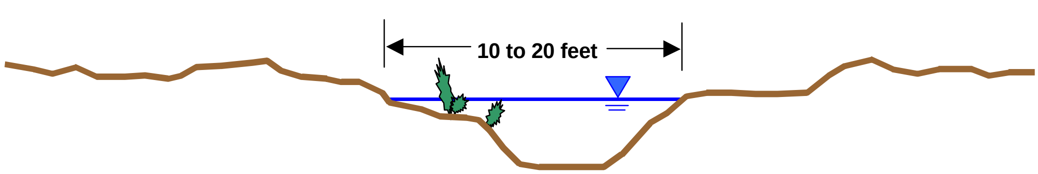
Alternative 1D would require modification of the existing operation of the check dam and operation of the diversion. It would be necessary to install all the flashboards at the check dam and raise the pond level in order to divert inundation flows. If Putah Creek Settlement Agreement flows are diverted for inundation, the boards might typically be installed in late March; if water is pumped from the Toe Drain, natural flows or other sources are utilized, then installation might occur earlier, perhaps by mid-February, to better meet timing requirements for native fishes. In either case, further hydraulic analysis would be recommended to evaluate upstream flooding with the flashboards in place and potential scour downstream of the structure when it is overtopped. The diversion gate or valve would be opened when flows are available and then closed after native fish spawning and initial rearing is complete. A representative of CDFG or another organization would monitor flows, install the flashboards on the check dam,



Habitat Restoration Concept
Alternative 1D



Cross Section A-A
(not to scale)



Cross Section B-B
(not to scale)

Figure 5-8.
Alternative 1D, Inundation Concept and Typical Cross Sections

pump water as required, and operate the diversion gate during dry years when the Yolo Bypass is not inundated and managed floodplain inundation is required. An operating manual for managing and maintaining the floodplain inundation habitat would be required as part of design.

Table 5-4 describes the typical characteristics of the inundated floodplain provided by the three Putah Creek alternatives and indicates how they meet the design criteria described earlier. For Alternative 1D, the maximum inundated area that would be provided for native fishes is estimated to be about 70 acres. It would take about 2 days to fill the inundated floodplain, absorbing most of the attraction flows provided by the Putah Creek Settlement that reach the check dam (see earlier section on Project Hydrology). Natural flood flows on Putah Creek might provide attraction flows in some years. At steady state, depths and velocities would vary over the project, with maximum depths exceeding two feet along the main channel. Velocities along the access channel from the Toe Drain would average 2.7 feet/second. These are thought to be sufficiently low for upstream migration by adult splittail. However, utilization of the habitat requires the splittail to migrate about 1,600 feet from the Toe Drain against these velocities and this may affect the ultimate utilization of the inundated floodplain habitat provided by Alternative 1D. Concept-level costs are summarized in Table 5-5; a later section provides details on the assumptions that underlie these costs.

The following issues would require further investigation during the next stages of design:

- The discharge point for water from Putah Creek would remain at, or very near, the mouth of the existing Putah Creek. Chapter 6 discusses potential implications for the Settlement Agreement.
- Potential flooding upstream of the check dam might result from earlier installation of flashboards. This is discussed further in a later section of this chapter.
- Potential damage to the check dam or scour of the downstream channel might occur from overtopping of the check dam when flashboards are installed. Further hydrologic and hydraulic analysis would be required to identify design flows, tailwater levels, and water surface profiles for evaluation of potential scour. These analyses may indicate that protective works are required near the check dam.
- Potential changes to the Yolo Bypass flood profile need to be assessed. We anticipate that the proposed works would not significantly alter the flood profile in the Yolo Bypass. However, additional hydraulic analyses are required to confirm this tentative conclusion and identify any necessary mitigation or compensation.

Alternative 1D would only divert flow from Putah Creek during a one- to two-month period in the spring. Flood flows would be maintained in the existing Putah Creek channel. Consequently, we anticipate that the project would result in only minimal changes to the lower channel. As a result, there would be no improvements for upstream passage of fall-run Chinook salmon. Earlier installation of the flashboards may potentially cause storage of sediment behind the check dam in the spring. These sediments would then be flushed by high flows the following winter, slightly altering the sediment transport regime. The potential for changes in Putah Creek upstream of the check dam are discussed in a later section and in Appendix K.

Table 5-5. Concept-Level Costs for Putah Creek Alternatives

Alt. #	Approx. Total Area (ac)	Construction Approach	Estimated Costs: Construction Cost [1]	Estimated Costs: Haul Cost	Estimated Costs: Engineering Cost [2]	Estimated Costs: Contingency [3]	Estimated Costs: Total	Comments
1D	70	Inundated area built by combination of excavation and berms -- earthwork balanced on site	$ 600,000	$ -	$ 180,000	$ 180,000	$ 960,000	
1D	70	Inundated area built by excavation; all excavated material hauled on 2 mile round trip	$ 880,000	$ 500,000	$ 180,000	$ 180,000	$ 1,740,000	
1D	70	Inundated area built by excavation; all excavated material hauled on 20 mile round trip	$ 880,000	$ 1,400,000	$ 180,000	$ 180,000	$ 2,640,000	
2B	580	Inundated area built by combination of excavation and berms -- earthwork balanced on site	$ 2,300,000	$ -	$ 570,000	$ 570,000	$ 3,440,000	
2B	580	Inundated area built by excavation with low berms; remaining excavated material hauled on 2 mile round trip	$ 3,300,000	$ 1,700,000	$ 570,000	$ 570,000	$ 6,140,000	
2B	580	Inundated area built by excavation with low berms; remaining excavated material hauled on 20 mile round trip	$ 3,300,000	$ 4,700,000	$ 570,000	$ 570,000	$ 9,140,000	
3D	1100	Inundated area built by combination of excavation and berms -- earthwork balanced on site	$ 3,700,000	$ -	$ 750,000	$ 750,000	$ 5,200,000	Does not include costs to join the new Putah Creek channel from the check dam to the existing channel upstream or some other items
3D	1100	Inundated area built by excavation with low berms; remaining excavated material hauled on 2 mile round trip	$ 5,500,000	$ 2,600,000	$ 750,000	$ 750,000	$ 9,600,000	Does not include costs to join the new Putah Creek channel from the check dam to the existing channel upstream or some other items
3D	1100	Inundated area built by excavation with low berms; remaining excavated material hauled on 20 mile round trip	$ 5,500,000	$ 7,600,000	$ 750,000	$ 750,000	$ 14,600,000	Does not include costs to join the new Putah Creek channel from the check dam to the existing channel upstream or some other items

1. Construction costs include mobilization, channel excavation, grading, berm construction, small water control structures and vegetation.
2. Engineering costs are set at 30% of construction for balanced earthwork approach for Alternative 1D; 25% for Alternative 2B; and 20% for Alternative 3D.
3. Contingency costs are set at 30% of construction for balanced earthwork approach for Alternative 1D; 25% for Alternative 2B; and 20% for Alternative 3D.

Alternative 2B Concept Design

Alternative 2B would divert flows from Putah Creek—during the time periods suitable for native fishes such as splittail and young salmon—from the south side of the pool just upstream of the check dam (Figure 5-9). The intake would consist of a culvert, pipe, or channel with a gate or valve so that the diversion flows can be shut off to drain the inundated floodplain site after spawning, incubation and initial rearing.

The flows for floodplain inundation would either be from Putah Creek Settlement Agreement flows, water pumped to the headpond of the check dam from the Toe Drain by the CDFG, nearby wells, Putah Creek water obtained by a water transfer deal from a riparian user or a North Delta Canal water user, or from a combination of these sources. The intake capacity might be set to take advantage of flood flows that occasionally pass down Putah Creek in February and March, providing deeper and more extensive inundation for part of the spawning period or providing attraction flows. If the project is only to operate during dry years, then cost savings might be achieved by sizing the intake to the high flow pulse released from Putah Creek Diversion Dam and the sustained minimum flow of about 40 cfs. It would be prudent to ensure that the project also functions at lower flows to maintain benefits if the minimum sustained flows are not available some years. Further hydrologic and biological benefit analysis would be required during detailed design.

Water from the intake would be diverted into a constructed ditch that leads to the existing South Drain. Water would then be diverted into the inundation site from the South Drain. The South Drain would be upgraded as required, removing accumulated sediment and beaver dams to restore capacity, and the control structure at the outlet to the Toe Drain would be repaired so that the floodplain area could be inundated. Water could be pumped directly to the project site from the Toe Drain with a temporary facility in the South Drain though it might be expensive to provide the minimum flow of 40 cfs with this approach.

The inundation site would be on the right (south) bank of the existing South Drain near the Toe Drain, at elevations of approximately 9 feet (NAVD 1988; Figure 5-9). The site consists of an existing area of low floodplain that would be ponded so that maximum depths exceed 2 feet. Perimeter berms may be required to contain water in the inundation area. Existing surveys are not sufficiently detailed to indicate the extent or elevation of berms that would be required (Figure 5-3). The inundation area would be connected to the Toe Drain at elevation 4 feet by a narrow channel that maintains depths of 2 feet or so at the downstream end of the inundated area and provides upstream passage for migrating fishes (Figure 5-10). The crest invert of the outlet channel would be set to typical low elevation in the inundation area so that complete drainage is possible. The outlet channel would not have pools or other depressions so that it drains completely to the Toe Drain when flows are shut off.

The basic concept for the floodplain inundation site would be to pond water over an existing grassed floodplain along the Toe Drain to maximum depths of about 2 feet under steady state inflows (Figure 5-10). Minor grading of existing topography would be anticipated as part of the project to fill depressions and develop variability in the pond bottom. Berms would be constructed from local floodplain material and small islands or other features added to the pond to vary depths in the inundated area and maximize shoreline length. The inundated area would appear as a large pond with vegetated islands.

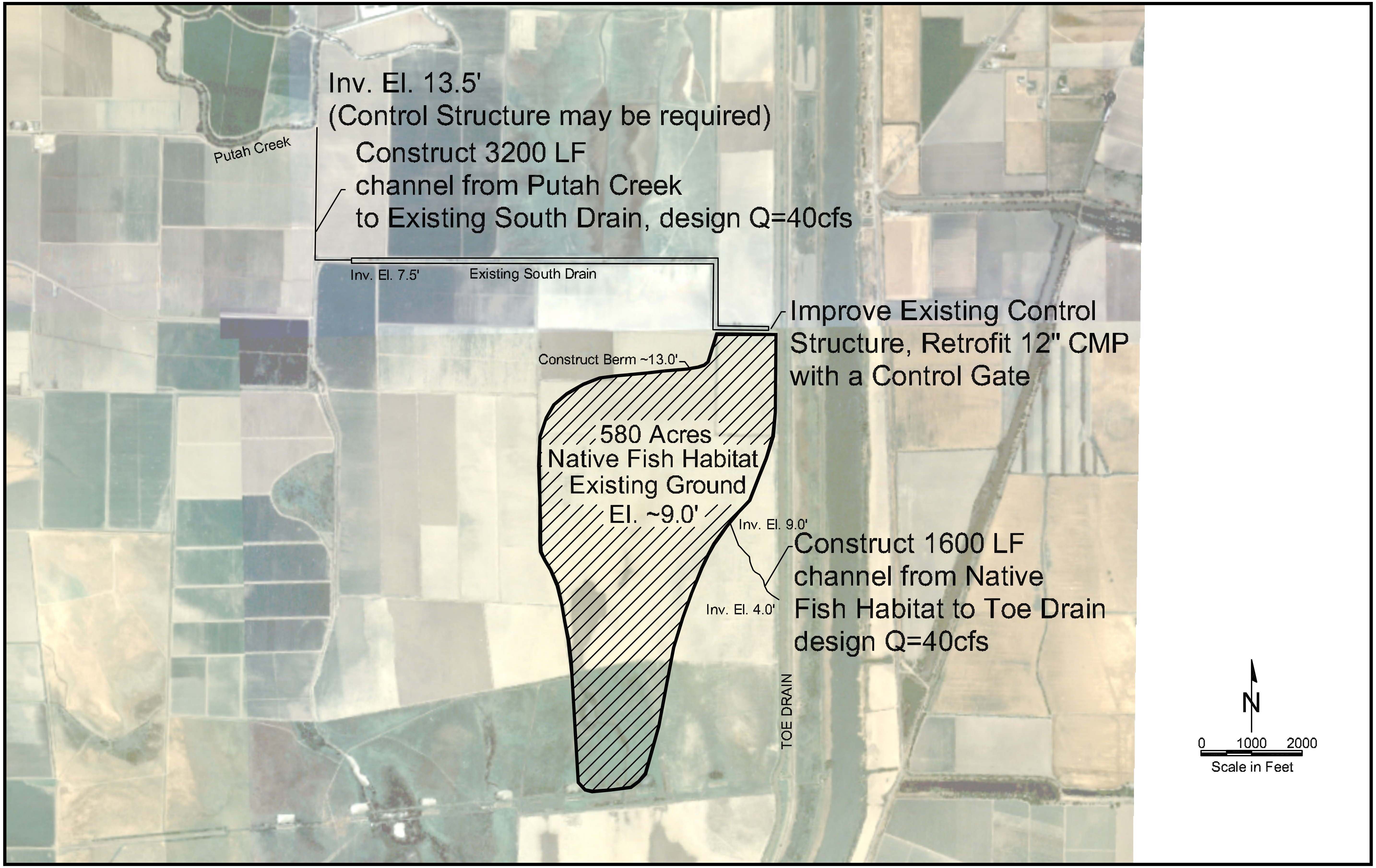


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Figure 5-9

Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Alternative 2B, Floodplain Inundation Plan
December 18, 2002

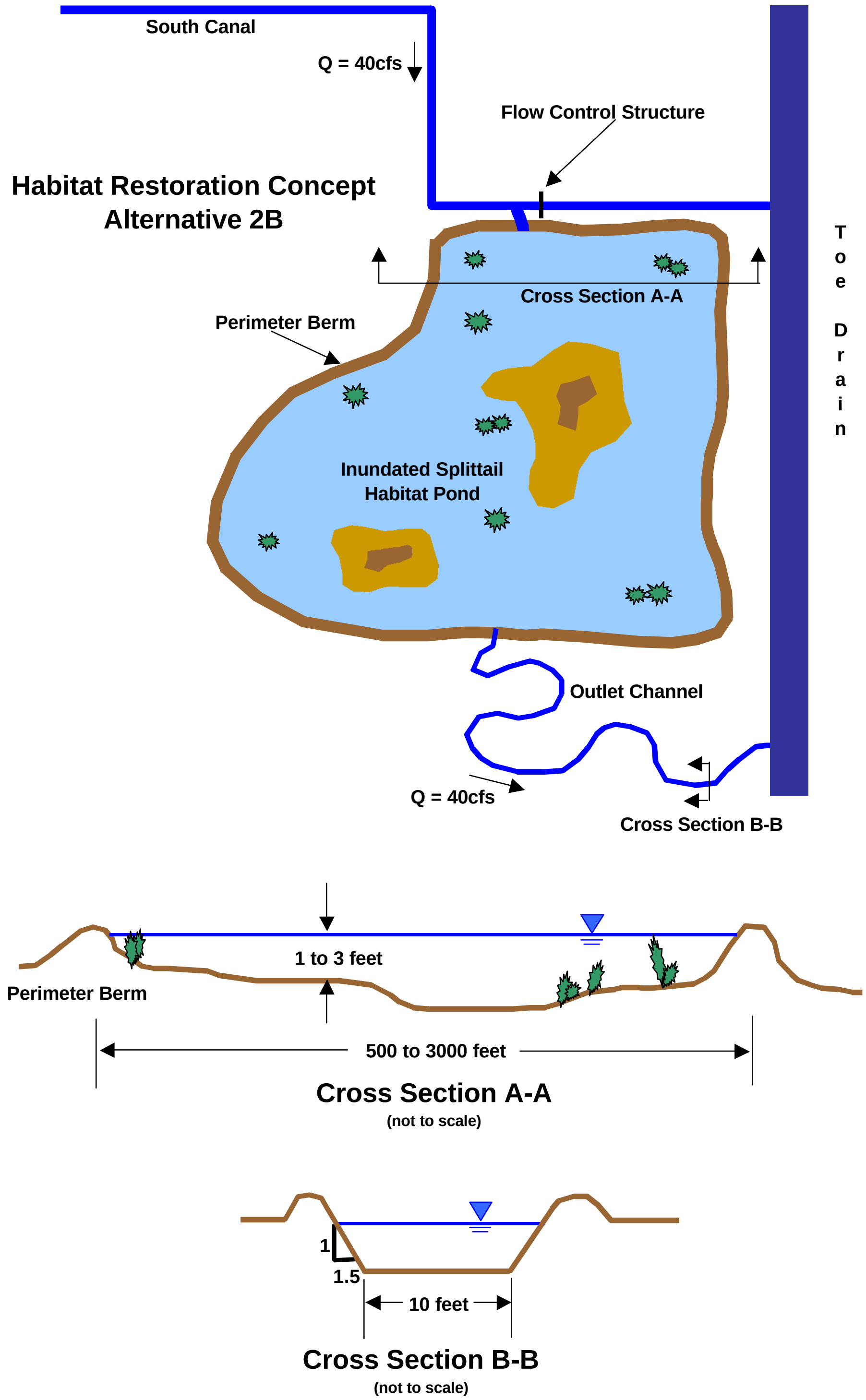


Figure 5-10.
Alternative 2B, Inundation Concept and Typical Cross Sections

Alternative 2B would require modification of the existing operation of the check dam and operation of the diversion, similar to Alternative 1D. It would be necessary to install all the flashboards at the check dam and raise the pond level in order to divert inundation flows. If Putah Creek Settlement Agreement flows are diverted for inundation, the boards might typically be installed in late March; if water pumped from the Toe Drain to the check dam pond or natural flows are utilized, then installation might occur earlier, perhaps by mid-February, to better meet splittail timing requirements. In either case, further hydraulic analysis would be recommended to evaluate upstream flooding with the flashboards in place and potential scour downstream of the structure when it is overtopped.

The diversion gate or valve would be opened when flows are available and then closed after fish spawning, incubation and initial rearing is complete. A representative of CFDG or another organization would monitor flows, install the flashboards on the check dam, pump water as required, and operate the diversion gate during dry years when the Yolo Bypass is not inundated and managed floodplain inundation is required. Maintenance of the South Drain would also be required, particularly to prevent blockage by beavers. An operating manual for managing and maintaining the floodplain inundation habitat would be required as part of design. As noted above, one alternative might be to install temporary pumps in the South Drain and provide water directly to the inundation site. Such an approach would eliminate the early installation of the flashboards and operation of the diversion gate at the check dam, but may not easily meet minimum flow requirements, resulting in a shallower pond.

Table 5-4 describes the typical characteristics of the inundated floodplain provided by Alternative 2B. The maximum inundated area that would be provided for native fishes is estimated to be about 580 acres. Either altering the outlet channel dimensions or shortening the perimeter berms could provide a smaller inundation area. Depths would vary over the project, with maximum depths exceeding two feet. Velocities would be very low throughout the pond (except near the inlet from the south drain).

A 580-acre pond would have a residence time of about 15 days, assuming a constant inflow of 40 cfs. Consequently, it would require at least that long to fill the pond, assuming average depths of 2 feet and minimal outflow from the pond, and about the same time period to drain the pond. The large storage volume would absorb attraction flows released as part of Putah Creek Settlement flows that reach the check dam and initial discharges from the pond would be less than the 40 cfs inflow, unless large natural flows occur on Putah Creek, gradually increasing to this maximum value as the pond fills. Depths would not be constant over the entire 30-day inflow period. Further detailed analysis would be required to predict pond depths over time and the outflow hydrograph, given attraction flow releases, natural floods, and a constant 30-day inflow. Ultimately, the pond volume might be adjusted to the best compromise between pond depth, residence time and the outflow hydrograph. One other alternative would be to install a flow control structure at the pond outlet to speed pond filling and allow release of an “attraction” flow. Such a structure would be removed prior to migration.

The geometry of the downstream channel for Alterative 2B was assumed to have a base width of 5 feet and side slopes of 1.5 to 1. The energy slope of the channel was calculated using the ground elevation at the site (about 9 feet NAVD 1988) and a channel invert of 4 feet at the Toe Drain over a 1,600-foot channel (0.0031 feet/foot). A roughness coefficient of n=0.045 was chosen to represent the dense vegetation that would likely grow in the channel. Using the

Manning formula, a normal channel depth of 2.2 feet was calculated for a discharge of 40 cfs in the channel. Because the depth of the inundation site would be controlled by the water surface elevation of the channel, inundation levels would also be limited to about 2.2 feet when water levels in the Toe Drain are low. Deeper inundation levels could be achieved by lengthening the channel or by installing small flow control structures. Typical velocities along the access channel from the Toe Drain would average 2.0 to 2.5 feet/second. These are thought to be sufficiently low for upstream migration by adult splittail. However, utilization of the habitat requires the adult fishes to migrate 1,600 feet from the Toe Drain against these velocities and this may affect the ultimate utilization of the inundated floodplain habitat provided by Alternative 2B. Concept-level costs are summarized in Table 5-5; a later section provides details on the assumptions that underlie these costs.

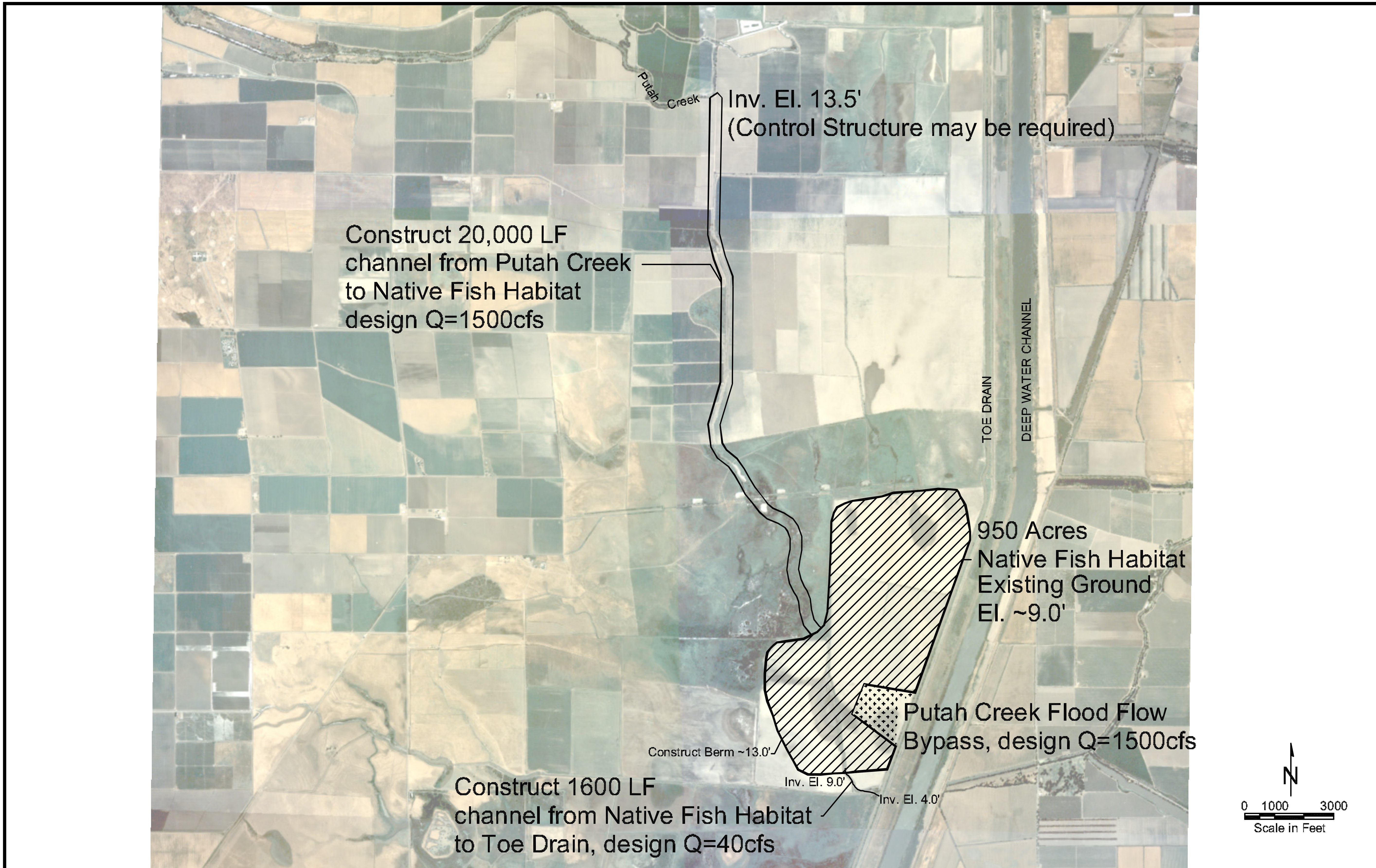
The following issues would require further investigation during the next stages of design:

- The discharge point for water from Putah Creek during late winter and early spring would be moved downstream along the Toe Drain. Chapter 6 discusses potential implications for the Settlement Agreement.
- Potential flooding upstream of the check dam might result from earlier installation of flashboards. This is discussed further in a later section of this chapter. As discussed, pumping directly to the project site from the Toe Drain would eliminate these potential impacts.
- Potential damage to the check dam or scour of the downstream channel might occur from overtopping of the check dam when flashboards are installed. Further hydrologic and hydraulic analysis would be required to identify design flows, tailwater levels, and water surface profiles for evaluation of potential scour. These analyses may indicate that protective works are required near the check dam.
- Potential changes to the Yolo Bypass flood profile need to be assessed. We anticipate that the proposed works would not significantly alter the flood profile in the Yolo Bypass. However, additional hydraulic analyses are required to confirm this tentative conclusion and identify any required mitigation or compensation.

Alternative 2B would only divert flow from Putah Creek during a one- to two-month period from February through April. Fall and winter flood flows would be maintained in the existing Putah Creek channel. Consequently, we anticipate that the project would result in only minimal changes to the lower channel. However, this alternative would do nothing to improve upstream passage of fall-run Chinook salmon. Potentially, earlier installation of the flashboards may result in storage of sediment behind the check dam in the spring. These sediments would then be flushed by high flows the following winter, slightly altering the sediment transport regime. The potential for changes in Putah Creek upstream of the check dam are discussed in a later section of this chapter and in Appendix K.

Alternative 3D Concept Design

Alternative 3D would essentially replace the lower, excavated portion of Putah Creek with a new channel to the south of the present alignment (Figure 5-11). The new channel could potentially be located on a variety of alignments and arrangements. The arrangement shown on Figure 5-11 allows all construction to occur on CDFG lands.



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Habitat Improvement Plan for Native Fish in the Yolo Bypass
Feasibility Report

Figure 5-11

Alternative 3D, Floodplain Inundation Plan
December 18, 2002

Under Alternative 3D, a new channel would connect to the existing Putah Creek some distance upstream of the check dam, providing a smooth transition between the existing and new channel profiles. Considerable further discussion would be required to select and design an appropriate new channel alignment and connection to the existing Putah Creek and may require negotiation with Los Rios Farms regarding construction on their property. Such an approach would also require maintaining part of the existing Putah Creek channel to convey Putah Creek irrigation water to canal intakes behind the check dam or construction of new diversions and head ponds for water delivery to Los Rios Farms and the Wildlife Area. Storage in new ponds created to convey irrigation water or to store water for flow releases might be used for a fall attraction flow for adult Chinook, replacing that created by removing the flashboards at the existing check dam.

The flows for floodplain inundation would either be from natural flows or Putah Creek Settlement Agreement flows, water released from new headponds along Putah Creek, water pumped to the headpond of the check dam from the Toe Drain by CDFG, nearby wells, Putah Creek water obtained by a water transfer deal from a riparian user or a North Delta Canal water user, or from a combination of these sources.

Water would be diverted into a 4-mile-long new Putah Creek channel with a capacity of about 1,500 cfs that flows south, joining together existing marshes and sinks. The channel would consist of a low-flow main channel with 150-foot floodplains on either side. The main channel was assumed to be trapezoidal with a base width of 10 feet and side slopes of 2 to 1. The energy slope of the channel was assumed to be about equal to the average ground slope along the channel alignment, or 0.00035 feet/foot. The 150-foot floodplains were assumed to be densely vegetated, and a roughness coefficient of n=0.045 was used. However, the main channel was assumed to be cleaner due to regular inundation, resulting in a roughness value of n=0.030. Applying the Manning formula to the channel results in normal depths of 2.2 feet and 5.7 feet for discharges of 40 and 1,500 cfs, respectively. Existing sinks and depressions along the alignment may retain water and not drain completely at the completion of the one month inundation period. Flood flows would inundate the low flow channel and filling to the crest of the containment berms on each side of the channel; capacity might also be achieved by excavation, depending on local topography relative to the adopted invert profile for the new Putah Creek. This new channel maintains about the same capacity as the existing Putah Creek; however, greater or lesser capacities may be adopted during detailed design, depending on the land uses ultimately selected for the Tule (Glide) Ranch.

The new channel would flow into a large inundation site near the Toe Drain, at elevations of approximately 9 feet (Figure 5-11). The site consists of an existing low floodplain that would be inundated to maximum depths of about 3 feet. Perimeter berms may be required to contain water in the inundation area. Existing surveys are not sufficiently detailed to indicate the extent or elevation of berms that would be required (Figure 5-3). The inundation area would be connected to the Toe Drain at elevation 4 feet by a narrow channel that maintains depths of 2 to 3 feet at the downstream end of the inundated area and provides upstream passage for migrating fishes (Figure 5-12). The outlet channel for Alternative 3D was assumed to have the same geometry as those presented in Alternatives 1D and 2B. The crest invert of the channel would be set to typical minimum elevations in the inundation area so that complete drainage is possible. The outlet channel would not have pools or other depressions so that it drains completely to the Toe Drain when flows recede in the late spring and early summer.

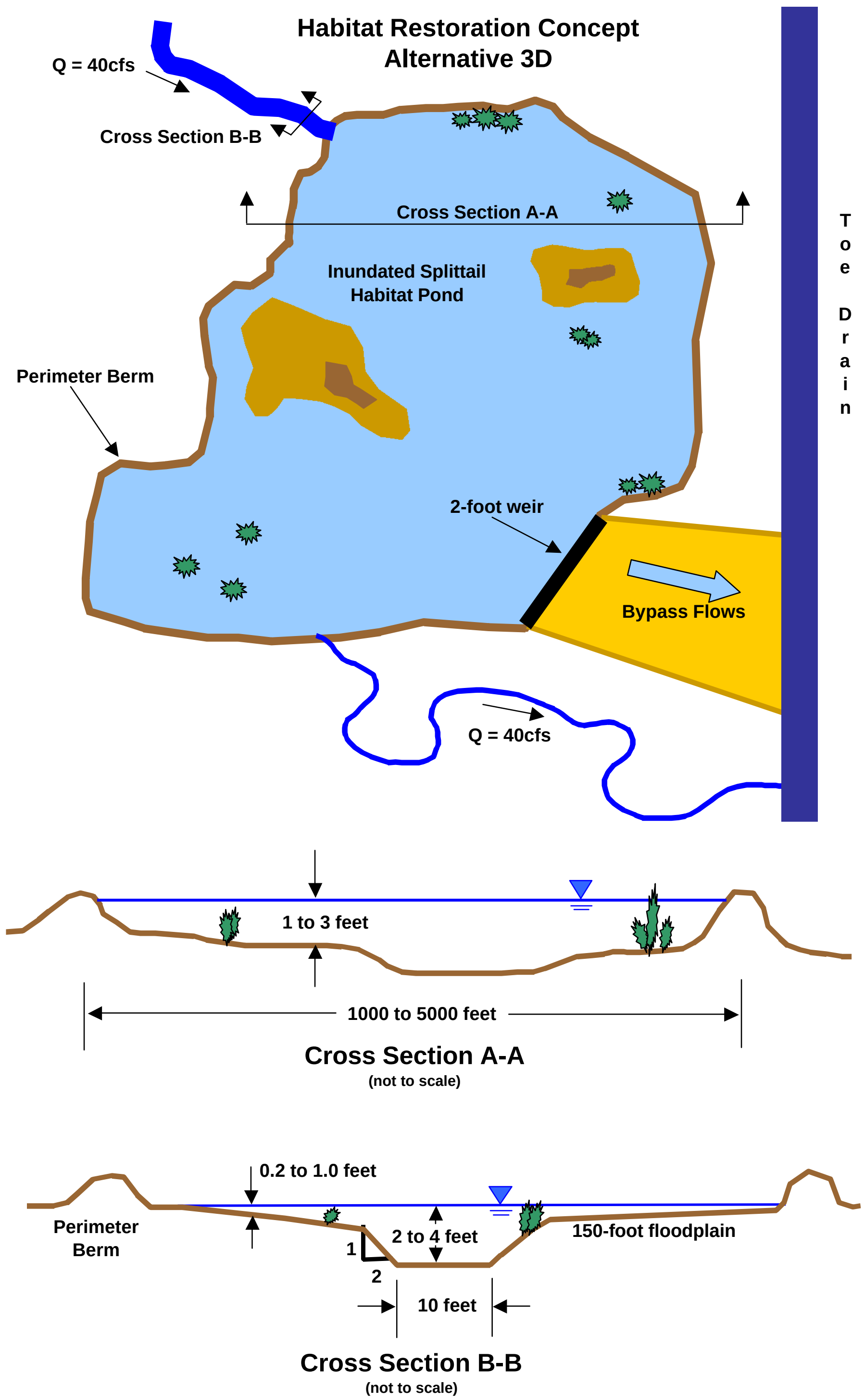

Figure 5-12.
Alternative 3D, Inundation Concept and Typical Cross Sections

Flood flows would pass through the pond and discharge to the Toe Drain over a low weir (Figure 5-12). These flows may provide attraction flows and contribute to filling of the inundated floodplain habitat near the Toe Drain during some years. The general arrangement of the weir and its discharge capacity would be determined during detailed design.

The basic concept for the floodplain inundation site would be to submerge existing grassed floodplain along the Yolo Bypass to maximum depths of about 2 feet or so under steady state inflows. Minor grading of existing topography to fill depressions would be anticipated as part of the project. Berms would be constructed from local floodplain material and small islands or other features added to the floodplain to vary depths in the inundated area and maximize shoreline length.

Alternative 3D would eliminate annual operation of the check dam. Either the flashboards would remain in place all year to maintain water levels for the diversion, or the dam removed and the lower channel filled, while maintaining the headpond. Maintenance of the new channel may be required to remove blockage by beavers and to manage sediment accumulation.

Table 5-4 describes the typical characteristics of the inundated floodplain provided by the new channel including the large inundated area near the Toe Drain. The maximum inundated area that would be provided for fish habitat is estimated to be about 1,100 acres, with most situated near the Toe Drain.

The maximum inundated area along the constructed channel for native fishes is estimated to be about 140 acres. It would take about 4 days to fill the inundated floodplain assuming a constant inflow of 40 cfs, absorbing all of the attraction flows that might be provided by the Putah Creek Settlement Agreement. At steady state, depths and velocities would vary over the project, with maximum depths exceeding two feet along the main channel and velocities averaging 1.0 to 1.5 feet/second in the main channel. Depths and velocities would be much greater during flood discharges approaching capacity (Table 5-4). Natural floods on Putah Creek may fill some of the floodplain storage.

Depths would vary over the 950-acre inundated area near the Toe Drain, with maximum depths exceeding two feet. Velocities would be very low throughout this area. Assuming a constant inflow of 40 cfs, it would have a residence time of 24 days; in dry years it would require at least that long to fill or drain. The large storage volume would absorb attraction flows released as part of Putah Creek Settlement flows; as a result, initial discharges from the pond would be far less than the 40 cfs inflow, gradually increasing to this maximum value as the pond fills. However, flood flows in January or February may fill the large area next to the Toe Drain in some years and provide attraction flows.

Because of the large floodplain volume, in dry years, depths may vary gradually over the spawning and incubation period and the outflows would be attenuated and extended over a much longer period than the inflows. Further detailed analysis would be required to predict water depths over time and the outflow hydrograph, given attraction flow releases and a constant 30-day inflow. Ultimately, the channel shape might be adjusted to the best compromise between water depth, residence time and the outflow hydrograph. One other alternative would be to install a flow control structure at the pond outlet to speed filling and allow release of an "attraction" flow. Such a structure would be removed prior to the migration of native fishes such as adult splittail.

Velocities along the access channel from the Toe Drain would average 2.2 feet/second. These are thought to be sufficiently low for upstream migration by adult splittail. However, utilization of the habitat requires the fish to migrate about 1,600 feet from the Toe Drain against these velocities and this may affect the ultimate utilization of the inundated floodplain habitat provided by Alternative 3D. Concept-level costs are summarized in Table 5-5; a later section provides details on the assumptions that underlie these costs.

The following issues would require further investigation during the next stages of design:

- The discharge point for water from Putah Creek during late winter and early spring would be moved downstream along the Toe Drain. Chapter 6 discusses the implications for the Settlement Agreement.
- Increased flooding upstream of the check dam might result from either the new intake or the newly constructed channel. This is discussed further in a later section of this chapter and in Appendix K.
- The new channel is expected to alter the frequency of flooding of lands on the Tule (Glide) Ranch from Putah Creek. Some consideration of future land use and potential changes to floodplain vegetation would be required as part of designing the capacity of the new channel.
- Potential changes to the Yolo Bypass flood profile need to be assessed. We anticipate that the proposed works would not significantly alter the flood profile in the Yolo Bypass. However, additional hydraulic analyses are required to confirm this tentative conclusion and identify any required mitigation or compensation.

Alternative 3D would eliminate flood flows from the existing reach of lower Putah Creek between the intake for the new channel and the Toe Drain, leading to changes in the channel downstream of the check dam if it is not filled. Some flow would remain in the lowermost segment from leakage through the check dam, but that segment would be expected to gradually fill with suspended sediment during Yolo Bypass flood events.

Channel adjustments along Putah Creek upstream of the diversion point are discussed in a later section of this chapter. There is a potential for adjustments along the new channel and the existing channel depending on their relative slopes. Typically, potential degradation or other changes along the upstream end of the new channel would be managed either by design of the transition slopes or by providing erosion resistant linings along the channel near the transition point.

Concept-Level Costs

Table 5-5 summarizes costs for the three preferred alternatives. For each alternative, costs are provided for three construction approaches. Under the first approach, the project is constructed from a combination of excavation and berm construction with no material hauled from the site. The other approaches require hauling of material from the site, with round trip distances either of 2 miles or 20 miles.

For Alternative 1D, we assumed average grading of 0.5 feet over the project area for the first approach and average grading of 1 foot over the project area for the second and third approaches. For Alternatives 2B and 3D, we assumed average grading of 0.5 feet over half of the inundated area for the first approach and average grading of 1 foot over half of the project area for the second and third approaches. Re-vegetation of graded areas provided a significant component of the overall construction costs. Unit rates for excavation, hauling and revegetation were calculated from time and motion studies based on equipment rates or other rates quoted in Means 2003.

Costs for Alternative 3D do not include removal of the check dam, filling of the lower Putah Creek channel or connection of the new Putah Creek channel from the vicinity of the check dam to the existing channel upstream of the dam or for construction of ponds to store attraction falls for fall Chinook migration or other purposes.

RECOMMENDED STRATEGY

A major objective of this feasibility study was to recommend a demonstration-scale managed floodplain inundation project in the Yolo Bypass that could be implemented within the next several years. Putah Creek emerged from the screening process described in Chapter 4 as the most promising site for such a project. We recommend Alternative 3D, which would re-route the South Fork Putah Creek to a longer course through lowlands in the south, as the most suitable project to pursue.

Alternative 3D has several advantages for project development. Because it inundates a substantial area of floodplain habitat (up to 1,100 acres), it best meets the project scale needed to detect changes in the responses of aquatic organisms to managed seasonal inundation. It also creates an excellent opportunity to improve fish passage for adult salmon to migrate up Putah Creek. Alternative 3D works with existing topography to simulate the historical alignment and floodplain features of Putah Creek. Overall, the project comes closest to creating a “naturally” functioning floodplain.

If Alternative 3D were to be implemented over the next one to two years, several issues identified during concept design would need to be addressed quickly. Defining the flows from Putah Creek that are available for a floodplain inundation project is the next step prior to detailed design. One component of this analysis would be discussions with the Lower Putah Creek Coordinating Committee regarding conveyance losses from project development, instream flow criteria at the Toe Drain, and the need to provide additional water to meet them. Once the available flows from Putah Creek are defined, the need for supplemental flows for floodplain inundation can be assessed or the concept design for Alternative 3D can be adjusted. Detailed design would then require site surveys for the intake, grading plans for the floodplain inundation area and the containing and constricting berms, and the outlet channel to the Toe Drain.

CHAPTER 6. LEGAL AND REGULATORY COMPLIANCE ANALYSIS AND STRATEGY

INTRODUCTION

The purpose of this chapter is to identify the universe of legal and regulatory compliance issues that may arise for the long- and short-term Yolo Bypass restoration strategies proposed in this feasibility study. There are three types of legal issues applicable to Yolo Bypass activities: (1) legal issues associated with acquisition of land and water rights; (2) environmental impact analyses; and (3) compliance with numerous state and federal environmental laws and regulations. Although Yolo Bypass activities are designed to improve the environment, environmental regulatory processes are nonetheless complicated, time consuming and sometimes controversial.

Actual compliance needs vary dramatically; some activities may be exempt, whereas others may entail a multi-year compliance effort. It is therefore important to examine the legal issues associated with potential activities in the feasibility study phase, since legal issues directly affect project complexity, feasibility, cost and timing.

Specifically, this chapter will: briefly describe the purpose and requirements of the laws and regulations applicable to various potential restoration strategies; analyze the unique legal issues associated with different strategies; and discuss the consequences for project planning and implementation. The latter will focus on consequences specific to the recommended alternative from this feasibility study (Putah Creek Alternative 3D). Alternative 3D has a detailed project description in Chapter 5, meets numerous goals and objectives for a demonstration floodplain inundation project (Chapter 1), and appears feasible in the short-term; thus it will receive a detailed legal analysis. Compliance for this alternative may be completed in a 1–2 year period.

Implementation of the recommended alternative does not exclude other proposed restoration strategies for the Bypass, however. For example, a Sacramento River/Fremont Weir alternative (Chapter 4) can be implemented in whole or part, in conjunction with or separately from the Putah Creek alternative over a number of years. The conceptual models developed in Chapter 3 for a long-term Yolo Bypass adaptive management plan suggest such a strategy may be the most beneficial for splittail and salmon. For this reason, the legal analysis will also briefly consider consequences for a Sacramento River/Fremont Weir alternative. Compliance for this option will be complex, likely requiring 3 or more years to complete.

This chapter does not describe the regulatory process in detail nor identify every clearance that may have to be obtained. It focuses upon the most important legal considerations that impact project planning and implementation. A more comprehensive analysis of regulatory compliance is available in the "Guide to Regulatory Compliance for Implementing CALFED Actions" (CALFED 2001), prepared by the CALFED Bay-Delta Program.

Preliminary Considerations

Relationship to Other Efforts

It is important to consider the context in which Yolo Bypass activities will be undertaken. Some Yolo Bypass restoration activities may be considered actions of the CALFED Bay-Delta Program for which special compliance procedures apply. Program-level environmental impacts analyses and regulatory compliance documentation has been completed for the CALFED Program. Activities funded by CALFED or implemented by CALFED agencies in furtherance of the CALFED plan are covered by and must "tier" off of the program-level compliance. This feasibility study analyzes some activities proposed in the CALFED Ecosystem Restoration Program Plan. Every proposed Yolo Bypass restoration activity will be implemented by and will require regulatory approval from one or more CALFED agency, and some activities could receive funding from the CALFED Program. It is not always clear when proposed Yolo Bypass restoration actions should be treated as CALFED actions. Tiering from CALFED documents is described in more detail in the Environmental Impact Analysis and Endangered Species Act Issues sections below.

Coordination is also essential with ongoing flood management efforts in the Bypass. As previously mentioned, the Yolo Bypass is a crucial element of the Sacramento Flood Control Project, relieving flood pressure from the major levees ringing the City of Sacramento. The proposed Yolo Bypass activities cannot be implemented without adequate modeling of potential flood conveyance impacts and corresponding mitigation. Mitigating flood impacts may be more complicated and pose greater environmental impacts than the restoration project alone; but mitigation will be necessary if the restoration project decreases Yolo Bypass conveyance capacity for large floods or increases the frequency of inundation of neighboring lands within the Bypass.

Furthermore, some Yolo Bypass activities might be best undertaken as part of large-scale flood conveyance actions that *incorporate* environmental restoration elements. It may be more valuable to work with the Sacramento Area Flood Control Agency (SAFCA), State Reclamation Board and USACE to incorporate environmental restoration elements in future flood control projects, thereby leveraging resources for modeling, funding and regulatory compliance and establishing wider support for the projects. The USACE's Comprehensive Study may provide such an opportunity for a Sacramento River/Fremont Weir alternative.

The Yolo Bypass Wildlife Area Memorandum of Understanding (MOU) between the California Department of Fish and Game (CDFG), State Reclamation Board, California Department of Water Resources (DWR), and the U.S. Fish and Wildlife Service (USFWS) offers a special opportunity for Yolo Bypass restoration efforts, especially for the Putah Creek alternative. The MOU articulates an agreement between these agencies on construction and maintenance of the Wildlife Area within flood control and Endangered Species Act constraints. Amending the MOU to include the Putah Creek alternative could expedite the legal compliance process.

Basic Compliance Advice

- Incorporate time to complete environmental impact analyses and regulatory compliance into project design and decision-making.

- Carefully consider the source of funding and selection of lead agencies and applicable compliance concerns and timing. Where possible, apply state funds for activities implemented by state agencies and federal funds for federal activities to minimize duplicative environmental impact analysis and regulatory compliance procedures.
- Consider opportunities to "bundle" separate activities into one compliance process. This avoids the legal problem of "piecemealing" projects, increases the ability to make projects self-mitigating, and saves time in the long run.
- Consult with responsible agencies early. Address agencies' concerns at the earliest phases of compliance.
- Because the Yolo Bypass involves a long-term effort, project proponents should develop strategies to simplify and ease the compliance process. Examples may include convening a compliance team comprising regulatory personnel, and providing funding to regulatory agencies to dedicate to the compliance process.
- Tier off of CALFED program-level regulatory compliance documentation when necessary or expedient.
- Anticipate all regulatory approvals required during NEPA and CEQA environmental impact analyses. Modify the project description to avoid impacts triggering regulatory compliance, incorporate the necessary analyses, or add the mitigation measures required by the regulation. The approving agencies will use the project's impact analysis to study and disclose the effects of granting its approval.
- Build off of completed analyses and documentation. Environmental documents prepared for other projects in the Yolo Bypass, such as the Project Modification Report and EA/IS for the Yolo Bypass Wildlife Area, the North Delta Refuge, and the Pope Ranch Giant Garter Snake Mitigation project, should also be referred to and applicable analyses and findings be incorporated into Yolo Bypass project documents.
- Anticipate environmental impacts and incorporate mitigation into project design. This will expedite environmental impact analysis and regulatory compliance.

ENVIRONMENTAL IMPACT ANALYSIS

The most common legal compliance issue is the analysis and disclosure of the environmental impacts of proposed activities. The two laws in this category are the California Environmental Quality Act (CEQA), applicable to "projects" potentially affecting the environment carried out by or approved by state and local governmental entities, and the National Environmental Policy Act (NEPA), applicable to proposals for "major federal actions significantly affecting the quality of the human environment." Many Yolo Bypass activities will require compliance with both CEQA and NEPA. Joint NEPA/CEQA documents can and should be prepared in these circumstances.

California Environmental Quality Act (CEQA)

The California Environmental Quality Act (CEQA) applies to discretionary "projects" proposed to be carried out or approved by California state and local agencies. A "project" is the "whole of an action which has the potential for resulting in either a direct physical change in the environment or a reasonably foreseeable indirect physical change in the environment. (Cal. Pub. Res. Code (hereafter CEQA) § 21065, Cal. Code Regs., tit. 14 (hereafter CEQA Guidelines) § 15378(a)).

Activities that do not have the potential to impact the environment, or those that have not yet been proposed to be implemented, such as this feasibility study, are not "projects" and CEQA is therefore not applicable. (CEQA §§ 21102, 21150; CEQA Guidelines § 15262). Some "projects" may nonetheless be exempt from compliance if they fall within a statutory or categorical exemption. Activities such as land acquisition for wildlife refuges and minor alterations to land may qualify (see Appendix L). Most Yolo Bypass activities, however, will not qualify for exemptions, so an Initial Study will have to be prepared to determine whether the project may have any significant impacts. A Negative Declaration shall be prepared if there is no substantial evidence that the project may have a significant environmental effect. Alternatively, a mitigated Negative Declaration may be prepared if potentially significant impacts will be reduced to a less-than-significant level with adopted mitigation measures. An Environmental Impact Report (EIR) must be prepared when a "fair argument" can be made that the project may have a significant effect on the environment. Negative Declarations take about 5–10 months to prepare, and EIRs typically require one or more years.

National Environmental Policy Act (NEPA)

Projects carried out by federal agencies, receiving federal approval, or using federal funds must comply with the National Environmental Policy Act. NEPA is applicable to proposals for "major federal actions significantly affecting the quality of the human environment." The substantive and procedural elements of NEPA are similar to CEQA. NEPA will apply if Yolo Bypass activities are implemented by a federal agency (not likely unless the USACE modifies a flood control facility or if the USFWS takes actions to expand the North Delta Wildlife Refuge), are funded with federal money, or receive approval from a federal agency (such as Clean Water Act 404 or ESA compliance).

Similar to Categorical Exemptions in CEQA, some major federal actions may qualify for Categorical Exclusions. For those actions that are not exempt, an Environmental Analysis (EA—equivalent to an Initial Study) must be prepared. A Finding of No Significant Impact (FONSI—equivalent to a Negative Declaration) shall be prepared if the federal action will have no significant impact. EAs or FONSIs usually satisfy the environmental impact analysis requirement for federal agencies' regulatory approval, except for large or complicated actions. FONSIs typically require 3–8 months to complete. An Environmental Impact Statement (EIS—similar to an EIR) shall be prepared if the action may "significantly affect the quality of the human environment." EISs usually take from 9 months to over one year to complete.

Assorted federal laws and executive orders must be integrated into the NEPA process. A few that are applicable to Yolo Bypass activities include the Floodplain Management Executive Order, National Historic Preservation Act, and the Fish and Wildlife Coordination Act. These laws are described in more detail in the section "Regulatory Compliance and Permitting," below.

Specific NEPA and CEQA Issues

Tiering

There is an opportunity—or in some cases, a requirement—to tier off of programmatic NEPA/CEQA documents of other programs, such as the completed CALFED documents or USACE's in-development Comprehensive Study.

Yolo Bypass "projects" and "actions" funded by CALFED or clearly falling within the CALFED Plan must tier off the CALFED Programmatic Environmental Impact Statement/Environmental Impact Report (PEIS/EIR), which is structured to be used as a tiering document. Individual, second-tier projects can use the analysis as a basis from which to supplement and refine the level of detail and can incorporate by reference relevant provisions in the EIS/EIR. Tiering will assist the agencies in focusing on issues that are ripe for decision at each stage of environmental review and to exclude from consideration issues that have already been decided or that are not ready for decision. Second-tier documents will be prepared to concentrate on issues specific to the individual project being implemented and site(s) chosen for the action before construction can be initiated.

The environmental review and initial studies or environmental assessments for project-specific, second-tier projects can "concentrate on the environmental effects which (a) are capable of being mitigated, or (b) were not analyzed as significant effects on the environment in the prior environmental impact report." (CEQA § 21068.5; see also NEPA Guidelines, 40 C.F.R. 1500.4(c), 1502.4(d)). Where a second-tier project involves impacts that are addressed in the EIS/EIR, the mitigation strategies adopted by CALFED will be used by the lead agencies as a basis to formulate project-level mitigation measures and enforcement programs. Because all the potential actions and impacts for tiered projects cannot be anticipated at a programmatic level, each lead agency needs to select those strategies applicable to the impacts associated with the specific location and type of action.

Tiering could save Yolo Bypass activities time in conducting analyses since some of the critical work has already been done at the program level. On the other hand, Yolo Bypass activities tiering off of CALFED documents are bound to the decisions already made, such as for mitigation measures. Tiering presents unique legal procedures and issues. Although this feasibility study is funded in part by CALFED, only some activities, such as those funded by CALFED, will be CALFED actions. As described below, the lower Putah Creek strategy is probably not a CALFED action, since the activities would occur within a state-owned wildlife area not funded by CALFED.

Yolo Bypass activities could also tier off the Program EIS for the Comprehensive Study, expected to be completed in 2003.

Relationship to Regulatory Compliance

Complete and comprehensive NEPA and CEQA documents are also the keys for efficient regulatory compliance. Regulatory agencies reviewing the project's permit applications must evaluate the environmental effects of granting the permit approval. The most efficient way to accomplish this is by completing the necessary analysis in the project's documentation, rather than having the agency prepare another document (which the permittee may have to pay for). By properly evaluating the activities' impacts, designing the activities to not have significant impacts, and incorporating adequate mitigation measures in the NEPA or CEQA document will shorten the compliance time. CEQA requires consultation with and review by CEQA responsible and trustee agencies with authority over regulatory compliance and NEPA requires consultation with cooperating agencies and agencies with regulatory authority.

NEPA or CEQA?

In most cases, the proposed Yolo Bypass activities will be implemented by a state lead agency, triggering CEQA, but some federal approval triggering NEPA, like a 404 permit, would also be necessary. There are also foreseeable scenarios in which federal actions require state approvals, such as a flood encroachment permit from the Reclamation Board. Funding can also complicate NEPA and CEQA compliance if federal funds are provided for a state action, or vice versa, in which case the project must comply with both NEPA and CEQA. If CALFED funds are used, such difficulties may be avoided, since CALFED typically allocates federal money for federally initiated and led projects and state money for state projects.

Consider a typical scenario. A CEQA document is prepared by the state lead agency, and then the federal agency determines whether a NEPA document must be prepared to analyze the impact of its regulatory approval. Many federal approvals (e.g., for Nationwide Permits, described below) qualify for NEPA exclusions. In other cases, at most a FONSI would be required, so the subsequent NEPA review would not take long. Large, complicated projects should be addressed differently. For example, if the project will require an EIR for the project and an EIS for the regulatory approval, the best approach may be to prepare a joint NEPA/CEQA document initially.

Types of NEPA and CEQA Documents Required

Land acquisition not involving construction is generally exempt from NEPA and CEQA review. Almost every other habitat enhancement activity in the Yolo Bypass will trigger CEQA compliance, and the regulatory approvals they require will require NEPA compliance. If the CALFED PEIS/EIR analyzed all types of potential impacts of a particular habitat enhancement project, the project-level EIS and/or EIR need not repeat the regional-scale impact analysis. Because Yolo Bypass activities are restoration projects, most will not cause adverse environmental impacts or are self-mitigating. Fortunately, many of these activities may be eligible for Negative Declarations and FONSIs. Some larger Bypass activities, such as a Fremont Weir modification alternative, probably require a joint EIS/EIR.

The significance of impacts, and therefore whether a Categorical Exclusion/Exemption, FONSI/Negative Declaration or EIS/EIR is applicable, depends on the scope of the proposed action, whether the impacts and effectiveness of mitigation are known, and thresholds of significance for certain sensitive resources and issues. Because Yolo Bypass activities will be designed to improve the quality of the environment, it can be assumed that ecological impacts will be minimal and less than significant in most cases, and where possible mitigation will be built into the project description. The types of impacts for which Yolo Bypass activities may not be able to avoid or self-mitigate—creating the possibility of “significant environmental impacts” necessitating preparation of an EIR or “significantly affecting the quality of the human environment” requiring preparation of an EIS—include agricultural land impacts, flood conveyance impacts, and water quality impacts. Unless impacts to these resources can be adequately avoided or clearly mitigated, an EIR and/or EIS may have to be prepared. These sensitive resources are considered in more detail below.

Agricultural land conversion may pose a problem in the Yolo Bypass. A significant amount of the targeted environmental restoration would occur on, and therefore "convert," agricultural land, and there are few practical ways to mitigate for conversion (see Appendix M). Agricultural land impacts should be avoided if possible, but is difficult since much of the Bypass is farmed. Conversion may not be such a problem for this project, however, since much of the floodplain inundation will entail seasonal, shallow flooding of idled agricultural land, and does not necessarily require vegetation. This form of winter-spring flooding alone does not constitute a land use change or conversion, since the Bypass is not farmed in those periods. The creation of perennial wetland habitat, however, may constitute conversion. The key task is to determine thresholds of significance of conversion: how much agricultural land conversion is considered "potentially significant," can it be mitigated in a FONSI or Negative Declaration, or is an EIS or EIR triggered? The lead agency, in consultation with responsible agencies (e.g., the county Board of Supervisors and the California Department of Food and Agriculture), may determine proper mitigation standards for the Bypass, possibly permitting the loss of a certain percentage of agricultural land to perennial wetland habitat in exchange for permanent agricultural conservation easements elsewhere, etc.

Flood conveyance impacts pose a problem similar to agricultural land conversion: even small impacts may be significant. The State Reclamation Board presently approves only projects that cause zero net increase in the 100-year flood stage. It may be possible to design the floodplain project to avoid an increase in flood stage. If not, the project may have to be expanded to include mitigation measures. The most cost-effective mitigation measures could involve large offsite projects that realistically could only be completed as a joint effort with other agencies involved in improving flood management in the lower Sacramento Valley. If modeling is completed early in the project design phase or in the NEPA/CEQA process, responsible agencies could agree that there will be no significant impacts and approve a FONSI or Negative Declaration. If there is any doubt, project proponents will have to prepare an EIS or EIR.

Mercury methylation may also be a significant impact. Mercury enters the Bypass from the Coast Range, principally from Cache Creek. Mercury in shallow flooded environments has the potential to methylate, which is a form harmful to wildlife and potentially carcinogenic to people.. There is the concern that methyl mercury will be picked up in municipal drinking water sources, especially the North Bay Aqueduct. No projects in the Yolo Bypass have encountered any mercury problems nor addressed the issue. If agencies express concern, this potential impact could be mitigated with monitoring and discontinuing the activity if problems arise.

NEPA and CEQA Issues Specific to Alternatives

The Putah Creek alternative may require compliance with both CEQA and NEPA. CDFG will likely be the lead agency, triggering CEQA, but federal regulatory approvals could trigger NEPA.

As proposed, restoration may occur solely on CDFG's recently acquired 16,000-acre Glide Ranch, depending on final channel alignment. CDFG is in the process of developing a wildlife area management plan that will propose and analyze at a general level of detail many of the

Lower Putah Creek activities described in this feasibility study. Wildlife area management plans considering future actions not yet approved, adopted or funded are exempt from CEQA. (CEQA §§ 21102, 21150; Cal. Code Regs, tit. 14 [CEQA Guidelines] § 15262; see also Cal. Code Regs, tit. 14 [CDFG CEQA Regulations] § 757, subd. 7). CDFG expects to complete the management plan in approximately two years. CDFG will solicit a great deal of public input and has agreed in the Yolo Basin MOU to not change land use (i.e., not begin restoration) until the management plan is in place (Dave Feliz, CDFG, pers. comm.).

Activities carried out pursuant to management plans causing an effect on the environment require CEQA review. If CDFG and DWR desire to begin this project as soon as possible, the specific project proposal could be developed and CEQA review initiated concurrently with the management planning process, since the management plan will not provide a detailed project description. The activities requiring compliance with CEQA include the construction of a new lower Putah Creek channel (realignment). While the channel realignment does not qualify for any Categorical Exemptions, the project is not likely to cause a significant effect on the environment and should qualify for a Negative Declaration. If there are any potential significant effects such as mercury methylation or construction-related short-term impacts on species, adequate mitigation measures could be adopted in the Negative Declaration.

This alternative would also require state and federal regulatory approvals. The CEQA analysis must include the environmental analysis required to support the state regulatory approvals (e.g., Clean Water Act 401 certification, Streambed Alteration Agreement, and Reclamation Board Encroachment Permit) to obviate the need for additional CEQA compliance. The only anticipated federal approval, a dredge or fill permit under section 404 of the Clean Water Act, is likely exempt from NEPA compliance. These approvals and required environmental impact analyses are described in more detail below.

A Sacramento River/Fremont Weir alternative is not yet well developed in this feasibility study, but the construction-related environmental impacts and the long-term changes in habitat, water flow and flood management would be potentially significant. The state and federal regulatory compliance requirements would also be numerous and complex. A joint EIS/EIR may therefore be necessary.USACE is the most likely candidate for lead agency in this effort.

ENDANGERED SPECIES ISSUES

<u>Endangered Species Acts and Natural Community Conservation Planning Act Compliance</u>

Applicability of Laws Generally

Three species protection laws may apply to Yolo Bypass activities: the federal Endangered Species Act (ESA), the California Endangered Species Act (CESA) and the California Natural Community Conservation Planning Act (NCCP). Among these, the ESA is likely to pose the greatest constraints on design and operation of the floodplain project. Section 7 of the ESA applies to federal actions, actions on federal land, and federal regulatory approvals. It requires federal agencies to ensure that their actions will not jeopardize the continued existence of any listed species or result in the destruction or modification of critical habitat. Section 7 compliance is accomplished through a process called consultation. The federal actions receive take authorization if the USFWS or NMFS finds that the activity will not jeopardize the existence of listed species. Taking that is incidental to and not intended as part of an action is not prohibited, provided that such taking complies with the terms and conditions of an incidental take statement contained in a biological opinion. In most cases, a federal agency includes the terms and conditions contained in a biological opinion in any grant or permit (e.g., a CWA Section 404 permit) it issues to an implementing entity for the exemption in Section 7 to apply.

It is unlikely, but some Yolo Bypass activities could involve nonfederal entities and not involve any federal land, funding, or approvals. In these instances, a Habitat Conservation Plan (HCP) under ESA Section 10 may be required. Pursuant to an HCP the non-federal entity receives an incidental take permit. Permittees under Section 10 are protected by the "No Surprises" policy in which USFWS and NMFS assure that additional commitments of land, water, or financial compensation or additional restrictions on the use of land, water, or other natural resources beyond the level provided for federally covered species in the permit will not be required without the implementing entity's consent. The Section 10 compliance process is more burdensome than the Section 7 process.

Nearly every Yolo Bypass activity envisioned will require some federal approval, such as a permit for discharge of dredge or fill material (described in detail below) or use federal funds, so that consultation under section 7 is applicable, and project applicants need not comply with Section 10 and possibly prepare an HCP. Those activities not having a federal nexus would probably have so little impact that there would be no impact to listed species. Section 7 is generally considered preferable to Section 10 from a compliance perspective, such that applicants often strive for federal agency involvement. On the other hand, some provisions like the "no surprises" policy is only available under Section 10.

Special Procedures for CALFED Actions

If the Yolo Bypass activities are CALFED actions, special CALFED ESA, CESA and NCCP compliance procedures apply. All CALFED agencies implementing, approving, or funding CALFED actions have agreed in the August, 28, 2000 Conservation Agreement Regarding the Multi-Species Conservation Strategy to follow the CALFED Multi-Species Conservation Strategy (MSCS). The MSCS is the CALFED Program-level compliance with ESA, CESA and NCCP. The MSCS does not authorize take of listed species. As with NEPA and CEQA, project compliance tiers off the Program-level MSCS. Compliance may be accomplished two ways: (1) by a finding of no adverse affect on "covered species" or critical habitat by the CALFED agencies with written concurrence of the Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS) or the California Department of Fish and Game (CDFG); or (2) by preparing Action-Specific Implementation Plans (ASIPs).

ASIPs are environmental review documents that incorporate the informational requirements of ESA and NCCP in one format, and are intended to streamline site-specific compliance, thus saving significant time (see Appendix N). Put another way, ASIPs are Biological Assessments with additional information for NCCP compliance. The ASIP will be based on and tier from the data, information, analysis, and conservation measures in the MSCS. ASIPs include a project description, the life histories of potentially affected species, the potential impact on species, and conservation measures (i.e., avoidance, minimization and mitigation measures).

The implementing entity will coordinate development of the ASIP with USFWS, NMFS, and CDFG to ensure that the ASIP incorporates appropriate conservation measures for the proposed CALFED action(s), consistent with the MSCS. USFWS and NMFS will review the ASIP for compliance with the ESA, primarily under Section 7. They will consider issuing an ESA Section 10(a)(l)(B) permit if a nonfederal entity proposes to implement one or more CALFED actions that are not authorized, funded, or carried out by a federal agency. The ASIP will contain all information required for compliance under either ESA Section 7 or Section 10(a)(1)(B). USFWS and NMFS may also use Section 10 or Section 7 of ESA to authorize take of species evaluated in the MSCS but not included in the federally covered species list in the programmatic biological opinions. CDFG will review the ASIP for compliance with NCCPA. For CALFED actions that may affect species that are listed under CESA, but are not state-covered species under CDFG's programmatic NCCP determination, the ASIP may also be used as the basis for obtaining an incidental take permit pursuant to Section 2081 (b) of the California Fish and Game Code.

Compliance Procedure

The implementing entity should request a species list from NMFS, USFWS and CDFG and arrange an informal meeting to discuss the project and its potential impacts on listed and non-listed species. These meetings will help the implementing entity design the project to avoid adverse impacts (and if CDFG requires it for non-listed species, to provide additional conservation measures), and allow the parties to determine whether the project can go forward or whether a Biological Assessment or an ASIP (for CALFED actions) must be prepared. For CALFED actions, USFWS, NMFS and CDFG will assist the implementing entity in preparation of the ASIPs through a team dedicated to reviewing CALFED actions.

The Biological Assessment or ASIP should be developed concurrently with the draft NEPA and CEQA documents. If the elements of the Biological Assessment or ASIP, especially the conservation measures, are integrated into the NEPA and CEQA documentation, ESA, CESA and NCCP compliance can be completed within the time to complete NEPA and CEQA compliance. If Section 7 consultation must be initiated, the process is usually completed within 135 days. Consultation typically takes 90 days, and USFWS and/or NMFS take approximately 45 days to prepare a Biological Opinion that authorizes the action. In many cases, a Biological Assessment or ASIP that shows no adverse impact or shows species benefits (as most Yolo Bypass activities should) will be approved more quickly. Compliance for especially complicated activities, such as modification of the Fremont Weir with fish passage facilities, may require more than 135 days to complete.

The Biological Assessment or ASIP should also be developed in coordination with regulatory compliance. Regulatory agencies must comply with ESA, CESA and NCCP when granting regulatory approval in the same way they must analyze the environmental impacts under NEPA and CEQA. The ASIPs therefore have to anticipate and assure ESA, CESA and NCCP compliance for the regulatory approvals.

"Safe Harbor" Assurances

Safe Harbor Agreements are voluntary agreements between the USFWS and/or NMFS and nonfederal landowners to benefit endangered species while assuring the landowner that no additional restrictions will be imposed. 50 C.F.R. §§ 17.22, 17.32; Final Safe Harbor Policy—Fish and Wildlife Service, National Marine Fisheries Service, 64 Fed.Reg. 32713, June 17, 1999.

Safe Harbor is authorized by Section 10(a)(1). The USFWS or NMFS will provide assurances that when the landowner undertakes actions to benefit listed species, they may elect in the future to cancel the agreement and cease the action benefiting species, provided that, at a minimum, baseline conditions (pre-Safe Harbor) of the property are maintained. In exchange for undertaking the actions, USFWS and/or NMFS will provide an Authorized Take Permit under Section 10(a)(1)(A).

Safe Harbor agreements may have two applications in the Yolo Bypass. The restoration project may obtain an agreement based on the project's benefit to listed species in exchange for an Authorized Take Permit so that vegetation on the site can be maintained to maintain flood conveyance capacity. The project could in the future cancel the agreement if the Authorized Take Permit did not provide adequate coverage for the required maintenance activities. The Reclamation Board may actually require this type of agreement.

Yolo Bypass landowners that desire to undertake environmental restoration but are concerned that activities on their property will become restricted from the presence of listed species may also seek a safe harbor agreement. For example, a landowner who agrees to permit increased flooding on his or her property to benefit listed species could obtain an Authorized Take Permit to cover ongoing agricultural practices.Therefore, to be protected by a safe harbor agreement, an incidental take permit must cover the landowner. The project could provide the landowner funding and technical assistance to obtain the Safe Harbor Agreement.

Neighboring Landowner Assurances/Protections

"Neighboring" or "cooperating landowner" assurances are often confused with Safe Harbor Agreements. With these neighboring landowner assurances, the benefiting or protected landowners are not directly involved in the endangered species protection. Rather, they are neighbors of the restoration site or Safe Harbor property who fear their activities could be restricted if listed species migrate onto their property or if their abundance increases. While listed species are already present in the Bypass and the proposed restoration activities should solve many of the threats to species (e.g., stranding and migration barriers), there is still a concern that the abundance and time-listed species are present will increase.

The USFWS, NMFS and CDFG have agreed in the CALFED MSCS to include appropriate cooperating landowners protection measures in every ASIP. Cooperating landowner measures can also be provided for non-CALFED actions. Cooperating landowner protection measures are assurances to voluntarily cooperating landowners that they will not be prevented from continuing their existing, compatible land uses because of the implementation of CALFED or other restoration actions. Based on these measures, USFWS, NMFS, and CDFG can authorize limited incidental take by cooperating landowners as necessary or appropriate to protect compatible existing uses of land and water that could be affected by the action. Acceptance of cooperating landowner commitments will be strictly voluntary. Landowners and local public entities may withdraw from the cooperating landowner commitments program at any time without penalty. Cooperating landowner commitments will not create a new exception or exemption to the requirements of ESA or CESA.

The MSCS describes a few scenarios relevant to the Yolo Bypass.

- Cooperating landowner commitments regarding agricultural activities will allow for the continuation of routine and ongoing agricultural activities on agricultural lands near land preserved by CALFED for wildlife conservation purposes. If necessary and appropriate, mitigation for incidental take of wildlife originating from preserved wildlife habitat will be provided by the appropriate CALFED agency or other implementing entity that carried out the action or associated conservation measure that resulted in the preservation of wildlife habitat.
- Cooperating landowner commitments regarding levee maintenance can allow for both routine repair and maintenance and emergency repair and maintenance of levees. If necessary, mitigation for incidental take of wildlife resulting from repair and maintenance of levees on which wildlife habitat has been restored or enhanced will be provided by the CALFED agency or other implementing entity that carried out the action or associated conservation measure that resulted in the restoration or enhancement of wildlife habitat on such levees.
- Cooperating landowner commitments regarding the installation, operation, and maintenance of fish screens will preserve existing diversions to the greatest extent practicable. In addition, CALFED will provide funds or assist the cooperating landowner to seek funds to cover any incremental increase in the cost of operating and maintaining the diversion structure that is incurred because of the installation of the fish screens.

Cooperating landowner protections can be accomplished through a variety of mechanisms: provide the landowner with take authorization from USFWS, NMFS and CDFG; provide assurances from USFWS, NMFS and CDFG not related to take authorization; or provide financial and other contractual assurances.

One mechanism is to include in the Biological Assessment or ASIP project description the landowner's activities that could affect listed species (thus directly covering the landowner). The project could adopt a conservation measure that avoids, mitigates or minimizes the landowner's impact on listed species. For example, the project could screen the landowner's water diversions if fish are affected. Of course, the project would pay for any required conservation measures. Another simple approach is to seek take authorization for the landowner's activities, since the restoration project will provide adequate species conservation. Either way, the landowner would receive take authorization and would be relieved of personal obligations.

Some landowners may be reluctant to be covered by an incidental take permit or a federal agency's incidental take authorization. USFWS, NMFS and CDFG have provided landowners with informal assurances. For example, the USFWS has issued a letter of assurance to the Reclamation Board with respect to the Pope Ranch Giant Garter Snake Mitigation Bank that USFWS would not change their enforcement practices in the Yolo Bypass.

Some landowners will not want to cooperate with the wildlife agencies at all. The project could contractually provide financial assurances for any crop damage, mitigation, or increased regulation.

One opportunity to investigate innovative neighboring landowner assurances is through the "Working Landscape Workgroup" and its “Local Partnerships Planning Process”. A short-term goal of the process is to develop options and strategies for CALFED projects, including mechanisms to cover neighboring landowners under take permits, financial mechanisms to compensate landowners for ESA-related costs, etc. The workgroup is looking for a test case such as the Yolo Bypass to further develop these concepts. This group could provide technical assistance and possibly funding to implement the necessary ESA protections.

ESA Compliance Issues Specific to Alternatives

Most aspects of the Putah Creek alternative would have minimal species impact, with the exception of abandonment and dewatering of the former Putah Creek streambed. Dewatering the former streambed may raise concerns about impacts to listed species such as the Giant Garter Snake. Conservation measures to avoid construction-related impacts of the creek realignment would also have to be adopted. The Yolo Bypass Wildlife Area MOU covers current CDFG wildlife management actions, and the parties to the MOU could amend the agreement to cover the proposed Putah Creek alternative. Because the lower Putah Creek activities would affect anadromous fish species, NMFS could be made party to the amended MOU, or the MOU could be submitted for their review and approval as required by the ESA. The limited scope of impacts of the lower Putah Creek strategy makes neighboring landowner ESA assurances unnecessary.

ESA compliance for a Fremont Weir modification would be complex. CALFED’s North Delta Program is investigating the feasibility of a Fremont Weir fish ladder. In all likelihood a pilot study would be required that would entail monitoring fish migration patterns and abundances, studying the hydraulics of a fish passage structure, and construction of a test ladder to evaluate impact on fishes. Some take of listed fishes could occur, so incidental take authorization may be necessary. If the Interagency Ecological Program or other agency has received incidental take authorization for species monitoring and sampling, it might be possible to tier or build off of those biological opinions. ESA assurances are not essential but could increase Yolo Bypass landowners’ comfort with this large-scale alternative.

Regulatory Compliance and Permitting

Numerous environmental laws and regulations may apply to Yolo Bypass activities. The laws and regulations listed below are those most likely to apply, but should not be considered an exclusive list. Some of the regulatory processes below are merged with the NEPA and CEQA processes (e.g., State Historic Preservation Act and Floodplain Management Executive Order in NEPA), are complied with concurrent to NEPA and CEQA compliance, or are only initiated after NEPA and CEQA compliance.

Dredge and Fill Permit

Section 404 of the Clean Water Act requires a permit issued by the USACE for the discharge of “dredge or fill material” into “waters of the United States.” (33 U.S.C. § 1344). The Yolo Bypass activities would occur within a designated floodway both receiving flow from and contributing flow to navigable waters and on lands subject to tidal inundation in the southern Yolo Bypass, and is therefore considered a “water of the U.S.” The USACE (and EPA for water quality regulation) therefore has jurisdiction, which is unaffected by the recent contraction of 404 jurisdiction from the SWANCC case (Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers, 531 U.S. 159 (2001)). Activities potentially discharging dredge or fill material, necessitating obtainment of a general or standard permit, include grading to improve drainage, excavation to create a new channel for Putah Creek and for other wetland and riparian features, and fill to create berms, small impoundments, etc.

There are two types of Corp-issued permits: General Permits and Standard Permits. General permits, including Regional General Permits and Nationwide Permits (NWPs), are preferable in that activities with minimal adverse effects receive expedited review and limited paperwork. There are only four Regional General Permits for California, and they are not likely applicable to this project. The two that could be applicable are General Permit 008, Fill for Spawning Areas, and General Permit 014, Sacramento San Joaquin River Delta Dredging For Levee Maintenance.

In contrast, there are 43 NWPs covering activities that involve minor discharges, such as repair and maintenance of existing structures, short-term construction, and other minor perturbations (Appendix O). Multiple NWPs can be used on a single project provided that the acreage limitation of the NWP with the highest acreage limit is not exceeded (67 Fed.Reg. 2020, 2090 (Jan. 15, 2002) (General Condition 15)). In limited circumstances, the permittee can begin construction immediately under the terms of the NWP. In most circumstances, the permittee must submit a Preconstruction Notification (PCN) to the District Engineer that provides a brief description of the project, its purpose, direct and indirect effects, and documentation of the prior condition of the site (*Id.* (General Condition 13(b)(3), (b)(8))). The USACE has 30 days to determine whether the PCN is complete, and another 45 days to notify the permittee in writing to proceed or whether an individual permit is required (*Id*. at 2090 (General Condition 13(b)(3), (b)(8))).

Standard permits, including Individual Permits and Letters of Permission, are required on projects not eligible for NWPs (e.g., those exceeding the acreage or fill limits of NWPs) or that could have significant adverse effects. Letters of Permission typically require 45 days to process, whereas Individual Permits take 90–180 days or more. Note that individual permits require an alternatives analysis that requires identification/selection of the least environmentally damaging practicable alternative that, if not closely integrated into the NEPA or CEQA process, could require significant additional delay. Like other permitting requirements for Yolo Bypass activities, the type of permit(s) required depends on the scope and timing of activities. While small activities eligible for NWPs could be pursued separately, an Individual Permit covering a variety of activities could save time and project and regulatory staff resources in the long run.

Many activities of restoration projects (but not those modifying flood control facilities) may be eligible for NWP 27, Stream and Wetland Restoration Activities. NWP 27 covers activities "associated with the restoration of former waters, the enhancement of degraded tidal and non-tidal wetlands and riparian areas, the creation of tidal and non-tidal wetlands and riparian areas, and the restoration and enhancement of non-tidal streams and non-tidal open areas." (67 Fed.Reg. 2020, 2082). There is no acreage limit for this NWP. This NWP does not require compensatory mitigation provided that the activity results in a net increase in aquatic habitat. This NWP may, however, serve as a compensatory mitigation project or mitigation bank for other activities not eligible for NWP 27 and requiring mitigation. For instance, it may be advisable to pursue lower Putah Creek work under NWP 27 and request that it serve as mitigation credit for future work in the Bypass requiring mitigation, if any.

Under NWP 27, if the permitted activity occurs on non-federal public or private lands in accordance with a binding wetland enhancement, restoration or creation agreement with the USFWS, NRCS or NMFS or consists of wetland restoration actions documented by the NRCS pursuant to regulations, the permittee need not provide the USACE with Pre-Construction Notification (PCN) otherwise required in General Condition 13 and can begin construction. (*Id.*, NWP 27(b)). Otherwise, the permittee must submit a PCN to the District Engineer that provides a brief description of the project, its purpose, direct and indirect effects, and documentation of the prior condition of the site. (*Id*. at 2090, General Condition 13(b)(3), (b)(8)). The USACE has 30 days to determine whether the PCN is complete, and another 45 days to notify the permittee in writing to proceed or an individual permit is required. (*Id*. at 2090, General Condition 13(b)(3), (b)(8)).

The Putah Creek alternative involves realignment of the streambed, requiring a CWA 404 permit (and a similar Streambed Alteration Agreement described below). Realignment of the creek should qualify for NWP 27, described above. The USACE need not prepare a NEPA document, since NWPs are categorically excluded from NEPA.

Given the scope of a Sacramento River/Fremont Weir alternative, an individual 404 permit would be required. Individual permits require a "least environmentally damaging alternative" analysis that must be integrated into EIS/EIR preparation.

Water Quality Certification

All Yolo Bypass activities carried out by federal agencies, requiring a federal approval for a permit or license (such as a 404 permit) or receiving federal funding, must also comply with Clean Water Act section 401. Section 401 requires a certification or waiver from the state or tribal authority (here, the State Water Resources Control Board [State Board]) that the activity will not violate state water quality standards.

Yolo Bypass project managers/lead agencies must submit 401 certification/waiver applications to the Central Valley Regional Water Quality Control Board. For activities requiring a change in an existing or application for a new appropriation of water, applications should be submitted to the State Board. 401 applications should be submitted at the same time as seeking 404 authorization, and should include the 404 and streambed alteration agreement (described below) applications or permits. A 401 Certification must be obtained before a CWA Section 404 permit may be issued. Application fees start at $500, and processing time is typically 30–60 days.

RWQCB approval of 401 cert/waiver is discretionary, triggering CEQA. Some activities may qualify for a Central Valley RWQCB general permit. Some activities, such as those authorized by certain NWPs, may qualify for a waiver. The State Board certified seventeen Nationwide Permits that should not result in more than minimal individual or cumulative impacts, exempting projects using those NWPs from CEQA compliance (Cantú 2002). This means activities authorized by certified NWPs need not obtain a certification/waiver, but if the NWP requires PCN, then the Regional Board must also be notified. Certification of the other NWPs will be considered on an individual project–specific basis. For projects requiring individual certification, the Central Valley RWQCB should be involved in preparation of project's CEQA document to ensure it is adequate for the RWQCB to evaluate the impacts associated with issuance of the cert/waiver.

CWA 401 certification is usually straightforward and uncomplicated. In the Bypass, however, there is the concern of mercury methylation in shallow flooded wetlands and the fear additional mercury may be picked up in drinking water taken from the North Bay Aqueduct. Much is unknown of mercury methylation, and the only feasible strategy at this time is to monitor and discontinue restoration efforts if mercury poses a problem. Environmental compliance documentation of all other wetland restoration projects in the area should be reviewed to determine the regional board and water agency stances on mercury and adopt all relevant findings and mitigation strategies.

The lower Putah Creek will require a 404 permit (NWP 27 and possibly other NWPs), requiring compliance with CWA 401. Because the State Board did not pre-certify NWP 27, certification will have to be obtained from the Central Valley RWQCB (Cantú 2002). Therefore, water quality impacts must also be adequately evaluated in the CEQA review.

A Sacramento River/Fremont Weir alternative would require an individual 404 permit and therefore an individual 401 certification.

Streambed Alteration Agreement

The California Department of Fish and Game regulates actions that substantially divert or obstruct the natural flow or changes the bed, channel or bank of any river, stream, or lake, or use material from a streambed. (Cal. Fish & Game Code § 1600-1607). Public agency actions obtain Streambed Alteration Agreements under section 1601, and private parties obtain them under section 1603. CDFG usually requires that 404 and 401 compliance be complete before applying for a Streambed Alteration Agreement. If appropriate mitigation is developed for the 404 permit, CDFG may not require additional mitigation. Compliance takes up to 60 days, depending on the nature of environmental impacts and the sufficiency of existing mitigation. Fees are described in Cal. Code Regs, tit. 14 § 699.5.

The Putah Creek alternative would require a streambed alteration agreement to realign the creek channel. A Sacramento River/Fremont Weir alternative would require a streambed alteration agreement if habitat enhancement work is undertaken in Tule Canal or the water bodies draining into the canal.

Reclamation Board Flood Encroachment Permit

The California Reclamation Board has jurisdiction over the Yolo Bypass as a designated floodway. The Reclamation Board requires permits for activities, called "encroachments," in designated floodways, on land between project levees, and in designated river reaches.

The Reclamation Board General Manager may waive the permit requirement for minor, non-injurious alterations (Cal. Code Regs., tit. 23, § 6, subd. (e)).

The Reclamation Board generally requires permitted restoration projects to provide assurances to ensure proper vegetation and levee maintenance in the floodway without concern of ESA regulation.

Approval time varies depending on the complexity and controversy of the project, and small activities take between one to three months. Early consultation with the Reclamation Board will expedite the permit approval process. The Board should be consulted early in the NEPA and CEQA process to incorporate Board-recommended design guidelines and mitigation measures. As with other state-issued permits or clearances, the regulatory agency will utilize the project's environmental impact analysis to assess the impacts of its approval.

The Reclamation Board has been apprised of proposed Yolo Bypass activities, and is supportive. In fact, the Reclamation Board has sought CALFED funds to model the impact of potential actions. Avoidance of negative impacts on the100-year flood stage is highly desirable because mitigation would be costly and would substantially delay the approval process. If project managers conduct an adequate CEQA analysis and submit a complete application with modeling showing no impact, the permit should be quickly approved.

All alternatives would require an encroachment permit, waiver, or an agreement under Cal. Water Code section 8618. A Water Code 8618 agreement—an agreement with the Reclamation Board for maintenance of a floodway by a governmental entity—exists for the Yolo Bypass Wildlife Area. This agreement could be expanded to cover the Putah Creek alternative if the MOU is amended. The Putah Creek alternative will be designed to cause no impact to flood conveyance capacity, or to include mitigation. NHC is conducting the flood impact study and will seek approval from the Reclamation Board. The permit requirement of a Sacramento River/Fremont Weir alternative is unknown.

Other Regulations and Approvals

The following regulations are those in which the lead or approving agency must consult or conduct an initial screening, but in all likelihood are not applicable to Yolo Bypass activities. Also listed are some regulations that are easily complied with. This is not intended to be an exclusive list of all regulations and approvals that may be necessary.

Dam and Levee Construction, Modification and Removal

Existing check dams on Putah Creek and elsewhere in the Yolo Bypass are not subject to DWR Division of Dam Safety jurisdiction; none are greater than 25 feet high or have a capacity greater than 50 acre-feet. Levees and other impoundments that may be constructed, modified or removed in the Bypass are exempt from regulation if they are federally-constructed, are dams or levees 6 feet high or less, are dams or levees with an impounding capacity of 15 acre-feet or less; are flood control levees; etc. All Yolo Bypass activities should fall into these categories.

National Historic Preservation Act

The NHPA applies to actions sponsored or permitted by federal agencies, that are federally funded, or that occur on federal land, and are the type of activities that have the potential to affect historic properties. Historic properties are those listed or eligible for listing on the National Register of Historic Places (NHRP). If the action meets these criteria, the federal agency must initiate consultation with the State Historic Preservation Office (SHPO). Consultation should be initiated as soon as possible during the NEPA process. If the SHPO determines that the action will not affect historic resources, the NHPA compliance process is completed. Alternatively, the SHPO may require the federal agency to incorporate mitigation into the project description in the event historic resources are discovered, thereby completing the NHPA compliance process. In the next step the federal agency must then determine whether there are and NHRP-eligible properties. If there are none, as is the likely case in the Yolo Bypass, the compliance process is completed. Should historic resources be impacted, the compliance process can be very time consuming. No alternative recommended in this study is likely to impact historic resources.

Floodplain Management Executive Order 11988

Executive Order 11988 requires federal agencies that manage lands, sponsor federal actions or provide funding to consider alternatives to actions within floodplains and minimize their potential harm. The federal agency must prepare and circulate a notice describing the action, alternatives considered, and compliance with state and local floodplain regulations. Compliance with the Floodplain Executive Order is usually integrated into NEPA compliance.

This Order would not apply to the Putah Creek alternative, provided there will be no substantial federal involvement. This order would likely apply to a Sacramento River/Fremont Weir alternative, since USACE is the most likely lead agency.

Caltrans Encroachment Permit

If work is done along the I-80 causeway in the Caltrans right-of-way, a Caltrans encroachment permit may be needed. Impacts in the right-of-way would be minimal and should be avoided, if possible. It is unknown whether any alternative would affect the Caltrans right-of-way.

UPRR Approval for Work in Right-of-Way

If Yolo Bypass activities require work in the Union Pacific Railroad right-of-way or modification of the trestle, UPRR approval may be required. UPRR has no local office, so approval could be difficult to obtain. It is unknown whether any of the alternatives would affect the UPRR right-of-way.

Gas Well Easement Encroachments

There are numerous natural gas wells and pipelines in the Yolo Bypass. The locations of the wells and pipelines and their easements (on file with Yolo County and Solano County) should be determined for every alternative during the environmental impact analysis phase. Impact to these facilities must be avoided, and in some cases approval for encroachment on the easements would be necessary.

Yolo County and Solano County Zoning Regulations

This project occurs primarily within unincorporated Yolo County, and some activities in the southern Yolo Bypass, such as the tidal inundation alternative, may occur within Solano County. Yolo County and Solano County impose zoning controls on property in the Yolo Bypass. The Yolo County Zoning Code chapter on Flood Damage Prevention specifies regulations for construction within flood-prone areas. A flood development permit may be required for building, grading, filling, excavation or other construction within 100-year floodplains (see Appendix P for excerpts of flood damage regulations and required findings). "'Encroachment' means the advance or infringement of uses, plant growth, fill, excavation, buildings, permanent structures or development into a floodplain which may impede or alter the flow capacity of a floodplain." (Yolo Planning Code § 8-3.209). Solano County would require a review for land use consistency. If the proposed activity is not a consistent or "conforming" use under the applicable land use designation, then a use permit could be required.

These county zoning ordinances cannot be applied against the state or any state agency likely to be involved in this project (such as CDFG), since the state has not consented to regulation. (*See City of Orange v. Valenti*, 37 Cal.App.3d 240, 244 (1974); Cal. Gov. Code §§ 53090-53091 (the state is not a "local agency" that must comply with local building and zoning ordinances). Thus, the Yolo County ordinances would not apply to CDFG and the Putah Creek alternative.

In some cases, local zoning ordinances can be applied against the federal government. Local ordinances would not apply if in direct conflict with federal law. Whether the ordinances would apply to federal activities in the Yolo Bypass would depend upon the language of the statutes that authorize the activity. The exact nature of federal involvement in this project, and therefore whether the zoning controls would apply, is unknown at this time.

These zoning ordinances could apply to wholly private activities in the Yolo Bypass, however, wholly private actions are not anticipated in this project.

FLOOD EASEMENTS

The Sacramento Flood Control Project and constituent flood control agencies have obtained flood and flowage easements on nearly all of the properties in the Yolo Bypass (and all of the properties on the eastern side where the proposed flooding would occur) to permit what would otherwise be an invasion of the landowner's property interests. The easements were obtained between 1916 and 1994, and their language varies significantly. (Yolo Bypass et al. 2001).

Coverage of Existing Easements

Most Yolo Bypass restoration strategies require new flood regimes. They vary by water source (e.g., tidal inundation, Sacramento River, and tributary waters sources such as the Putah Creek alternative), by location and property ownership (e.g., on public property only for the Putah Creek alternative), by hydrologic conditions (e.g., every year regardless of hydrologic condition or only in years when the Sacramento River reaches a certain stage) and by purpose (fish and bird habitat solely or joint flood control and environmental restoration). Whether proposed flooding regimes will be covered under the existing easements depend on the answers to the following questions: (1) Is the proposed flooding expressly authorized by the language of the easements?; (2) If not expressly authorized, is it consistent with the language and purpose of the easement?; (3) If the flooding is neither expressly permitted nor barred, what are the consequences of going forward with the increased flooding?

The exact number of easements in the Yolo Bypass is unknown. NHI reviewed 34 representative Yolo Bypass easements. Twenty-one of those address flood and flowage easements. The location of the potential restoration sites relative to these easements is unknown at this time. The language of the representative easements varies. Of those 21 easements, 17 contain variants of the following language:

> *First party does hereby grant to the party of the second part [the Sacramento and San Joaquin Drainage District], its successors and assigns, a perpetual right and easement without recourse to compensation for damage therefrom, past, present or future, for the passage of all flood waters of the Yolo Bypass, which may from*

> *time to time inundate, or which has theretofore inundated, the lands of the party of the first part, over and upon and across all of the following described property. . . .(Deed #467)*

The four other flood and flowage easements vary significantly from the language above. One provides that the landowner grantor has no right to compensation for damage caused by "any and all waters and material which may, as a result of any present or future flood control project in the state of California from time to time inundate . . . said real property" (Deed #4211). Three others state that there will be no compensation for "the passage of all waters of the Sacramento Flood Control Project" (Deeds #4381, 1320). None of the easements include language that limits the time of year that inundation may occur. They all appear to be perpetual easements.

Whether the flooding is expressly authorized by these easements depends largely upon the definitions of "flood waters" and "all waters." California law defines "floodwaters" as those that, because of their height, escape from a stream or other body of water and overflow the adjacent property. Implicit in the definition of floodwaters is the element of abnormality, in that they do not normally occur. *See Everett v. Davis*, 18 Cal. 2d 389, 393 (1941). This definition does not fit well in the Yolo Bypass since arguably the floodwaters are "managed" to recur regularly. This definition is therefore ambiguous with respect to regularly recurring, intentional flooding. "All waters" does not have a precise legal definition, but it is of course broader than floodwaters; the best definition in these circumstances are waters related to the *operation* of the flood control project, but not necessarily abnormally occurring floodwaters. The four easements for "all waters" presumably would permit any new flooding regime related to the operation of the flood control project, such as lowering the height of the Fremont Weir allowing the Sacramento River to top at lower stages. Conversely, flooding from a tributary water source or tidal inundation is unrelated to the purpose of the flood control project. An ambiguous situation involves year-round flows from a low-flow notch in the Fremont Weir; it is *related* to the project but does not serve a flood control purpose.

Since the definition of "flood waters" is ambiguous with respect to intentional flooding, the best test is whether the proposed flood regime is consistent with the language and purpose of the easement. The central purpose of these easements is to provide for the conveyance of floodwaters and flood damage reduction. Intentional flooding therefore must have a flood control purpose to be covered by the easements; being flood control "project-related" is probably not enough. Modification of the weir(s) to top at lower flood stages seems permissible, since flood pressure is reduced, although incidental environmental benefit is created. A weir notch to provide perennial low flows serves a non-flood control purpose, and would not be covered.

Only in a few circumstances would the proposed flooding regimes be clearly permitted under the existing easements. Even where it appears permissible, there is enough ambiguity for objecting landowners to raise colorable claims challenging the new flooding operations. If deemed a violation of the easement, landowners could sue for trespass and enjoin the flooding and/or receive damages. California public agencies operating flood control projects do not share the federal government's immunity from flood damage; they are liable for damages resulting from unreasonable conduct or unreasonable operation of flood control facilities. Litigation costs would be high, even if the public agencies sought a declaratory judgment. Negotiating amendments to the easements rather than litigation would strengthen relations with Yolo Bypass landowners and would be more cost-effective. Amendment could be sought only with volunteering landowners or could require the payment of small fees. In any circumstance, the easements at issue must be closely evaluated on a case-by-case basis.

Issues and Options Specific to Alternatives

If the flooding envisioned in the Putah Creek alternative occurs solely on property owned by CDFG, flood easements are not necessary.

For a Sacramento River/Fremont Weir alternative, one option is to overlay a new flood and/or conservation easement over the properties. A conservation easement (or conservation restriction) is a legal agreement between a landowner and a land trust or government agency that permanently limits uses of the land in order to protect its conservation values. The owner may continue to use the land, pass it on to heirs or sell it. A landowner may sell or donate a conservation easement. If the donation benefits the public by permanently protecting important conservation resources and meets other federal tax code requirements, it can qualify as a tax-deductible charitable donation. It can also result in a substantial state tax break for the landowner, under the California Natural Heritage Preservation Tax Credit Act of 2000. The amount of the donation is the difference between the land's value with the easement and its value without the easement. Easements may also result in property tax savings (but a loss to the County).

Since Yolo Bypass properties already have easements, there is likely no additional property tax savings. Landowners may require payment of a fee to permit the increase flooding, possibly citing increased farm maintenance costs.

The Yolo Land Trust has established conservation easements in the County, including one on the Los Rios Farms. The California Farmland Conservancy Program Fund may provide funds for such a purpose. The program was created by the Agricultural Land Stewardship Program Act of 1995. (Cal. Pub. Resources Code §§ 10200-10277). The program is administered by the Department of Conservation. One criterion for funding is that the land is likely to be converted to nonagricultural use in the foreseeable future. The California Wildlife Conservation Board also provides funding for a variety of wetland and agricultural conservation programs. Many other easement and conservation programs may be applicable (e.g., Yolo Bypass et al. 2001, pp. 2-10 through 2-13).

WATER RIGHTS ACQUISITION

Riparian and Appropriative Water Rights

New water rights will have to be obtained or existing rights will have to be amended for nearly every alternative and major action. New sources of water will have to be found, and a permit to appropriate be granted by the State Water Resources Control Board (State Board), to supply water for strategies such as low-flow water delivered by a notch in the Fremont Weir. For other alternatives a water source may be available, but a petition may have to be submitted to the State Board to change the point of diversion, place of use or purpose of use.

There are two primary types of surface water rights in California: riparian rights arising as an incident to ownership of land abutting a watercourse; and appropriative rights, the right to divert water for use on nonriparian lands. Appropriative water rights obtained after 1914 are subject to the permitting jurisdiction of the State Board. Some properties targeted for restoration in the Yolo Bypass, such as the Glide Ranch property, already have riparian rights to flow in the Toe Drain or Tule Canal. The water beneficially used under these rights may be used for restoration purposes without seeking any approval from the State Board. If properties have appropriative rights, a change petition must be submitted if the purpose of use will change (e.g., from an agricultural use to environmental uses), or if the place of use or place of diversion will change. Formal change petitions may require six months if there are no protests and no hearing is required. Small changes in the mode of diversion (e.g., new pump) or place of diversion (e.g., moving diversion 100 feet) may be subject to simple and less complicated procedures. If new appropriative rights must be obtained, small projects diverting 3 cfs or less with minimal protests may take six to eight months for, and large projects greater than 3 cfs usually require over one year, depending upon the complexity and amount of protest (State Water Resources Control Board 2000).

Lower Putah Creek Water Rights

Putah Creek Settlement Flows

The quality, quantity, timing and reliability of Putah Creek flows are sufficient to meet some project goals in part. A small but reliable source of water is provided by the public trust and instream flow settlement of 2000 between the Solano Parties (Solano County Water Agency, Solano Irrigation District, Maine Prairie Water District and the cities of Vacaville, Fairfield, Vallejo and Suisun City) and the Putah Parties (Putah Creek Council, City of Davis and University of California). The settlement was entered in and is enforced by the Sacramento Superior Court, thereby resolving and dismissing Case Nos. 3 CIVIL No. C025527 and 3 CIVIL C025791, which were appeals of a Sacramento County Superior Court trial decision in Case No. 515766. The settlement ended litigation over minimum instream flow requirements and requires that specified minimum flows be met at different points along the Creek, from the Putah Diversion Dam to the east Toe Drain in the Yolo Bypass, with two sets of flows for drought and non-drought years.

Parties to the Putah Creek Settlement have suggested that the settlement flows can be used for the environmental purposes of this project, provided that the magnitudes and timing of flow, including the minimum flows and the pulse or attraction flows, are not substantially modified (Marovich, Sanford and Krovoza pers. comm.). Because this alternative proposes realignment of the Putah Creek channel, the east Toe Drain compliance point of the Settlement Agreement would be moved. However, the Settlement Agreement does not include a map; it simply describes the compliance point location verbally as the point where Putah Creek enters the east Toe Drain of the Yolo Bypass. Thus, as long as the flow criteria are met at the new location, formal revision of the Settlement Agreement might not be necessary. Parties to the Settlement Agreement have indicated they would be amenable to an administrative change in the point of compliance provided that there will be net environmental benefit and no additional water cost (Marovich, Sanford and Krovoza pers. comm.).

The Putah Creek alternative considered for the floodplain habitat project would likely increase flow losses upstream of the Toe Drain by increasing the water surface area exposed to evaporation and seepage. Also, the pulse flow that occurs when the check dam flashboards are removed in fall—which is considered to be an important attraction flow for migrating adult salmon—would be eliminated if the flashboards permanently installed or removed and the lower Putah Creek channel filled. It is assumed that the floodplain project would be responsible for obtaining supplemental water to offset increased flow losses and replace the fall attraction flow pulse.

Further, the Putah Creek water is released via an appropriate permit held by the U.S. Bureau of Reclamation. A change petition for the settlement flows has been submitted but has not yet been decided by the State Board (Application 11199, Permit 10657; Application 12578, Permit 10658; Application 12716, Permit 10659). Realignment of creek could require modification of the change petition before it is approved, or submission of a new change petition after the change petition has been approved, to change the authorized place of use, i.e., to shift the place of use from Putah Creek at the Toe Drain to a point downstream. However, the change petition does not specify the exact place of use at the Toe Drain. Modification of the existing petition or submission of a new change petition may therefore be unnecessary. Alternatively, an administrative amendment of the permit may be adequate.

Additional Water Sources

The existing Putah Creek flow regime might not be sufficient to sustain the floodplain inundation continuously for 30 days in all years, and additional water would also be needed to offset the increase in flow losses and possibly the elimination of the fall attraction flow pulse. An additional source of water would have to be provided. Fortunately, the location of the floodplain project is such that several potential sources of supplemental water are available. These include water pumped from the Toe Drain under riparian right, on-site groundwater (pumped pursuant to the correlative rights of overlying landowners), water purchased from an existing Solano Project user, a water transfer with a North Delta Aqueduct user, water exchanged by paying an upstream riparian diverter to switch to groundwater, or water yielded by enforcement actions against illegal riparian diverters downstream of I-80. Some of the latter sources may be constrained by cost or institutional issues. For example, the water supply contracts for Solano Project users give them the first right of refusal for any surplus water before it can be offered to outside entities. Because the Solano Project supply does not fully meet the water needs of its contractors, any surplus water would almost certainly be claimed by another internal contractor.

The Glide Ranch property has substantial riparian water rights in the Toe Drain. The quantity of the Glide Ranch water rights is not fixed, but as a general rule the quantity historically used for irrigation on the property can be applied for the new fish and wildlife uses, subject to correlative sharing in times of shortage. The Glide Ranch water rights can be pumped to the new impoundments on Putah Creek using the existing Yolo Bypass Wildlife Area diversion facilities. The Toe Drain at Glide Ranch is tidally influenced, suggesting there is ample water available to augment the Putah Creek flows for floodplain inundation without injuring other water users. It is unknown at this time whether the historically diverted Glide Ranch riparian rights, used in conjunction with the Putah Creek flows, are adequate to create the proposed floodplain habitat, or whether the diversion timing and quantity will have to be substantially changed.

Water Rights for a Sacramento River/Fremont Weir Alternative

Acquiring new water from the Sacramento River by a Fremont Weir modification is complicated, and may require obtaining a new appropriative right. If the Fremont Weir is modified to simply overtop at a lower flood stage, then only floodwaters would be conveyed and an appropriative permit is unnecessary.

Diverting water through a low-flow notch, either for perennial low flows or only for salmonid and sturgeon migration periods, requires an appropriative permit. The Sacramento River is fully appropriated. As a general rule all new appropriations for in-basin uses in the Sacramento River and San Joaquin River systems, such as this one, have to comply with Term 91, a special condition attached to all water right permits (1 cfs or 100 acre-feet and larger) to ensure protection of Bay-Delta water quality standards (State Water Resources Control Board, Water Right Decision 1594 [D-1594]). Term 91 states that the permittee cannot divert when State Water Project and Central Valley Project stored water is being released to augment natural flows in order to meet Bay/Delta standards (Johns 2001). This period would rarely occur during the late winter to early spring period when this project desires to divert for floodplain inundation, but it would affect a year-round, low-flow notch diversion. The State Board has discretion to waive Term 91, and may consider waiving it for this project since the water would flow out of the Delta, provided that consumptive losses (i.e., evapotranspiration and other conveyances losses) would be minimal. The State Board, however, suggested that if the project agreed to accept Term 91, the State Board would likely approve the permit (Jerry Johns, formerly SWRCB, pers. comm.).

Water rights downstream of the Fremont Weir would still have to be analyzed, notwithstanding Term 91. If other in-basin uses exist downstream of the diversion, they would have a higher priority. Water should be available for appropriation in the winter and early spring before the irrigation season, but a year-round diversion would occur in high-demand periods when water would not normally be available. The State Board could still grant the right to appropriate a small amount of water in the summer and fall provided no water user between the diversion and return flow suffers injury, but the petition could face considerable opposition. For these reasons the weir notch should have operable gate that can be closed when Term 91 or any other special terms and conditions require, or when fish migration could be harmed by the diversion into the Bypass.

The appropriation would likely be greater than 5 cfs, and the State Board would consider it a large project for which formal a hearing(s) may be necessary. The time to obtain the permit would likely be greater than one year.

Conclusion: Next Steps and Compliance Process

Putah Creek Alternative

- Coordinate with the CDFG Wildlife Area Manager. Continue development of Management Plan. Ensure that the proposed restoration actions are considered in the plan.
- Discuss amendment of the Yolo Basin MOU to include the Putah Creek alternative with the MOU parties. Consider adding NMFS to the MOU.
- Continue modeling potential flood conveyance impacts of restoration actions.

- Meet with the Putah Creek parties to determine whether the settlement agreement would need to be amended to accommodate a new streambed alignment.
- Begin CEQA compliance as soon as practicable. Because CDFG has committed to not change land use until a Wildlife Area Management Plan is complete, CEQA compliance likely will not be initiated until the Management Plan is complete or near complete. A Negative Declaration will likely be sufficient for this alternative.
- Meet with the CALFED permitting team once CEQA compliance initiated to investigate options for streamlined permitting.
- Initiate ESA/CESA/NCCP compliance once CEQA compliance initiated. Meeting informally with the wildlife agencies' CALFED team. Start by requesting a species list. If there are potential impacts to listed species, begin preparation of a Biological Assessment or an ASIP (if a CALFED action).
- Initiate CWA 404 compliance once the draft project description is available. The Putah Creek realignment should be authorized NWP 27. Start by obtaining a wetland delineation. Once the draft Negative Declaration complete, submit the NWP 27 Preconstruction Notification (PCN).
- Submit a CWA 401 certification/waiver application when the NWP PCN is submitted.
- Initiate the process to obtain Reclamation Board Encroachment Permit.
- Incorporate any necessary mitigation and conservation measures into the Final Negative Declaration.
- Submit a Streambed Alteration Agreement once the 404 PCN is accepted.
- Complete the Reclamation Board, *Yolo County*, and ESA/CESA/NCCP compliance processes.

Sacramento River/Fremont Weir Alternative

- Coordinate with the USACE's Comprehensive Study and SAFCA.
- Conduct a feasibility study of possible weir modifications. Determine the properties potentially impacted by the flooding alternatives.
- Analyze flood easements on the potentially affected properties. Discuss the coverage of the easements with the landowners.
- Conduct fish passage analyses.
- Determine whether there is water available for appropriation in the Sacramento River. Submit a petition to appropriate.
- Begin consultation with the wildlife agencies early, since this alternative could affect a large number of listed fishes.
- Investigate options for safe harbor and neighboring landowner assurances under the Endangered Species Act.

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APPENDICES

APPENDIX A: 2001 IEP YOLO BYPASS FISH WORK PLAN

IEP Element 2001-047

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2. Project Overview

The Yolo Bypass is the primary floodplain of the Sacramento Valley, approximately doubling the wetted area of the Delta during major storm events (Figure 1). Studies by the IEP Yolo Bypass Project Work Team have demonstrated that this extensive area of shallow water habitat supports at least 40 fish species including winter-run Chinook salmon, delta smelt, splittail, steelhead trout and sturgeon (DWR 1999). The Bypass is particularly important to splittail, which forage, spawn and rear on the floodplain (Sommer et al. 1997). The results of 1997–2000 studies suggest that the area supports excellent growth of salmon as a result of high food availability and warmer temperatures. Also, the Bypass is used by migratory fish during low flow periods—we have evidence that adult salmon and perhaps steelhead periodically enter the Toe Drain in autumn, months before the region is inundated.

In recognition of the value of the Yolo Bypass, the CALFED program is interested in conducting restoration activities in the basin to improve its benefits to fisheries. Examples of potential projects include more frequent inundation of the floodplain, increasing the acreage of wetlands, and fixing fish passage and stranding problems (DWR 1999). However, the 1997–2000 data are too limited to provide a reasonable baseline to evaluate the success of future restoration actions. In particular, we are lacking data for drier years, when some of the restoration actions are proposed.

3. Study Objectives and Potential Benefits

The study has been designed to continue testing a new field method, provide descriptive information about how fish species use the floodplain and help develop hypotheses. Each of these objectives is summarized below. The expected approach for each is provided in Table 1.

Methodological Objectives

- Continue testing a fyke trap as a means for collection of adult fish.

Descriptive Objectives

- Describe Yolo Bypass seasonal and interannual trends in fish community composition and abundance.
- Describe the species composition and timing of adult migrants into the floodplain.

Research Objectives

The present study is primarily descriptive because the floodplain represents a “new” habitat for the Interagency Ecological Program. As a consequence, the primary purpose of this study is to collect baseline data that can be used to develop and evaluate hypotheses. Based on initial results, we have several tentative hypotheses about fish dynamics and habitat that we hope to test once we have developed a satisfactory database. Some of our major initial ideas are summarized below as research questions. Because of the limited database, it is probably not reasonable to evaluate these questions using strict hypothesis testing procedures. On the other hand, we believe it is important to provide an indication of the major research issues we hope to address, most of which focus primarily on the question of whether or not floodplain habitat provides special advantages to native fish. More formal hypotheses (e.g., null and various alternatives) will be developed once data are collected from a broader range of water years.

- Is fish diversity consistently higher in the Yolo Bypass as a result of more diverse and variable habitat?

  Based on initial results, we hypothesize that we will find higher fish diversity in the Yolo Bypass than the Sacramento River as a result of more diverse habitats and environmental conditions.

- Does seasonal flooding benefit native fish more than introduced species?

  We hypothesize that winter and early spring flooding will preferentially benefit natives, which are adapted to spawn in cooler water.

- Can we identify environmental conditions (e.g., flow, temperature) that support better production of native fish?

  Based on published information on species life history, we hypothesize that cooler temperatures and long duration, early season flooding will enhance production of native fish.

- Is growth and survival of salmon consistently better in the Yolo Bypass than the Sacramento River in wet years? What about dry years?

Initial CWT and size results suggest that Yolo Bypass salmon growth and survival is better in wet years. We expect relatively poor Yolo Bypass growth survival in dry years as a result of high predator densities in the Toe Drain and lack of access to floodplain rearing habitat.

- To what degree are salmon stranding rates affected by environmental factors such as hydrology and temperature?

  We hypothesize that salmon stranding rates will be highest as a result of small early-season pulses, followed by no additional flow.

- What are the habitat preferences for splittail spawning and rearing?

  The spawning and rearing preferences of splittail are poorly understood. We hypothesize that adult spawning occurs primarily on inundated vegetation, and that larvae and juveniles prefer shallow areas (<3.2 feet).

  The program element will be deemed successful if we can address the majority of the objectives. The study addresses the following 1998 IEP Long Term Planning Considerations and Actions: 2J, 3C, 3D and 7F. The program would have multiple benefits:

- Describe the relationship between the Yolo Bypass and the rest of the Estuary. This includes information about resident and migratory fish species such as salmon, steelhead, delta smelt, sturgeon and splittail for different water year types and seasons.

  Releases of coded-wire-tag (CWT) salmon would provide estimates of survival, growth and migration time of salmon through the Yolo Bypass versus the Sacramento River.

- Provide baseline data for the evaluation and design of future Yolo Bypass restoration activities.

  Additional data are needed to describe seasonal and interannual variability.

- Collect data for other Yolo Bypass PWT members.

  In Year 2001 we propose to collect drift samples, zooplankton and chlorophyll data as part of food chain studies for the Bypass.

4. Project Start Date and End Date

The project began December 1998 and is expected to continue through the end of year 2001. For this study season, field data collection will begin in October 2000 and continue through June 2001. We recommend that this monitoring program be considered annually for at least several more years to provide data from a range of water year types.

5. Estimated Annual Catch of Delta Smelt, Winter-Run Salmon, Spring-Run Salmon, Steelhead Trout and Splittail by Lifestage

The reasonable likely **take** of threatened or endangered species by Yolo Bypass field sampling is summarized below:

Species/Life Stage	Reasonable Likely Take
Winter-run Chinook (juveniles/adults):	50/10
Spring-run Chinook (juveniles/adults):	500/10
Steelhead Trout (yearlings/adults):	50/10
Splittail (adults/juvenile):	500/5,000 with less than 10% mortality
Delta smelt:	100

Note, however, that these levels are for wet year sampling only. In dry years the total take of juvenile salmonids is likely to be less than 5 for each species. We assume that all take levels will be included in the IEP permit. Daily take will be reported electronically using the IEP reporting system.

6. Estimated Number, Classification and Agency of Personnel Needed

Environmental Specialist IV (Sommer)	DWR
Environmental Specialist III (Harrell)	DWR
Scientific Aides (2)(O'Leary, Conrad)	DWR

7. Estimated Project Costs (total for personnel, operating and equipment)

The budget for the project is about **$100,000** (Table 2).

8. Major Equipment Required

The key pieces of equipment are a small boat and truck (supplied by DWR), a screw trap (supplied by USFWS), and a fyke trap (supplied by CDFG-CVBDB). If a Yolo Bypass screw trap is damaged, DWR would use another FWS trap as a back-up.

9. Summary of Project Logistics

The major activities are summarized in Table 3 along with crew assignments. The sampling locations have been selected based on previous work during 1997–2000, allowing comparisons between years, seasons and water year types. Detailed methods are as follows. Contingency plans are provided in Table 4 for each sampling method. In addition to the field activities, monthly crew safety meetings would be organized by principal investigator Harrell to cover handling of boats, sampling gear, vehicles, rescue methods and emergency protocol. Training activities for the present year includes swiftwater rescue (summer 2000) and fish identification (spring 2001).

Juvenile/Adult Fish Sampling: An eight-foot rotary screw trap will be operated in the Toe Drain (Figure 2) up to 7 days a week during the January–June 2001 period. Ebb tides are sufficient to operate the trap in any water year type—in 1998, 1999 and 2000 we successfully fished a trap in the Toe Drain using the tidal cycle for many weeks after inundation from Fremont Weir had ceased. A detailed screw trap field protocol is provided as Attachment 1. Data will be recorded on the number of fish collected/day and, in wetter years, fish/volume.

In wet years the monitoring crew would also conduct biweekly beach seining at 2–5 established stations located around the perimeter of the Bypass, depending on water level. Data collected from adjacent FWS beach seine stations would be used for comparison. After the Yolo Bypass drains we plan to seine at several reference locations to provide an index of stranding rates. During dry years or non-flooded periods of wet years beach seining will be conducted monthly at three reference stations: a Yolo Basin Wetlands "study pond", a permanent pond located below Fremont Weir and a shoal near the Toe Drain screw trap site.
A detailed field protocol for beach seining is provided as Attachment 2.

As in 1998,1999, and 2000, we propose to conduct a release of CWT salmon fry in the Yolo Bypass and Sacramento River. A total of 200,000 fry would be tagged at Feather River Fish Hatchery, to allow a total of four release groups of 50,000. The proposed release schedule is:

Release 1: Late January–early February
Fremont Weir: 50,000
Elkhorn boat ramp: 50,000

Release 2: mid- to late-February
Fremont Weir: 50,000
Elkhorn boat ramp: 50,000

Tags will be recovered downstream by IEP sampling and the ocean fishery. Further details about this study component are provided in Attachment 3.

The handling and sub-sampling protocol for all fish is designed to minimize impacts to salmon, particularly the endangered winter-run Chinook. Fish will be placed on wetted plexiglass measurement boards, identified, then measured to the nearest mm fork length. Any fin-clipped salmon will be euthanized using MS-222, bagged in a whirl-pak bag marked with information on sampling location, date, gear type, fork length, weight, time and temperature, then placed on ice in a cooler until transferral to a deep freeze. The tags will be read by USFWS Stockton biologists.

Additional Adult Fish Sampling: Screw traps and beach seines do not effectively capture upstream migrating adult fish. A fyke trap will be used to monitor the adult fish abundance and species composition. We know that adult splittail, salmon and sturgeon are present in the Bypass in wet years and perhaps also dry years. However, the timing and abundance levels are unclear. We plan to use a 10-foot diameter fyke trap similar to those used by CDFG Stockton for sturgeon and striped bass. The interior terminal chamber of the trap will be lined with 3/4 inch square plastic mesh to improve collection and protection of splittail. The trap will be fished in the Toe Drain near levee mile 6.5 and retrieved using a truck-mounted winch. The trap will be fished 7 days a week during the October–June period. However, if Fremont Weir spills, trapping may be temporarily suspended until high flow and debris levels subside. The field protocol for this study component is provided as Attachment 4.

Larval Fish Sampling: Fixed nets will be used to collect larval fish from the Yolo Bypass and Sacramento River. The larval net is constructed with 500 micrometer mesh and is conical in shape. The round mouth opening is two feet in diameter and the net is about eight feet in length. Flow will be recorded using a General Oceanics meter mounted in the mouth of the egg and larval fish net. Sampling would be conducted once monthly on an ebb tide during dry or unflooded conditions and every two weeks when the Bypass is inundated. Early- to mid-morning (before 10:30 am) samples are preferred. Each sample should have a tag and be preserved in formalin. Sample custody would be the responsibility of one of the field crew, who will maintain sample records for the archives. The samples would be delivered as a group to an external laboratory for identification purposes. Note that the laboratory protocol for sample analysis remains to be determined, however we expect that identification would be performed by either Johnson Wang or CDFG Stockton. We would coordinate QA/QC procedures with the designated contractor.

Splittail Experimental Pond Study: In 2000 Department of Water Resources, Natural Heritage Institute and Yolo Basin Foundation received funding from CALFED to examine the feasibility of developing a demonstration-scale project based on managed Yolo Bypass flooding for splittail and other aquatic species. Central questions for splittail include: 1) will they spawn on intentionally flooded terrestrial lands? 2) what are suitable spawning habitats? 3) what physical conditions trigger spawning, and 4) what are suitable rearing habitats for larvae and juveniles? The existing Yolo Bypass monitoring program and earlier IEP splittail studies have only partially addressed these issues. In this study component, we propose to answer some of these questions using intensive spawning, larval and juvenile observations on splittail intentionally stocked into a small experimental wetland pond. This approach is somewhat artificial because splittail will not have access to a complete range of habitat types; however, we believe that pond studies will help us generate useful hypotheses for testing on a larger scale. Our basic approach will be to do intensive observations on splittail in a Department of Fish and Game Demonstration Wetlands Pond, located at the Yolo Basin Wildlife Area. The protocol for this study component is described in detail in Attachment 5.

Physical Data: Water temperature and weather will be recorded on all sampling days. Onset temperature loggers will be deployed January–June at the Yolo Bypass Toe Drain screw trap site and the Sacramento River Sherwood Harbor dock. The loggers will be visited every two weeks throughout the sampling period to download data using a laptop computer. A fluorometer and EC meter will be deployed for continuous sampling in the Toe Drain. Data loggers and probes will be secured in a custom aluminum box, which will be bolted to the screw trap. Flow data will be recorded on a spreadsheet using data from California Data Exchange Center and Solano County Water Agency (Putah Creek only).

10. Data Reduction

Data will be recorded using data sheets based on standard Interagency Ecological Program forms that have been modified slightly to include salmon life stage and other factors. For the salmon codes, the first four characters would identify race ("CHNF", "CHNW","CHNL", "CHNT" or "CHNS"). For salmon and steelhead, the life stage ("P"=parr, "X"=transitional or "S"=smolt) would also be recorded.

Data QA/QC will be a four-stage process. First, the data sheets will be error checked at the end of each day by the crew leader. Data will then be entered into an IEP-designed Microsoft Access form with automatic error-checking and data validation. Third, data entry personnel will compare the original data sheets to the electronic database. Finally, each data field will be sorted and/or summarized based on unique records. In addition to data QA/QC, project leadpersons (Harrell and Sommer) will accompany field crews on a regular basis to check methods for accuracy and consistency with previous years and, where necessary, implement corrective actions. We do not anticipate any problems, as the field crew will be similar to last year. For electronic data, corrections would be the responsibility of both the crew and the leadpersons. Completed data files would conform to standard IEP format for fish sampling.

11. Data Analysis

Data analysis would be conducted using Statistica or Minitab software packages by the leadpersons with major assistance from the crew. Expected statistical analyses are summarized in Table 1. Where appropriate, data series will be checked for normality and homogeneity of variance. Some of the data analyses will be tabular, with no specific hypothesis to be tested.

Many of the data analyses will be similar to Sommer et al. (1998) and DWR (1999). Species composition and density comparisons will be made: 1) within Yolo Bypass regions (Figure 1); 2) to FWS beach seine stations in the Sacramento River; 3) between seasons and 4) between water years (i.e., versus 1997–2000). The primary environmental variables that we intend to evaluate include: flow, depth and temperature. The present sampling design should be sufficient to address most of the research questions, however contingency plans are provided in Table 4 should major data gaps occur. Because of the extreme hydrologic and spatial variability in this habitat, we expect that it will be particularly important to develop a long-term database to reflect the range of conditions.

12. Products and Due Dates

Data from the Yolo Bypass monitoring will be posted on the IEP Home Page within one year after the completion of the field season. As in previous years, database structure would be similar to other IEP fish monitoring program elements. During year 2001 we will contribute IEP quarterly reports and an IEP Newsletter article summarizing field results.

The lead persons are planning to complete two articles by December 2001 on juvenile salmon for peer-reviewed journals (Can. J. Fish. Aq. Sci., Trans. Am. Fish. Soc.), which might include some results from year 2000 sampling. However, we expect that the present year's results would be incorporated into a fish community paper by year 2002. The longer period to publication is based on the need to collect multiple years of data to analyze community trends.

13. Review Team Members

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Matt Nobriga, DWR - ESO (916) 227-2726

14. References

DWR. 1999. Results and recommendations from 1997–1998 Yolo Bypass studies. Prepared by DWR for CALFED. April 1999.

Sommer, T., R. Baxter and B. Herbold. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. Trans. Am. Fish. Soc. 126: 961–976.

Sommer, T., M. Nobriga and B. Harrell. 1998. Results of 1997 Yolo Bypass sampling. IEP Newsletter 11(1): 39–42.

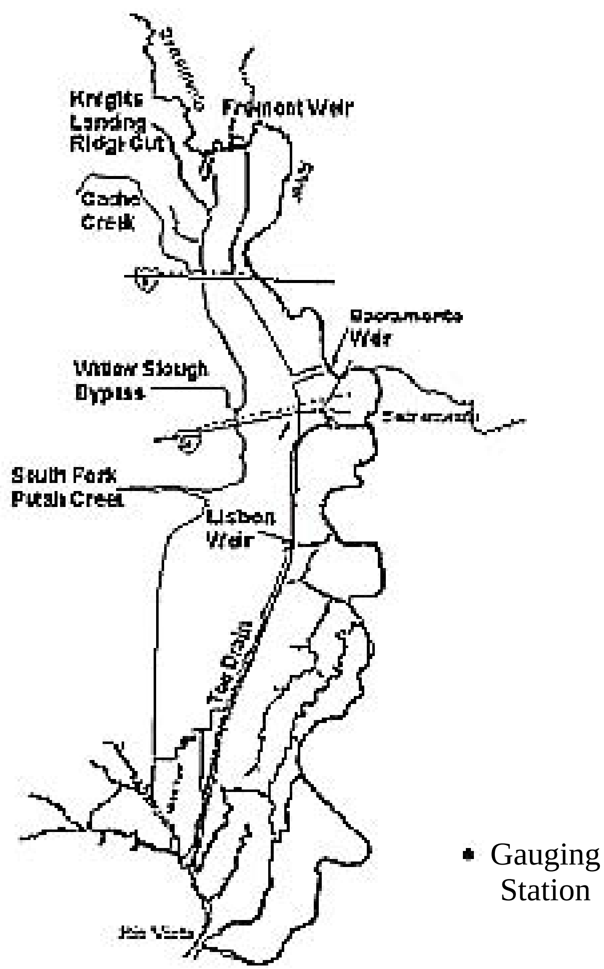

Figure 1
Yolo Bypass Hydrologic Inputs and Gauging Stations

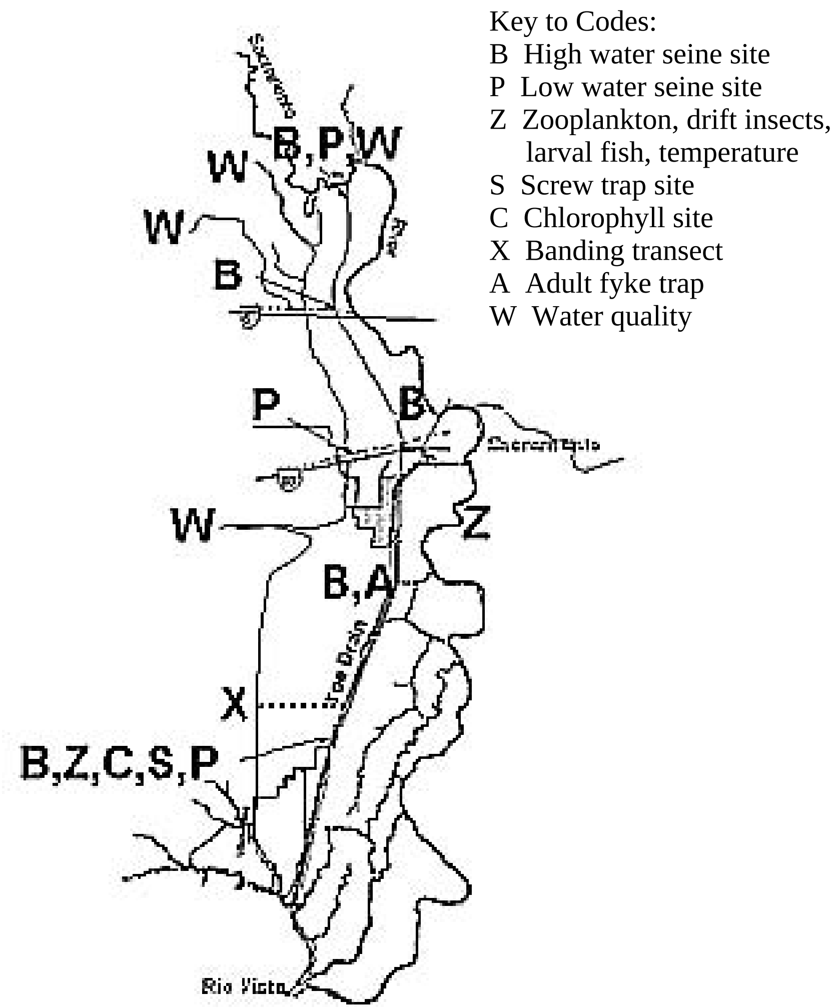

Figure 2
Yolo Bypass Sampling Areas

Table 1. Summary of Data Analyses

Research Question	Database	Proposed Analyses	Comments
Test fyke trap.	Fyke	Tabular summary of species composition and timing.	Year two testing this method for adult fish sampling.
Describe fish community composition and periodicity in the Yolo Bypass	Screw trap Beach seine Fyke	Tabular summary of life history use in Yolo Bypass.	Gear types not effective for resident adults.
Compare fish diversity on floodplain versus river habitat	Beach seine	T-test on Shannon Diversity indices for Yolo Bypass and Sacramento River.	In past years, sample effort has been different between the two locations, so sample size may have to be equalized. However, previous year's sampling indicates that the present level of effort is sufficient to detect differences between years.
Determine importance of seasonal flooding to native and introduced fish	Screw trap Beach seine	Conceptual analysis: examine observed species periodicity versus the floodplain hydrograph. Multivariate techniques (see below) will also be used.	Multiple years of data will be required for a reasonable analysis, but we have no initial estimates. Variable hydrology makes data interpretation complicated. Low sample sizes for many species.
Determine environmental conditions that support better production of native fish	Screw trap Beach seine Fyke?	Multivariate techniques (e.g., PCA or CCA) on species composition versus hydrograph, temperature, habitat and other factors.	Multiple years of data will be required for a reasonable analysis, but we have no initial estimates. Variable hydrology makes data interpretation complicated. Low sample sizes for many species.

Table 1--Continued

Research Question	Database	Proposed Analyses	Comments
Compare the value of Yolo Bypass and the Sacramento River to Chinook salmon rearing	Screw trap Chipps Island Beach seine	ANOVA methods to compare growth, survival and migration time for CWT recaptures from Yolo and Sac. River releases. Regression or ANOVA methods to examine effects of environmental conditions on growth, survival.	Low recapture rates. Although we have found the present level of effort is adequate to address growth, many years of data will be required for statistical significance for 1) survival comparisons; 2) identifying key physical parameters. Boot strapping may be used as tool to address this problem.
Examine spawning and rearing behavior of splittail.	Egg tiles Light traps Snorkeling	Frequency distribution of spawning or rearing intensity for different habitat types and environmental conditions. ANOVA methods may also be used.	This is a very experimental study component. There is no assurance that splittail will spawn in the experimental pond or that we will be able to monitor them. At the very least, we hope to learn enough to conduct a more efficient study by next year.
Examine rates of salmon floodplain emigration between years.	Screw trap Beach seine	Timing of screw trap emigration may be compared between seasons and years after normalizing data. Statistical test to be determined. ANOVA or Mann-Whitney U-test comparison of beach seine densities before and after floodplain ponding. Comparison of stranding rates between years under different environmental conditions. Possible use of ANOVA or multivariate techniques.	Previous field sampling indicates that it is not feasible to develop accurate estimates of stranding rates because of the patchy distribution of fish. We have not yet determined whether the stranding indices are suitable for gross comparisons between water years.

Table 2. Summary of Yolo Bypass Fish Study Budget

	Staff	Time	Months	Rate	Total
Coordination	ES.IV	0.20	8	10,788	19,418
	ES. III	0.50	8	6,477	25,910
Crew	Sci. Aides (1)	1.00	9	2,280	20,520
				Subtotal	69,087
		100,000 CWT fry			12,000
		Supplies and Equipment			10,000
		Larval Fish ID			7,000
		Total			$98,087

Table 3. Summary of Yolo Bypass Field Activities and Responsibilities

Activity	Task	Frequency[a]	Who is Responsible
Administrative	Principal Investigator Crew Leader Field crew Crew alternates	Continuous	Sommer, Harrell Harrell O'Leary, Conrad Seesholtz, Sears, Sommer, Itoga
Physical	Flow (CDEC,SCWA) Temperature loggers/data "Events"	Continuous Every 2 weeks Continuous	O'Leary Conrad O'Leary
Biological	Screw trap Beach seining Fyke Trap Stranding survey Zooplankton, insects, eggs and larvae Sample archives Splittail pond study	4 or 7 days/week 1 or 2 times/month 3 to 7 days/week Daily after drainage 1 or 2 times/month Continuous 4–5 days/week	O'Leary, Conrad O'Leary, Conrad O'Leary, Conrad Additional sci. aides O'Leary Conrad All staff
Data	Entry and QA/QC Take Reports IEP ES Take Reporting	Continuous Monthly Weekly	O'Leary, Conrad Harrell O'Leary

[a]Lower range for each represents tidal/unflooded conditions, upper range represents flooded conditions.

Table 4. Contingency Plans for Sampling

Method	Contingency Plans
Screw trapping	An extra trap is available if the field unit becomes lost or inoperable. Linear interpolation appears to be a satisfactory method to “fill” missing data points. These data are primarily descriptive, so minor data gaps do not have severe consequences.
Beach seining	Missing data stations are likely to be our major problem, reducing the power of regional comparisons. Nonetheless, our only alternative may be to lump regional stations where data are missing.
Splittail pond study	This is a very experimental study component. There is no assurance that splittail will spawn in the experimental pond or that we will be able to monitor them. At the very least, we hope to learn enough to conduct a better study next year.
Fyke trap	This will be a high-frequency data set, hopefully allowing interpolation to fill missing dates. However, if sampling is curtailed for an extended time period (i.e., > 1week) due to high flow and debris, no contingency is available.
CWT releases	There is no contingency plan if CWT fish are not available for release or if the Chipps Island trawl is not functional. Additional years of data are our only way to deal with this type of problem.
Physical data	The flow data set is unlikely to be incomplete. The presence of multiple gaging stations should allow reasonable estimates even if one station is somehow inoperative. Temperature probes are periodically lost, which is why we visit them frequently and replace when necessary. In the past, we have used regression relationships from other regional stations to fill in missing data series.

Attachment 1:
PROTOCOL FOR YOLO BYPASS SCREW TRAP MONITORING

INTRODUCTION

In this study we propose to examine the timing and magnitude of outmigration of fish passing through the Yolo Bypass relative to different physical conditions. The focus will be on Chinook salmon; however, useful data will be collected on other fish. Outmigration will be monitored using rotary screw fish traps. Screw traps are sturdy, relatively easy to move within the stream, relatively easy to operate and maintain, and are able to capture fish without harm in fast-moving water. One trap will be installed at the lower end of the Yolo Bypass Toe Drain and operated during January through June 2001. Supplemental sampling with beach seines will be performed to provide information about rearing and outmigration behavior.

OBJECTIVES

1) Examine species composition of outmigrants and resident species.

2) Identify general salmonid emigration attributes such as timing, abundance, life stage composition, condition, and investigate the influence of the factors initiating downstream migration such as flow, tidal cycle, time of day, turbidity, and water temperature.

3) To compare species composition and densities in the Yolo Bypass Toe Drain and floodplain.

4) Develop an estimate of juvenile salmon residence time using Coded Wire Tags (CWT).

5) Collect samples for other study components: larval fish, insect drift and zooplankton.

FIELD METHODS

Gear

One eight-foot diameter EG Solutions screw traps (Corvallis, Oregon) have been borrowed from USFWS Stockton. The trap will be transported to the study sites using the USFWS trailers.

The screw trap operates in the following manner to capture fish: with the trapping cone lowered into the water, water strikes the angled surface on the inside of the trapping cone, causing the cone to rotate; fish enter the upstream end of the rotating trapping cone, become trapped inside the trapping cone, and are carried rearward into the livebox.

Study Site

A single rotary screw trap will be deployed at mile 14.5 near the base of the Yolo Bypass Toe Drain (Figure 1). The trap site has been selected based on the following criteria for installation, operation, and maintenance: 1) suitable depth: greater than six feet at minimum flow; 2) suitable velocity: greater than two feet per second (fps) at minimum flow; 3) suitable anchoring point; and 4) limited public access.

Once installed, the trap will be reached by truck via the Sacramento Deep Water Ship Channel levee. The road is in poor condition in wet conditions, requiring at least 45–60 minutes driving time from DWR-ESO. The traps will be accessed using a small boat with an outboard motor purchased for the project.

Trap Installation

An overhead cable was installed for the Toe Drain trap in December 2000. After installation, flashing warning signs were rigged to the cable. The CDFG Yolo County warden and Yolo Basin Wetlands manager (Dave Feliz) will be notified that the cable is in place. On the installation day the trap was towed down the Ship Channel levee road. The trap was constructed from shore and towed into place, then clipped onto the cables.

Sample Frequency

The Toe Drain trap will be fished daily during the months of January through June. The trap will be serviced every day or two on weekdays, but will generally not be visited weekends unless the Bypass floods or there are high fish densities and debris loads. The trap may be serviced seven days a week if the Bypass floods.

Trap Crew

A total of four staff (Sommer, Harrell, O'Leary and Conrad) are assigned to the Yolo Bypass project. The crew will alternate in pairs to service the trap daily during operation. Crew leader is Bill Harrell. Two additional staff may be hired if the Bypass floods.

Physical Data

Flow data will be collected from the Yolo gage near Woodland (USGS) and from Putah Creek (Solano County Water Agency). Additional data will be collected on temperature (air/water), weather (e.g., clear, rain, cloudy) using standard Interagency Ecological Data sheets (Attachment 1).

Insect Sampling

Drift insects would be collected using a net fished off of the Toe Drain screw trap deck and from the Sherwood Harbor dock on the Sacramento River. A General Oceanics flow meter will be mounted to the unit to record volume. A similar net system will also be used to sample zooplankton and eggs and larvae. Under tidal conditions (i.e., dry or unflooded Bypass), samples should be collected once a month by setting the nets in the early- to mid- morning on ebb tides. The frequency would be increased to every two weeks if the Bypass floods. All samples would be rinsed into bottles with CWT labels and formalin.

Fish Handling

The handling and sub-sampling protocol would follow CDFG (1997) to minimize impacts to salmon, particularly the endangered winter-run Chinook. Debris will be netted from the live box then the cone is raised. A custom crowder will be used to concentrate the fish to the rear of the livebox. All fish will be netted and transferred to buckets.

Juvenile Chinook salmon will be quickly sorted between winter-run and juveniles of other races based on visual culling using Fisher's daily size criteria. Any winter-run sized salmon will be immediately transferred to a separate bucket and processed first. In samples where less than five winter-run sized fish are captured, they can be released back into the Bypass with less handling mortality than would occur with anesthesia. In the unlikely event that many winter-run sized salmon are present, these fish would be transferred in groups of up to six to a bucket containing tricain methane sulfonate (MS-222). The exact dosage would vary based on the energy level of the fish upon recovery and water temperature. Dosage is determined by the observed effectiveness of a solution as follows: The initial anesthetizing solution is prepared in a separate container by adding approximately 1/4 gram of powdered MS-222 to 2.5–3.0 gallons of Bypass water and mixing thoroughly. One salmon is netted, added to the solution then observed for 15 to 30 seconds to see if it becomes lethargic. If it does, it will be removed from solution and measured (see below), then returned to a tub of fresh water for recovery. Winter run would then be added to the solution a few at a time and the process is repeated. Additional quantities of a more concentrated solution mixed in a separate container will be added if necessary. When fish in the recovery bucket are again responsive, approximately 3–5 minutes, they are released by gently dumping the tub into the river. In the even more unlikely situation where very large numbers of winter-run sized salmon are captured (e.g., >50), subsampling would be used to minimize handling.

Each fish will be identified and counted, then fork length to the nearest millimeter will be measured for up to 50 of each species. Any juvenile fish that cannot be field identified will be preserved in formalin and identified at our Sacramento office. Any fin-clipped salmon will be euthanized in MS-222, bagged <u>individually</u> in whirl-pak bags marked with information on sampling location, date, gear type, fork length, weight, time and temperature, then placed on ice in a cooler until transferred to a deep freeze. Captured salmonids will be inspected for characters such as presence of yolk sac, parr marks, silvery appearance, and deciduous scales to determine life stage and/or degree of smolting. A simple life stage designation will be determined for each fish measured:

1. clearly parr = a darkly pigmented fish with characteristic dark, oval- to round-shaped parr marks on its sides
2. between parr and smolt = the fish is not clearly parr, but is not yet clearly a smolt either

3 clearly a smolt = highly faded parr marks, or lacking them completely, bright silver or nearly white color, and deciduous scales

Fish will be returned immediately to the Toe Drain, except for samples collected for otolith and stomach content analyses or trap efficiency trials.

Daily effort will be based on total hours fished. Volume through the trap is also an option during flooded periods, however this is not a feasible method when the Toe Drain is tidally influence.

If the Bypass floods, trap efficiency will be evaluated as often as possible. Note, however, the wild salmon should not be held more than 48 hours. The fish will be marked with Bismarck brown using the attached protocol (Attachment A) and released approximately one kilometer upstream of each trap.

Data Entry

Data will be recorded using data sheets based on a modified version of "standard" Interagency Ecological Program forms. Data QA/QC will be a four stage process. First, the data sheets will be error checked at the end of each day by the crew leader. Data will then be entered into a custom Microsoft Access form with automatic error-checking and data validation. Third, data entry personnel will compare the original data sheets to the electronic database. Finally, each data field will be sorted and/or summarized based on unique records.

Data Analysis

The primary environmental variables that we intend to evaluate include: flow, secchi depth, and temperature. For each salmon life stage, percent catch will be calculated and timing of emigration will be evaluated. Additional analyses such as calculation of diversity indices will be performed on other native and non-native species.

Attachment 2:
PROTOCOL FOR YOLO BYPASS SEINING AND STRANDING STUDY

INTRODUCTION

Since 1997 we have been conducting seining surveys in Yolo Bypass perennial ponds, seasonal ponds and inundated floodplain (Sommer 1998). In 2001 we will continue this sampling at a reduced level to help provide a long-term database on fish use of the basin. The following is a detailed description of the proposed field protocol.

OBJECTIVES

Perennial Ponds

- To examine seasonal fish species abundance and diversity in the Yolo Bypass versus the Sacramento River.
- To examine species abundance and composition in different water year types.

Inundated Floodplain

- To examine species abundance and composition in different water year types.
- To compare fish abundance and diversity between Yolo Bypass regions.
- To estimate growth rates and densities of salmon in the Yolo Bypass versus the Sacramento River.

Seasonal Ponds

- To measure the diversity and abundance of fish species trapped in ponds located in different regions and habitats.
- To compare relative densities of fish before and after floodplain drainage.
- To examine the sources of fish mortality in seasonal ponds including temperature, desiccation and predation.
- To develop long-term annual Yolo Bypass stranding indices for reference locations.
- To examine relationships between annual stranding indices and physical variables such as hydrology and temperature.

FIELD METHODS

Sample Frequency and Location

Perennial Ponds: The three reference sites are: 1) Yolo Basin Wetlands "study pond", located next the tree grove at I-80 Causeway, 2) a Fremont Weir wetlands pond, located approximately 1 mile south of the weir along the east levee, and 3) the boat ramp located at the screw trap site (Figure 1). These sites will be sampled monthly with a single haul, except when the Bypass floods.

Inundated Floodplain: In 1998 we established stations at Fremont Weir, I-5, Yolo Causeway, Lisbon Weir and the screw trap site (Figure 1). All but the Yolo Causeway site are located on the east levee. As many of these stations as possible will be sampled each two weeks during flooding of the Bypass. However, sites such as the Yolo Causeway ramp cannot be sampled except at high flows (e.g., >30,000 cfs). A single haul would be performed at each site.

Seasonal Ponds: The proposed reference locations are: 1) Fremont Weir (weir and study pond); 2) Sacramento Bypass (scour pond and large earthen pond at south levee); 3) Yolo Basin Wetlands study pond and 4) the boat ramp at the screw trap site (Figure 1). We will begin sampling in the northern Bypass, then gradually work southward as the basin drains. Depending on pond size, 1–3 three standard "U.S. Fish and Wildlife-style" beach seine hauls would be performed at random coordinates around the perimeter of each site. If time permits, sampling may also be conducted near Lisbon Weir.

Trap Crew

A total of four staff (Sommer, Harrell, O'Leary and Conrad) are assigned to the Yolo Bypass project. The crew will alternate in pairs to service the trap daily during operation. Crew leader is Bill Harrell. Two additional staff will be hired if the Bypass floods.

Physical Data

Flow data will be collected from the Yolo gage near Woodland (USGS) and from Putah Creek (Solano County Water Agency). Additional data will be collected on temperature (air/water), weather (e.g., clear, rain, cloudy) using modified Interagency Ecological data sheets.

In 1997 and 1998 we prepared aerial photos to identify the areas and locations of ponding. Pond boundaries were added to scanned images using AUTOCAD and processed using a GIS system (GRASS) to calculate areas by U.S. Geological Survey quad. No additional aerial photographs are budgeted for the coming year. As a result, we will assume that 1998 pond area estimates are applicable to 2001, if flooding occurs.

Netting Protocol

A 50-foot beach seine will be used to sample during all hydrologic phases. The area sampled will be recorded based on the length and width of the area swept. Comparative data for the Sacramento River will be obtained from the USFWS Sacramento-San Joaquin Estuary Fishery Resource Office, Stockton, California for the following five stations adjacent to Yolo Bypass (Elkhorn, SR071E; Discovery Park, SR060E; Garcia Bend, SR049E; and Clarksburg, SR043W).

Fish Handling

The handling and sub-sampling protocol would follow CDFG (1997) to minimize impacts to salmon, particularly the endangered winter-run Chinook. Juvenile Chinook salmon will be quickly sorted between winter-run and juveniles of other races based on visual culling using Fisher's daily size criteria. Any winter-run sized salmon will be immediately transferred to a separate bucket and processed first. Fish will be identified and counted. Fork length will be measured to the nearest millimeter on a wetted measuring board for up to 50 of each species. Any juvenile fish that cannot be field identified will be preserved in formalin and examined at our Sacramento office. Any fin-clipped salmon will be euthanized in MS-222, bagged individually in whirl-pak bags marked with information on sampling location, date, gear type, fork length, time and temperature, then placed on ice in a cooler until transferred to a deep freeze. Captured salmonids will be inspected for characters such as presence of yolk sac, parr marks, silvery appearance, and deciduous scales to determine life stage and/or degree of smolting. A simple life stage designation will be determined for each fish measured:

1. clearly parr = a darkly pigmented fish with characteristic dark, oval- to round-shaped parr marks on its sides
2. between parr and smolt = the fish is not clearly parr, but is not yet clearly a smolt either
3. clearly a smolt = highly faded parr marks, or lacking them completely, bright silver or nearly white color, and deciduous scales

In samples where less than five winter-run sized fish are captured, they can be processed with less handling mortality than would occur with anesthesia. In the unlikely event that many winter-run sized salmon are present, these fish would be transferred in groups of up to six to a bucket containing tricain methane sulfonate (MS-222). The exact dosage would vary based on the energy level of the fish upon recovery and water temperature. Dosage is determined by the observed effectiveness of a solution as follows: The initial anesthetizing solution is prepared in a separate container by adding approximately 1/4 gram of powdered MS-222 to 2.5–3.0 gallons of Bypass water and mixing thoroughly. One salmon is netted, added to the solution then observed for 15 to 30 seconds to see if it becomes lethargic. If it does, it will be removed from solution and measured (see below), then returned to a tub of fresh water for recovery. Winter run would then be added to the solution a few at a time and the process is repeated. Additional quantities of a more concentrated solution mixed in a separate container will be added if necessary. In situations where very large numbers of winter-run sized salmon are captured (e.g., >50), subsampling would be used to minimize handling.

For ponds that drain to the Delta, all salmon would be returned to the ponds that they are collected from. For isolated ponds, all salmon will be transferred immediately to aerated coolers, and then transported to the Sacramento River or Toe Drain within one hour. Any individuals anesthetized with MS-222 would be checked for responsiveness before being released to the river. All other salmon and splittail will be relocated within several hours of collection. Other fish species will be returned to the area they were collected from.

During seasonal pond sampling in 1997 crew members got swimmer's itch rashes at the Yolo Basin Wetlands. As a result, we recommend that all crew wash their arms with an alcohol-swab within ten minutes of contact with pond water.

Data Entry

Data will be recorded using data sheets based on a "standard" Interagency Ecological Program forms that have been modified slightly to include salmon life stage and other factors. For the salmon codes, the first four characters would identify race ("CHNF", "CHNW","CHNL", "CHNT" or "CHNS") and a fifth character would be added to identify life stage ("P"=parr, "X"=transitional or "S"=smolt).

Data QA/QC will be a four-stage process. First, the data sheets will be error checked at the end of each day by the crew leader. Data will then be entered into a Microsoft Access form with automatic error-checking and data validation. Third, data entry personnel will compare the original data sheets to the electronic database. Finally, each data field will be sorted and/or summarized based on unique records.

Data Analysis

Many of the data analyses will be similar to Sommer et al. (1998). Species composition and density comparisons will be made: 1) within Yolo Bypass regions (Figure 1); 2) to FWS beach seine stations in the Sacramento River; and 3) between seasons and water years. The primary environmental variables that we intend to evaluate include: flow, turbidity, depth and temperature.

Attachment 3:
PROTOCOL FOR RELEASE OF CODED WIRE TAG SALMON IN YOLO BYPASS

INTRODUCTION

In 1998 and 1999 we conducted a salmon growth and survival study using coded wire tag (CWT) hatchery salmon. Results of this study showed that salmon released in the Bypass had higher growth rates and migrated faster than in the Sacramento River. Moreover, initial survival estimates suggest that survival rates were higher for the Yolo Bypass fish. However, these results were from a single year. We recommend that this study be continued as frequently as possible for several years.

OBJECTIVES

1) Examine survival of salmon released in the Yolo Bypass versus the Sacramento River for several water year types.

2) Provide an estimate of juvenile salmon residence time in the Bypass for several water year types.

3) Examine the growth of fish released in the Sacramento River versus the Yolo Bypass for several water year types.

4) Examine the migration rate of fish released in the Sacramento River versus the Yolo Bypass for several water year types.

5) Examine the distribution of salmon stranded in the Yolo Bypass.

FIELD METHODS

Hatchery Fish

Eight lots of 25,000 salmon fry will ordered from Feather River Fish Hatchery. Each lot will be adipose fin-clipped and marked with coded wire "half tags" with unique codes. The fish will be transported in one or more transport trucks (in one or more loads) and released as soon as possible into the Yolo Bypass and Sacramento River.

Release Date and Location

CWT salmon will generally not be available until February. The exact release date depends on hydrology—we prefer to release the salmon in late inundation phase or early drainage phase.

In wet years, half of the salmon would be released downstream of Fremont Weir at the northern habitat transect site. A boat would be used to slowly distribute the salmon across the entire breadth of the floodplain. The Sacramento River group(s) would be released at Elkhorn boat ramp. Note that the Sacramento release group would be released at Miller Park in Sacramento if Sacramento Weir is open. In the event of a dry year, the Yolo Bypass group(s) would be released at the Yolo Causeway bike lane and Miller Park. Approximately 1,000 fish would be retained for a trap efficiency study—these salmon would be marked with Bismark brown and released about 1 km upstream of the screw trap site. Trap efficiency measurements would not be made in wet years as the width of the Bypass is great (1.5–8 miles) to provide reasonable estimates.

Collection of CWT Salmon

Yolo Bypass fish would be collected by screw trapping and perhaps by beach seines if the Bypass floods. Sacramento River CWT fish may be collected by U.S. Fish and Wildlife Surveys at the following beach seine stations: SR071E, SR060E, SR049E, SR043W and others further downstream. Depending on the timing of the study, CWT fish from all release groups would be collected downstream at Chipps Island either daily or every other day. Some salmon may also be collected as adults as part of the ocean fishery.

Trap Crew

A total of four (Sommer, Harrell, and two Scientific Aides) are assigned to the Yolo Bypass project. Additional staff may be hired in the Yolo Bypass floods. The project leader for this study is Sommer.

Physical Data

Stage data will be collected from existing recorders at Lisbon Weir. Additional data will be collected on secchi depth, temperature (air/water), weather (e.g., clear, rain, cloudy) using standard Interagency Ecological Data sheets.

Data Entry

As described in detail in the other study protocols, screw trap and beach seine data will be recorded using data sheets based on "standard" Interagency Ecological Program forms using a four stage QA/QC process. Chipps Island survival, migration time and size data will be obtained from USFWS Stockton.

Data Analysis

Survival of salmon released in the Yolo Bypass versus the Sacramento River would be analyzed by comparing the numbers of each CWT release group collected at Chipps Island and subsequent ocean recoveries. Obviously, we will have to wait several years to obtain the ocean CWT data. Juvenile salmon residence time and growth will be examined by looking at the collection dates and sizes for different locations within the Bypass and at Chipps Island. Otolith analyses by Dr. Titus of Chipps Island fish may yield additional information about when individual fish exited the Yolo Bypass. Finally, the distribution of salmon stranded if the Yolo Bypass floods would be examined by reviewing the locations where CWT were recovered during the stranding study.

Attachment 4:
PROTOCOL FOR YOLO BYPASS FYKE TRAP TESTING

INTRODUCTION

In this study we propose to test the feasibility of using a large fyke trap to catch adult fish using the Yolo Bypass Toe Drain. In addition, we hope to examine adult species composition and the timing and duration of fish migration through the Yolo Bypass relative to different physical conditions. The focus will be on anadromous fish species, however useful data will be collected on other fish. One trap will be installed at the lower end of the Yolo Bypass Toe Drain and operated during October 2000 through June 20001. Fyke trap sampling will be done in conjunction with screw trap and beach seine sampling.

OBJECTIVES

1) Test the feasibility of using a fyke trap in the Yolo Bypass Toe Drain.

2) Examine adult species composition.

3) Identify general timing and duration of anadromous species use relative to different physical conditions.

4) To the extent possible, compare timing and duration of species captured in the Yolo Bypass to those captured in other Sacramento Valley tributaries.

FIELD METHODS

Gear

One ten-foot diameter fyke trap has been borrowed from CDFG Stockton. The trap will be transported to the study site using a CDFG trailer designed for the trap.

When the fyke trap is deployed and operational, fish enter the downstream opening of the trap, move through the fyke funnels, and become trapped inside the upstream compartment.

Study Site

A single fyke trap will be deployed at levee mile six near the base of the Yolo Bypass Toe Drain (Figure 2). The trap site has been selected based on the following criteria for installation, operation, and maintenance: 1) suitable depth: greater than ten feet during low flow;

2) suitable anchoring point; 3) suitable bank: absent of large woody debris; and 4) limited public access.

Once installed, the trap will be reached by truck via the Sacramento Deep Water Ship Channel levee. The road condition is poor in wet weather, requiring at least 45 to 60 minutes driving time from DWR Central District. The trap will be accessed using a bumper mounted truck winch purchased for the project.

Trap Installation

The fyke trap will be installed in October 2000. During installation, one warning float is attached to the downstream end of the trap and two warning floats are rigged to the upstream anchoring (nose) cable. The CDFG warden dispatch and Yolo Basin Wetlands manager (Dave Feliz) will be notified that the trap is in place. On the day of installation the trap will be towed down the Ship Channel Levee road. Trap guide and anchor cables will be installed and anchored to t-posts and/or suitable trees. Two guide ropes are also set to help guide the trap when it is rolled up the bank. The trap is then rolled off the trailer and attached to the guide and anchoring cables. Once installed, the center pull cable is locked around a t-post.

Sample Frequency

The fyke trap will be fished daily during the months of October through June. The trap will be serviced every two days on weekdays, but will generally not be visited weekends unless the Bypass floods or there are high fish densities and debris loads. The trap may be serviced seven days a week if the Bypass floods.

Trap Crew

A total of four staff (Sommer, Harrell, O'Leary and Conrad) are assigned to the Yolo Bypass project. The crew will alternate in teams of three to service the trap daily during operation. The crew leader is Bill Harrell. One additional staff from ESO may be used if the Bypass floods.

Physical Data

Flow data will be collected from the Yolo gage near Woodland (USGS) and from Putah Creek (Solano County Water Agency). Additional data will be collected on temperature (air/water), weather (e.g., clear, rain, cloudy) using standard Interagency Ecological Data sheets (Attachment 1).

Fish Handling

The handling and sub-sampling protocol would follow CDFG (1997) to minimize impacts to salmon and splittail. The trap will be rolled using the winch to the edge of the Toe Drain channel in about 0.5 to 1.5 meters of water depending on the number of fish in the trap.

The trap door is then opened and the fish are netted out using a long handled dip net. All fish will be netted individually, transferred to a wetted measuring board, and then released back into the Toe Drain. Chinook salmon and splittail will be sorted from other species and processed first.

Each fish will be identified and counted, then fork length to the nearest millimeter will be measured for up to 50 of each species when practical.

Daily effort will be based on total hours fished.

Data Entry

Data will be recorded using data sheets based on a modified version of "standard" Interagency Ecological Program forms. Data QA/QC will be a four stage process. First, the data sheets will be error checked at the end of each day by the crew leader. Data will then be entered into a custom Microsoft Access form with automatic error-checking and data validation. Third, data entry personnel will compare the original data sheets to the electronic database. Finally, each data field will be sorted and/or summarized based on unique records.

Data Analysis

The primary environmental variables that we intend to evaluate include: flow, secchi depth, and temperature. For selected species, catch per unit effort will be calculated and timing of migration will be evaluated. Additional analyses such as calculation of diversity indices and CCA may be performed.

Attachment 5: EVALUATION OF SPLITTAIL REPRODUCTION AND REARING IN A DEMONSTRATION FLOODPLAIN WETLAND

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INTRODUCTION

In 2000 Department of Water Resources, Natural Heritage Institute and Yolo Basin Foundation received funding from CALFED to examine the feasibility of developing a demonstration-scale project based on managed Yolo Bypass flooding for splittail and other aquatic species. This funding will be used in part to allow IEP to continue collection of baseline fish monitoring data for Yolo Bypass. The monitoring methods will remain similar to those described in our 2000 IEP work plan. However, we are also hoping to collect data that will help evaluate the biological feasibility of managed flooding and develop restoration design criteria. Central questions for splittail include: 1) will they spawn on intentionally flooded terrestrial lands? 2) what are suitable spawning habitats? 3) what physical conditions trigger spawning? and 4) what are suitable rearing habitats for larvae and juveniles? The existing Yolo Bypass monitoring program and earlier IEP splittail studies have only partially addressed these issues. In the following study, we propose to answer some of these questions using intensive spawning, larval and juvenile observations on splittail intentionally stocked into a small experimental wetland pond. This approach is somewhat artificial because splittail will not have access to a complete range of habitat types; however, we believe that pond studies will help us generate useful hypotheses for testing on a larger scale.

STUDY SITE

Our basic approach will be to do intensive observations on splittail in a Department of Fish and Game Demonstration Wetlands Pond, located at the Yolo Basin Wildlife Area (Figure 1). The pond is approximately 0.1 acres and presently has a low grassy turf, bordered by waist-high vegetation. A modest current will be created in the pond by recirculating water using a submersible pump. This site was selected because it is: 1) immediately adjacent to the Yolo Bypass, a major spawning area for splittail; 2) was available for experimental study; and 3) was specifically designed as a smaller version of actual wetlands in the Yolo Bypass floodplain.

INITIAL COLLECTION AND HANDLING OF ADULT FISH

We propose to collect up to 15 adult splittail during their spawning migration, probably in February or March. These fish would be collected using a 10-foot diameter fyke trap, which has been seasonally operated in the Yolo Bypass Toe Drain near Lisbon Weir since November 1999. Our goal is to capture at least 8 splittail, half of which would have "male" characteristics (e.g., <340 mm, thinner profile).

Adult splittail will be removed from the fyke trap using a dip net and placed in a 485 liter ice chest filled with water from the Toe Drain. The water will be treated with NovAqua brand water conditioner and aerated with commercial grade oxygen to saturation. A maximum of eight splittail will be placed in the ice chest during a given transport. These fish will be quickly transported via truck to the nearby CDFG Yolo Basin Headquarters, where they will be stocked in the Demonstration Wetlands pond. At the conclusion of the study (late May or early June), surviving splittail would be collected and released in the Yolo Bypass Toe Drain.

POND METHODS

Spawning Observations: Shortly before the fish are added, the pond would be filled to a depth of approximately 2 feet. Observers will be based at the edge of the pond as frequently as possible to record spawning behavior and distribution. Observational data to be recorded include the location and timing of spawning activity. Based on laboratory observations of adult splittail, it appears that variation in water surface elevation triggers spawning (Dr. Hung, UCD, pers. comm.). If splittail do not spawn within the first two weeks of stocking, we will test this hypothesis by reducing water depths by up to one foot. The pond would be refilled within several days.

Location of Spawning Areas: Substrates will be placed in different parts of the pond to collect eggs. We propose to use terra-cotta tiles with a string attached to a small float. Each tile will have a grid drawn on its surface to allow estimates of egg density. Habitat types to be examined include: 1) open water; 2) open water near water intake; 3) open water near outlet;

4) submerged vegetation; and 5) vegetated terrestrial edge. Five replicate tiles will be randomly placed within each habitat type and checked at least 4–5 days each week for eggs. We tentatively plan to record the proportion of the tile grid with eggs present.

Larvae and Juvenile: Distribution, diet and hatch date are key factors we plan to assess for juveniles and larvae. Larval distribution will be examined using light traps set in the same habitat types used for egg tiles. The frequency distribution of larval catch by habitat type would be used for data analysis. Snorkel observations will be also be used to identify habitat types for larvae and juveniles. Observations would be made at both sunrise and mid-day during two time periods assess diel and temporal variation in distribution. One or two divers will cover the entire pond stratified into each of the five previously identified habitat types. Divers will record the approximate number of fish (actual count for <10 individuals, 10–49, 50–99, 100+), water column position (top third, middle third or bottom third of water column) and depth (actual location for individuals, center of the "school" for groups). Position in the water column is of particular interest as initial laboratory observations suggest that the earliest life stages of splittail are benthic, with no pelagic schooling behavior for at least 3–4 days (Dr. Swee Teh, UCD, pers. comm.). The frequency distribution of each variable would be analyzed for each habitat type, depth and water column position. Schools of fish would be counted as a single observation.

Diel trends in larval and juvenile feeding would be analyzed by collecting fish over the course of a 48 hour period. Ten fish would be collected each of the following times: Pre-dawn, dawn, midday, dusk, early evening and midnight. The fish will be preserved in alcohol and dissected in the laboratory for diet analysis. The hatch date of these larvae would also be determined by otolith analysis. The methods are yet to be determined; however, we plan to validate the otolith approach by stocking tetracycline-marked fish in a mesh pond enclosure for a known period of time.

Physical Conditions: An Onset logger will be used for continuous measurement of water temperatures. Daily weather will be recorded as part of other Yolo Bypass study components. A staff gage will be used to measure water elevation in the pond. Oxygen and pH levels may also be recorded periodically.

TAKE OF LISTED SPECIES

The reasonable likely take of threatened or endangered species by all Yolo Bypass field sampling is provided below. Take of adult splittail from this study component would remain within these limits.

Species/Life Stage	Reasonable Likely Take
Winter-run Chinook (juveniles/adults):	50/10
Spring-run Chinook (juveniles/adults):	500/10
Steelhead Trout (yearlings/adults):	50/10
Splittail (adults/juvenile):	500/5,000
Delta smelt	100

with less than 10 percent mortality for all species except delta smelt (100 percent mortality): Note, however, that these levels are for wet year sampling only. In dry years the total take of juvenile salmonids is likely to be less than 5 for each species**.**

Program Element Title: Yolo Bypass Fish Monitoring

Program Element Number: 2001-047

Workplan Review

____________________________________ __________

Matt Nobriga, DWR date

____________________________________ __________

Randy Baxter, CDFG date

____________________________________ __________

Program element Review Team member date

Workplan Accepted by Management Team

____________________________________ __________

IEP Program Coordinator date

APPENDIX B: 2001 IEP YOLO BYPASS FOOD WEB STUDIES WORK PLAN

1. Name, Email Address and Phone Number of Principal Investigators

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2. Project Overview

The Yolo Bypass is the primary floodplain of the Sacramento Valley, approximately doubling the wetted area of the Delta during major storm events. The different hydrologic inputs are typically poorly mixed, forming distinct "bands" when the basin is flooded. Studies by the IEP Yolo Bypass Project Work Team demonstrate that this region provides important habitat to several fish species, particularly young Chinook salmon and splittail (DWR 1999; Sommer et al 1997; Sommer et al., In press). The floodplain may also be an important area for the downstream estuarine food chain. However, the structure and composition of the floodplain food chain remains poorly understood.

A key objective of the present study will be to provide baseline data on the quantity and quality of material at the base of the Yolo Bypass food chain. Chlorophyll sampling at Rio Vista during 1997–2000 indicated that the floodplain was a major source of phytoplankton to the Estuary (DWR 1999, Sommer et al., In prep). Year 2000 Yolo Bypass monitoring using fluorometry and grab samples confirmed that the floodplain phytoplankton production is higher than the Sacramento River, at least during floodplain drainage (Sommer et al., In prep; Schemel et al. in prep). Higher seasonal phytoplankton production on floodplain habitat is also supported by recent modeling work by Jassby and Cloern (2000). Additional research is needed to describe the spatial and temporal variability of this production.

A second area of research emphasis will be continued monitoring of invertebrates to identify factors affecting diversity and abundance. Monitoring of Yolo Bypass zooplankton during 1998 and 1999 showed fairly similar levels to the adjacent Sacramento River (Sommer et al. 2001). However, Daphnia feeding experiments in the laboratory using water samples from floodplain and riverine environments suggest that zooplankton get growth benefits from floodplain habitat (Anke Mueller Solger, UCD, unpublished data). It is possible that some lower velocity/high residence time regions of the floodplain could support higher densities of zooplankton, although transects conducted in 1998 showed no evidence of substantial lateral variability (DWR 1999).

Unlike zooplankton, results from 1998 and 1999 indicate that the floodplain has substantially more drift invertebrate production that the adjacent Sacramento River (Sommer et al. 2001). This is of major importance for rearing Chinook salmon, which use this food source as a primary prey item. The reason for high levels of drift invertebrates has not yet been established, however the results to data suggest that the response time of the drift invertebrate population to flood pulses is very fast, probably on the order of a week or less. One possibility is that the high invertebrate levels originated from floodplain ponds and were flushed into the water column. Alternatively, the fast response may be a result of hatching of resting eggs on the floodplain. In either case, it appears that conditions are sufficient to sustain dense populations of drift invertebrates for many weeks throughout the flooded period. Production during flooded phases could be supported by phytoplankton production or detrital material. The limited chlorophyll data to date suggest that phytoplankton production is not enhanced on the floodplain at peak flows, but may be abundant during receding hydrographs. This does not, however, mean that we can exclude phytoplankton as the major source of food for the drift invertebrates. It is possible that higher abundance of drift invertebrates on the floodplain is not a trophic response—rather, it may be a result of more suitable habitat (i.e., substrate).

3. Study Objectives

The research objectives of the proposed study include the following. The null hypothesis and an alternative hypothesis are listed for each. Note that there are many other alternative hypotheses—we have focused on the most plausible alternative for each case. The project will be considered successful if it is able to address the majority of the listed objectives.

- To estimate phytoplankton production from the Yolo Bypass floodplain based on chlorophyll, secchi depth and flow.

  Null hypothesis: There is no phytoplankton production in Yolo Bypass because of low residence time, cold temperatures and high turbidity.
  Alternative hypothesis: Yolo Bypass supports phytoplankton production, particularly during descending hydrographs, when residence time is long.

- To examine variation in zooplankton densities in high and low velocity habitats.

  Null hypothesis: There is little lateral variation in zooplankton abundance.
  Alternative hypothesis: Zooplankton abundance will be higher in low velocity areas (e.g., western Bypass, downstream of levees, edge habitat).

- To describe trends in zooplankton diversity and abundance in years with different hydrographs.

  Null hypothesis: There is little variation in zooplankton diversity and abundance between years.
  Alternative hypothesis: There will be little variation in zooplankton diversity, but substantial variation between years with different hydrographs. Zooplankton abundance will be lowest in extreme high flow years.

- To examine trends in drift invertebrate diversity and abundance in years with different hydrographs.

Null hypothesis: There will be little variation in drift invertebrate diversity and abundance between years.
Alternative hypothesis: There will be substantial variation in drift invertebrate diversity and abundance. Extreme high flow years and years with highly variable hydrographs will result in the highest abundance and diversity.

4. Management Value of the Study

A variety of restoration activities are being considered in the Yolo Bypass including more frequent inundation of the floodplain and increasing the acreage of wetlands and fixing fish passage and stranding problems. However, the 1997–2000 data are too limited to provide a reasonable baseline to evaluate the success of future restoration actions. There are also substantial gaps in our knowledge about the linkages between floodplain lower trophic levels and fish. The study addresses the following IEP 2000 Long Term Planning Considerations and Actions: 2C, 3B, 3C and 3D. The program would have multiple benefits including the following:

- The project would improve our knowledge about the relationship between the Yolo Bypass food chain and the rest of the Estuary.
- The program would provide baseline data for the evaluation and design of future restoration activities in the Yolo Bypass and other floodplains.

5. Project Start Date and End Date

Most of the proposed activities were initiated in January 2000. We recommend that the phytoplankton, zooplankton and invertebrate drift monitoring considered annually for at least 2–4 years total to provide data from a range of water year types.

6. Estimated Annual Catch of Delta Smelt, Winter-Run Salmon, Spring-Run Salmon, Steelhead Trout and Splittail by Lifestage

Delta smelt (larvae)=100, winter-run size salmon (juveniles)=0, spring-run size salmon (juveniles)=0, steelhead trout (yearlings)=0 and splittail (adults/juvenile)=0/100. Daily take will be reported electronically using the IEP reporting system.

7. Estimated Number, Classification and Agency of Personnel Needed

Environmental Specialist IV (Sommer, DWR)
Environmental Specialist III (Harrell, DWR)
Scientific Aides (2, DWR)
Control Systems Technician II (Dempsey, DWR)

8. Estimated Project Costs (total for personnel, operating and equipment)

The total budget for the study is $86.400 (Table 1), which will includes funding for DWR and San Francisco State University. This cost includes sharing of staff and equipment from year 2001 Yolo Bypass fish sampling, included as a separate IEP proposal.

9. Major Equipment Required

The key pieces of equipment are a john boat, a jet boat and truck, all supplied by DWR.

10. Summary of Project Logistics

The proposed Year 2001 Yolo Bypass activities (Table 2) include January–June sampling for zooplankton, drift invertebrates and chlorophyll. Detailed methods are discussed below. The sampling locations have been selected based on previous work during 1998–2000, allowing comparisons between years, seasons and water year types. The present study is closely linked to field activities of the companion study plan for adult and juvenile fish ("Yolo Bypass Adult and Juvenile Monitoring). In addition to the field activities, monthly crew safety meetings would be organized by Bill Harrell (DWR) to cover handling of boats, sampling gear, vehicles, rescue methods and emergency protocol. Fall 2000 training activities included swiftwater rescue.

Zooplankton and Insect Drift Monitoring: Fixed nets will be used by DWR crew to collect zooplankton and insect drift samples from the Yolo Bypass screw trap site and Sacramento River at Sherwood Harbor. The drift net dimensions are 0.46 m x 0.3 m mouth, 0.91 m length and 500 um mesh. Zooplankton sampling be conducted with a Clarke-Bumpus net (0.13 m diameter, 0.76 m length, 160 um mesh). Nets will be fished for approximately 30 minutes during mid-morning and volume will be recorded using a flowmeter (General Oceanics Model 2030R). Yolo Bypass sampling would be conducted monthly on an ebb tide during dry or unflooded conditions and weekly when the Bypass is inundated. Boats will be used for sampling in the event that water velocities are too low (e.g., <2 fps). Up to ten paired drift samples would be taken in year 2000, with higher frequency sampling during inundated periods. Each sample should have a tag and be preserved in formalin. Zooplankton identification will be performed by DWR staff at CDFG's Stockton laboratory. Insect drift samples will be analyzed by a DWR contractor, Wayne Fields.

Zooplankton Transects: A new project element is to examine whether low velocity areas support higher zooplankton densities than higher velocity habitat. As noted previously, limited transect sampling in 1998 suggested that there was no substantial lateral variability in zooplankton abundance (DWR 1999). However, the 1998 study did not specifically target low velocity areas for comparison. In 2001 we propose to look at spatial variation along an east-west transect located between I-80 and the Southern Pacific Railway trestle bridge. If time and hydrology permits, we may also do a transect at Lisbon Weir. Major challenges at both locations include: 1) samples need to be taken at the same time to minimize potential diel variability; and 2) the method must be able to sample both low velocity and high velocity habitat; and 3) boats may be difficult to use in the western portion of the Bypass at all but the highest flows. To address these issues, we propose to use the following approach.

- Crew size: Staff will be split into two groups, each with two crew members.
- Location: One crew will sample the western portion of the Bypass from the Yolo Causeway, the other will sample the eastern portion from a john boat. Sampling would be located in areas with both "low" velocity (e.g., <0.25 fps) and "high" velocity habitat (e.g., >1 fps).

Specific sampling locations would be selected using random coordinates in each habitat type (i.e., stratified random).

- Timing: Sampling would be conducted twice (inundation and drainage phases) with two successive sampling days for each period.
- Frequency: Each sampling day would be divided into a morning (9–11) and an afternoon (2–4) session. One or two paired ("high" and "low" velocity) set of samples would be collected each session.
- Zooplankton Sampling Method: A Clarke-Bumpus (CB) net would be placed in the current in "high" velocity habitats. For "low" velocity habitats, the john boat crew would perform a 15–20 minute tow. The Yolo Causeway crew would use a pole-mounted CB net and perform a "tow" by walking along the shoreline. Zooplankton storage and identification would be as indicated for standard weekly monitoring.
- Other parameters to be measured. Standard IEP measurements will be taken including weather, depth and water temperature. Mean water velocity would also be taken during each session using a Price AA flow meter.

Chlorophyll: DWR will continue to operate a Turner fluorometer at Rio Vista. A portable Wetlabs mini-fluorometer will be installed at the Yolo Bypass screw trap site. The Rio Vista fluorometer will be calibrated by DWR with monthly grab samples, with more frequent samples during peaks in fluorescence. Chlorophyll samples will be taken in the Yolo Bypass on at least a weekly basis during January–June and analyzed by the DWR Bryte Laboratory.

Physical Data: Water temperature and weather will be recorded on all sampling days. Onset temperature loggers will be deployed January–June at the Yolo Bypass Toe Drain screw trap site and the Sacramento River Sherwood Harbor dock. The loggers will be visited every two weeks throughout the sampling period to download data using a laptop computer. Stage and flow data will be recorded on a spreadsheet using data from California Data Exchange Center and Solano County Water Agency (Putah Creek only).

11. Data Reduction

Data will be recorded using data sheets based on a standard Interagency Ecological Program forms along with custom forms for recording abundance and concentration of food chain factors. Data QA/QC will be a four-stage process. First, the data sheets will be error checked at the end of each day by the crew leader. Data will then be entered into an IEP-designed Microsoft Access form with automatic error-checking and data validation. Third, data entry personnel will compare the original data sheets to the electronic database. Finally, each data field will be sorted and/or summarized based on unique records. In addition to data QA/QC, project leadpersons will accompany field crews on a regular basis to check methods for accuracy and consistency with previous years and, where necessary, implement corrective actions. For electronic data, corrections would be the responsibility of both the crew and the leadpersons. Completed data files would conform to standard IEP format.

12. Data Analysis

Data analysis would be conducted using the Statistica software package by the leadpersons with major assistance from the crew. Expected statistical analyses are summarized in Table 3. Where appropriate, data series will be checked for normality and homogeneity of variance. Because of the extreme hydrologic and spatial variability in this habitat, we expect that it will be particularly important to develop long-term data base to reflect the range of conditions.

Phytoplankton production estimates will be calculated based on field measurements of chlorophyll, secchi depth and flow. Daily wetted area and mean depth of the Yolo Bypass will be estimated using a physical model based on daily stage at four Yolo Bypass locations and cross-sectional geometry of about 200 floodplain transects. The species composition and density of zooplankton and invertebrate drift and POM food quality will be compared between: 1) Yolo Bypass and the Sacramento River; 2) the Yolo Bypass-Sacramento River and Cosumnes River-floodplain complexes; and 3) seasons and water years. The primary environmental variables that we intend to evaluate include: flow, secchi depth, mean depth, surface area and temperature.

13. Products and Due Dates

Data from the Yolo Bypass study will be posted on the IEP Home Page. We would also prepare articles for the IEP Newsletter and peer-reviewed journals to report any significant findings by the end of the calendar year. The leadpersons are planning to complete at least two articles by the end of the year 2001 for peer-reviewed journals (e.g., Can. J. Fish. Aq. Sci., Regulated Rivers). The longer period to publication is based on the need to collect multiple years of data to analyze community trends.

14. Review Team Members

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Anke Mueller-Solger, DWR – ESO

15. References

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Table 1. Yolo Bypass Food Web Budget

	IEP Staff	Time	Mos.	Rate	Total
Coordination	Env. Spec. IV	0.20	9	10,788	19,419
	Env. Spec. III	0.20	9	6,477	11,659
Instruments	Control Sys. Tech II	0.05	5	9,219	2,305
Crew	Sci. Aide	1.00	9	2,280	20,520
				Subtotal	53,902
				Chlorophyll Analyses	3,000
				Kimmerer Contract	4,000
				Drift invertebrate identification	4,000
				Supplies and Equipment	1,000
				Total	86,422

Assumptions

1) IEP staff time includes administrative costs, benefits and overheads.
2) Drift invertebrate identification costs are $100/sample.
3) Invertebrate identification costs include analysis of archived 1999–2000 samples.
4) The budget is based on economies gained by parallel field activities for IEP Yolo Bypass fish sampling.

Table 2. Summary of Yolo Bypass Field Activities and Responsibilities

Activity	Task	Frequency[a]	Who is Responsible
Administrative	Project oversight	Continuous	DWR
Physical	Flow, stage	Continuous	DWR
	Temperature loggers/data	Every 2 weeks	
	"Events"	Continuous	
Field Sampling	Zooplankton (monitoring)	Monthly-	DWR
	Zooplankton (transect)	Weekly	
	Chlorophyll	Two events	
	Drift	Weekly	
Laboratory Analyses	Zooplankton	Batchwise	DWR
	Chlorophyll	Weekly	Bryte Lab
	Drift	Batchwise	W. Fields
Data and Reporting	Entry, QA/QC, Analysis	Continuous	DWR SFSU

[a]Lower range for each represents tidal/unflooded conditions, upper range represents flooded conditions.

Table 3. Proposed Analyses on the Results of Each Study Component

Research question	***Database***	***Proposed analyses***	***Comments***
Effect of physical conditions on chlorophyll levels	Water quality	Graphical analysis to examine effects of major variables. Potential use of raw data to compare production in river and floodplain.	New method
Factors affecting zooplankton abundance and diversity	Zooplankton	Graphical, tabular and multivariate analyses	Depends on development of a long-term database
Factors affecting drift abundance and diversity	Drift	As above	As above
Spatial variability in zooplankton	Zooplankton	Two-way ANOVA (habitat x location)	Dry conditions will prevent us from doing spatial sampling

APPENDIX C: YOLO BYPASS LAND USE IMAGES

Aerial photographs were taken of the Yolo Bypass during 5 flights (February 25, 1997; March 3, 1998; March 18, 1998; April 28, 1998; and February 28, 2001). The flights were flown at an elevation of 6,000 feet to produce photographs at a scale of 1:24,000, comparable to USGS 7.5 minute quads. The aerial photographs cover an area spanning from the Fremont Weir to the Liberty Island/Holland tract. Aerial photographs from the 1997 and 1998 flights are georeferenced to UTM Zone 10 NAD 27 projection. The aerial photographs are included on the accompanying CD-ROMs as TGA, JWG, TFW and TIF files.

Landscape attributes were extracted from the 1998 flights and are georeferenced to the same projection. Landscape attributes included in the report are pond types, drains and land use. The pond type files are labeled according to the region in which the pond is located and the type of pond. DWR has divided the Yolo Bypass into 7 regions for their fish surveys: Fremont Weir (fw), Cache Creek sinks (ccs), Sacramento Bypass (sb), Yolo Basin (yb), Putah Creek sinks (pcs), Southern Bypass (stb), and Liberty Island/Holland tract (lh). Pond types were characterized on their connectivity to drainages. Pondtype 1 refers to large, deep ponds isolated from drains that potentially strand fish. Pondtype 2 refers to large, deep ponds connected to drains that do not strand fish. Pondtype 3 refers to agricultural row crops that were ponding during the time of the flight but were not holding fish. Geographic coordinates of the locations of culverts draining into the Toe Drain in 1999 were recorded and saved. The culvert locations are included on the CD-ROMs as two shapefiles: “drains1.shp” and “drains2.shp”. Land use was identified from the aerial photographs. A postscript file of a land use map, entitled “RevisedBypasslu.eps”, is included in the report. The land uses identified are crops; grain and hay; idle land; pasture; rice; truck, nursery and berry crops; native riparian; native vegetation; riparian and water habitat; and urban.

The aerial photographs from 2001 have not been georeferenced; however, the files are included on the CD-ROMs as JPEG files. A directory of files for the attached CD-ROMs is presented in Table C-1.

Table C-1. Directory for Aerial Photograph and Landscape Attribute Files on CD-ROMs

Disk	Flight	File name	File description
1	1997, February 25	2623Z10.TGA	Aerial photograph
		2723Z10.TGA	Aerial photograph
		2724Z10.TGA	Aerial photograph
		2823Z10.TGA	Aerial photograph
		2824Z10.TGA	Aerial photograph
		2923Z10.TGA	Aerial photograph
		2924Z10.TGA	Aerial photograph
		3023Z10.TGA	Aerial photograph
		3024Z10.TGA	Aerial photograph
		3123Z10.TGA	Aerial photograph

Disk	Flight	File name	File description
2	1997, February 25	BYPZ10.TGA	Color mosaic of aerial photos covering portion of Bypass
		SPOTZ10.TGA	B&W mosaic of aerial photos covering entire Bypass
		YOLOBYP.TGA	Mosaic covering entire Bypass
3	1998 Flight 2 (March 18) and Flight 3 (April 28)	MOSAIC 2. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 3. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 4. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
4	1998 Flight 2 (March 18 and Flight 3 (April 28)	MOSAIC 5. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 6. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 7. TFW, TIF	Mosaic of aerial photos covering portion of Bypass
5	1998 Flight 2 (March 18 and Flight 3 (April 28)	MOSAIC 8. TFW, TIF, JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 1. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 2. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 3. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 4. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 5. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 6. WG, JPG	Mosaic of aerial photos covering portion of Bypass
		MOSAIC 7. JWG, JPG	Mosaic of aerial photos covering portion of Bypass
		YOLOMOSAIC. JWG, JPG	Mosaic of aerial photos covering entire Bypass
6	1998 Combo aerial	ccs	Polygon shapefile of Cache Creek sinks region
		fw	Polygon shapefile of Fremont Weir region
		yb	Polygon shapefile of Yolo basin region
		lh	Polygon shapefile of Liberty Island and Holland tract region

Disk	Flight	File name	File description
		pcs	Polygon shapefile of Putah Creek sinks region
		sb	Polygon shapefile of Sacramento Bypass region
		stb	Polygon shapefile of Southern Bypass region
		Pondtype1	Polygon shapefile of large, deep ponds isolated from drain and hold fish
		Pondtype2	Polygon shapefile of large, deep ponds connected to drain and hold fish
		Pondtype3	Polygon shapefile of row crops that were inundated at time of flight but do not hold fish
		Drain1	Point marking culvert
		Drain2	Point marking culvert
		RevisedBypasslu.eps	Map of land use within Bypass
7	2001, February 28	#_#.JPG	Aerial photograph

APPENDIX D: AQUATIC ANALYSES PAPERS

(1)

California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture

(2)

Floodplain rearing of juvenile Chinook salmon: Evidence of enhanced growth and survival

(3)

Patterns of adult fish use on California's Yolo Bypass floodplain

(4)

Floodplain as habitat for native fish: Lessons from California's Yolo Bypass

(5)

Effects of landscape-level hydrologic variation on the biota of river channel and floodplain habitats

California's Yolo Bypass:
Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture

ABSTRACT

Unlike conventional flood control systems that frequently isolate rivers from ecologically-essential floodplain habitat, California's Yolo Bypass has been engineered to allow Sacramento Valley floodwaters to inundate a broad floodplain. From a flood control standpoint, the 24,000 ha leveed floodplain has been exceptionally successful based on its ability to convey up to 80% of the flow of the Sacramento River basin during high water events. Agricultural lands and seasonal and permanent wetlands within the bypass provide key habitat for waterfowl migrating through the Pacific Flyway. Our field studies demonstrate that the bypass seasonally supports 42 fish species, 15 of which are native. The floodplain appears to be particularly valuable spawning and rearing habitat for the splittail (*Pogonichthys macrolepidotus*), a federally-listed cyprinid, and for young chinook salmon (*Oncorhynchus tshawytscha*), which use the Yolo Bypass as a nursery area. The system may also be an important source to the downstream food web of the San Francisco Estuary as a result of enhanced production of phytoplankton and detrital material. These results suggest that alternative flood control systems can be designed without eliminating floodplain function and processes, key goals of the 1996 Draft AFS Floodplain Management Position Statement.

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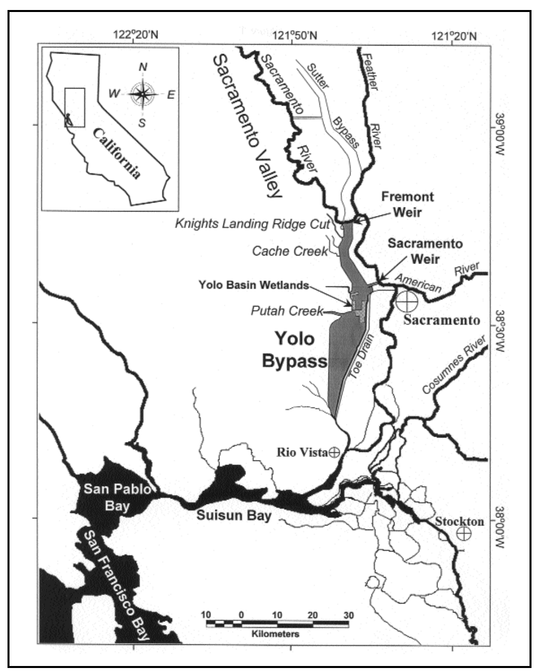
Introduction

The adverse environmental effects of conventional flood control techniques such as levee and dam construction, river channelization, and riprapping are well-documented (Bayley 1991; Toth et al. 1993; Galat et al. 1998). Additional criticisms have come from geologists, who note that dams face long-term limitations from sedimentation and levees are particularly sensitive to tectonic activity and global climate change (Mount 1995). These concerns led to the draft AFS Position Statement for Floodplain Management (Rasmussen 1996), which recommended the use of non-structural flood control methods to the extent possible. When structural measures are used, setback levees, gated levees, and levees with spillways were suggested as environmentally superior techniques. This guidance was based on substantial evidence demonstrating that natural floodplains have exceptional habitat values for numerous species at different trophic levels (Junk et al. 1989; Bayley 1991). Unfortunately, there is little information about the ecological performance of some of the structural alternatives.

In the present article we report on the Yolo Bypass, a unique large-scale engineered floodplain with many of the features cited as desirable alternatives in the draft AFS Position Statement. The flood control system has been regularly operated since the early 1930s, providing an excellent opportunity to evaluate the effectiveness of an established engineered floodplain. In this paper we summarize some of the major attributes of the Yolo Bypass and its associated benefits to fisheries, wildlife, and wetlands. We believe that the Yolo Bypass provides an instructive example of how flood control projects can be designed and operated without eliminating processes needed to sustain aquatic and wetlands systems.

Figure 1. Location of Yolo Bypass (shaded area) relative to the Central Valley, the San Francisco Bay and its tributaries.



History

The historical Sacramento Valley floodplain above Sacramento, California occupied much of the valley floor (Figure 1), when periodic floods filled a large part of the alluvial valley.

One of the most dramatic of these events occurred in 1862, when the valley was essentially converted into an inland sea. This legendary event helped fuel a 50-year debate on the best flood control approach to protect the valley's rapidly-growing communities (Kelley 1989). Initial recommendations in 1905 for high river levees were based on a relatively short hydrologic record. Coincidentally, the release of the flood engineering report was followed immediately by the extreme flood of 1907 in which an estimated 120,000 ha of the valley were inundated by Sacramento River flows of about 17,000 m^3/sec. An additional large flood in 1909 convinced flood managers that other alternatives were needed. The solution had its roots in an 1860s proposal by newspaper editor Will Green to construct a broad bypass system that would more closely mimic the Sacramento River's natural floodplain functions. Based in part on Green's concept, the U.S. Army Corps of Engineers eventually developed a network of weirs and bypasses, which became the Sacramento Flood Control Project. Central features of the plan included the development of two engineered floodplains, the Yolo and Sutter bypasses, to safely convey floodwaters around Sacramento and other valley communities. Much of the system was in place by the early 1930s, although there were several additions over the next several decades, including the development of upstream reservoirs.

Hydrology

Inundation of the Yolo Bypass (Figure 1) is one of the most dramatic seasonal events in California's Sacramento Valley. The Yolo Bypass presently floods in more than half of water years, creating a large expanse of shallow water habitat (Photograph 1).

This has a major physical effect on the San Francisco Estuary and its two component regions: 1) the Sacramento-San Joaquin Delta, a network of channels bordered by the cities of Sacramento, Stockton, and a point 20 km downstream of Rio Vista; and 2) the chain of downstream bays including Suisun, San Pablo, and San Francisco bays. At Yolo Bypass flows greater than about 2,100 m^3/sec the partially leveed 24,000 ha floodplain is fully inundated; this level of inundation approximately doubles the wetted area of the delta and is equivalent to about one-third the area of San Francisco and San Pablo bays. Besides Yolo Bypass, the only other delta region with substantial connectivity to portions of the historical floodplain is Cosumnes River, a small undammed watershed. The floodplain has historically been inundated as early as October and as late as June, with a typical peak period of inundation during January–March (Figure 2).

The hydrology of the system is complex, with inundation possible from several different sources (Figure 1). The primary input to the Yolo Bypass is through Fremont Weir in the north, which conveys floodwaters from the Sacramento and Feather rivers. The typical sequence of inundation is as follows. Flow pulses in the Sacramento River are first diverted into Sutter Bypass, a 7,300 ha agricultural floodplain with many similarities to Yolo Bypass. The Sacramento River immediately upstream of

Photograph 1. Seasonally flooded shallow water habitat in the Yolo Bypass, a 24,000 ha engineered floodplain of the San Francisco Bay-Delta Estuary.

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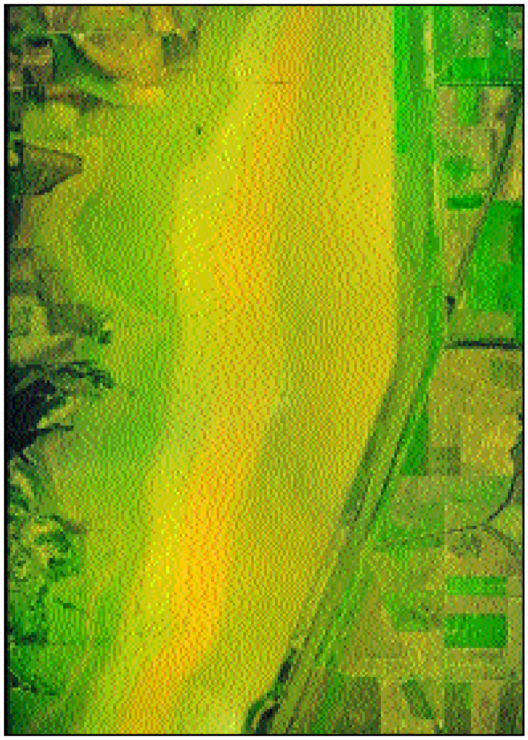
Fremont Weir has a relatively low channel capacity (800 m^3/sec), so Sutter Bypass flooding is often initiated in modest flow pulses. When the combined flow of Sutter Bypass and Sacramento and Feather rivers raises stage at Fremont Weir to a level of 9.2 m National Geodetic Vertical Datum, water subsequently enters Yolo Bypass. The relative distribution of flow from different tributaries affects the timing that this stage threshold is reached; however, Yolo Bypass flooding typically occurs when total flow from the Sutter Bypass and two rivers surpasses 1,600 m^3/sec. Floodwater through Fremont Weir initially flows through the "Toe Drain," a perennial riparian channel on the eastern edge of the bypass before spilling onto the floodplain when discharge in this small channel exceeds 100 m^3/sec. The floodplain is considered inundated when the stage of the Toe Drain at Lisbon Weir exceeds 2.5 m (NGVD datum). In major storm events (e.g. >5,000 m^3/sec), additional water enters from the east via Sacramento Weir, adding flow from the American and Sacramento rivers.



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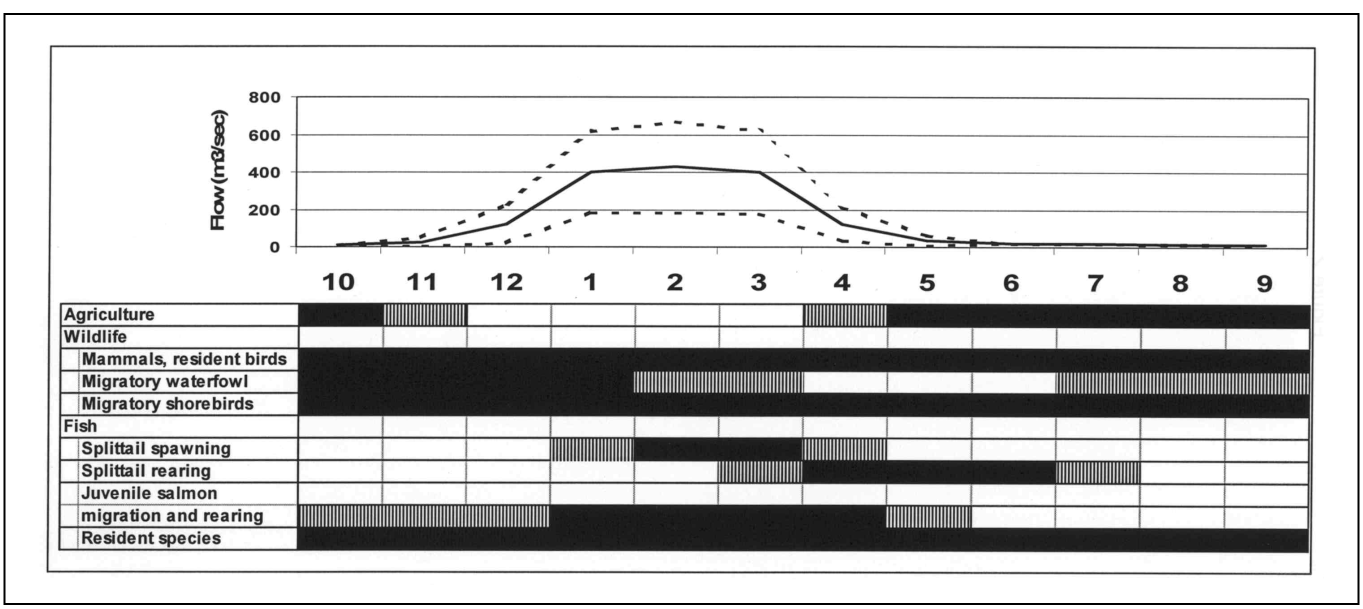
Photograph 2. Natural color aerial photograph of a portion of the Yolo Bypass. The color bands are formed by flow from tributaries, which remain hydrologically separated throughout its 64 km length.

Flow also enters the Yolo Bypass from several small west side streams: Knight's Landing Ridge Cut, Cache Creek, Willow Slough Bypass, and Putah Creek. These tributaries can substantially augment the Sacramento basin floodwaters or cause localized floodplain inundation before Fremont Weir spills. Interestingly, the diverse inputs from the Sacramento Basin and west side streams create distinct water masses that are visible across much of the length of the 64-km long bypass (Photograph 2).

Examination of archived aerial photographs indicate that water mass banding is a regular phenomenon, occurring during both low flow and extreme high flow events. Presumably this

Figure 2. Yolo Bypass hydrograph relative to agricultural and environmental activity in the floodplain by month (x-axis). The mean (solid line) and standard error (dashed line) of total daily Yolo Bypass flow is shown for October 1967–September 1996, the period when all major dams were completed in the Sacramento Valley. For agricultural and environmental uses of the floodplain, the primary (solid bars) and marginal (dashed bars) periods are shown. During dry periods (e.g. flows <100 m^3/sec), resident fishes are confined to the perennial waters which occupy less than 5 percent of the total floodplain area.



occurs because the size of the turbulent eddies that would mix these water masses is limited by the shallow depth. The mean depth of the floodplain does not exceed 3 m, except in the most extreme flood events.

After floodwaters recede, the basin empties through the Toe Drain. The floodplain is relatively well-drained as a result of land-grading for agriculture; there are no major topographic features to impede the drainage of flood flows to the lower Sacramento-San Joaquin Delta. During drier months the tidally-influenced Toe Drain channel is the primary source of perennial water in the Yolo Bypass, feeding a complex network of canals and ditches.

From a flood control standpoint, the Yolo Bypass has saved valley communities numerous times. The maximum design flow for the Sacramento River channel below the Sacramento metropolitan area is 3,100 m^3/sec. By contrast, the adjacent Yolo Bypass floodplain is engineered to convey approximately 14,000 m^3/sec. To illustrate this point, in 1999 flow in the Sacramento River was maintained below 3,000 m^3/sec during high flow events by diverting up to 1,350 m^3/sec excess flow to the Yolo Bypass floodplain (Figure 3a). As an indication of the frequency that the Yolo Bypass has been needed, total Sacramento River basin flow exceeded the design capacity of the river below Sacramento in 58% of years during 1956–1998 (Figure 4). During these wetter years, the design flow was exceeded an average of 23 days. The design capacity of the Yolo Bypass has not yet been exceeded, despite major floods such as 1997, estimated to be a 70-year recurrence interval event.

Agriculture and Wetlands

Land use in the Yolo Bypass is dominated by seasonal agriculture, but approximately one third of the area is a mosaic of more “natural” habitat types on the floodplain including wetlands, riparian, upland, and pond areas. By contrast, the adjacent Sacramento River has little habitat diversity. Like most other delta channels, the Sacramento River is bounded by steep levees covered with riprap or thin corridors of riparian vegetation (Photograph 3). The deep (typically >5 m mean depth) channel has minimal shallow water habitat, essentially no submerged vegetation and only minor strips of emergent vegetation.

The primary agricultural crops in Yolo Bypass are sugar beets, rice, wild rice, safflower, tomatoes, corn, and other grains. Farming activity is concentrated in late spring and summer, when flooding is uncommon (Figure 2). The state government has flood easements during all months, which can delay spring planting in the event of unusual late season storms. Crop yield data are not available specifically for the Yolo Bypass, but yields are generally lower than other nearby regions as a result of high clay content in the soils of the eastern half of the floodplain and by occasional late-season flooding. Nonetheless, the Yolo Bypass remains a key crop production area for Yolo County, where agriculture is the major source of revenue (Robert Crowder, California Farm Bureau, pers. comm.). The current wholesale market value of

Figure 3 (a-e). Results of floodplain and river sampling for 1999 adapted from Sommer et al (2001). a. Mean daily flow (m^3/sec) in Yolo Bypass (solid line) and Sacramento River (dashed line). b. Mean daily water temperature (°C) at Yolo Bypass (solid line) and Sacramento River (dashed line); c. Mean daily chinook salmon fork length for Yolo Bypass (solid symbols) and Sacramento River (open symbols) beach seine stations. For presentation purposes, only the daily mean fork lengths are shown; d. Weekly density of zooplankton in Yolo Bypass (solid symbols) and Sacramento River (open symbols); e. Density of dipterans in weekly drift samples in Yolo Bypass (solid symbols) and Sacramento River (open symbols).

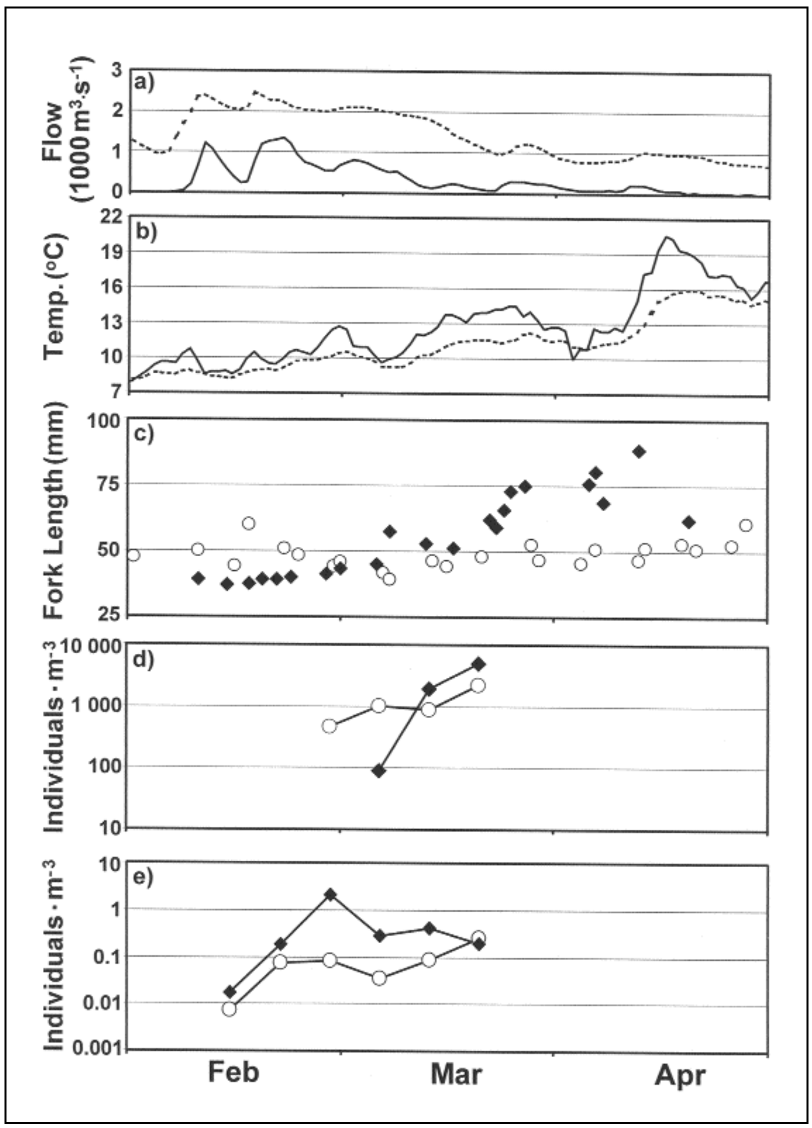
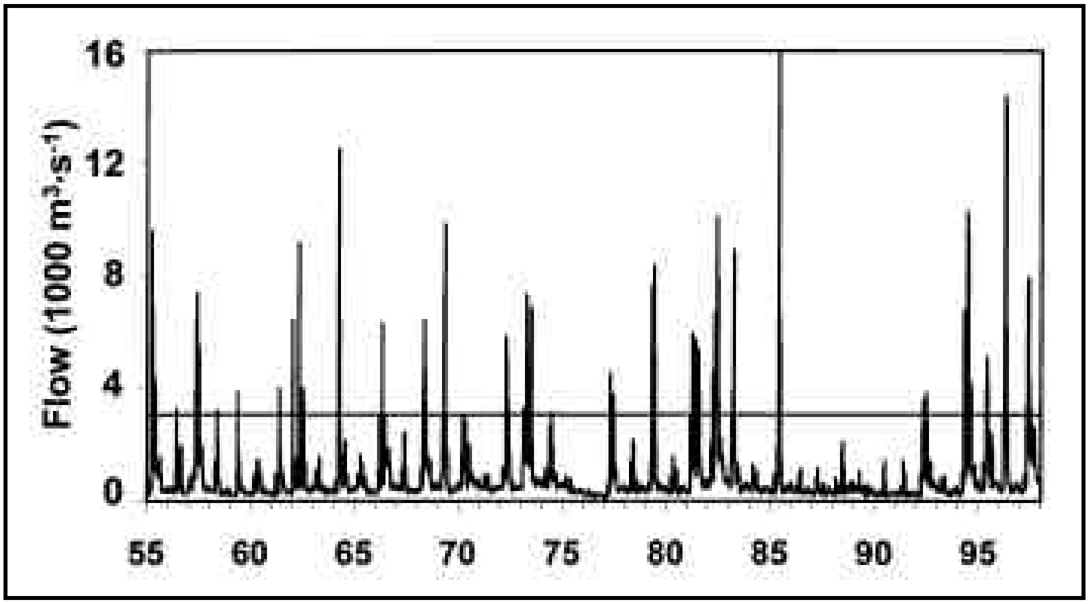


Figure 4. Total daily Sacramento Basin flow (m³/s) during 1956–1998. The horizontal line at 3,100 m³/s indicates the channel design capacity of the Sacramento River below Sacramento.



agricultural crops from Yolo County is approximately $300 million each year.

The floodplain also has large areas of wetlands, many of which are managed for waterfowl. The best example is the Yolo Basin Wetlands, a 1,250 ha project (Figure 1), reported to be one of the largest wetlands restoration projects in the western United States. Land for the project was purchased in 1991 and wetlands were constructed through the cooperative efforts of the U.S. Army Corp of Engineers, California Department of Fish and Game, Yolo Basin Foundation, U.S. Fish and Wildlife Service, California Department of Water Resources, California Wildlife Conservation Board, and Ducks Unlimited. The project was officially dedicated in 1997 by President Clinton. Habitat types in the Yolo Basin Wetlands include seasonal wetlands (940 ha), uplands (196 ha), perennial wetlands (75 ha) and riparian forest (11 ha).

The Yolo Bypass occupies a critical part of the Pacific Flyway, a migration route traveled by vast numbers of waterfowl. Examples of species that use the newly-created Yolo Basin Wetlands wildlife area include mallards, northern pintails, American wigeon, green-winged teal, northern shovelers, ruddy ducks, snow geese, Ross's geese, and Canada geese (Table 1).

Wildlife managers seasonally flood the area in October and maintain ponds for migratory waterfowl through January (Figure 2). The region also supports numerous species of shorebirds (e.g., sandpipers, curlews, and avocets), raptors (e.g., northern harriers, red-tailed hawks, and kestrels), songbirds (e.g., orioles, towhees, and bluebirds), and mammals (e.g., raccoons, skunks, and grey foxes). Yolo Bypass appears to be especially important to the Swainson's hawk, a state-listed

Photograph 3. A typical reach of the Sacramento River showing heavy channelization and minimal shallow water habitat.

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threatened species which uses the floodplain as foraging habitat. In recent years, up to 70 individuals have been observed foraging on the floodplain at the same time during dry periods. (Dave Feliz, Calif. Department of Fish and Game, pers. comm.).

Fish

Since 1997 we have conducted fish sampling in the Yolo Bypass, with emphasis on juvenile chinook salmon (*Oncorhynchus tshawytscha)* and other native species. Our major research questions have included: 1) what fish species use floodplain habitat; 2) what functions does floodplain habitat provide for fish; 3) is habitat quality better on floodplain than river channels; 4) is invertebrate species composition and biomass different on floodplain habitat than river channels; and 5) what is the effect of the floodplain on the downstream San Francisco estuary? The area presents formidable sampling challenges due to its large size and hydrologic variability, requiring diverse methods to address different biological questions. Our sampling program has included: egg and larval tows (1998-2001), screw trap, drift and zooplankton nets (1998–2001), beach seine (1997–2001), and purse seine (1998). Comparative data were also collected by U.S. Fish and Wildlife Service in the Sacramento River using beach seine and trawling methods (Sommer et al. 2001).

Our results show that the Yolo Bypass provides valuable aquatic habitat to 42 fish species, 15 of which are native (Table 2).

Many of these species are year-round residents in perennial waters in the floodplain. The bypass seasonally supports several state and federally-listed species: delta smelt (*Hypomesus transpacificus*), splittail, steelhead trout (*Oncorhynchus mykiss*), and spring-run and winter-run chinook salmon. Popular game fish are also present including white sturgeon (*Acipenser transmontanus*), striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), and white crappie (*Pomoxis annularis*). Like other parts of the Sacramento-San Joaquin Delta, there are more exotic than native fish species in the Yolo Bypass. Exotic species are one of the major environmental problems in the delta, where they frequently dominate the fish fauna on a year-round basis (Bennett and Moyle 1996). We hypothesize that floodplain may provide special benefits to native fish because of the seasonal hydrology of the floodplain. As illustrated in Figure 2, the majority of the floodplain habitat is seasonally dewatered and therefore cannot be dominated by exotic fish except in perennial waters. In other words, the Yolo Bypass is largely a "clean slate" at the beginning of each winter. Moreover, the typical winter and spring spawning and rearing period for native delta fishes (Moyle 2002) coincides with the timing of the flood pulse. By contrast, most of the introduced species shown in Table 2 spawn in late spring or summer, when the floodplain is drained. The hypothesis that the timing of the flood cycle may provide a competitive advantage to native fish (or at least helps to maintain coexistence with introduced species) is difficult to test because the floodplain-river system is exceptionally large and variable. However, we can at least demonstrate that floodplain habitat itself has direct benefits to native fish. To illustrate the importance of the Yolo Bypass to fish we discuss observations on two native species, splittail and juvenile chinook salmon.

Splittail, a large native cyprinid (Photograph 4), is perhaps the most floodplain-dependent species in the Sacramento-San Joaquin Delta. In 1999 the species was listed as threatened under the federal Endangered Species Act as a result of concerns about reduced abundance and distribution (USFWS 1999). The legal status of splittail is currently being reviewed as part of court proceedings; however, the species remains a major focus of water management and restoration activities in the Delta. Splittail reside in the San Francisco Estuary, but seasonally migrate upstream through the Sacramento-San Joaquin Delta and its tributaries to spawn (Sommer et al. 1997). The Yolo Bypass represents key habitat for the species and year-class strength is strongly correlated with the duration of floodplain inundation. Sommer et al. (1997) found that adults move onto the floodplain in winter and early spring to forage and spawn on flooded vegetation. Splittail rear on the floodplain and emigrate to the river channels and estuary as floodwaters recede. These results are consistent with more "natural" floodplains such as the Cosumnes River, a nearby undammed watershed that was recently identified as a major spawning and

Table 1. Counts of several major bird groups from 12 monthly surveys at Yolo Basin Wildlife Area during 1998 and 1999. The total number of individuals is shown for each year with the total number of species (in parentheses). Note that the observations represent the results of one survey day each month and therefore do not represent annual population estimates. Source: Dave Feliz, California Department of Fish and Game, unpublished data.

Bird Group	1998 Total	1999 Total	Dominant Species (top three)
Diving ducks	4,631 (7)	6,281 (7)	Ruddy, canvasback, scaup
Puddle ducks	44,493 (7)	173,323 (7)	Wigeon, mallard, shoveler
Geese and swans	136 (5)	192 (4)	Canada goose, white-front goose, snow goose
Raptors	224 (11)	269 (13)	Northern harrier, red-tailed hawk, Swainson's hawk
Shorebirds	3,485 (14)	18,530 (11)	Western sandpiper, dowitcher spp., dunlin
Wading birds	452 (2)	1,222 (2)	Black-necked stilt, American avocet

rearing area for splittail (Moyle, unpublished data). Sommer et al. (1997) concluded that the decline in numbers of splittail during the 1987–1992 drought was likely due to the lack of access to floodplain spawning habitat, although the relatively long life span of the fish (frequently > 5 years) allows it to survive periods without access to this habitat. Results from 1998–2000 also indicate that another native minnow, Sacramento blackfish (*Orthodon microlepidotus*) uses the bypass for spawning and rearing (T. Sommer, unpublished data).

Juvenile chinook salmon represent another good example of the value of the Yolo Bypass for native fish. Most young chinook salmon emigrate from the Sacramento River and its tributaries during winter and spring and enter the Sacramento-San Joaquin Delta (Fisher 1994). In low flow periods, the Sacramento River and similar delta channels are the only migratory paths, but during flood pulses the Yolo Bypass floodplain provides an alternative migration corridor. The results of Sommer et al. (2001) suggest that inundation of the Yolo Bypass may provide better rearing conditions than the adjacent Sacramento River. Chinook salmon rearing has been well-documented in river channels and estuaries (Kjelson et al. 1982; Healey 1991; Levings et al. 1995) and in off-channel habitats in small Pacific Northwest rivers and streams (Swayles et al. 1986; Swales and Levings 1989; Richards et al. 1992). However, our studies of the Yolo Bypass described in part below present the first solid evidence that we are aware of demonstrating that seasonal floodplains in large, low elevation rivers represent major areas for rearing. Like splittail, initial results from the Cosumnes River suggest that more "natural" floodplains also provide good habitat for young salmon (Moyle, unpublished data).

Photograph 4. Sacramento splittail (*Pogonichthys macrolepidotus*), a federally-listed minnow which uses the Yolo Bypass as key spawning, rearing, and foraging habitat.

We have collected juvenile salmon in all inundated regions of the floodplain and in all habitat types including agriculture, riparian, and wild vegetation. However, salmon are most abundant in areas with velocity refuges such as trees, shoals, and the downstream portions of levees. This observation is not surprising given the preference of chinook salmon fry for low velocity areas (Everest and Chapman 1972). The Yolo Bypass has substantially more of this habitat than the Sacramento River, which has little habitat complexity as a result of channelization and riprapping. As one indicator of the amount of low velocity habitat, we examined the amount of "edge" habitat in March 1998 aerial photographs (Photograph 2). For this analysis, we calculated the measured shoreline length for adjacent reaches of the Yolo Bypass and Sacramento River that each had a total linear distance of 55,500 m. The Yolo Bypass shoreline estimate was primarily based on the levee margins of the floodplain, but also included perimeters of internal islands and inundated riparian patches. Yolo Bypass had a total of 320,500 m of shoreline (5.8 m shoreline/m linear distance) compared to the Sacramento River, which had 95,200 m of shoreline (1.7 m shoreline/m linear distance). In other words, the Yolo Bypass had over three times as much shoreline habitat than the Sacramento River. However, edge habitat is a gross underestimate of the total amount of low velocity rearing habitat because it does not include the broad shoals that cover most of the western bypass. We are presently working on a physical model to estimate this additional shallow inundated area.

As evidence of better habitat quality for juvenile salmon in Yolo Bypass compared to the river, Sommer et al. (2001) found that mean salmon size increased significantly faster in the seasonally-inundated Yolo Bypass floodplain than in the Sacramento River, suggesting better growth rates. Their results for 1999 are shown in Figure 3c; however, we have observed the same trend each winter during 1997–2000. There are several habitat characteristics that could account for faster growth of young salmon. First, Yolo Bypass was significantly warmer than adjacent Sacramento River channels (Figure 3b) as result of the shallower depth and greater surface area of the floodplain. Higher water temperatures up to a point can enhance salmon growth, provided that there is sufficient energy to offset increased metabolic requirements (Brett 1995). Salmon diet analyses showed that the two major prey items for river and floodplain salmon are dipterans and zooplankton (Sommer et al. 2001). In 1999, there was little difference in zooplankton abundance between the Yolo Bypass and Sacramento River (Figure 3d) during the main period of flooding; however, dipterans were up to an order of magnitude more abundant in the floodplain drift net samples than the river due to high densities of chironomids (Figure 3e). Hence, food resources are substantially better in Yolo Bypass. Sommer et al. (2001) found that these differences led to significantly higher feeding success of young salmon on the floodplain than in the adjacent Sacramento River. Differences in water velocity between the river and floodplain could also potentially influence bioenergetics. For example, during the primary period of inundation in 1999 (February–March), we estimate that mean channel velocity in Yolo Bypass was approximately 0.1–0.3 m/sec, compared to Sacramento River that exceeded 1.0 m/sec. The lower velocity Yolo Bypass habitat is closer to the velocity preferences of young salmon (Everest and Chapman 1972) and may result in lower energy expenditure. The benefits of floodplain habitat are consistent with Pacific Northwest studies by Swales et al. (1986) and Swales and Levings, who found that coho salmon grew faster in off-channel ponds than main river channels.

Although our results suggest that several measures of habitat quality may be better for young salmon in the Yolo Bypass, floodplain habitat carries risks from avian predation and stranding when water levels drop. Some predation occurs as a result of wading birds such as egrets and herons; however we believe that these birds are unlikely to have a major population effect as the densities of wading birds are typically low (e.g., Table 1) relative to the thousands of hectares of available fish rearing habitat. The relative importance of stranding mortality is difficult to evaluate because the number of salmon emigrating from the Sacramento River and its tributaries is unknown, despite substantial monitoring efforts by several agencies. The floodplain is exceptionally well-drained because of grading for agriculture, which likely helps promote successful emigration of young salmon. Moreover, water stage decreases are relatively gradual; for example, the maximum stage decreases in 1998 were 1 cm/hr (Figure 4), well below levels that have been found to result in high stranding rates in experimental systems (Bradford 1997). Sommer et al. (2001) examined the survival issue by doing paired releases of juvenile coded-wire-tagged salmon in Yolo Bypass and Sacramento River to obtain comparative data. They found that the Yolo Bypass release groups had somewhat higher survival indices than Sacramento River fish in both 1998 and 1999, but the sample size (n=2 paired releases) was too low to demonstrate statistical significance.

Importance of the Yolo Bypass to the San Francisco Estuary

High flow years are known to enhance populations of a variety of fish and invertebrates of the San Francisco Estuary (Jassby et al. 1995). However, the exact mechanisms for these relationships remain largely unknown. Possible reasons for the positive effects of higher flow on fish include increased habitat availability, food supply and larval transport and reduced predation or competition (Bennett and Moyle 1996). Floodplain inundation is one of the unique characteristics of above normal flow years and may be responsible for some of the positive effects. The previously-described fish studies demonstrate that floodplain is important habitat for many fish. However, we also have evidence that floodplain inundation may also affect organisms downstream in the brackish portion of the estuary. Studies by Schemel et al. (1996) indi-

Table 2. Yolo Bypass fish species documented during 1997–2001. Federally-listed species are identified as threatened (FT) or endangered (FE) and state-listed species are identified as threatened (ST) or endangered (SE). Species names are listed in alphabetical order.

NATIVE SPECIES	
white sturgeon	*Acipenser transmontanus*
Sacramento sucker	*Catostomus occidentalis*
prickly sculpin	*Cottus asper*
threespine stickleback	*Gasterosteus aculeatus*
delta smelt (FT,ST)	*Hypomesus transpacificus*
tule perch	*Hysterocarpus traski*
river lamprey	*Lampetra ayresii*
Pacific lamprey	*Lampetra tridentata*
hitch	*Lavinia exilicauda*
Pacific staghorn sculpin	*Leptocottus armatus*
steelhead trout (FT)	*Oncorhyncus mykiss*
chinook salmon	*Oncorhynchus tshawytscha*
fall-run	
sprint-run (ST)	
winter-run (FE,SE)	
Sacramento blackfish	*Orthodon microlepidotus*
splittail (FT)	*Pogonichthys macrolepidotus*
Sacramento pikeminnow	*Ptychocheilus grandis*
INTRODUCED SPECIES	
yellowfin goby	*Acanthogobius flavimanus*
American shad	*Alosa sapidissima*
white catfish	*Ameiurus catus*
black bullhead	*Ameiurus melas*
brown bullhead	*Ameiurus nebulosus*
goldfish	*Carassius auratus*
common carp	*Cyprinus carpio*
red shiner	*Cyprinella lutrensis*
threadfin shad	*Dorosoma petenense*
western mosquitofish	*Gambusia affinis*
wakasagi	*Hypomesus nipponensis*
channel catfish	*Ictalurus punctatus*
green sunfish	*Lepomis cyanellus*
warmouth	*Lepomis gulosus*
bluegill	*Lepomis macrochirus*
redear sunfish	*Lepomis microlophus*
inland silverside	*Menidia beryllina*
smallmouth bass	*Micropterus dolomieu*
spotted bass	*Micropterus punctulatus*
largemouth bass	*Micropterus salmoides*
striped bass	*Morone saxatilis*
golden shiner	*Notemigonus crysoleucas*
bigscale logperch	*Percina macrolepida*
fathead minnow	*Pimephales promelas*
white crappie	*Pomoxis annularis*
black crappie	*Pomoxis nigromaculatus*
shimofuri goby	*Tridentiger bifasciatus*

cate that the Yolo Bypass is the major pathway for sediment into the estuary in wet years. They also found that the floodplain is the dominant source of organic carbon in wet years, when estuarine production of aquatic organisms is enhanced (Jassby et al. 1995). Although much of the carbon from river-floodplain sources may not be bioavailable (Jassby et al. 1996), floodplain organic carbon still remains a potentially major contribution to the estuary. As evidence, our results demonstrate that the Yolo Bypass can be a modest exporter of phytoplankton, a high quality source of organic carbon for the food web. In 1998 chlorophyll *a* (an indicator of phytoplankton biomass) trends downstream of the Yolo Bypass closely followed the floodplain hydrograph, with a peak as floodwaters receded (Figure 5), presumably caused by shallower water, increased residence time, and warmer temperature in the floodplain. As noted by Sommer et al. (2001), enhanced primary productivity is unlikely to be a result of agricultural fertilizer use in the bypass because nutrients are rarely limiting to phytoplankton in the San Francisco estuary. Modeling studies by Jassby and Cloern (2000) also confirm that Yolo Bypass is an important local source of phytoplankton. Post-flood blooms of phytoplankton have been reported for tropical (Schmidt 1973; Garcia de Emiliani 1997) and temperate locations (Heiler et al. 1995; Hein et al. 1999).

Higher floodplain production of phytoplankton may be relatively brief in Yolo Bypass; however, it still probably represents an important carbon subsidy to the downstream estuarine food web. Phytoplankton are responsible for most of the primary production in the estuary (Jassby et al. 1996), but there has been a major long-term decline in biomass (Lehman 1992). Reasons for reduced phytoplankton biomass include the effects of grazing by introduced bivalves (Alpine and Cloern 1992), water exports and low outflow (Jassby et al. 1995), and climate change (Lehman 2000). To illustrate the magnitude of this decline, Alpine and Cloern (1992) found that mean annual chlorophyll *a* concentrations decreased from >10 μg/L in 1980 to less than 1 μg/L by 1990 in Suisun Bay, a major rearing area for estuarine fish and invertebrates.

The degree to which the floodplain contributes invertebrate biomass to the estuary remains to be determined. As noted previously, sampling to date shows that Yolo Bypass zooplankton biomass is not higher than the adjacent Sacramento River during floodplain inundation (Figure 3d). The drift invertebrate results (Figure 3e) suggest that invertebrate production within the floodplain is substantial; however, we have not determined how much of this biomass is used by downstream consumers.

Summary

Yolo Bypass was originally constructed based on engineering considerations. At the turn of the century, a passive floodplain system was the most reasonable approach given the extreme seasonal and annual variability in California hydrology. Its economic effectiveness versus conventional levees and dams has not yet been evaluated, but the fact that the system has not failed after many decades of operation suggests a high degree of success. Moreover, the Yolo Bypass appears to provide substantial benefits to aquatic, terrestrial, and wetland species, while still being compatible with agriculture. Although the system is an engineered basin rather than a natural floodplain, it shares some ecological characteristics with the natural large river-floodplain systems described by Junk et al. (1989). Like natural floodplains, habitat diversity

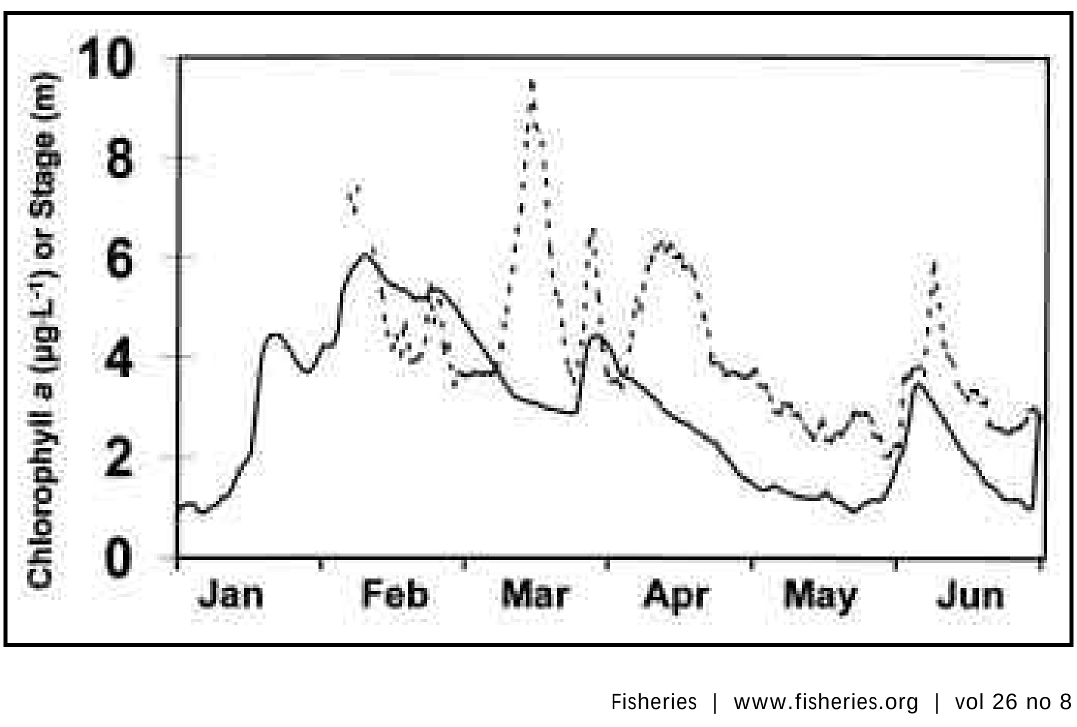

Figure 5. Chlorophyll *a* (μg/L; solid line) trends as measured using a fluorometer (Turner Designs) at Rio Vista and Yolo Bypass floodplain stage (m, NGVD datum; solid line) versus date during January–June 1998. Rio Vista is located at the confluence of the Sacramento River and the outflow from the Yolo Bypass.

in the Yolo Bypass is much higher than adjacent river channels. Yolo Bypass has a mosaic of habitats including wetlands, ponds, riparian corridors, and upland areas, whereas the adjacent Sacramento River is a relatively homogenous channel bordered by steep levees covered with riprap or some vegetation. Junk et al. (1989) note that natural floodplain production from lower trophic levels is a major input to channels, which is consistent with Yolo Bypass drift insects and phytoplankton exports to downstream areas. Finally, our data on splittail and salmon growth support the observations of Junk et al. (1989) that more natural river-floodplain systems can result in higher fish production on the floodplain than in the river channels.

On the whole, we believe that the Yolo Bypass example discussed here provides strong support for the use of a carefully designed and engineered floodplain as an alternative to conventional flood control techniques. This is not to say, however, that the Yolo Bypass is optimally designed. Examples of possible improvements to the Yolo Bypass include the construction of more wetlands for wildlife, fixing fish passage and stranding problems at the floodplain weirs, and increasing the frequency of floodplain inundation in drier years. These and other actions are being considered as part of the CALFED (2000) program, an ambitious state, federal, and local effort to resolve long-standing problems in the San Francisco Estuary and its tributaries. We acknowledge that the Yolo Bypass model is not wholly applicable to many areas. For example, the Missouri River shows bimodal flood pulses in March–April and June (Galat et al. 1998), making crop production before July less feasible in that region's floodplain. While large areas of Missouri River floodplain are also managed to promote fall and spring use by migratory waterfowl, overwintering is not a primary habitat function as in the Yolo Bypass. As a consequence, regional analyses are needed to determine the compatibility of different land uses in potential engineered floodplain projects.

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Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival

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Abstract: In this study, we provide evidence that the Yolo Bypass, the primary floodplain of the lower Sacramento River (California, U.S.A.), provides better rearing and migration habitat for juvenile chinook salmon (*Oncorhynchus tshawytscha*) than adjacent river channels. During 1998 and 1999, salmon increased in size substantially faster in the seasonally inundated agricultural floodplain than in the river, suggesting better growth rates. Similarly, coded-wire-tagged juveniles released in the floodplain were significantly larger at recapture and had higher apparent growth rates than those concurrently released in the river. Improved growth rates in the floodplain were in part a result of significantly higher prey consumption, reflecting greater availability of drift invertebrates. Bioenergetic modeling suggested that feeding success was greater in the floodplain than in the river, despite increased metabolic costs of rearing in the significantly warmer floodplain. Survival indices for coded-wire-tagged groups were somewhat higher for those released in the floodplain than for those released in the river, but the differences were not statistically significant. Growth, survival, feeding success, and prey availability were higher in 1998 than in 1999, a year in which flow was more moderate, indicating that hydrology affects the quality of floodplain rearing habitat. These findings support the predictions of the flood pulse concept and provide new insight into the importance of the floodplain for salmon.

Résumé : Notre étude démontre que le canal de dérivation Yolo, la principale plaine d'inondation de la région aval de la rivière Sacramento (Californie, É.-U.), offre de meilleurs habitats pour l'alevinage et la migration des jeunes Saumons Quinnat (*Onchorhynchus tshawytscha*) que les bras adjacents de la rivière. En 1998 et 1999, la taille des saumons a augmenté plus rapidement dans la plaine d'inondation agricole, sujette aux débordements saisonniers de crue, que dans la rivière, ce qui laisse croire à de meilleurs taux de croissance. De plus, des jeunes saumons marqués à l'aide de fils de métal codés et relâchés dans la plaine d'inondation étaient plus gros au moment de leur recapture et avaient des taux de croissance apparente plus élevés que des poissons relâchés dans la rivière en même temps. L'amélioration des taux de croissance dans la plaine de débordement résultait en partie d'une consommation significativement plus importante de proies, le reflet d'une plus grande disponibilité des invertébrés de la dérive. Un modèle bioénergétique laisse croire que le succès de l'alimentation a été meilleur dans la plaine d'inondation que dans la rivière, en dépit du coût métabolique d'alevinage significativement plus grand dans les eaux plus chaudes de la plaine d'inondation. Les indices de survie des poissons marqués et relâchés dans la plaine d'inondation étaient quelque peu plus élevés que ceux des poissons de la rivière, mais les différences n'étaient pas statistiquement significatives. La croissance, la survie, le succès de l'alimentation et la disponibilité des proies étaient tous supérieurs en 1998 par comparaison avec 1999, une année à débit plus modéré, ce qui indique que l'hydrologie affecte la qualité des habitats d'alevinage dans la plaine d'inondation. Nos résultats appuient les prédictions du concept de pulsion de crue (flood pulse concept) et mettent en lumière l'importance de la plaine d'inondation pour le saumon.

[Traduit par la Rédaction]

Introduction

Although the trophic structure of large rivers is frequently dominated by upstream processes (Vannote et al. 1980), there is increasing recognition that floodplains plays a major role in the productivity and diversity of riverine communities (Bayley 1995). Based largely on observations from relatively undisturbed river–floodplain systems, Junk et al. (1989) proposed the flood pulse concept, which predicts that annual inundation is the principal force determining productivity and biotic interactions in river–floodplain systems. Floodplains can provide higher biotic diversity (Junk et al. 1989) and increased production of fish (Bayley 1991; Halyk and Balon 1983) and invertebrates (Gladden and Smock 1990). Potential mechanisms for floodplain effects include increased habitat diversity and area (Junk et al. 1989), large inputs of

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terrestrial material into the aquatic food web (Winemiller and Jepsen 1998), and decreased predation or competition due to intermediate levels of disturbance (Corti et al. 1997). Nonetheless, the degree to which floodplains support riverine ecosystems remains poorly understood, particularly in regulated and temperate rivers. Uncertainties about river–floodplain relationships are due, in large part, to the difficulty in separating the relative contribution of floodplain versus channel processes and sampling problems in seasonal habitats, which are frequently subject to extreme environmental variation.

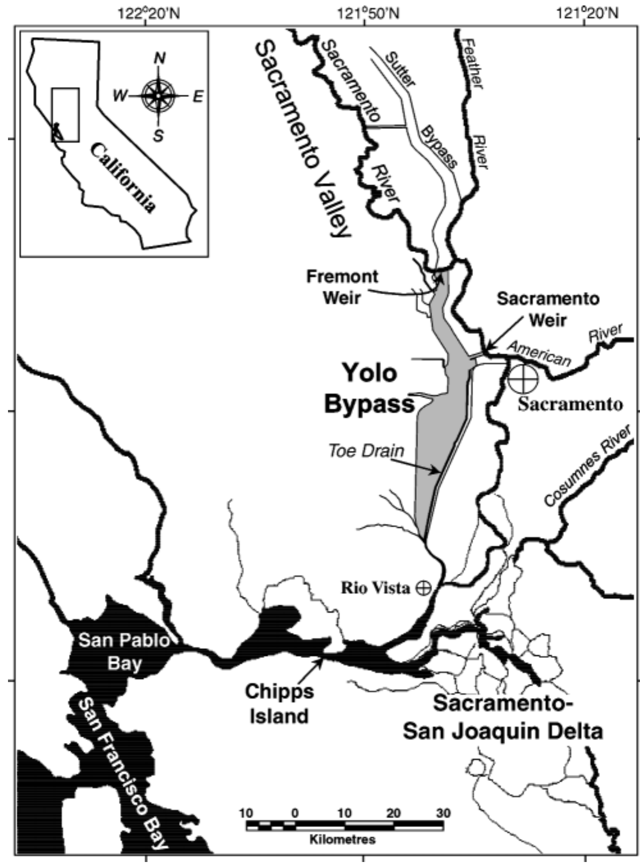


Fig. 1. The location of Yolo Bypass in relation to the San Francisco Estuary and its tributaries. The San Francisco Estuary encompasses the region from San Francisco Bay upstream to Sacramento. Feather River Fish Hatchery is located on the Feather River approximately 112 km upstream of Yolo Bypass.

In the this study, we examined the relative importance of floodplain and riverine habitat to juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento River (California, U.S.A.), a large regulated river (Fig. 1). The system is particularly well suited to a comparative study, because young salmon migrating down the lower Sacramento River to the San Francisco Estuary in wet years have two alternative paths: they may continue down the heavily channelized main river or they may pass through the Yolo Bypass, an agricultural floodplain bordered by levees. We had two reasons to believe that the floodplain might be important habitat for young salmon. First, years of high flow are known to enhance populations of a variety of species in the San Francisco Estuary (Jassby et al. 1995) and the survival of chinook salmon (Kjelsen et al. 1982). However, the specific mechanisms for these benefits have not been established. Possible reasons for the positive effects of flow on fish include increased habitat availability, migration cues, food supply, larval transport, and reduced predation rates (Bennett and Moyle 1996). Floodplain inundation is one of the unique characteristics of wet years, during which the Yolo Bypass is likely to be a significant migration corridor for young chinook salmon in the Sacramento Valley. During high-flow events, the Yolo Bypass can convey >75% of the total flow from the Sacramento River basin, the major producer of salmon among tributaries of the San Francisco Estuary. Second, floodplains are known to be among the most important fish-rearing areas in a variety of river systems, yet in developed regions, the availability of this habitat has been greatly reduced by channelization and levee and dam construction (Rasmussen 1996). A high degree of habitat loss may greatly enhance the biological significance of remnant floodplains in heavily modified systems, such as the San Francisco Estuary and its tributaries.

This study tests the hypothesis that the agricultural floodplain provides better habitat quality than the adjacent river channel. For the purpose of this analysis, we focus on salmon growth, feeding success, and survival as indicators of habitat quality. Obviously, there are many other possible measures of habitat quality, such as reproductive output of adults or physiological indicators. However, we believe that the chosen suite of parameters is reasonably representative of habitat quality. For example, Gutreuter et al. (2000) successfully used growth as a factor to test the hypothesis that floodplain inundation had a major effect on fish production.

The San Francisco Estuary is one of the largest estuaries on the Pacific Coast (Fig. 1). The system includes downstream bays (San Pablo and San Francisco) and a delta, a broad network of tidally influenced channels that receive inflow from the Sacramento and San Joaquin rivers. The estuary and its tributaries have been heavily altered by levees, dams, land reclamation activities, and water diversions. The primary floodplain of the Sacramento River portion of the delta is the Yolo Bypass, a 24 000-ha leveed basin that conveys excess flow from the Sacramento Valley, including the Sacramento River, Feather River, American River, Sutter Bypass, and westside streams. The 61 km long floodplain floods seasonally in winter and spring in about 60% of years, and is designed to convey up to 14 000 $m^3 \cdot s^{-1}$. During a typical flooding event, water spills into the Yolo Bypass via the Fremont Weir when Sacramento Basin flows surpass approximately 2000 $m^3 \cdot s^{-1}$. Except during extremely high flow events, the mean depth of the floodplain is generally less than 2 m, creating broad shoal areas. During dry seasons, the Toe Drain channel, a permanent riparian corridor, remains inundated as a result of tidal action. At higher levels of Sacramento Basin flow (e.g., >5000 $m^3 \cdot s^{-1}$), the Sacramento Weir is also frequently operated. Agricultural fields are the dominant habitat type in Yolo Bypass, but approximately one-third of the floodplain area is natural vegetation, including riparian habitat, upland habitat, emergent marsh, and permanent ponds.

There are four races of chinook salmon in the Sacramento Valley: winter, spring, late fall, and fall run (Yoshiyama et al. 2000). Historical data indicate that all races have decreased in abundance since the 1950s, but the spring, winter, and late-fall runs have shown the most pronounced declines. There are multiple causes for these long-term reductions, including habitat loss, habitat degradation, water diversions, and oceanic conditions. In the present study, we focused on the fall run, the numerically dominant race in the Sacramento Valley. The typical life-history pattern for these salmon is for young to migrate from the tributaries to the bay–delta area at the “fry” stage (Brandes and McLain2000), when most individuals are approximately 35- to 70-mm fork length (FL). In low flow years, there may be substantial upstream rearing in the Sacramento River. Peak juvenile emigration from the tributaries occurs during winter and spring (Kjelsen et al. 1982).

Materials and methods

Physical conditions

During 1998–1999, flow measurements in Yolo Bypass and the adjacent stretch of the Sacramento River were obtained from gauges operated by the U.S. Geological Survey (USGS). Daily water temperatures for each site were calculated as the mean of maximum and minimum daily measurements for single stations in the Sacramento River (USGS) and a temperature recorder (Onset Corp) installed in the Yolo Bypass Toe Drain channel (Fig. 1). However, from 1 February to 26 March 1998, these data were not available for Yolo Bypass. During this period, before the recorder was installed, discrete measurements were taken at the same location, typically during mid or late morning.

Fish sampling

Salmon FL (mm) was measured during January–April in 1998 and 1999 on samples collected with 15-m beach seines (4.75-mm mesh). Samples were collected weekly at five core locations located around the perimeter of the Yolo Bypass, during periods when the basin was flooded. After the bypass drained, additional samples were collected at random locations around the perimeter of ponds near the core locations. Comparative data on salmon size in the adjacent reach of the Sacramento River were collected by the U.S. Fish and Wildlife Service (USFWS) at five beach-seine sites, using techniques similar to those used when the the bypass was flooded.

FLs of salmon obtained from beach-seine sampling were compared to determine whether there was evidence of major differences in salmon size between the Yolo Bypass and the Sacramento River. However, these data were not considered unambiguous evidence of growth differences, because the two systems were open to immigration and emigration during much of the study, and migrating salmon include multiple races of salmon that cannot be readily separated. We addressed this issue by using paired releases of coded-wire-tagged (CWT) juvenile salmon in Yolo Bypass and the Sacramento River. This approach allowed comparisons of growth among fish of similar origin and provided a relative estimate of migration time and survival. The salmon were produced and tagged at the Feather River Fish Hatchery and released on 2 March 1998 and 11 February 1999. The release sites were in Yolo Bypass below Fremont Weir (52 000 in 1998; 105 000 in 1999) and in the adjacent reach of the Sacramento River (53 000 in 1998; 105 000 in 1999). The fish had a mean FL of 57.5 ± 0.5 mm (SE) in 1998 and of 56.8 ± 0.4 mm (SE) in 1999. A small portion of each group was subsequently collected by trawling at the seaward margin of the delta at Chipps Island, which is located downstream of the confluence of the Yolo Bypass and the Sacramento River (Fig. 1). The USFWS Chipps Island survey samples a single channel location with a midwater trawl towed at the surface (Baker et al. 1995; Brandes and McLain 2000). Ten 20-min tows were made each day, except during March in 1998 and 1999, when sampling was conducted every other day. Data on migration time (days) and FL (mm) were recorded for fish recaptured from each release group. Apparent growth rate was also calculated for each fish, as: (FL of individual at Chipps Island – mean FL of CWT release group) × (migration time)$^{-1}$. Survival indices of the paired CWT releases were calculated by USFWS by dividing the number of fish recovered for each release group at Chipps Island by the number released, corrected for the fraction of time and channel width sampled (Brandes and McLain 2000).

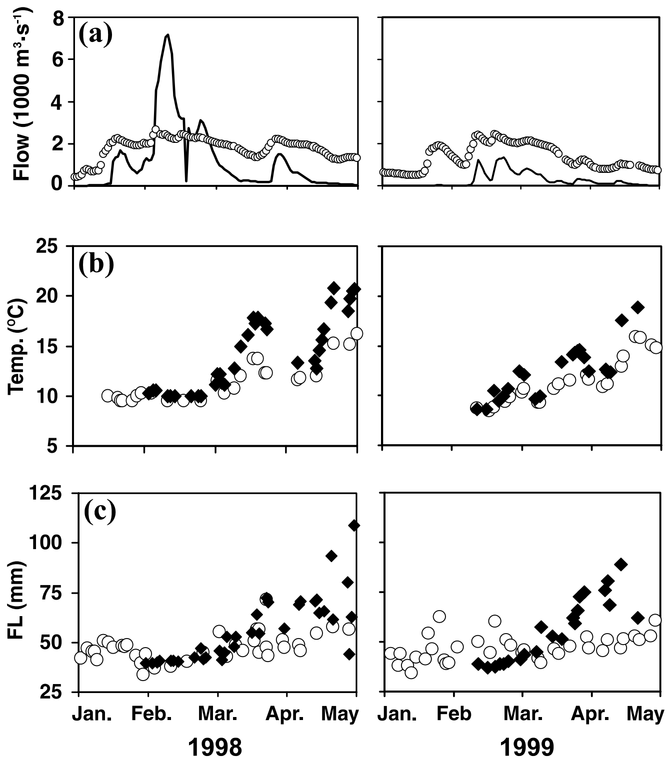
Diet

We performed diet comparisons on fall-run juvenile salmon (33–81 mm) collected in beach-seine samples during February–March of 1998 and 1999 from the Yolo Bypass (103 individuals) and the Sacramento River (109 individuals). Fish samples were tagged and stored individually in a deep freeze. After thawing, stomachs were removed from the fish and the contents were identified (using a dissecting microscope) to order (insects and arachnids), genus (crustaceans), or phylum (rarely eaten taxa such as oligochaetes). To develop average invertebrate length estimates, up to 10 individuals of each prey type encountered were measured. Prey dry weight estimates were calculated from average lengths, using regression equations for delta crustaceans obtained from J. Orsi (California Department of Fish and Game, Stockton, CA 95205, unpublished data) and from literature sources. Diet results were compared as an index of relative importance (IRI) (Shreffler et al. 1992) for each month. The index was calculated as: IRI = (% numeric composition + % weight composition) × % frequency of occurrence.

Prey availability

Invertebrates were sampled in February–March of 1998 and 1999, to examine prey availability in the Yolo Bypass and the Sacramento River. Sampling was not designed as a comprehensive evaluation of spatial and temporal variation of prey. Rather, it was intended to provide information on whether variation in salmon diets between the two locations was consistent with gross differences in prey type or relative abundance. We focused on Diptera (adults, pupae, and larvae) and crustacean zooplankton, which comprised over 90% of the diets of Yolo Bypass and Sacramento River juvenile salmon. Weekly drift samples were collected at fixed stations on the Yolo Bypass and the Sacramento River during periods when the floodplain was inundated. The sampling points were located away from overhanging vegetation and bank eddies, in water velocities of approximately 15–60 $cm \cdot s^{-1}$, depending on flow. Net (500-μm mesh) dimensions were 0.46 × 0.3 m mouth and 0.91 m length. The nets were fished for approximately 30 min during mid-morning, to coincide with the time period when most fish-stomach samples were taken. Sample volume was calculated using a flowmeter (General Oceanics Model 2030R) and net dimensions. Drift samples were stored in ethanol or formaldehyde, then identified to family or order using a dissecting microscope. In 1998, zooplankton were collected in the Yolo Bypass at two fixed stations with battery-operated rotary-vane pumps with a mean flow rate of 17 $L \cdot min^{-1}$. Samples were taken via pipes with outlets at multiple locations beneath the water surface. Discharge was directed into a 150 μm mesh net held in a basin on the bank. Flow rate was recorded at the beginning and end of the sample period, which varied from 1 to 6 h. No samples were taken in the Sacramento River during a comparable period in 1998. In 1999, zooplankton samples were taken with a Clarke–Bumpus net (160-μm mesh, diameter 0.13 m, length 0.76 m) placed in surface flow in the Yolo Bypass and Sacramento River. Sample volume was recorded as for the drift net. Zooplankton samples were concentrated and stored in 5%

Fig. 2. Chinook salmon size versus physical conditions in Yolo Bypass and the Sacramento River during winter and spring in 1998 and 1999. (*a*) Mean daily flow ($m^3 \cdot s^{-1}$) in Yolo Bypass (solid line) and the Sacramento River (circles). (*b*) Mean water temperature (°C) in Yolo Bypass (solid symbols) and the Sacramento River (open symbols). (*c*) Mean daily chinook salmon FL for Yolo Bypass (solid symbols) and Sacramento River (open symbols) beach-seine stations. For presentation purposes, only the daily mean FLs are shown; however, individual observations for February–March were used for statistical analyses.



formaldehyde, for later identification to genus using a dissecting microscope.

Bioenergetics

Feeding success was examined in two ways: (1) prey biomass estimated from stomach contents and (2) prey biomass estimated as a function of maximum theoretical consumption. For the first measure, we used the previously described stomach-content data to calculate total-prey biomass for individual fish.

A limitation of using prey biomass as a measure of feeding success between locations is that thermal history affects how consumption alters growth rate (Hewett and Kraft 1993). As will be discussed in further detail, water temperatures were significantly higher in the Yolo Bypass floodplain than in the Sacramento River. To correct for this problem, our second approach used bioenergetic modeling to incorporate the metabolic effects of water temperature. We used methods similar to those of Rand and Stewart (1998) to calculate a wet weight ration index, which uses prey biomass for each sampled individual as a proportion of the theoretical maximum daily consumption. The stomach-content data were used as our estimate of prey biomass for individual fish. The theoretical maximum daily consumption rate (C_{max}) was modeled using Fish Bioenergetics 3.0 (Hanson et al. 1997), using observed body size and water temperature at the time each beach-seine sample was collected. The model input also required fish mass, which we estimated from FL data, using length–weight relationships from Sacramento River juvenile salmon (Petrusso 1998). The caloric value of the prey was taken from weight conversion factors provided by Hanson et al. (1997). Model parameters were derived from those of Stewart and Ibarra (1991) for chinook salmon. The model was run for individual fish collected at each sampling location in 1998 and 1999.

Table 1. Robust regression statistics for Yolo Bypass and Sacramento River salmon FLs for 1998 and 1999.

	1998		1999	
	Parameter ± SEM	*t*	Parameter ± SEM	*t*
Intercept	29.4±0.6	46.8	23.5±0.5	43.7
Location	6.4±0.6	10.2	11.1±0.5	20.6
Day	0.3±0.01	34.5	0.3±0.01	48.5
Location:day	–0.14±0.01	–18.4	–0.21±0.01	–33.6

Note: The *t* values are all highly significant ($p < 0.0001$).

We emphasize that the second approach provides an *index*, rather than an *absolute* measure of feeding success. The wet weight ration index is conceptually analogous to "*P*" in Hanson et al. (1997), a model parameter that indicates what fraction of C_{max} is obtained over the course of the day. The major difference is that *P* is based on prey consumption over a 24-hour period, whereas our wet weight ration index is based on instantaneous measurements of stomach contents, which may not represent mean trends over the entire day. An additional limitation is that the Stewart and Ibarra (1991) model parameters were developed for adult salmon and we applied the model to juveniles. We did not have sufficient field or laboratory data to develop bioenergetic-model parameters specific to the earliest life stages. Nonetheless, other studies (Rand and Stewart 1998) have demonstrated that similar wet weight ration indices can provide an effective technique for comparing relative salmonid feeding success between seasons and years.

Statistical analysis

Overlapping temperature measurements from continuous recorders and the discrete measurements during 26 March – May 1998 were analyzed with Wilcoxon's matched-pairs test, to determine whether the two methods yielded different results. Mean water temperature for Yolo Bypass and the Sacramento River during the primary period of floodplain inundation (February–March) was analyzed with a generalized linear model with a variance function that increased with the mean squared, since variances were not homogeneous (Venables and Ripley 1997). Salmon FL measurements for Yolo Bypass and the Sacramento River during February–March of 1998 and 1999 were compared with a robust iteratively reweighted least squares regression procedure ("rlm"; Venables and Ripley 1997), because we detected substantial numbers of outliers in preliminary graphical evaluations of the data. Initial analyses revealed a substantial difference in the effects of location between years, so years were analyzed separately. Results from the CWT and bioenergetic studies were analyzed using a factorial-design analysis of variance, to evaluate the effects of location (Yolo Bypass, Sacramento River) and year (1998, 1999). Residuals from each model were examined graphically, to confirm that they met the assumption of normality and homogeneity of variance. Cochran and Levene's tests were also used, to test the assumption of homogeneity of variance. Logarithmic transformation was performed where necessary.

Results

Physical conditions

Yolo Bypass was inundated in 1998 and 1999 but the hydrology was substantially different in the two years (Fig. 2).

Table 2. Results of salmon collections at Chipps Island for 1998 and 1999 coded-wire-tagged groups released concurrently in Yolo Bypass and the Sacramento River.

	1998		1999	
	Yolo Bypass	Sacramento River	Yolo Bypass	Sacramento River
Fork length (mm)	93.7±2.0	85.7±1.4	89.0±2.6	82.1±1.7
Migration time (days)	46.2±2.3	55.4±3.5	58.2±2.8	58.6±4.1
Apparent growth rate ($mm \cdot day^{-1}$)	0.80±0.06	0.52±0.02	0.55±0.06	0.43±0.03
Survival index	0.16	0.09	0.09	0.07
Sample size	9	10	9	8

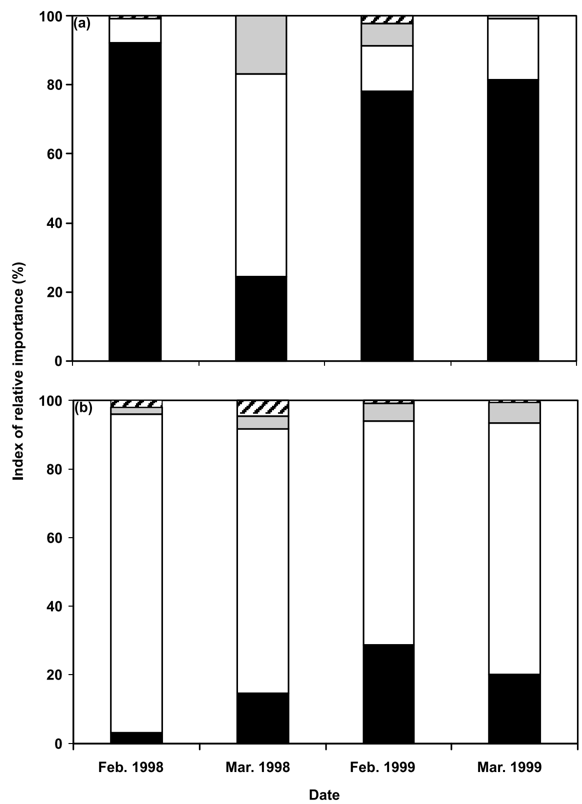
Note: Values for FL, migration time, and apparent growth rate are mean ± standard error (SEM).

The first year was extremely wet, with multiple flow pulses and a peak flow of 7200 $m^3 \cdot s^{-1}$. In 1999, floodplain hydrology was more moderate, with a peak of 1300 $m^3 \cdot s^{-1}$. Flows in the Sacramento River were much less variable than in the floodplain and generally remained at or below 2000 $m^3 \cdot s^{-1}$, a level within the design capacity (2800 $m^3 \cdot s^{-1}$) of the channel. Overlapping sampling between the continuous-temperature recorders and the discrete measurements during March–May 1998 showed a mean difference of 0.9°C between the two approaches, but this disparity was not statistically significant (Wilcoxon's matched-pairs test, $p > 0.25$). In 1998 and 1999, temperatures increased fairly steadily throughout the study period; however, in both years, temperature levels in Yolo Bypass were up to 5°C higher than those in the adjacent Sacramento River during the primary period of inundation, February–March. Temperature in the Yolo Bypass was described in 1998 by $T_y = -7.7 \pm 2.1 + (1.9 \pm 0.2)T_s$ and in 1999 by $T_y = -3.5 \pm 1.2 + (1.5 \pm 0.1)T_s$, where T_y is the temperature of the Yolo Bypass, T_s is the temperature of the Sacramento River, and the range for each value is the 95% confidence limit.

Fish growth, migration time, apparent growth rate. and survival

Salmon increased in size substantially faster in the Yolo Bypass than in the Sacramento River during each of the study years (Fig. 2). Robust regression results showed that the effect of location was highly significant ($p < 0.00001$) in each year (Table 1). This result is consistent with the CWT data (Table 2), which showed that the 1998 and 1999 Yolo Bypass CWT release groups had significantly larger mean length ($F = 14.34$, $p = 0.0006$) and higher apparent growth rates ($F = 20.67$, $p = 0.0007$) than the Sacramento River release groups. There was also a statistically significant effect of year: both release groups had larger mean sizes ($F = 4.42$, $p = 0.04$) and higher apparent growth rates ($F = 16.47$, $p = 0.0002$) in 1998 than in 1999. The 1998 Yolo Bypass CWT group showed the fastest migration time, arriving an average of at least 9 days ahead of any other release group. However, there was no statistically significant ($F = 2.22$, $p = 0.15$) effect of release location on migration time in the analysis of variance (ANOVA). As for fish size and apparent growth rate, mean migration time was less in 1999 than in 1998 ($F = 5.60$, $p = 0.02$). There was no statistically significant interaction between location and year for salmon size ($F = 0.07$, $p = 0.78$), apparent growth rate ($F = 1.62$, $p = 0.21$), or migration time ($F = 1.8$, $p = 0.18$). The survival indices were somewhat higher for CWT groups released in the Yolo Bypass than for those released in the Sacramento River for both 1998 and 1999. However, the lowest coefficient of variation based on a Poisson distribution of the CWT recaptures is 32%, and the actual (unknown) distribution of counts is likely to have higher variance than a Poisson distribution. Clearly the confidence limits of the paired survival indices would overlap, so the differences are not statistically significant.

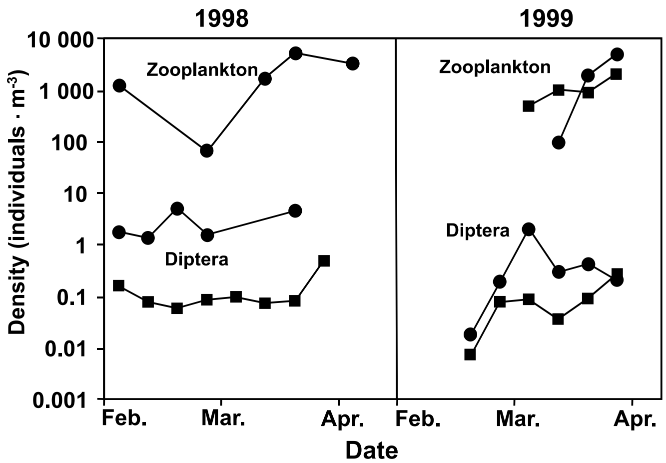
Fig. 3. Chinook salmon diet during February and March of 1998 and 1999 in Yolo Bypass (*a*) and the Sacramento River (*b*). The index of relative importance (*y*-axis) is defined in the text. Diptera (solid bars), zooplankton (open bars), other aquatic prey (shaded bars), and other terrestrial prey (striped bars) are shown for each month.



Diet

The diet of young salmon in the Yolo Bypass was dominated by dipterans, principally chironomid pupae and adults (Fig. 3). The second most common prey item was zooplank-

Fig. 4. Weekly abundance (log10·m^{-3}) of zooplankton and Diptera in Yolo Bypass (circles) and the Sacramento River (squares) during 1998 and 1999. Note that 1998 zooplankton data were not available for the Sacramento River.



ton, mostly cladocerans and copepods. Except for March 1998, zooplankton comprised less than 15% of the Yolo Bypass diets. Other aquatic (mainly amphipods and collembola) and terrestrial (mainly ants and arachnids) prey were relatively minor diet items. As for the floodplain samples, dipterans and zooplankton comprised over 90% of the diets of Sacramento River salmon; however, zooplankton were the dominant prey item in all months. Other aquatic (mostly amphipods, oligochaetes, and collembola) and terrestrial (mostly ants and other terrestrial insects) prey were consumed infrequently.

Prey availability

The drift samples contained many of the same taxa observed in the salmon diets, with Diptera (principally chironomids) as the major type at both sampling locations. However, the density of Diptera was much higher in the Yolo Bypass than in the Sacramento River (Fig. 4), particularly in 1998, when densities were consistently an order of magnitude higher. In general, dipteran drift densities were higher at each location in 1998 than in 1999. There was little difference in zooplankton density in the Yolo Bypass between 1998 and 1999 or between Yolo Bypass and the Sacramento River in 1999.

Bioenergetics

Young salmon from the Yolo Bypass had higher total-prey weights (F = 39.2, df = 1, p < 0.0001) than those from the Sacramento River (Fig. 5). The bioenergetic-modeling results showed that Yolo Bypass salmon also had higher wet weight ration indices than those from the Sacramento River (F = 19.3, df = 1, p < 0.0001). The interaction between location and year was significantly different for both the wet weight ration indices (F = 10.0, df = 1, p = 0.02) and the prey weights (F = 4.7, df = 1, p = 0.03).

Discussion

Chinook salmon that rear in the Yolo Bypass floodplain have higher apparent growth rates than those that remain in the adjacent Sacramento River channels. Mean length increased faster in the Yolo Bypass during each study year, and CWT fish released in the Yolo Bypass were larger and had higher apparent growth rates than those released in the Sacramento River. It is possible that these observations are due to higher mortality rates of smaller individuals in the Yolo Bypass or of larger individuals in the Sacramento River; however we have no data or reasonable mechanism to support this argument.

Apparent growth differences between the two areas are consistent with water temperature and stomach-content results. We found that the Yolo Bypass floodplain had significantly higher water temperatures and that young salmon from the floodplain ate significantly more prey than those from the Sacramento River. The wet weight ration indices calculated from bioenergetic modeling suggest that the increased prey availability in Yolo Bypass was sufficient to offset increased metabolic requirements from higher water temperatures. Higher water temperatures in the Yolo Bypass are expected as a result of the shallow depths on the broad floodplain. Increased feeding success in the Yolo Bypass is consistent with trends in prey availability. While Yolo Bypass and the Sacramento River had similar levels of zooplankton, Yolo Bypass had more dipteran prey in the drift, particularly in 1998. Studies of juvenile chinook salmon diets by Rondorf et al. (1990) showed that zooplankton were the least-favored prey items. Therefore, the dominance of zooplankton in the diets of Sacramento River salmon probably reflects a relatively low availability of other more energetically valuable prey items.

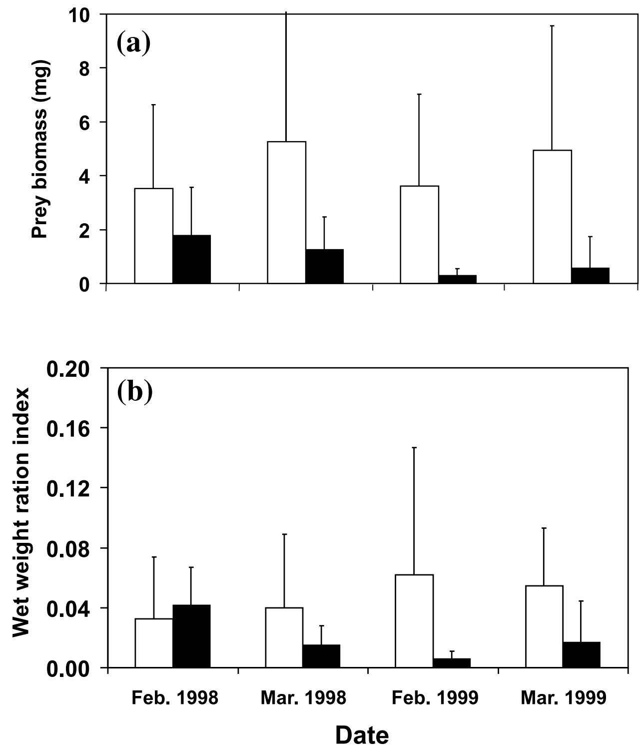
Recoveries of paired releases were too few to determine whether the higher survival indices for the Yolo Bypass release groups represent actual survival differences or random variation. Additional validation is needed from new release studies and from CWT recoveries in the adult ocean fishery and escapement. Nonetheless, the hypothesis that floodplain rearing could improve survival is substantiated by the growth data and bioenergetic modeling. Faster growth rates reflect improved habitat conditions, which would be expected to lead to improved survival, both during migration and later in the ocean. Elevated Yolo Bypass survival rates are also consistent with significantly faster migration rates in 1998, the likely result of which would be reduced exposure time to mortality risks in the delta, including predation and water diversions.

Improved survival is consistent with other habitat differences between the Yolo Bypass floodplain and the Sacramento River channel. We estimate that complete inundation of the Yolo Bypass creates a wetted area approximately 10 times larger than the reach of the Sacramento River we studied. This level of inundation is equivalent to a doubling of the wetted area of the entire delta portion of the San Francisco Estuary. Much of the floodplain habitat consists of broad shoals composed of soil and vegetation that are typical of the low-velocity conditions selected by young salmon (Everest and Chapman 1972). An increase in rearing area should reduce competition for food and space and perhaps reduce the probability of encountering a predator. In contrast, the Sacramento River channel is relatively narrow, with steep rock-reinforced banks and little shallow habitat. Migration through the Yolo Bypass corridor would also prevent fish from entering the channels of the central delta, in which there are various risks, including major water diversions (Brandes and McLain 2000). However, the Yolo Bypass is a less-stable environment, with stranding risks when flood waters recede. The relatively well-drained topography of the Yolo Bypass floodplain may help to reduce the magnitude of this problem. This is not to say, however, that access to floodplain rearing habitat represents the only mechanism to account for possible improvements in juvenile salmon survival in wetter years. Other covariates, such as reduced water temperature (Baker et al. 1995), reduced predation losses from higher turbidity (Gregory and Levings 1998), and reduced water diversion effects (Kjelsen et al. 1982), also contribute to improved wet-year survival of salmon that migrate through the San Francisco Estuary.

The results from this study suggest that hydrology may affect salmon feeding success, migration, and survival in both floodplain and river habitat. The CWT results indicate that salmon grew faster, migrated faster, and may have had better survival rates in 1998 than in 1999. One clear difference between the years is that the flow pulses were higher and of longer duration in 1998 than in 1999. Higher flow could directly increase migration rates through higher water velocities and have multiple indirect effects on growth through factors such as food supply or water temperature. The abundance of Diptera in drift samples was substantially higher in 1998 than in 1999 in both locations. The significant interaction between location and year for both prey weights and the wet weight ration index indicates that the combined effects of diet and water temperature under 1998 hydrology should have resulted in higher growth rates. Higher growth rates and faster migration times in 1998 may, in turn, have improved survival by reducing predation risk. Higher-flow conditions in 1998 increased the quantity and duration of floodplain rearing area, perhaps reducing resource competition and predator encounter rates. Increased flow duration and magnitude in 1998 could also have improved survival on the floodplain by reducing stranding risks.

These results provide new insight into the significance of seasonal floodplain habitat for salmon rearing, which has been studied primarily in perennial waterways such as estuaries and rivers (Healy 1991; Kjelsen et al. 1982). Indeed, this is the first study we are aware of demonstrating that off-channel floodplain provides major habitat for chinook salmon. We do not believe that the benefits of the floodplain to chinook salmon are unique to Yolo Bypass. Initial results from the Cosumnes River, an undammed watershed in the delta, show similar growth enhancements for juvenile chinook salmon that rear on the floodplain rather than in adjacent river channels (Peter Moyle, University of California, Davis, CA 95616, personal communication). Moreover, the benefits of the floodplain to salmon are consistent with findings for other fish species. Sommer et al. (1997) found that the Yolo Bypass provides major spawning, rearing, and foraging habitat for the native cyprinid Sacramento splittail (*Pogonichthys macrolepidotus*). The spawning and rearing of fish on floodplains has been reported in diverse locations that range from small streams (Halyk and Balon 1983; Ross and Baker 1983) to large rivers (Copp and Penaz 1988) in both temperate (Gehrke 1992; Turner et al. 1994) and tropical (Winemiller and Jepsen 1998) locations. The growth effects of floodplain habitat have been described for several tropical locations (Welcomme 1979); however, the present study and the results of Gutreuter et al. (2000) represent the only examples from temperate rivers of which we are aware.

Fig. 5. Feeding success results for Yolo Bypass (open bars) and Sacramento River (solid bars) juvenile salmon during 1998 and 1999. (*a*) Estimated prey weights in stomach contents. (*b*) Wet weight ration indices. Means and standard errors are shown.



Differences between the invertebrate communities in floodplains versus river channels have been reported by Castella et al. (1991). The exceptional production of drift invertebrates on the Yolo Bypass floodplain is consistent with the results of Gladden and Smock (1990), who found that invertebrate production was one to two orders of magnitude greater on the floodplain than in adjacent streams. Although we did not monitor benthic invertebrates, results from other studies of large rivers indicate that benthic biomass may be up to an order of magnitude higher in the floodplain (Junk et al. 1989). The Yolo Bypass drift invertebrate results contrast with the results for zooplankton, which were not particularly abundant on the floodplain. This finding is comparable with that of Welcomme (1979), who reported that densities of zooplankton in natural floodplains are frequently low, except for low-water periods and localized concentrations near habitat interfaces such as shorelines.

The mechanism for greater abundance of drift invertebrates in the Yolo Bypass remains unclear, but is unlikely to be an artifact of land use on the floodplain. Possible explanations for increased drift abundance include increased food supply (e.g., primary production or detritus), more habitat, and longer hydraulic residence times. For each of these mechanisms, Yolo Bypass probably provides functions similar to more “natural” floodplains. Improved food supply is supported by the work of Jassby and Cloern (2000), whose modeling studies suggest that the Yolo Bypass should have enhanced phytoplankton production as a result of its large surface area and shallow depth. Inputs of fertilizers from agriculture in the Yolo Bypass would not be important contributing factors, as nitrogen and phosphorous are rarely limiting to phytoplankton production in the delta (Ball and Arthur 1979). Like less-disturbed floodplains in other regions (Junk et al. 1989), invertebrate production in the Yolo Bypass may be stimulated by an increased availability of detritus in the food web. Alternatively, the trends in invertebrate abundance we observed may be a consequence of physical differences between floodplain and channel habitat. Inundation of the floodplain may increase the amount of habitat for benthic invertebrates, a major source of drift biomass. Given the larger surface area and lower velocities in Yolo Bypass, the floodplain probably has a much longer hydraulic residence time than the Sacramento River, reducing the rate at which drift invertebrates would be flushed out of the system. Increased habitat area and hydraulic residence time would also have been functional characteristics of the historical floodplain.

In the broader context, the results for salmon and drift invertebrates are consistent with the flood pulse concept, which predicts that floodplains should yield greater fish and invertebrate production than channel habitat (Junk et al. 1989). This finding is significant in that the flood pulse concept was developed primarily on the basis of relatively undisturbed rivers, whereas our study was conducted in a regulated river with a floodplain dominated by agricultural uses. Gutreuter et al. (2000) showed similar enhancements in fish growth from floodplain inundation in the Upper Mississippi River, another large regulated river. These studies suggest that floodplains can maintain important functional characteristics even in heavily modified rivers. In the case of the San Francisco Estuary and its tributaries, we do not claim that floodplain inundation is the primary factor regulating the productivity of the system. The Yolo Bypass floodplain may be seasonally more productive than the Sacramento River for some fish and invertebrates, but we have no data regarding its contribution during dry months or years. Nonetheless, the results of the present study and of Sommer et al. (1997) are sufficient to demonstrate that the floodplain represents one of the most biologically important habitat types in the region. We believe that proposed large-scale restoration activities in the San Francisco Estuary and its tributaries (Yoshiyama et al. 2000) that would increase the area and connectivity of the floodplain offer particular promise for native fish populations such as chinook salmon and Sacramento splittail.

Acknowledgements

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Patterns of Adult Fish Use on California's Yolo Bypass Floodplain

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ABSTRACT. In this paper we describe initial results from a study to examine adult fish diversity, abundance and timing of occurrence in the Yolo Bypass, the largest floodplain of the San Francisco Estuary. A fyke trap was used to capture adult fish between November 1999 and June 2000. We observed over 1,600 individuals representing 19 species including federally listed winter-run and spring-run chinook salmon (*Oncorhynchus tshawytscha*), splittail (*Pogonichthys macrolepidotus*) and sport fish such as white sturgeon (*Acipenser transmontanus*), striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*) during the sampling period. Flow pulses immediately preceding floodplain inundation apparently triggered upstream movement of a suite of native fish including splittail, Sacramento sucker (*Catostomus occidentalis*), Sacramento pikeminnow (*Ptychocheilus grandis*) and Sacramento blackfish (*Orthodon microlepidontus*). However, we also observed immigration of chinook salmon, white sturgeon, American shad and striped bass during low flow periods, when there was no upstream connection to the Sacramento River. Concurrent screw trap sampling indicated that these migrations resulted in successful spawning of many species including splittail, American shad and striped bass. Our study demonstrates that the Yolo Bypass floodplain represents an important migration corridor and spawning habitat for Delta fish; however, restoration of the migration corridor will improve fish passage to upstream tributaries particularly during low flow periods.

INTRODUCTION

The San Francisco Estuary has been studied for the past several decades, yielding data on physical processes, biology and chemistry of channel, shoal and wetland regions (Monismith et al. 1996; Schemel et al. 1996; Kimmerer and Orsi 1996; Jassby et al. 1996; Bennet and Moyle 1996). However very little research has been conducted on floodplain habitats of the Estuary. In this paper we review a recent study on the Yolo Bypass floodplain, a little studied region of the Estuary (Figure 1). This is despite the fact that floodplain inundation is known to be a major process supporting ecosystems in other regions (Junk et al. 1989; Michener and Haeuber 1998). As noted in Sommer et al. (this volume), floodplain inundation may be one of the reasons why several aquatic species in the Estuary respond favorably to high flow years. Sommer et al. (this volume) describe how the Yolo Bypass is an important nursery area for young fish and may help to support the food web of the San Francisco Estuary. However, little is known about how adult fish use floodplain habitat. The main objective of this study was to provide basic information on trends in adult fish abundance in the Yolo Bypass. Specific questions examined in our study included: 1) what adult fish species use the floodplain; 2) what is the timing and duration of adult fish use; 3) what environmental factors are responsible for the observed trends; and 4) what are some of the functions of floodplain habitat for adult fish?

Study Area. The San Francisco Estuary has two component regions, a tidally-influenced Delta and downstream bays. The Yolo Bypass is a leveed 24,000 ha floodplain engineered to convey Delta flood flows from the Sacramento River, Feather River, American River, Sutter Bypass and westside streams and drains (Figure 1). The Yolo Bypass floods seasonally in approximately sixty percent of years and when fully inundated approximately doubles the wetted area of the Delta. The lower Bypass is designed to convey flood water flows up to 14,000 m^3/s. During peak flood events, up to 80 percent of inflow from the Sacramento basin passes through the Bypass. Most flow enters the Bypass via Fremont and Sacramento Weirs. The Toe Drain is a perennial tidal channel along the east side of the Bypass, which drains adjacent fields during low flow and agriculture periods and serves to connect west side Bypass tributaries with tributaries of the north Delta.

METHODS

A large cylindrical fyke trap was used as our primary method to examine trends in adult fish use of the floodplain. The fyke trap is about seven meters long, three meters in diameter, and is constructed of chain-link fence material stretched around a steel frame. The terminal chamber of the trap is lined with 20-mm square plastic mesh. The terminal chamber also includes two hinged access doors for removing fish. The trap is anchored and accessed using a series of cables and a truck-mounted winch. The trap was installed at the lower end of the Yolo Bypass Toe Drain in November 1999 and was operated through June 2000. Due to extreme high flows through the Yolo Bypass, fyke trap sampling was suspended temporarily between February 15 and March 20, 2000.

Adult catch data were examined using catch frequency plots to assess timing and duration of adult fish use. Canonical Correspondence Analysis (CCA) was used to identify environmental factors associated with abundance trends (ter Braak and Smilauer 1998). CCA is a non-linear, multivariate, weighted-average method in which community data can be directly related to environmental data. It extracts synthetic gradients (ordination axes) of species abundance and environmental variables to maximize niche separation among species. We first examined the environmental variables with Pearson product moment correlation tests to identify variables that were highly correlated. Environmental variables used in the analysis were month, water temperature, tide (spring or neap) and Yolo Bypass inflow; however, water temperature was omitted from the CCA because Pearson product correlation test determined it was highly correlated ($r>0.70$) with month. The only continuous variable, flow, was standardized to a mean of zero and a standard deviation of one.

To examine which species may have spawned in the Yolo Bypass, we conducted rotary screw trap sampling from January 5 through June 30, 2000 to collect data on juvenile fish abundance. A 2.5 meter diameter EG Solutions screw traps (Corvallis, Oregon) was installed in the Toe Drain near the bottom of the Bypass (Figure 1). The trap was secured to an overhead cable and fished near the center of the channel. The trap was checked three to five times per week and was generally fished continuously. At each check, fish were measured and counted then released downstream. For this analysis, we focused on fish that were less than 50 mm fork length because these fish were most likely young-of-the-year fish and a result of spawning during the current water year.

RESULTS

We captured over 1,600 individuals in the fyke trap representing 19 different species (Table 1). Fish captured included the federally listed winter-run and spring-run chinook salmon and splittail. Sport fish such as white sturgeon, striped bass and American shad were also collected during the sampling period.

At least two major patterns of adult fish use of the floodplain were apparent. One group showed a clear positive response to flow pulses. A second group showed strong seasonal patterns without a similar obvious flow effect. Within the second group, some species where most abundant during late season (spring periods), while others showed both autumn and spring peaks.

A suite of native fish showed a positive response to an early season (January) flow pulse before floodplain inundation (Figure 2). Splittail and Sacramento pikeminnow showed the most prominent catch peaks during the January pulse. Sacramento sucker and Sacramento blackfish showed a similar trend, but the response was less pronounced.

White sturgeon and American shad did not show detectable positive flow responses (Figure 3). Instead, they showed a late season (spring) pattern of migration into the Yolo Bypass. However, white sturgeon probably migrated onto the floodplain during the highest flow period (February 15 through March 20, 2000) but were not detected because sampling was suspended. Threadfin shad, black crappie and white crappie were prevalent early in the season (autumn) (Table 1), when Yolo Bypass flow was lowest.

Two anadromous species, chinook salmon and striped bass showed both late fall and spring peaks in abundance (Figure 3). Carp, channel catfish, white catfish and striped bass were present in all sampling months (Table 1).

The CCA biplot (Figure 4) demonstrated that most of the variability in adult fish use of the floodplain was explained by month and inflow. The first two CCA axes explain 58.9% (eigenvalue = 0.23) and 34.2% (eigenvalue = 0.14) of the species-environment relation, respectively. Month was the most important variable on axis 1, while inflow was the most important variable on axis 2. The CCA results are reasonably consistent with the two general patterns of adult use, described previously. To help illustrate these trends, the positive flow responsive group is highlighted in Figure 4 with an oval whereas the fish which showed seasonality are highlighted with two rectangles. The rectangle on the right corresponds to species which had peak abundance during the earlier part of the season and the left rectangle reflects species which peaked during late season.

A total of 20 fish species in the less than 50 mm length range were captured in the rotary screw trap (Table 2). Of the 19 species observed in the fyke trap as adults (Table 1), 12 were also captured as young-of-the-year (Table 2).

DISCUSSION

Our results confirm the findings of Sommer et al. (1997) and Sommer et al. (2001) that floodplain represents one of the most important fish habitats in the San Francisco Estuary. In the Yolo Bypass the fish fauna is relatively diverse, providing habitat for both native and non-native fish. The present study suggests the Yolo Bypass floodplain functions as both a migration corridor and spawning habitat. Although we did not sample in all months of the year, based on other fish surveys of the Yolo Bypass (CDWR, unpublished data), we believe that non-native fish such as channel catfish, threadfin shad, black crappie and white crappie use the floodplain as year round habitat.

The majority of fish species captured as adults in the fyke trap were subsequently collected as young-of-the-year in the screw trap, which provides evidence that the Yolo Bypass provides spawning habitat for many of these fish. Of the species captured as adults, there was evidence of substantial spawning (i.e., more than a few juveniles captured) for splittail, American shad, striped bass, threadfin shad, largemouth bass and carp. Other species for which there may have been at least limited spawning included bluegill, channel catfish, black crappie and Sacramento sucker. Several small fish such as golden shiner, yellowfin goby, mosquitofish and inland silverside were not observed in the fyke trap because their small size as adults, typically less than 100 mm, which allows them to swim through the trap mesh. However, substantial numbers of young-of-the-year were collected in screw trap sampling, suggesting they spawned in the Yolo Bypass.

Our data are not definitive proof of floodplain spawning of any of these species. We cannot rule out the possibility that the young we captured may have originated in tributaries. Juveniles could have entered the floodplain from the Sacramento River during February and March when the Fremont Weir was overtopped, or from Putah or Cache creeks during all months. The best example is chinook salmon, which were collected as both adults and young-of-the-year, but juveniles likely entered the floodplain from upstream tributaries during the high flow period. The Yolo Bypass lacks suitable gravel substrate that would support salmon spawning. Nonetheless, we think the Yolo Bypass would have provided good spawning conditions for most species collected as juveniles given their life history requirements and previous studies. For example, many of the fish collected are native to the Mississippi River, where floodplain spawning has been documented (Sabo and Kelso 1991). The results for splittail are consistent with Sommer et al. (1997), who reported that the Yolo Bypass was one of the most important locations in the Estuary for spawning. Striped bass and American shad also probably spawned in the Yolo Bypass; however, we believe these fish probably spawned in the perennial Toe Drain channel rather than on the seasonal floodplain because they did not appear in our screw trap until two months after the flood pulse had subsided. Successful spawning of American Shad was surprising because the Toe Drain is functionally a tidal slough during May and June, quite unlike higher flow channels thought to be preferred spawning habitat of American shad (Moyle 2001).

The Yolo Bypass appears to provide a potential migration corridor for chinook salmon, white sturgeon, splittail and perhaps other species such as Sacramento pikeminnow. Moderate to low flow pulses through the Bypass appears to trigger immigration of some native fish such as splittail. The fact that the January flow pulse came primarily from Cache Creek indicates that flow from the Sacramento River is not necessary to attract native fish into the floodplain. From a management perspective, it is important to note that some winter-run, spring-run and fall-run chinook salmon and white sturgeon migrate into Yolo Bypass when there is no flow into the floodplain via Fremont Weir. These fish are therefore unable to reach upstream spawning habitat in the Sacramento River and its tributaries. Future restoration efforts are needed to address this fish passage issue for these ecologically and economically significant fish.

ACKNOWLEDGEMENTS

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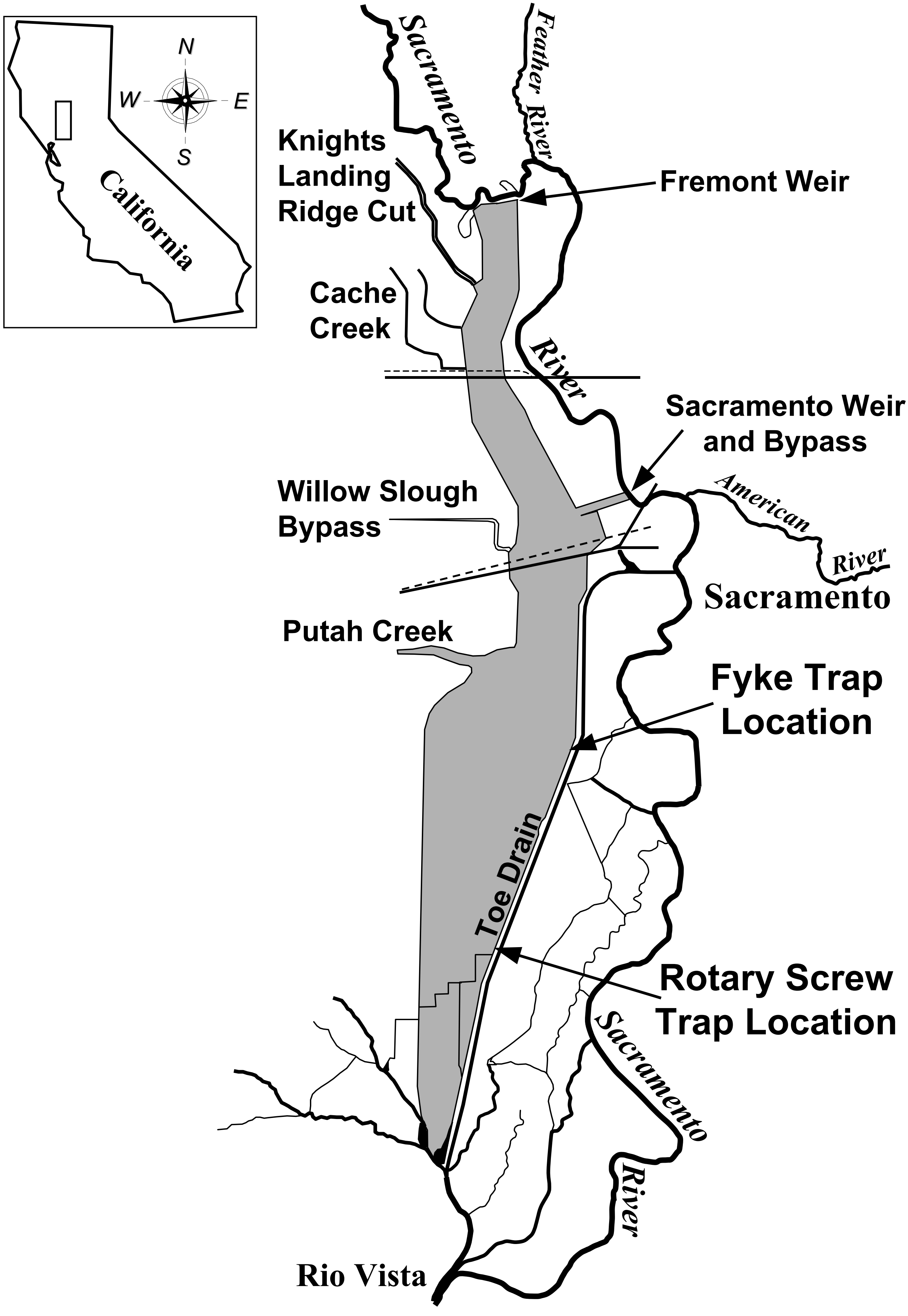
FIGURES

Figure 1. The location of the Yolo Bypass in relation to the adjacent portion of the Sacramento River. Trap and weir locations are indicated with arrows.

Figure 2. Selected native species catch in the fyke trap for the study period in relation to mean daily flow ($m^3 \bullet s^{-1}$) through the Yolo bypass floodplain.

Figure 3. Selected anadromus species catch in the fyke trap for the study period in relation to mean daily flow ($m^3 \bullet s^{-1}$) through the Yolo Bypass floodplain.

Figure 4. Environmental correlation vectors and species scores in the first two canonical correspondence analysis (CCA) dimensions for those species collected with the fyke trap. The vectors of environmental variables point in the direction of increasing values for each respective variable. The length of the vector signifies the strength of the correlation with each respective axis. The positive flow responsive group is highlighted with an oval whereas the fish which showed seasonality are highlighted with two rectangles. The rectangle on the right corresponds to species which had peak abundance during the earlier part of the season and the left rectangle reflects species which peaked during late season.



California
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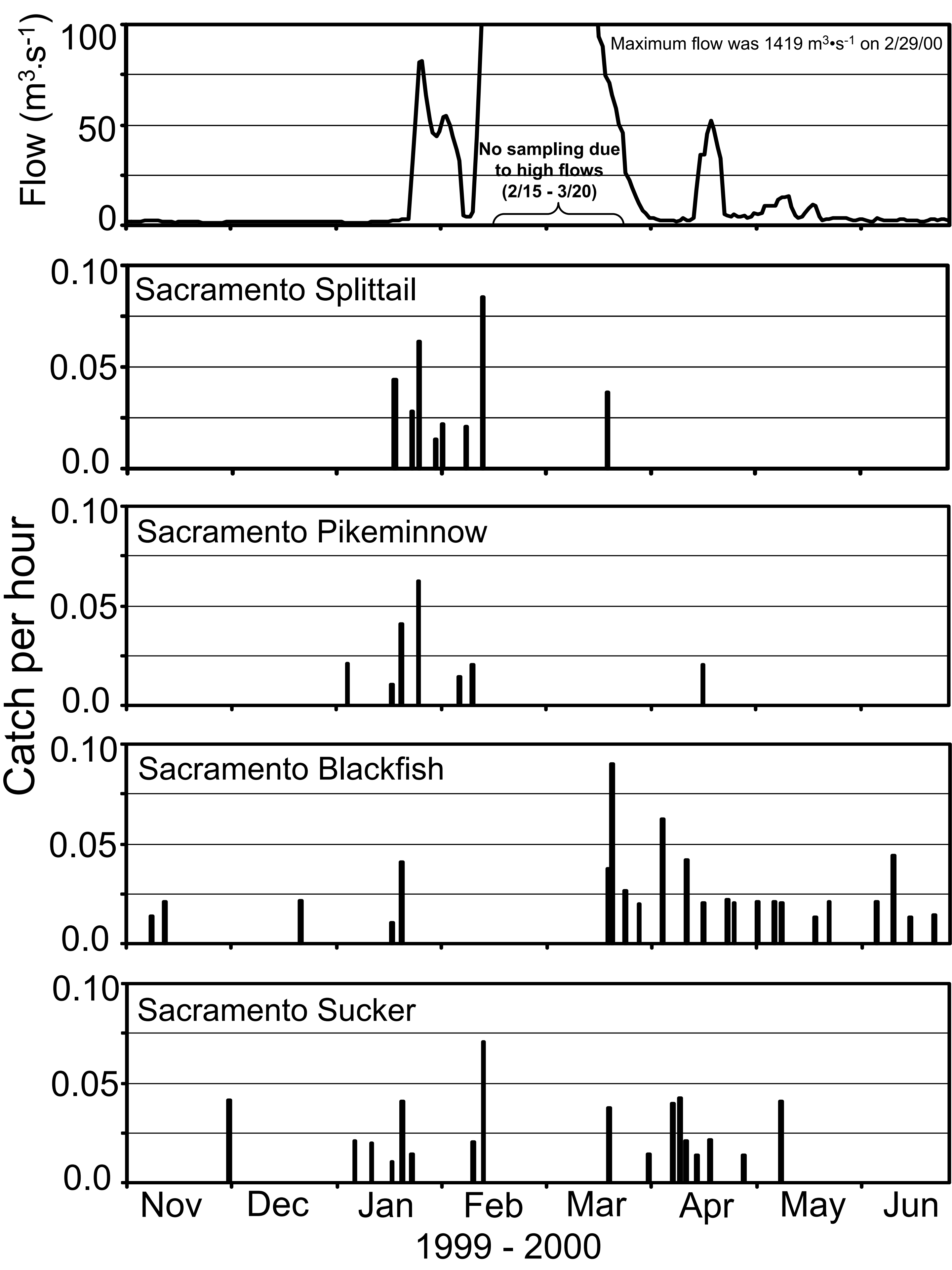
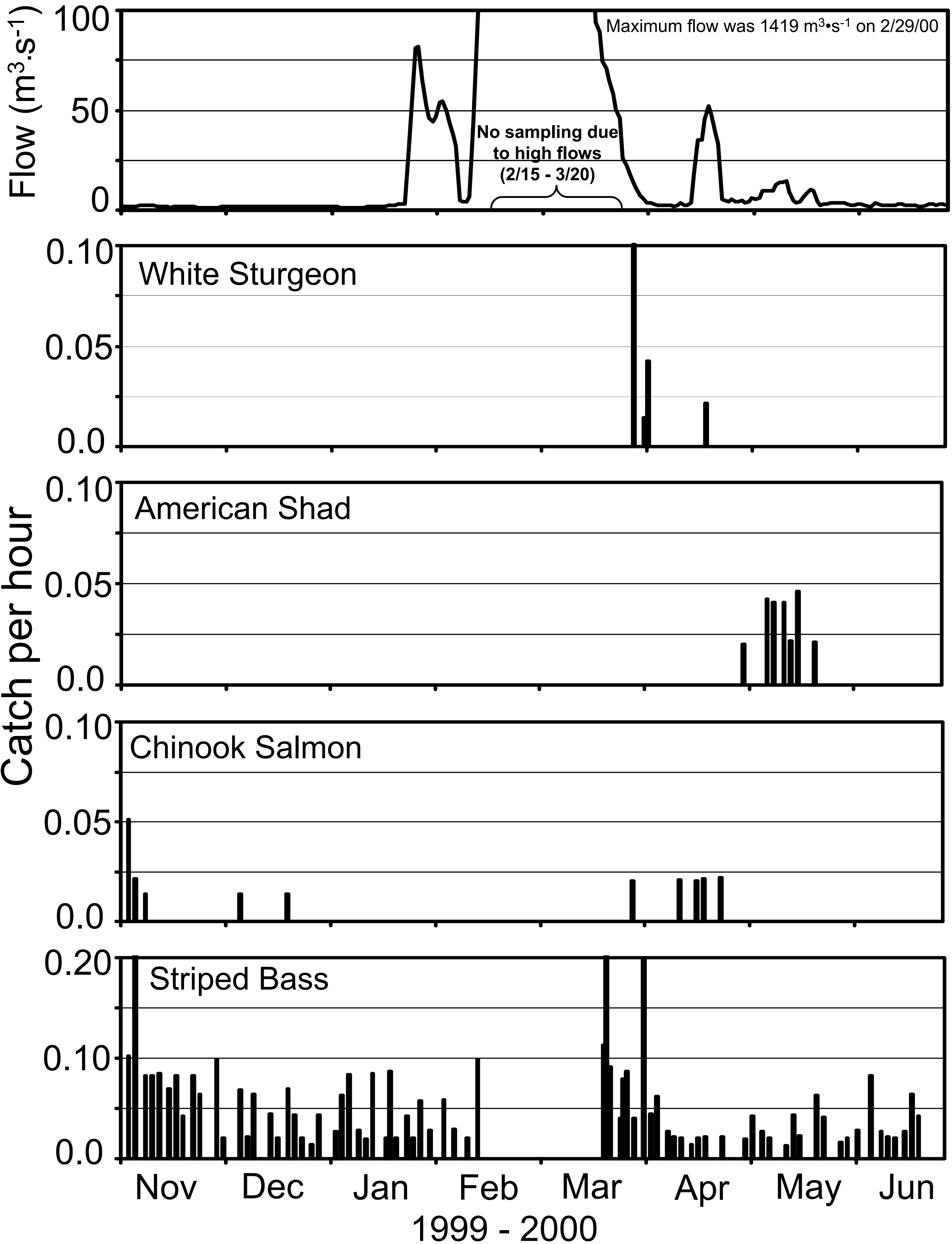
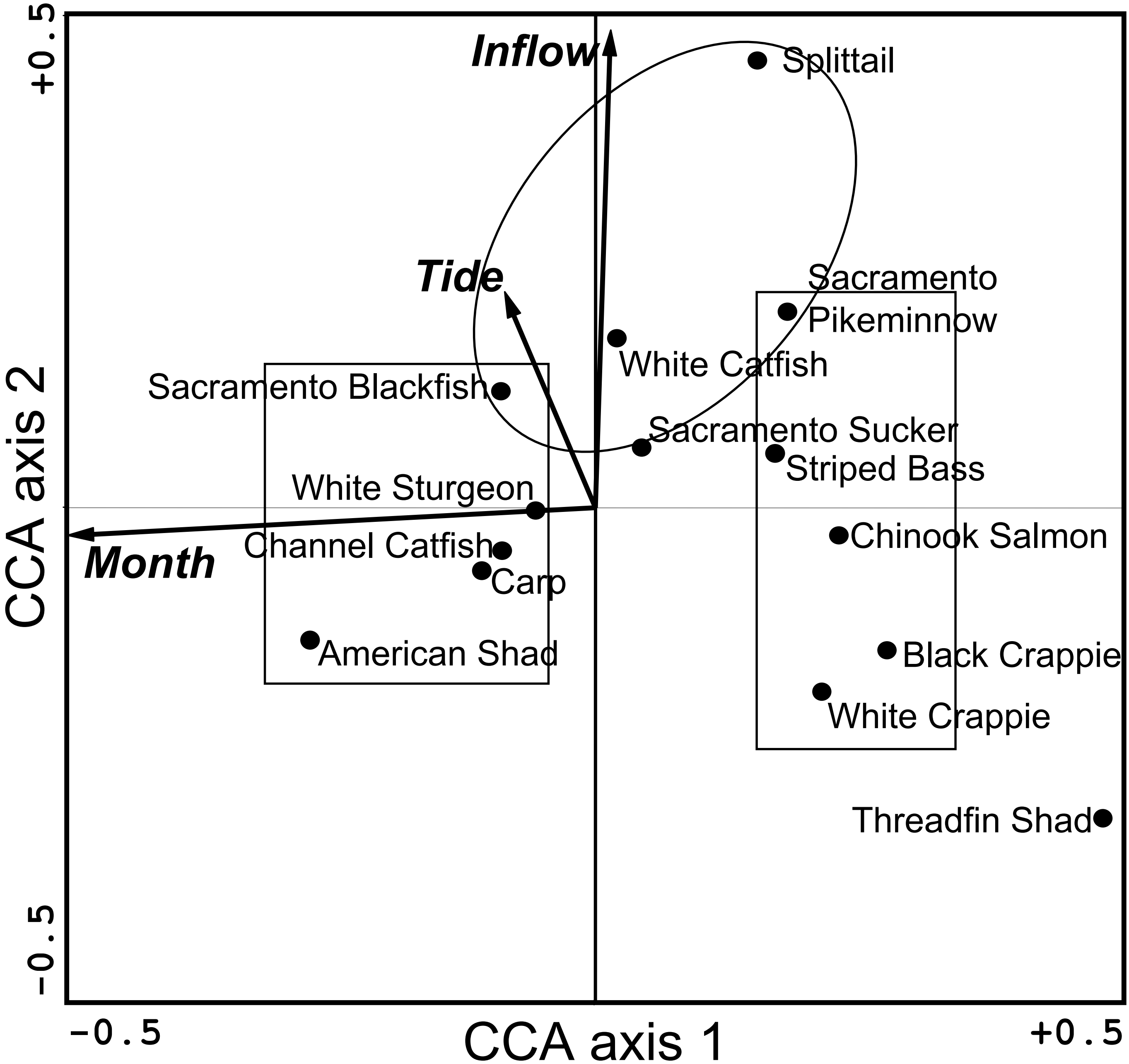
Knights Landing Ridge Cut
Fremont Weir
Cache Creek
River
Sacramento Weir and Bypass
American River
Willow Slough Bypass
Sacramento
Putah Creek
Fyke Trap Location
Toe Drain
Rotary Screw Trap Location
Sacramento
River
Rio Vista



Flow ($m^3 \cdot s^{-1}$)
100
50
0
Maximum flow was 1419 $m^3 \cdot s^{-1}$ on 2/29/00
No sampling due to high flows (2/15 - 3/20)
Catch per hour
Sacramento Splittail
Sacramento Pikeminnow
Sacramento Blackfish
Sacramento Sucker
0.10
0.05
0.0
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1999 - 2000



Flow (m3.s-1)
100
50
0
Maximum flow was 1419 m3•s-1 on 2/29/00
No sampling due
to high flows
(2/15 - 3/20)
Catch per hour
White Sturgeon
American Shad
Chinook Salmon
Striped Bass
0.20
0.10
0.05
0.0
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1999 - 2000


Inflow
Splittail
Tide
Sacramento
Pikeminnow
White Catfish
Sacramento Blackfish
Sacramento Sucker
Striped Bass
White Sturgeon
Chinook Salmon
Channel Catfish
Month
Carp
American Shad
Black Crappie
White Crappie
Threadfin Shad
+0.5
−0.5
CCA axis 2
−0.5
+0.5
CCA axis 1

Floodplain as Habitat for Native Fish: Lessons from California's Yolo Bypass

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ABSTRACT. The Yolo Bypass is the primary floodplain of the San Francisco Estuary. The partially leveed floodplain is a major flood control feature for the Sacramento Valley because it conveys floodwaters that would otherwise inundate Valley communities. Agricultural lands and seasonal and permanent wetlands within the Bypass represent resting and feeding areas for waterfowl migrating through the Pacific Flyway. Our studies demonstrate that the floodplain also provides important seasonal habitat for fish. The Bypass supports at least 42 fish species, including migratory and resident types. The floodplain appears to be especially valuable habitat for two federally-listed fish, splittail (*Pogonichthys macrolepidotus*) and juvenile chinook salmon (*Onchorhynchus tshawytscha*). The Bypass has considerable potential for additional fish and wildlife benefits as a result of new habitat restoration efforts.

INTRODUCTION

In California's Central Valley, few environmental events are as dramatic as the seasonal conversion of floodplain into an inland sea. These events have shaped the geography of the valley floor, creating unique plant and animal communities. Much of the historical floodplain has been lost to development, but some large tracts remain hydrologically connected to the river channels. In the Delta region of the San Francisco Estuary, the largest contiguous area of floodplain is the Yolo Bypass (Figure 1). We had several reasons to hypothesize that Yolo Bypass floodplain might be important to native fish. Floodplain has been found to be important habitat in a variety of other locations including small streams (Halyk and Balon 1983; Ross and Baker 1983) and large rivers (Copp and Penaz 1988) in temperate (Gehrke 1992; Turner et al. 1994) and tropical locations (Winemiller and Jepsen 1998). One of the most consistent patterns in the Estuary is that high flow years enhance populations of a variety of fish and invertebrates (Jassby et al. 1995). The exact mechanisms for flow effects remain largely unknown, but might include increased habitat availability, improved food supply, more efficient larval transport, and reduced predation and competition (Bennett and Moyle 1996). Floodplain inundation is one of the unique characteristics of above normal water years and may be responsible for some of the beneficial effects of high flow. Because much of the historical floodplain in the Sacramento Valley has been lost to development, river channelization and levee construction, we expected that remnant floodplain habitat such as Yolo Bypass would have exceptional biological value.

In this article we review recent research on how aquatic species use the seasonally inundated floodplain habitat of Yolo Bypass. We illustrate that: 1) floodplain represents one of the single most important habitats for native fish in the San Francisco estuary; and 2) the basin is also exceptionally important for flood control, agriculture, wetlands and wildlife. We suggest, therefore, that floodplain can support multiple land uses without eliminating processes needed to sustain aquatic species.

METHODS

We have been conducting sampling in the Yolo Bypass since 1995, with emphasis on juvenile chinook salmon (*Onchorhynchus tschawytscha*) and other native species. The area has formidable sampling challenges due to its large size and hydrologic variability, requiring diverse methods to address different biological questions. We have used egg and larval tows, screw traps, gill nets, electrofishing, drift and zooplankton nets, beach seines and purse seines. Details about these methods can be found in Sommer et al. (1997) and Sommer et al. (2001a).

STUDY AREA

The San Francisco Estuary and its two component regions, Sacramento-San Joaquin Delta (referred hereafter as the "Delta") and downstream Bays (Figure 1), comprise one of the largest estuaries on the Pacific Coast of North America. Yolo Bypass, a 24,000 ha floodplain, is the primary floodplain of the Delta. The majority of the floodplain basin is leveed to protect surrounding communities from floodwaters. The Yolo Bypass presently floods an average of every other year, typically during high flow periods in winter and spring. Complete inundation of the floodplain approximately doubles the wetted area of the Delta and is equivalent to about one-third the area of San Francisco and San Pablo bays. Besides Yolo Bypass, the only other Delta region with substantial connectivity to portions of the historical floodplain is Cosumnes River, a small unregulated watershed.

The hydrology of the Yolo Bypass is complex, with inundation possible from several different sources (Figure 1). The floodplain typically has a peak inundation period during January- March, but historically has been flooded as early as October and as late as June. The primary input to the Yolo Bypass is through Fremont Weir in the north, which conveys floodwaters from the Sacramento and Feather rivers. In major storm events (eg >5,000 $m^3 \cdot sec^{-1}$), additional water enters from the east via Sacramento Weir, adding flow from the American and Sacramento rivers. Flow also enters the Yolo Bypass from several small west side streams including Knight's Landing Ridge Cut, Cache Creek, and Putah Creek. These tributaries can substantially augment the Sacramento basin floodwaters or cause localized floodplain inundation before Fremont Weir spills. Receding floodwaters empty through the Toe Drain, a perennial channel on the eastern edge of the Bypass, then join the Sacramento River near Rio Vista. The floodplain is relatively well drained as a result of land grading for agriculture; there are no major topographic features to impede the drainage of flood flows to the lower Delta.

The floodplain was spared urban development due to the early recognition that high river levees alone would not protect valley communities from flooding (Kelley 1989). This remnant floodplain now forms an integral part of the Sacramento Flood Control System and has functioned exceptionally well. Total Sacramento basin flow exceeded the design capacity of the river channel below Sacramento in 58% of years during 1956-1998, when excess flows were diverted to the Yolo Bypass floodplain (Sommer et al. 2001b). The capacity of the Yolo Bypass has not yet been exceeded, despite 70-year flood events in 1986 and 1997.

Seasonal agriculture is the dominant land use on the floodplain, but approximately one third of the area is a mosaic of more “natural” habitat types including riparian, wetland, upland and permanent (perennial) pond. Farming activity is concentrated in late spring and summer, when flooding is uncommon. The primary agricultural crops in Yolo Bypass are sugar beets, rice, wild rice, safflower, tomatoes, corn and other grains. Flood control agencies have flood easements during all months, occasionally leading to a delay in spring planting after late season storms. The floodplain also has substantial areas of wetlands, many of which are managed for waterfowl. The largest contiguous area is the Yolo Basin Wildlife Area, a 1,250 ha complex (Figure 1) managed by the California Department of Fish and Game. Land for the project was purchased in 1991 and wetlands were constructed through the cooperative efforts of several agencies and environmental groups. Habitat types include seasonal wetland (940 ha), upland (196 ha), perennial wetland (75 ha) and riparian forest (11 ha). In autumn 2001 an additional 5,200 ha of agricultural land was purchased by the state for future expansion of the wildlife area.

The Yolo Bypass habitat represents a critical part of the Pacific Flyway, a migration route traveled by vast numbers of waterfowl. Examples of species that use the newly-created Yolo Basin Wetlands wildlife area and surrounding agricultural lands include mallard, northern shovelers, ruddy ducks, snow geese, northern pintails, American wigeon, green-winged teal, Ross’ geese and Canada geese. Refuge managers seasonally flood in October and maintain ponds for migratory waterfowl through January. The region also supports numerous species of shorebirds, raptors, songbirds and mammals.

In stark contrast to the mosaic of habitat types in Yolo Bypass, the adjacent Sacramento River (Figure 1) has little habitat diversity. Like much of the Delta, the Sacramento River is bounded by steep levees covered with rip-rap or narrow riparian corridors. The deep channel (typically >5 meters mean depth) has minimal shallow water habitat, essentially no submerged vegetation and only thin bands of emergent vegetation.

RESULTS OF FISH STUDIES

Yolo Bypass provides habitat to a diverse suite of fish species (Table 1). The floodplain is used by at least 42 fish species including seasonal fish that move in and out of the bypass with floodwaters and resident fish that are present year-round in perennial channels and ponds. Species using the Yolo Bypass include federal and state-listed fish (steelhead trout, delta smelt, spring-run and winter-run chinook salmon) and sport fish (striped bass and white sturgeon).

Similar to other Delta habitats (Brown 2000; Grimaldo et al. 2002), there are more introduced than native species in the Yolo Bypass floodplain (Table 1). Introduced species are one of the major environmental issues in the Delta, where they frequently dominate the fauna on a year-round basis (Bennett and Moyle 1996). However, unlike the other Delta habitats the floodplain is seasonally dewatered during late spring through autumn. This prevents exotic species from establishing year-round dominance except in perennial water sources. Moreover, many of the native fish are adapted to spawn and rear in winter and early spring during the winter flood pulse (Moyle 2002). Introduced fish typically spawn during late spring through summer, when the majority of the floodplain is not available to them. For these reasons, Sommer et al. (2001b) hypothesized that floodplain habitat provides greater benefits to native fish than introduced fish. Although this hypothesis is difficult to test, there is evidence that floodplain habitat offers special benefits to native fish. To help illustrate the importance of the Yolo Bypass we discuss observations on two native fish, splittail and juvenile chinook salmon.

The native splittail minnow is perhaps the most floodplain-dependent species in the Delta (Sommer et al. 2001b). In 1999 the species was listed as threatened under the Federal Endangered Species Act as a result of concerns about reduced distribution and abundance (USFWS 1999). The legal status of splittail is currently under review as a result of legal actions, but the species remains a major target of restoration activities and water management in the Delta. For much of the year, splittail are resident in the San Francisco Estuary; however, in autumn and winter they migrate upstream to spawn in the Delta and its tributaries. Studies by Sommer et al. (1997) demonstrated that the Yolo Bypass is one of the most important habitats for the species. Their sampling showed that adults move onto the floodplain in winter and early spring to forage and spawn on flooded vegetation. Splittail rear on the Yolo Bypass and emigrate to the river channels and estuary as floodwaters recede. Yolo Bypass thus resembles more "natural" floodplains such as the Cosumnes River, a nearby watershed that has recently been identified as a major spawning and rearing area for splittail (Dr. Peter Moyle, University of California at Davis, unpublished data). As one indication of the importance of the floodplain habitat to splittail, Sommer et al. (1997) showed that larval production of splittail for two floodplain habitats (Yolo and Sutter bypasses) was significantly higher than surrounding river channels. They also found that the duration of flooding of the Yolo Bypass was strongly correlated with splittail year class strength. Strong year classes are not produced unless there is at least three weeks of Yolo Bypass flooding during the March-April spawning and rearing period (Figure 2). It is therefore not surprising that Sommer et al. (1997) reported a major decline in the production of young splittail during the 1987-1992 drought, when the fish had no access to Yolo Bypass floodplain spawning habitat. Note, however, that at least modest spawning occurs in all water year types along river margins. The relatively long life span (frequently >5 years) of splittail probably also helps to buffer the population against the effects of extended drought.

Another native fish that benefits from floodplain habitat is the chinook salmon. There are four races of chinook salmon in the Sacramento Valley: winter, spring, late-fall and fall-run (Yoshiyama et al. 2000). Historical data indicate that all races have declined in abundance since the 1950s, particularly the spring, winter and late-fall run. There are multiple causes for these long-term reductions including habitat loss, habitat degradation, water diversions and oceanic conditions. These declines led to the federal listing of winter-run as “endangered” in 1991 and spring-run as “threatened” in 1999.

Most young chinook salmon of all races emigrate from upstream riverine spawning habitats between late autumn and spring, then enter the Delta (Fisher 1994). In low flow periods, downstream migrants are confined to the Sacramento River and similar Delta channels. During flood pulses the Yolo Bypass floodplain provides an alternative migration corridor. The results of Sommer et al. (2001a) indicate that this seasonal floodplain habitat provides better rearing conditions than the adjacent Sacramento River channel. They note two major advantages of floodplain: 1) increased area of suitable habitat and 2) increased food resources.

Chinook salmon fry typically prefer habitat that is shallow and has low velocity including edge and shoal areas (Everest and Chapman 1972). Sommer et al. (2001a) estimated that complete inundation of the Yolo Bypass floodplain creates a wetted area approximately ten times larger than the adjacent mainstem Sacramento River. Moreover, they observed that the river channel lacked broad, low velocity shoals because flows are confined to deep, narrow rip-rapped channels. By contrast, Sommer et al. (2001a) noted that Yolo Bypass has extensive shoals (mean depth typically < 2 meters) and greater habitat complexity. As an additional index of habitat availability, Sommer et al. (2001b) calculated that Yolo Bypass had about three times more "edge" habitat than the Sacramento River during a flood event in 1998.

Another important attribute of floodplain habitat is enhanced resources of food web organisms. Sommer et al. (2001a) found that drift insects (primarily chironomids) were up to 1-2 orders of magnitude more abundant in the Yolo Bypass than the adjacent Sacramento River channel during 1998 and 1999 flood events. This finding is consistent with other studies, which show that seasonal habitat is exceptionally productive for invertebrates (Gladden and Smock 1990). Sommer et al. (2001a) also observed that the higher drift insect abundance was reflected in the diets of juvenile salmon; Yolo Bypass salmon had significantly more prey in their stomachs than salmon collected in the Sacramento River. However, they noted that the increased feeding success may have been partially offset by significantly higher water temperatures on the floodplain habitat, resulting in increased metabolic costs for young fish. The higher water temperatures were a consequence of the broad shallow shoals, which warm faster than deep river channels. Through bioenergetic modeling, Sommer et al. (2001a) concluded that floodplain salmon had substantially better feeding success than fish in the Sacramento River, even after correcting for increased metabolic costs of warmer floodplain habitat.

Sommer et al. (2001a) found that improved rearing conditions allowed juvenile salmon to grow substantially faster in the Yolo Bypass floodplain than the adjacent Sacramento River. They showed that mean salmon size increased significantly faster in the seasonally-inundated Yolo Bypass floodplain than the Sacramento River, suggesting better growth rates. Results from the Cosumnes River suggest that more "natural" floodplains also provide good habitat for young salmon (Dr. Peter Moyle, University of California at Davis, unpublished data).

Although these results suggest that several aspects of habitat may be better for young salmon in the Yolo Bypass, fish using the floodplain risk stranding and avian predation as floodwaters recede. The relative importance of these sources of mortality are difficult to evaluate because we have no reliable estimate of the total number of salmon that migrate through the Sacramento River and its tributaries. However, Sommer et al. (2001b) note that wading birds are unlikely to have a major population effect on young salmon because their densities are quite low relative to the total amount of floodplain habitat. They also reported that efficient drainage appeared to promote successful emigration of young salmon, minimizing stranding. Yolo Bypass floodplain has been graded for agriculture using laser-leveling technology, resulting in an exceptionally well-drained topography. To try and quantify the net effects of floodplain rearing on salmon survival, Sommer et al. (2001a) conducted juvenile tagging studies. They used paired releases of juvenile coded-wire-tagged salmon in Yolo Bypass and Sacramento River to obtain comparative survival data for fish migrating through each habitat type. Based on recoveries of the tagged juvenile fish by USFWS trawling as the salmon emigrated the Delta, Sommer et al. (2001a) found that the Yolo Bypass floodplain release groups had somewhat higher survival indices than Sacramento River fish in both 1998 and 1999; however, the sample size (n = 2) was too low to demonstrate statistical significance. Tagged fish from the experimental releases are also being recovered in the ocean fishery, providing an independent estimate of survival. Ocean recoveries through 2001 suggest that survival rates of the floodplain release groups were 2-3 times greater than the river groups (Source: Pacific States Marine Fisheries Commission Regional Mark Information System, www.rmis.org).

OTHER BENEFITS OF FLOODPLAIN TO AQUATIC COMMUNITIES

Yolo Bypass fish studies demonstrate that the floodplain provides key habitat for native and non-native fish. However, floodplain inundation may also benefit organisms downstream in the brackish portion of the Estuary. At the base of the estuarine food web, phytoplankton are responsible for most of the primary production in the Estuary (Jassby et al. 1996). To the detriment of the Estuary, there has been a major long-term decline in phytoplankton biomass as a result of multiple factors including benthic grazers (Alpine and Cloern 1992), water exports and low outflow (Jassby et al. 1995) and climate change (Lehman 2000). Modeling studies by Jassby and Cloern (2000) suggest that phytoplankton produced in Yolo Bypass may be an important source of organic carbon to the Estuary, at least during flood events. This conclusion is supported by Sommer et al. (2001b), who found that chlorophyll peaks downstream of Yolo Bypass coincided with draining of the floodplain. Moreover, Yolo Bypass appears to be a major pathway for detrital (organic) material (Schemel et al. 1996), a significant additional source of organic carbon to the food web of the phytoplankton-deficient Estuary.

FUTURE RESTORATION EFFORTS

While our studies indicate that the Yolo Bypass floodplain presently represents one of the most ecologically important regions in the San Francisco Estuary, we believe that habitat values can be enhanced through habitat restoration. A suite of floodplain restoration projects are being considered as part of the CALFED (2000) program, an ambitious State, federal and local effort to cooperatively resolve long-standing problems in the San Francisco Estuary and its tributaries. The major limitation of Yolo Bypass is that it has poor connectivity to the remainder of the Delta in dry years. The Yolo Bypass is inundated an average of every two years, but native fish including young chinook salmon and splittail do not have access to the seasonal floodplain habitat during drought periods such as 1987-1992. Department of Water Resources is presently working on a CALFED-funded project to determine whether parts of the Yolo Bypass could be modified to create modest flooding in drier years, thereby supporting listed species such as salmon and splittail. The co-investigators on this project are Natural Heritage Institute and Yolo Basin Foundation, both local environmental groups. The idea of using managed flooding to improve habitat for aquatic species is conceptually similar to seasonal flooding used by Yolo Bypass wildlife areas and duck clubs to support waterfowl. However, floodplain habitat offers unique challenges for the management of native fish. Non-native fish and plants proliferate throughout the Delta (Bennett and Moyle 1996) and could dominate floodplain habitat if restoration efforts do not address the potential for species interactions. We hypothesize that restoration projects that focus on floodplain inundation in winter and early spring offer the greatest benefits native fish such as salmon and splittail. Floodplain projects designed for efficient drainage during spring would promote emigration of the young native fish, and limit reproduction of exotic fish species that typically spawn during late spring and summer. Pilot scale restoration projects are needed to test this hypothesis.

As described in our companion paper (Harrell and Sommer, this volume), adult fish that migrate upstream through the Yolo Bypass floodplain cannot pass Fremont Weir except during flood periods. Some species such as splittail may be able to spawn in the Yolo Bypass Toe Drain, but chinook salmon have no low flow option unless they locate Putah or Cache creeks. Sturgeon likely have difficulties passing Fremont Weir during flood flows, preventing them from reaching upstream spawning habitat in all years. As such, we believe that Fremont Weir represents one of the major fish passage issues in the lower Sacramento Valley and needs to be resolved through future restoration efforts.

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Table 1. Yolo Bypass fish species observed during 1997-2001. Federally-listed species are identified as Threatened (FT) or Endangered (FE) and state-listed species are identified as Threatened (ST) or Endangered (SE).

Source: Sommer et al. (2001b)

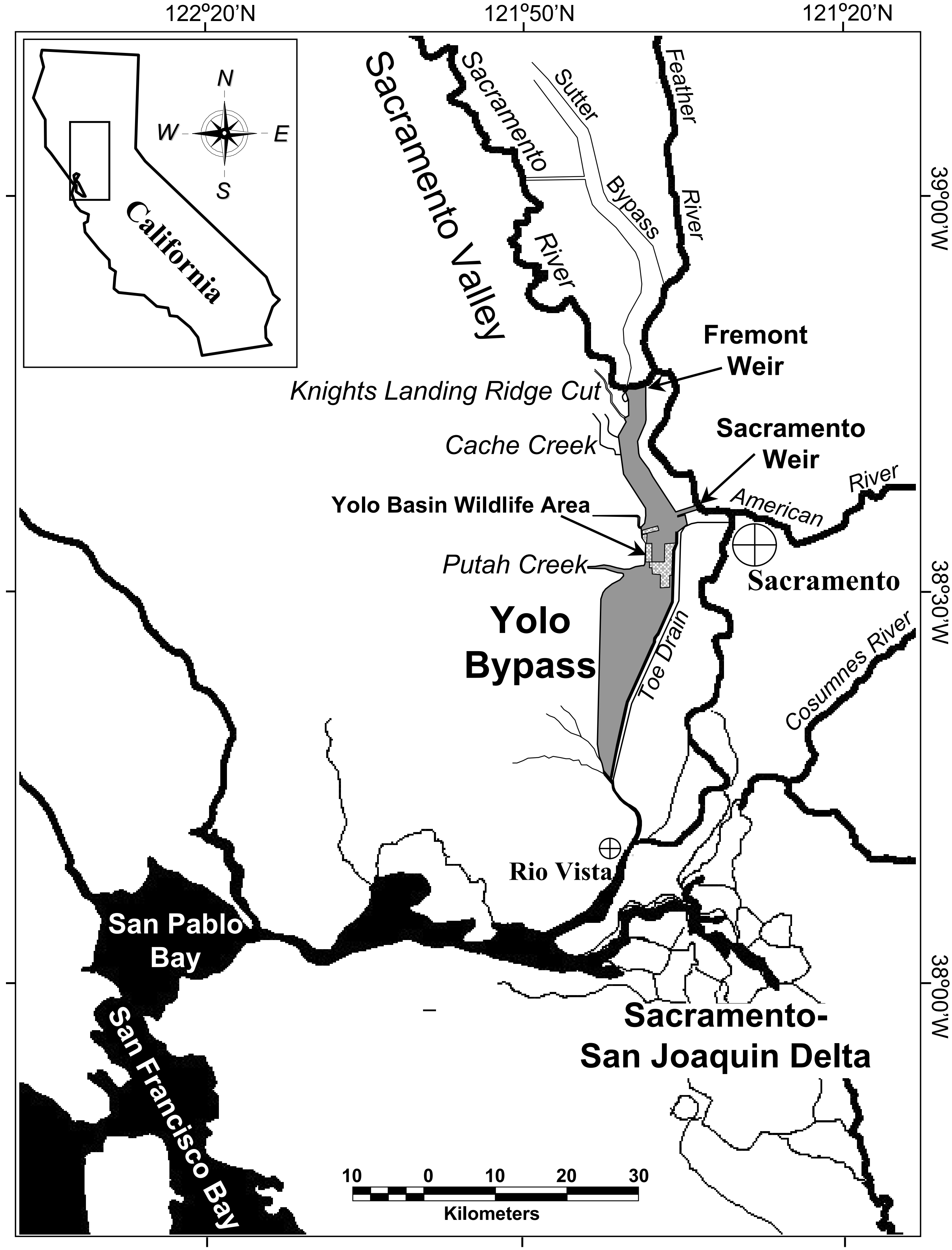
Native species		Introduced species	
Chinook Salmon	*Onchorhynchus tschawytscha*	American shad	*Alosa sapidissima*
Fall-run		Threadfin shad	*Dorosoma petenense*
Spring-run (ST)		Common carp	*Cyprinus carpio*
Winter-run (FE,SE)		Goldfish	*Carassius auratus*
		Fathead minnow	*Pimephales promelas*
Steelhead trout (FT)	*Oncorhyncus mykiss*	Golden shiner	*Notemigonus crysoleucas*
Pacific lamprey	*Lampetra tridentata*	Red shiner	*Cyprinella lutrensis*
River lamprey	*Lampetra ayresi*	Channel catfish	*Ictalurus punctatus*
Hitch	*Lavinia exilicauda*	White catfish	*Ameiurus catus*
Sacramento blackfish	*Orthodon microlepidotus*	Black bullhead	*Ameiurus melas*
Sacramento pikeminnow	*Ptychocheilus grandis*	Brown bullhead	*Ameiurus nebulosus*
Sacramento sucker	*Catostomus occidentalis*	Wakasagi (pond smelt)	*Hypomesus nipponensis*
Splittail (FT)	*Pogonichthys macrolepidotus*	Inland silverside	*Menidia beryllina*
Prickly sculpin	*Cottus asper*	Western mosquitofish	*Gambusia affinis*

Pacific staghorn sculpin	*Leptocottus armatus*	Bluegill	*Lepomis macrochirus*
Threespine stickleback	*Gasterosteus aculeatus*	Redear sunfish	*Lepomis microlophus*
Tule perch	*Hysterocarpus traski*	Green sunfish	*Lepomis cyanellis*
Delta smelt (FT,ST)	*Hypomesus transpacificus*	Warmouth	*Lepomis gullosus*
White sturgeon	*Acipenser transmontanus*	Black crappie	*Pomoxis nigromaculatus*
		White crappie	*Pomoxis annularis*
		Bigscale logperch	*Percina macrolepida*
		Largemouth bass	*Micropterus salmoides*
		Smallmouth bass	*Micropterus dolomieu*
		Spotted bass	*Micropterus punctatus*
		Striped bass	*Morone saxatilis*
		Shimofuri goby	*Tridentiger bifasciatus*
		Yellowfin goby	*Acanthogobius flavimanus*

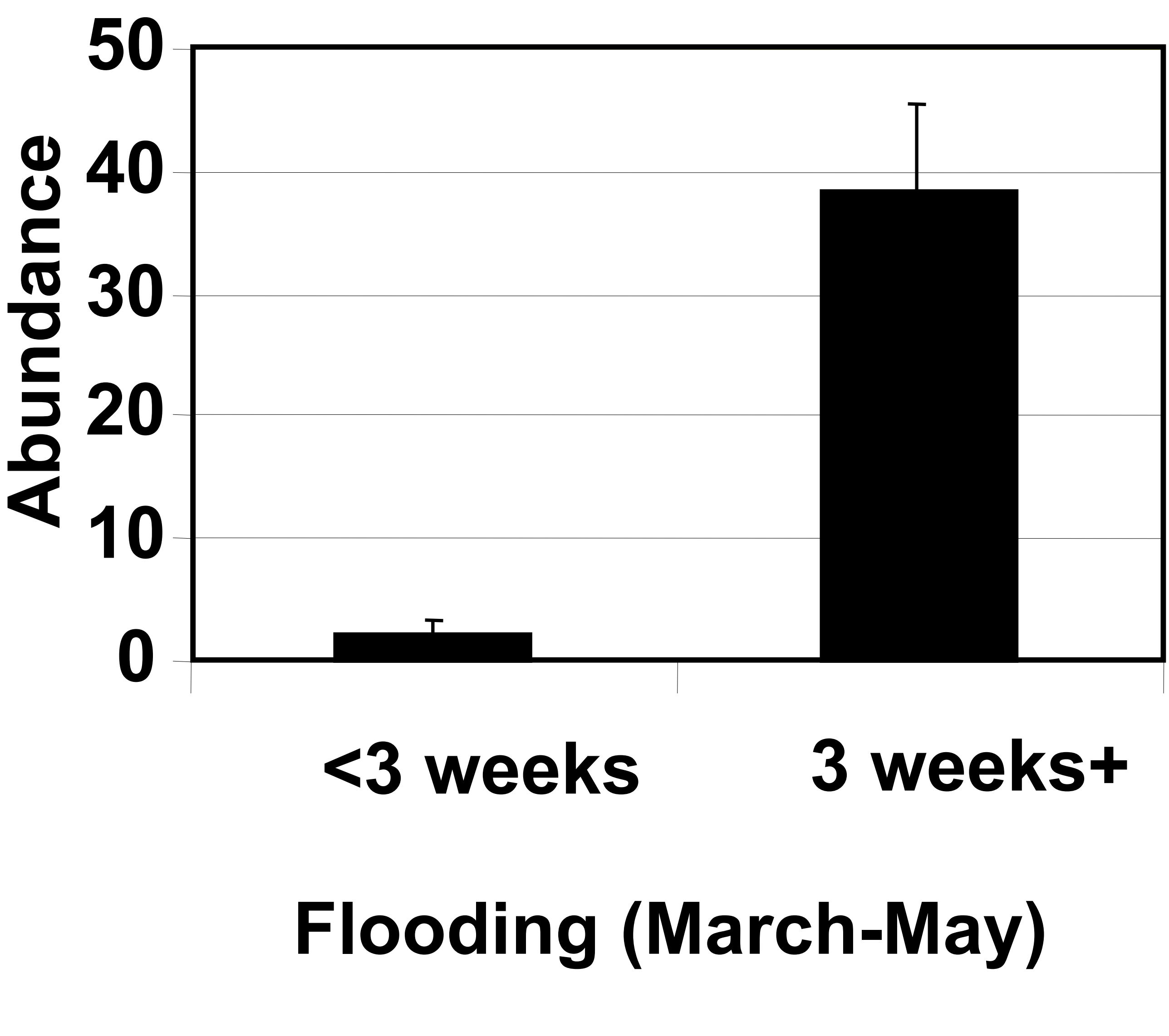
FIGURES

Figure 1: Location of Yolo Bypass relative to the Central Valley, the San Francisco estuary and its tributaries.

Figure 2: Mean year class strength of splittail in years when Yolo Bypass is inundated for less than three weeks during March-April and in years when the floodplain is inundated for more than three weeks. The standard errors are also shown. Abundance data are based on Sommer et al. (1997) from the fall midwater trawl survey for 1975-1998.



122°20'N
121°50'N
121°20'N
39°00'W
38°30'W
38°00'W
N
W
E
S
California
Sacramento Valley
Sacramento
Sutter
Feather
Sacramento
Bypass
River
River
River
Fremont
Weir
Knights Landing Ridge Cut
Cache Creek
Sacramento
Weir
River
American
Yolo Basin Wildlife Area
Putah Creek
Sacramento
Yolo
Bypass
Toe Drain
Cosumnes River
Rio Vista
San Pablo
Bay
Sacramento-
San Joaquin Delta
San Francisco Bay
10
0
10
20
30
Kilometers



50
40
30
20
10
0
Abundance
<3 weeks
3 weeks+
Flooding (March-May)

EFFECTS OF LANDSCAPE-LEVEL HYDROLOGIC VARIATION ON THE BIOTA OF RIVER CHANNEL AND FLOODPLAIN HABITATS

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Abstract. Despite progress in the development of conceptual models of river processes, the validation and application of these models to resources management may be limited by a deficit of tools for intermediate-scale (10 – 100 km) landscapes. Here, we developed a landscape-level hydrologic model to examine the effect of variation in flow on the responses of several trophic levels in a large temperate river (Sacramento River) and its seasonal floodplain (Yolo Bypass). Field data and hydrologic simulations were evaluated for three years: 1998, an extremely wet year; 2000, a moderately wet year; and 2001, a dry year. Chlorophyll *a* production was significantly higher in the floodplain than in the river for all years, consistent with longer hydraulic residence times, increased surface area of shallow water, and warmer temperatures in the floodplain. Trends in abundance of copepods and cladocerans suggested a negative effect of flow in both the river and its floodplain, attributable to low hydraulic residence times. During the two wet years, Diptera, other aquatic invertebrates, and terrestrial invertebrates in drift samples were generally more abundant on the floodplain than the river. Trends at each location generally tracked flow, probably because of variation in flooded surface area. Abundance of juvenile Chinook salmon was significantly higher in all years in the river than the floodplain because the river channel has less surface area for rearing and more salmon. During 1998 and 2000, hatchery and wild juvenile salmon grew significantly faster in the floodplain than the river, consistent with increased rearing area, warmer temperatures and higher prey availability in the floodplain. These results support the predictions of the flood pulse concept (Junk et al. 1989), and suggest that even modest improvements in river-floodplain connectivity could enhance nursery habitat for salmon and food web support to the system.

INTRODUCTION

The river continuum concept remains the foundation for much of our current understanding about river and stream structure and function (Vannote et al. 1980). This theoretical construct views river and streams as trophic gradients where processes are determined by longitudinal position along the channels. Several complementary models have been identified including serial discontinuity (Ward and Stanford 1995), the flood pulse concept (Junk et al. 1989) and the hyporheic corridor concept (Stanford and Ward 1988). Fausch et al. (2002) recently argued that the application of these models to river management has not yet been very successful because there has been insufficient work at scales appropriate for major management decisions. They note that most field studies are conducted at either very small scales (<10 km reaches) or at watershed scales (> 100 km reaches), whereas intermediate scales (10 – 100 km reaches) are frequently more relevant for resource management. A major challenge is that relatively few tools have been developed to analyze rivers at intermediate scales. Instream Flow Incremental Methodology, (IFIM) particularly the model PHABSIM, remains the most widely used approach to set flow criteria for streams and rivers (Reiser et al. 1989). But IFIM and PHABSIM continue to be criticized because of concerns about model accuracy, assumptions, and ecological relevance (Marthur et al. 1985; Castleberry et al. 1996). In the near future, new tools may be developed by landscape ecologists, who have successfully used methods such as patch dynamics and spatial ecology for resource management applications (Turner 1989; Hanson et al. 1993; Lomolino 1994). However, river-floodplain systems are one of the most dynamic environments on Earth, creating special challenges for ecologists with both variability and scale. For example, the hydrologic regime is the primary factor determining the structure and function of river-floodplain systems (Junk et al. 1989), yet detailed descriptions of basic characteristics such as surface area, depth, residence time, and velocity are lacking at ecologically relevant temporal and spatial scales. Moreover, ecological studies measuring the concurrent responses of multiple trophic levels in river and floodplain habitat are rare. In the absence of high resolution data on both hydrologic and biological processes, modeling studies of large river-food web dynamics (e.g. Power et al. 1995) have relied instead upon generalized hydrologic patterns. Results from such modeling efforts are congruent with empirical data showing that flood pulses in large rivers enhance production of invertebrates and fish (Welcomme 1979; Junk et al. 1989; Gutreuter et al. 2000).

To help address gaps in our knowledge about the functioning of rivers at intermediate scales, we applied a landscape-level hydrologic model to examine how variation in hydrology affects several trophic levels in a 60 km reach of a large temperate river-floodplain. We focused on two components of the upper San Francisco Estuary: 1) the lower Sacramento River; and 2) the Yolo Bypass, the primary floodplain of the Sacramento River (Figure 1). Although the Sacramento River and Yolo Bypass are highly altered, this river-floodplain system had several advantages for our evaluation. The Sacramento River channel is physically separated from its primary floodplain by a levee, allowing a well-defined comparison of their aquatic ecology. In addition, we had several years of concurrent ecological data on fish, invertebrates and phytoplankton (Sommer et al. 2001a). We also had sufficient monitoring data on the topography and hydrology of the river and floodplain to simulate physical descriptions on daily time scales. Finally, the region is the focus of a major habitat restoration effort in response to declines in abundance of many estuarine and riverine populations (CALFED 2000). Primary productivity is low relative to that in similar temperate estuaries and has undergone a long-term decline (Jassby et al. 2002). Populations of many consumers such as zooplankton and macroinvertebrates have declined substantially (Kimmerer and Orsi 1996; Orsi and Mecum 1996). Moreover, several native fish species show marked population decreases (Bennett and Moyle 1996), leading to the listing under the Federal Endangered Species Act of two races of Chinook salmon (*Onchyrhynchus tshawytscha*), delta smelt (*Hypomesus transpacificus)* and splittail (*Pogonichthys macrolepidotus*). Many of these organisms are more abundant in high flow years (Jassby et al. 1995), when floodplain is inundated. Thus, landscape-scale data on the responses of aquatic biota in river and floodplain habitat are relevant for resource management. Our hypotheses were that: 1) each trophic level will show strong responses to landscape level hydrologic factors such as surface area, residence time and velocity; and 2) the responses will differ substantially between river and floodplain habitat. Our basic approach was to use landscape level hydrologic modeling to help us interpret biological data collected in each study area.

STUDY SITE

The Sacramento River is the largest tributary to the San Francisco Estuary and its two component regions, the Sacramento-San Joaquin Delta and downstream brackish bays (Figure 1). This highly regulated river has a mean annual discharge of about 800

m^3/sec from a watershed of 70,000 km^2. In about 60 percent of years, the total Sacramento Valley flow exceeds 2,000 m^3/sec during winter or spring, then spills into the Yolo Bypass, a 24,000 ha floodplain (Sommer et al. 2001a). For most of the past two decades, the major land use on this 61 km long, partially-leveed floodplain was agriculture. As a result of recent restoration and land acquisition activities, the majority of the floodplain is now managed for wildlife in "natural" habitats including riparian and upland areas, emergent marsh and permanent ponds. Yolo Bypass also has a perennial channel along its eastern edge that is tidally influenced during low flow periods, and drains the floodplain after high flow events. Like many other large rivers in the Northern Hemisphere, the Sacramento River channel has been heavily altered by flood control and reclamation activities. The reach adjacent to Yolo Bypass has steep, rock-covered banks with a narrow riparian corridor, and minimal emergent vegetation; the lower half of this reach is a tidal freshwater channel. Outflow from the Yolo Bypass and Sacramento River rejoin at Rio Vista, then the combined discharge enters the brackish regions of the downstream Estuary.

METHODS

Physical Modeling

Because of the difficulty in directly measuring variables such as water velocity, depth and surface area in large river-floodplain systems, we used a hydrologic model to simulate daily trends in several physical variables at the landscape-scale. The model treated each of the two study areas as "reservoirs" described by 1) basin geometry; and 2) flow and stage time series. The Yolo Bypass floodplain geometry was developed from

200 cross-sections collected at 300 m intervals by the U.S. Army Corps of Engineers. Sacramento River geometry was taken from 75 cross-sections along the reach adjacent to Yolo Bypass (U.S. Geological Survey, unpublished data). We obtained mean daily stage and flow data from five gauging stations in Yolo Bypass and four stations in the Sacramento River (USGS, California Department of Water Resources). For each date in the time series, the model used linear interpolation between the gauging stations to estimate the stage at each cross-section. The estimated stage value was then used to calculate each cross-section's conveyance characteristics: area, width, and wetted perimeter. The daily results for each cross-section were used to estimate total inundated surface area, mean velocity and hydraulic residence time for each study area (reach). We also calculated the total surface area < 2 m depth as an index of shallow water habitat. Our selection of the <2 m depth index was somewhat arbitrary as there are multiple definitions of "shallow water"; however, the 2 m threshold has some biological relevance as it is an accepted criteria defining wetland littoral zones (Cowardin et al. 1979). It is also important to note that the velocity and hydraulic residence time calculation represent idealized rather than actual values. Our hydrologic model relied on a simple mass balance approach that did not account for daily tidal effects (i.e. "routing"), a particularly important factor during low flow conditions. To highlight this limitation, we will refer to these variables as *idealized hydraulic residence time* and *idealized mean velocity*. Nonetheless, we believe that the model provided a useful index of relative differences between the study areas. We measured mean daily water temperature from temperature recorders (Onset Corporation) placed in the Sacramento River and the perennial tidal channel of Yolo Bypass (Sommer et al. 2001b).

The large scale of the landscape made it too difficult to validate all of the simulated variables. As a partial validation of the model, we estimated total inundated area for Yolo Bypass using 1:24,000 scale area aerial photographs for three days (March 2, 1998; April 28, 1998; and February 28, 2001). We took aerial photographs of the entire floodplain, digitized, then georeferenced to satellite imagery. We delineated inundated area for each set of images using a GIS program (ARCVIEW), then compared total area to model estimates for the same dates.

Biological data

We compared the responses of three trophic levels for Sacramento River and the Yolo Bypass: primary producers (phytoplankton), primary consumers (zooplankton and drift invertebrates) and secondary consumers (fish). Our sampling was not intended as a comprehensive evaluation of the spatial and temporal variation of each organism. Rather, our data collection was designed to identify the major differences and trends in abundance, concentration or growth between the two study areas.

We measured phytoplankton biomass as chlorophyll *a* in discrete water samples collected weekly in Yolo Bypass and the adjacent Sacramento River according to procedures described in Mueller-Solger et al. (In press). We also collected weekly drift samples using nets at fixed stations on the Yolo Bypass and the Sacramento River (Sommer et al. 2001b). The nets (0.46 m x 0.3 m mouth, 0.91 m length and 500 µm mesh) were fished for approximately 30 minutes during mid-morning. We estimated sample volume using a flowmeter (General Oceanics Model 2030R) and net dimensions. Our drift samples were stored in ethanol or formaldehyde, then identified to family or order using a dissecting microscope. We collected zooplankton samples using different methods in 1998 than in following years. In 1998, we collected zooplankton in the Yolo Bypass at two fixed stations with battery-operated rotary vane pumps with a mean flow rate of 17 L/min. The samples were taken via pipes with outlets at multiple locations beneath the water surface. Discharge was directed into a 150 µm mesh net held in a basin on the bank. We recorded flow rate at the beginning and end of the sample period, which varied from one to six hours. We took few samples in the Sacramento River during the comparable period in 1998. For 2000 and 2001, we took zooplankton samples with a Clarke-Bumpus net (0.13 m diameter, 0.76 m length, 160 µm mesh) placed into surface flow in the Yolo Bypass and Sacramento River. Sample volume was recorded as for drift net. We concentrated the samples, stored them in 5% formalin, and later counted and identified the zooplankton to genus and using a dissecting microscope.

To assess the response of secondary consumers to river and floodplain habitat, we sampled juvenile Chinook salmon, the most abundant native fish species during winter and spring, The Sacramento Valley is unique in having four races of Chinook salmon: winter, spring, late-fall and fall-run (Yoshiyama et al. 2000). Our data collection focused on the fall-run, the numerically dominant race in the Sacramento Valley. The typical life history pattern is for young fall-run to migrate from the tribuaries during winter and spring to the estuary at a size of approximately 35-70 mm fork length (FL). We calculated salmon density for weekly beach seine (15 m nets with 4.75 mm mesh) samples at five core regions in the Yolo Bypass and four stations in the adjacent reach of the Sacramento River (Sommer et al. 2001b). In more than half of the study period, the data set did not include all of the core stations, so we used the mean of the available sites to calculate abundance. We compared the fork lengths of these young salmon for Yolo Bypass and Sacramento River to detect whether there were major differences in growth between the two locations. In addition, we assessed growth by doing paired releases of coded-wire-tagged (CWT) juvenile salmon in the Yolo Bypass and Sacramento River. This approach allowed growth comparisons on fish of a similar origin; the growth of wild fish is difficult to evaluate because multiple races of Chinook salmon migrate through this region (Yoshiyama et al. 2000). The tagged salmon were produced and tagged at the Feather River Fish Hatchery and released in February or early March of each year in lots of 50,000 – 100,000 fish (Sommer et al. 2001b). Over the next few months, the tagged fish were recovered and measured (mm FL) at the beach seine stations, and downstream trawls.

Statistical analyses

We used paired t-tests to compare biomass (chlorophyll *a*) or abundance (zooplankton, drift invertebrates, and wild salmon) in Yolo Bypass and Sacramento River. We compared sizes of salmon in Yolo Bypass and Sacramento River using a generalized linear model (GLM) with an appropriate variance function for each equation (Venables and Ripley 1997). We chose not do statistical analyses on the effect of the measured and simulated hydrologic variables on the different organisms because all of the hydrologic variables were highly autocorrelated. In addition, we had insufficient biological data for adequate time series analysis.

RESULTS

Physical habitat

As is typical for rivers in the western United States, flow conditions varied substantially among years (Figure 2a). Total flow was higher in the Sacramento River than the Yolo Bypass throughout the study except during winter 1998, when El Niño conditions in the Pacific Ocean resulted in a major flood event. In 2000 the hydrology was moderately wet, resulting in a typical winter flow pulse. In each of these years, flooding of the Yolo Bypass began when flow in the adjacent Sacramento River exceeded about 1,500 m^3/s. In 2001, a dry year, peak Sacramento River flows were insufficient to inundate the floodplain; all of the observed flooding originated from small streams entering the Yolo Bypass from the west. Water temperature increased gradually throughout each of the study years (Figure 2f). The Sacramento River and Yolo Bypass temperatures closely tracked one another, although the floodplain was warmer in each year.

Peak inundation of Yolo Bypass occurred during February 1998, when the total simulated surface area of 23,500 ha was close to our 24,000 ha estimate of basin surface area from aerial photographs (Figure 2b). The model and aerial photograph estimates (21,000 ha) were equivalent for March 2, 1998. The model was somewhat less accurate for April 28, 1998, when the simulated area of 6,750 was higher than the 5,050 ha calculated from aerial photographs, and for February 28, 2001, when the simulated area of 10,200 ha was higher than the 7,820 ha from aerial photographs. During 1998 and high flow pulses in 2000 and 2001, the total inundated surface area of Yolo Bypass exceeded that of the Sacramento River. Surface area in the Yolo Bypass closely followed the flow peaks, with successively smaller amounts of inundated area for each of the study years. By contrast, the total surface area in the Sacramento River varied little among months and years. This was also true for our index of shallow water habitat, the estimated total surface area < 2 m depth, which remained at a level of less than 500 ha throughout the study (Figure 2c). The total surface area < 2 m was generally an order of magnitude higher in Yolo Bypass than Sacramento River during the flood events. Even modest flow events such as February and March of 2001 resulted in peak inundation of over 10,000 ha of area < 2 m in Yolo Bypass. Unlike total surface area, the total surface area < 2 m showed a plateau at approximately 12,000 ha. For example, the extreme flood event in January and February 1998 had less total surface area < 2 m depth than the following month due to high water levels during the peak flood period. The total area < 2 m comprised 7 - 17 % of the total surface area of the Sacramento River, whereas this shallow area comprised 50-100 % of the total surface area in Yolo Bypass except during the February 1998 flood peak (Figure 2b,c).

Simulations of idealized mean water velocity tracked flow trends at each location; however, the estimates were at least 2 –3 times greater in the Sacramento River than the Yolo Bypass in all years except 2001 (Figure 2d). Idealized mean velocity in Yolo Bypass was actually highest in winter and spring of 2001, the driest water year, when all of the Yolo Bypass flow was confined to the perennial Toe Drain channel except for a short February-March pulse.

Idealized hydraulic residence time showed very little variation in the simulations for Sacramento River, remaining less than 5 days in all years (Figure 2e). In each year there were gradual seasonal increases; shortest residence times were found for 1998 (range = 1-2 days), the wettest year, and the longest residence times were during 2001 (range = 2-5 days), the driest study year. Idealized hydraulic residence times were much more complex for Yolo Bypass, and substantially longer than in the Sacramento River during all months except part of 2001. The high variability during late winter and spring of 2000 and 2001 corresponded to spring-neap tidal cycles.

Biological resources

Chlorophyll *a* levels were significantly higher in the Yolo Bypass than in the Sacramento River (Figure 3b, Table 1). At each location the levels were lowest during mid-winter, when flow was highest. The sharpest increases in floodplain chlorophyll *a* occurred during descending hydrographs (Figure 3a,b). Zooplankton in our study were dominated by copepods and cladocera. The most common genera of Cladocera were *Bosmina* and *Daphnia*. *Acanthocyclops* was the most common copepod, but substantial numbers of calanoid and harpactacoid copepods were frequently present. There was no significant difference in the abundance of cladocerans or copepods between Yolo Bypass and Sacramento River (Figure 3c,d; Table 1). The trends in Yolo Bypass and Sacramento

River zooplankton abundance appeared to be inverse to flow, although the winter 2001 flow pulse in Yolo Bypass did not result in a detectable decrease in cladocera.

The most abundant groups of organisms captured in drift samples were aquatic Diptera, mainly chironomids (Figure 4b). Diptera were more abundant in the Yolo Bypass than the Sacramento River in 1998 and the high flow period of 2000, but not 2001. The differences for entire years were statistically significant for 1998 only (Table 1). Yolo Bypass dipterans reached their highest abundance during flood events in the two wet years. There was also a variety of other aquatic species in the drift, with Naididae and Enchytraeidae (oligochaete worms), Physidae (snails), and Hydridae (cnidarians) as the most common families observed each year. As with diptera, these aquatic species were generally more abundant in the Yolo Bypass than the Sacramento River during the two wet years, but not during 2001 (Figure 4c). However, the differences were not statistically significant for any of the years (Table 1). Their trends in Sacramento River and Yolo Bypass suggested a positive effect of flow in each year (Figure 4a,c). Six taxonomic orders (Homoptera, Araneida, Hymenoptera, Collembola, Hemiptera, Coleoptera) comprised over 90 percent of the total catch of terrestrial invertebrates in drift samples. Terrestrial invertebrates were scarce in Sacramento River in each of the years, with higher levels in Yolo Bypass during most sampling dates (Figure 4d). Although these differences were substantial, the comparisons were not statistically significant (Table 1), presumably as a result of the small sample size. Trends of terrestrial invertebrates in the Yolo Bypass and the Sacramento River suggested a positive response to flow during 1998 and 2000.

In each year, juvenile salmon abundance showed a seasonal trend at both river channel and floodplain locations, with peak abundance during winter, followed by a gradual decline in spring (Figure 5b). Abundance was also related to hydrology (Figure 5b,c). Yolo Bypass had decreasing abundance of salmon across the progressively drier water years and Sacramento River had the lowest abundance of salmon in 2001, the driest year. Abundance in the Yolo Bypass was usually at least an order of magnitude lower than in the Sacramento River, and the differences were statistically significant (Table 1). In 1998 the size of tagged salmon increased significantly faster in the Yolo Bypass than in the Sacramento River (Figure 5c; Table 2). Unfortunately, there were no recoveries of either Sacramento River tagged salmon after early March 2000 or Yolo Bypass tagged salmon during all of 2001, it was not possible to compare size trends in the two study areas in those years. The mean sizes of wild juvenile Chinook salmon increased significantly faster in the Yolo Bypass than in the Sacramento River in 1998 and 2000 (Figure 5d; Table 2). As a result of dry conditions, there were insufficient numbers of wild salmon collected in Yolo Bypass during 2001 to assess growth trends.

DISCUSSION

Based largely on data from relatively undisturbed tropical river-floodplain systems, Junk et al (1989) proposed the flood pulse concept, which predicts that much of the productivity of large rivers originates from energy sources on the floodplain. Bayley (1991) has argued that concept should apply to large, regulated rivers in temperate regions; however, Thorpe et al. (1998) found little evidence that terrestrial inputs from a floodplain provided the basis for the structure of the food web of the Ohio River. While our study does not resolve the issue of the origins of carbon in the food webs of large rivers, our results for the Yolo Bypass at least support the predictions of the flood pulse concept (Junk et al. 1989) that floodplain habitat enhances the production of several trophic levels. Moreover, the landscape-level hydrologic modeling suggests reasonable mechanisms to explain these responses.

Several factors including hydraulic residence time, temperature, light, nutrient availability, and grazing pressure may have been responsible for higher primary production (chlorophyll *a*) on the floodplain than the river. We did not collect data on grazing rates of secondary consumers, but our zooplankton data suggest that there was relatively little difference between the populations in the river and its floodplain. We cannot rule out the potential effect of greater benthic grazing by the clam *Corbicula* in the river channel, an organism that may have played a role in the long term decline in primary production in the delta (Jassby et al. 2002). We also did not analyze nutrient levels, but nutrients appear to only rarely be a limiting factor in the San Francisco Estuary because of the overriding effect of nutrient enrichment from irrigation tailwaters and sewage treatment plants, and light limitation due to high suspended sediment concentrations (Jassby et al. 2002). Based on our simulations of the amount of total area < 2 m, phytoplankton in the floodplain experienced substantially shallower depths, increasing light availability. Shallower depths are likely the primary reason for significantly higher water temperatures on the floodplain than the river channel, an additional factor that can enhance phytoplankton production (Montagnes and Franklin

2001). Moreover, longer hydraulic residence times in Yolo Bypass than Sacramento River suggest that the floodplain provided more opportunities for biomass accumulation than the river channel. Our empirical results on chlorophyll *a* are consistent with the modeling analysis by Jassby and Cloern (2000), who predicted that the Yolo Bypass floodplain should enhance production of phytoplankton, and that this material is a net source of carbon to downstream regions of the San Francisco Estuary. Our observation that chlorophyll *a* appeared to be inversely related to flow (i.e. positively related to hydraulic residence time) is similar to results from several other floodplain studies that found higher levels of phytoplankton during low flow periods (Lewis, 1988; Garcia de Emiliani 1997; Heiler et al. 1995; Hein et al., 1999).

In contrast to chlorophyll *a*, there were no major differences in zooplankton abundance between the river and its floodplain. Zooplankton abundance trends are probably best explained in terms of population processes (e.g. grazing rates, food availability, temperature) and advective losses (Ketchum 1954). Of the two, we did not find strong evidence that population processes were responsible for the observed trends. While we did not measure grazing rates by zooplanktivorous fish, our sampling data suggest that grazing may not have been a major factor. Juvenile salmon (Figure 5b) and other zooplanktivorous fish (Sommer, unpublished data) were generally at less abundant in floodplain samples, especially during high flow periods, yet there were no detectable differences in zooplankton abundance between the two study areas. Similarly, our results for chlorophyll *a* and temperature suggest that there should have been more food and slightly higher water temperatures in the floodplain than in the river channel, both of which would have been favorable to zooplankton. Laboratory studies by Mueller-Solger et al. (In press) indicate that increased chlorophyll *a* concentration results in faster cladoceran growth rates in Yolo Bypass than in the Sacramento River. The fact that there was no detectable difference in zooplankton abundance between the two locations suggests that food availability and water temperature were not the major factors controlling zooplankton abundance. Given the apparent inverse relationship between abundance and flow (which controls residence time), we believe that advective processes (i.e. hydraulic residence time) probably had a more important effect. Seasonal variation in zooplankton abundance and differences in abundance among a wide range of habitats vary in a manner consistent with differences in hydraulic residence time (Pace et al. 1992). Relatively few data on zooplankton trends are available from river-floodplain systems; however, other floodplain studies have found similar negative effects of flow, with no detectable difference in zooplankton abundance between main channel and off-channel habitats (Speas 2000).

The most likely factors responsible for the higher abundance of in diptera and other aquatic invertebrates during the two wet years are food availability, habitat availability, water temperature and grazing rates. As discussed above, the Yolo Bypass had increased phytoplankton biomass, increased surface area during high flow (particularly shallow water habitat) and warmer water than the Sacramento River. The lower abundance of salmon in the Yolo Bypass indicates that predation rates on invertebrates may also be lower. Fish are well known to structure invertebrate communities in some habitats (Batzer and Resh 1992); predation rates are often lower in frequently disturbed habitats such as floodplain (Corti et al. 1997). However, the fact that all the drift invertebrate groups showed a positive flow response in both locations suggests that abiotic factors such as inundation area had a stronger effect than predation on invertebrate abundance. The most abundant aquatic macroinvertebrates included chironmomids, oligochaetes and mollusks, which show a strong association with substrate (Smith 2001). The increased abundance of invertebrates during high-flow periods may have been due either to increased substrate area or to higher velocities which made the invertebrates more vulnerable to our sampling gear. Yolo Bypass probably had higher abundance of terrestrial invertebrates during flood events because the floodplain had much more inundated terrestrial habitat than the Sacramento River. Somewhat paradoxically, terrestrial invertebrates were relatively abundant in Yolo Bypass during low flow periods, when flow was confined to the perennial tidal channel of the floodplain. One possible explanation for this pattern is that hydraulic residence time has a similar effect on terrestrial invertebrates as on aquatic invertebrates. The perennial channels of both locations have similar levels of terrestial vegetation along their immediate margins, but the floodplain has substantially longer hydraulic residence times, perhaps reducing advective losses of terrestrial invertebrates. Several other studies have shown that hydroperiod affects invertebrate communities of river-floodplain landscapes (Uetz et a. 1979; Castella et al. 1991; Corti et al. 1997; Braccia and Batzer 2001). Exceptional production of drift invertebrates on floodplain habitats has also been reported by Gladden and Smock (1990).

The observation of significantly higher juvenile salmon abundance in the Sacramento River than the Yolo Bypass is difficult to interpret because of potential interactions between population size and habitat availability. River-floodplain connectivity was intermittent during each sampling year, so young salmon did not have continuous access to Yolo Bypass. In 2000 and 2001, intermittent connectivity may have resulted in a lower effective population size in Yolo Bypass, thereby contributing to reduced density. However, river-floodplain connectivity was quite good during winter 1998, when there was often more flow in Yolo Bypass than the Sacramento River. Salmon abundance was substantially lower during this and all other periods, suggesting that habitat availability was also a major factor. Young salmon fry typically prefer to rear in low velocity, shallow water habitat (Everest and Chapman 1972). Our results indicate that Yolo Bypass had dramatically more shallow water habitat and lower water velocities than the Sacramento River; hence, Sacramento River abundance may have been consistently lower than Yolo Bypass because fish were more concentrated in the relatively small amount of suitable rearing habitat.

Faster growth of wild and tagged salmon in Yolo Bypass than Sacramento River was primarily due to increased water temperature and prey availability on the floodplain (Sommer et al. 2001b). Diptera, the major salmon prey type identified by Sommer et al. (2001b), were significantly more abundant in Yolo Bypass than Sacramento River in both the wet years. The other macroinvertebrate prey groups (aquatic and terrestrial invertebrates) showed a similar trend. The lower abundance of fish in the Yolo Bypass than the Sacramento River could potentially have contributed to faster salmon growth rates on the floodplain if density dependent effects limit juvenile salmon. Gutreuter et al. (2000) found similar enhancements in fish growth from floodplain inundation in the Upper Mississippi River, another large, regulated river.

We believe that this study may have important applications for resource management and restoration. Our data show that multiple trophic levels simultaneously responded to floodplain inundation at relatively rapid time scales (i.e. <60 d). Enhancement of lower trophic levels through floodplain restoration would clearly benefit species that reside in the floodplain or migrate through seasonally. It is likely that substantial production is exported to downstream estuarine habitat, where high quality carbon is in short supply (Jassby and Cloern 2000). Allochthonous inputs across landscapes have been found to be an important subsidy to both aquatic and terrestrial food webs (Polis and Hurd 1996). While we saw major improvements in the density or growth of aquatic biota in years with extensive floodplain inundation, there is poor river-floodplain connectivity in dry years such as 2001. In these drier years, migratory fish do not have access to the seasonal habitat and there is little opportunity for primary or secondary production to subsidize the downstream reaches of the estuary. Our results are therefore consistent with observations that some of the most serious declines in resources of the estuary have been observed during critically dry years (Bennett and Moyle 1996), and that the abundance of many organisms shows a positive relationship with flow (Jassby et al. 1995). As a consequence, we predict that even modest improvements in river-floodplain connectivity could enhance nursery habitat for Chinook salmon and provide food web support to the estuary.

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Table 1: Results of paired t-tests comparing biomass (chlorophyll *a*) or abundance (all other organisms) for biota in the Yolo Bypass and Sacramento River for each year. The P values are shown along with the t-statistics and degrees of freedom in parentheses.

Organism	1998	2000	2001
Chlorophyll a	N/A	0.014 (2.85, 13)	<<0.001 (5.1, 17)
Cladocera	N/A	0.22 (1.4, 5)	0.86 (0.19, 7)
Copepods	N/A	0.17 (1.6, 6)	0.24 (1.29, 7)
Diptera	0.01 (3.5, 6)	0.31 (1.1, 5)	0.12 (1.8, 6)
Other Aquatic Invertebrates	0.22 (1.4, 6)	0.34 (1.1, 5)	0.53 (0.67, 6)
Terrestrial Invertebrates	0.06 (2.3, 6)	0.33 (1.1, 5)	0.26 (1.2, 6)
Salmon	<<0.001 (-5.0, 17)	0.13 (-3.1, 9)	N/A

Table 2: GLM statistics for salmon fork lengths for Yolo Bypass and Sacramento River. The CWT results are based on an ANCOVA model, and the wild salmon results used a variance function that increased with the mean squared. The parameters were all significant from zero ($p < 0.0001$).

	CWT	Wild Fish	
	1998	1998	2000
	Parameter ± 95% CL	Parameter ± 95% CL	Parameter ± 95% CL
Intercept	-8625 ± 510	-4061 ± 237	-4088 ± 298
Location	-1855 ± 510	-1437 ± 237	-1310 ± 298
Day	0.6 ± 0.04	0.29 ± 0.02	27.8 ± 0.02
Location:day	-0.13 ± 0.04	-0.10 ± 0.02	0.09 ± 0.02

Figure Legends

Figure 1. Location of Yolo Bypass in relation to the San Francisco Estuary and its tributaries. The San Francisco Estuary represents the region from San Francisco Bay upstream to Sacramento.

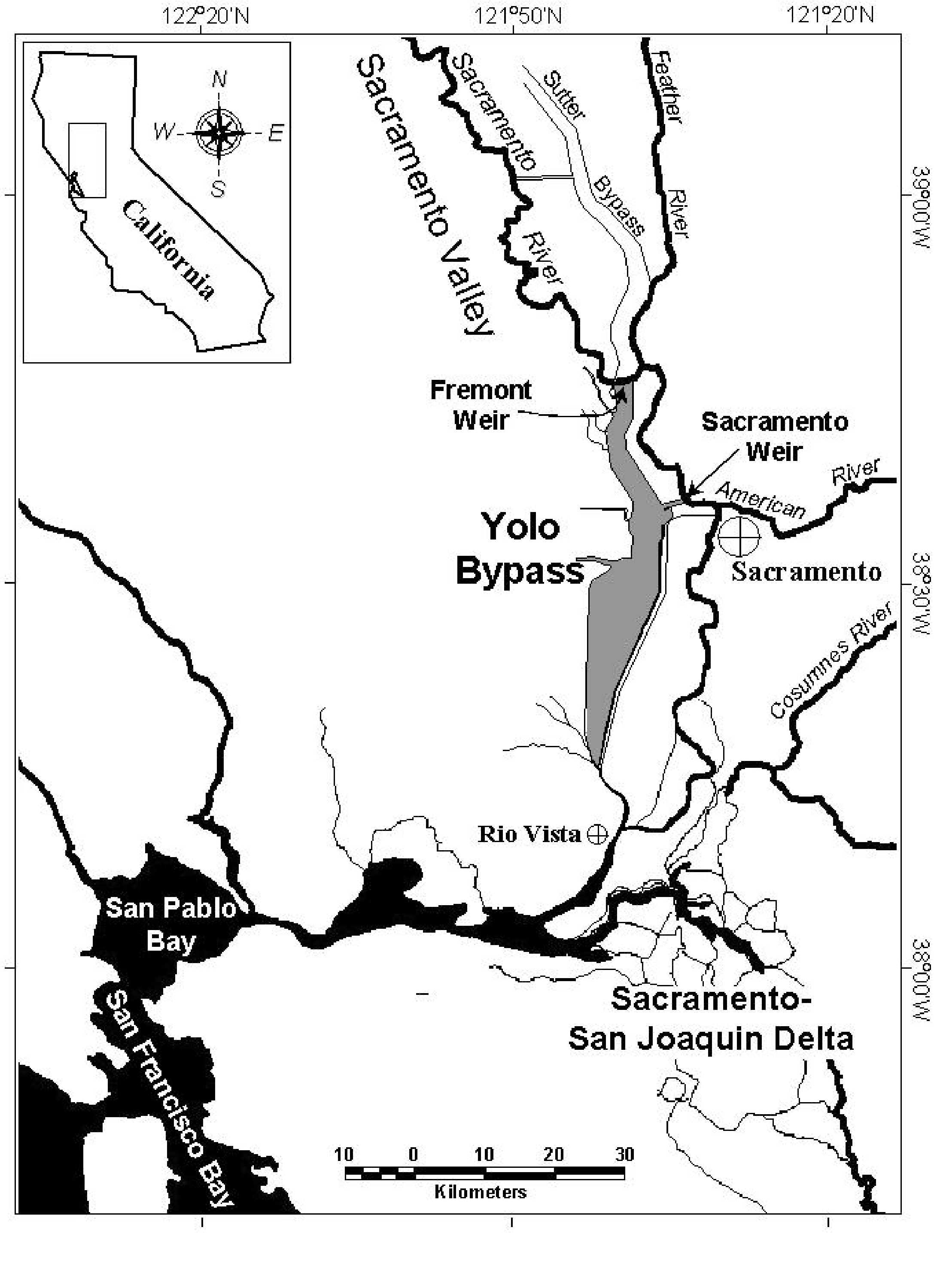
Figure 2. Results of hydrologic simulations and water temperature for the Yolo Bypass (thick line) and Sacramento River (thin line) during winter and spring of 1998, 2000 and 2001. (a) Mean daily flow (m^3/sec); (b) simulated total surface area (ha); (c) simulated total surface area <2 m depth (ha); (d) idealized mean water column velocity (m/sec); (e) idealized mean hydraulic residence time (days); and (f) mean daily water temperature (^oC). Flooded area on the Yolo Bypass, estimated from aerial photographs, is indicated with triangular symbols.

Figure 3. Trends in lower trophic levels in the Yolo Bypass (solid symbols) and Sacramento River (clear symbols) during winter and spring of 1998, 2000 and 2001. (a) Mean daily flow (m^3/ sec); (b) chlorophyll *a* (μg/l); (c) abundance (log10/m^3) of copepods; (d) abundance (log10/m^3) of cladocerans. Note that in 1998 chlorophyll *a* data were not collected. The 2000 chlorophyll *a* data for Yolo Bypass are from Mueller-Solger et al. (In press).

Figure 4. Abundance trends in drift invertebrates in the Yolo Bypass (solid symbols) and Sacramento River (clear symbols) during winter and spring of 1998, 2000 and 2001.

(a) Mean daily flow (m^3/ sec); (b) abundance (log10/m^3) of diptera; (c) abundance (log10/m^3) of aquatic invertebrates other than diptera; and (d) abundance of terrestrial invertebrates.

Figure 5. Trends in Chinook salmon in Yolo Bypass (solid symbols) and Sacramento River (clear symbols) during winter and spring of 1998, 2000 and 2001. (a) Mean daily flow (m^3 /sec); (b) wild salmon density (number/m^2); (c) tagged salmon size (mm FL); and (d) wild salmon size (mm FL). For tagged salmon data, symbols with a "dash" indicate fish captured using a midwater trawl. All other tagged salmon data were collected using beach seines. The mean daily FLs are shown for wild salmon for presentation purposes; however, individual observations were used for statistical analyses. Most of the 1998 wild salmon data are from Sommer et al. (2001b). There were insufficient wild and tagged salmon data for 2001 to compare the two study locations.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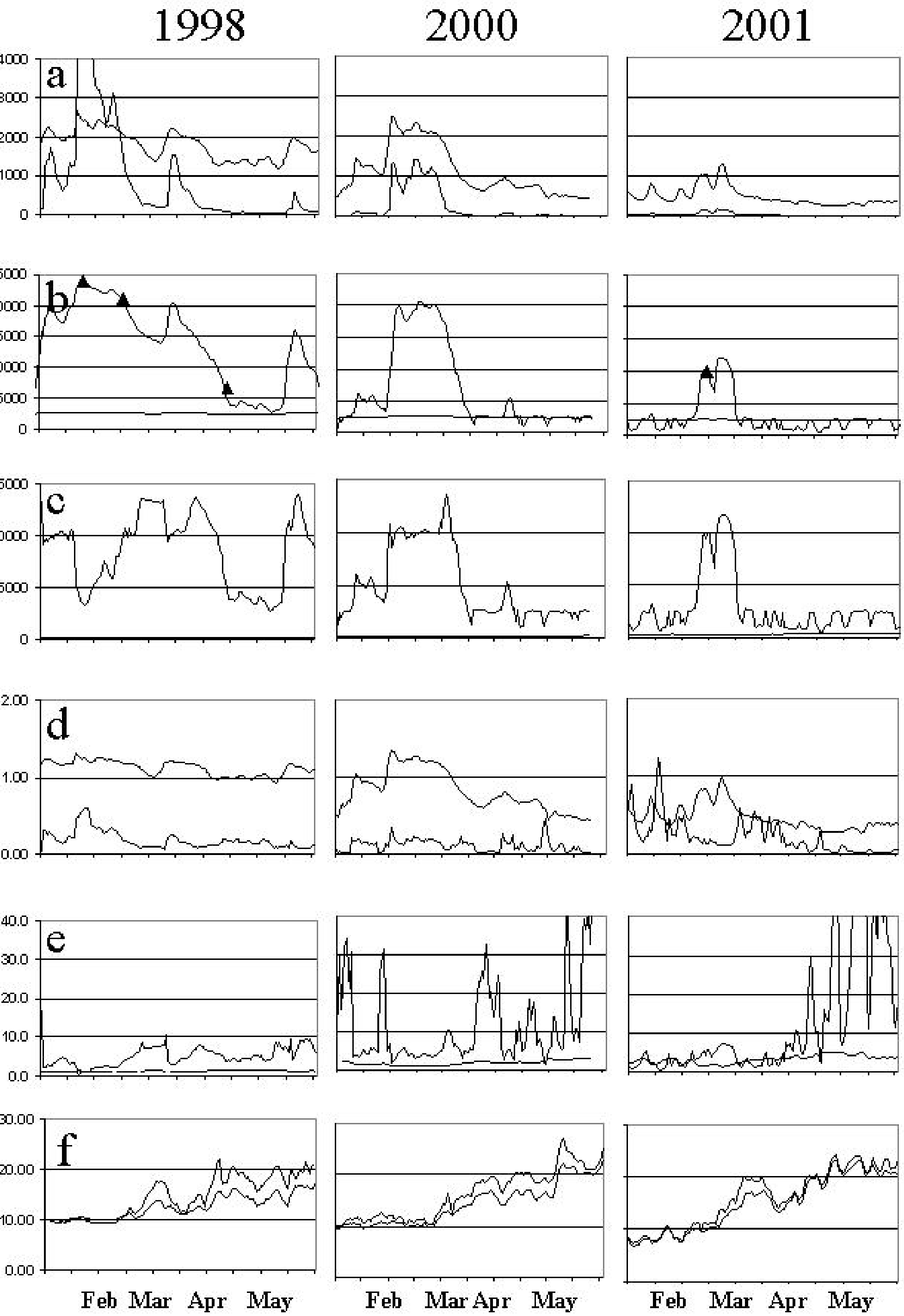
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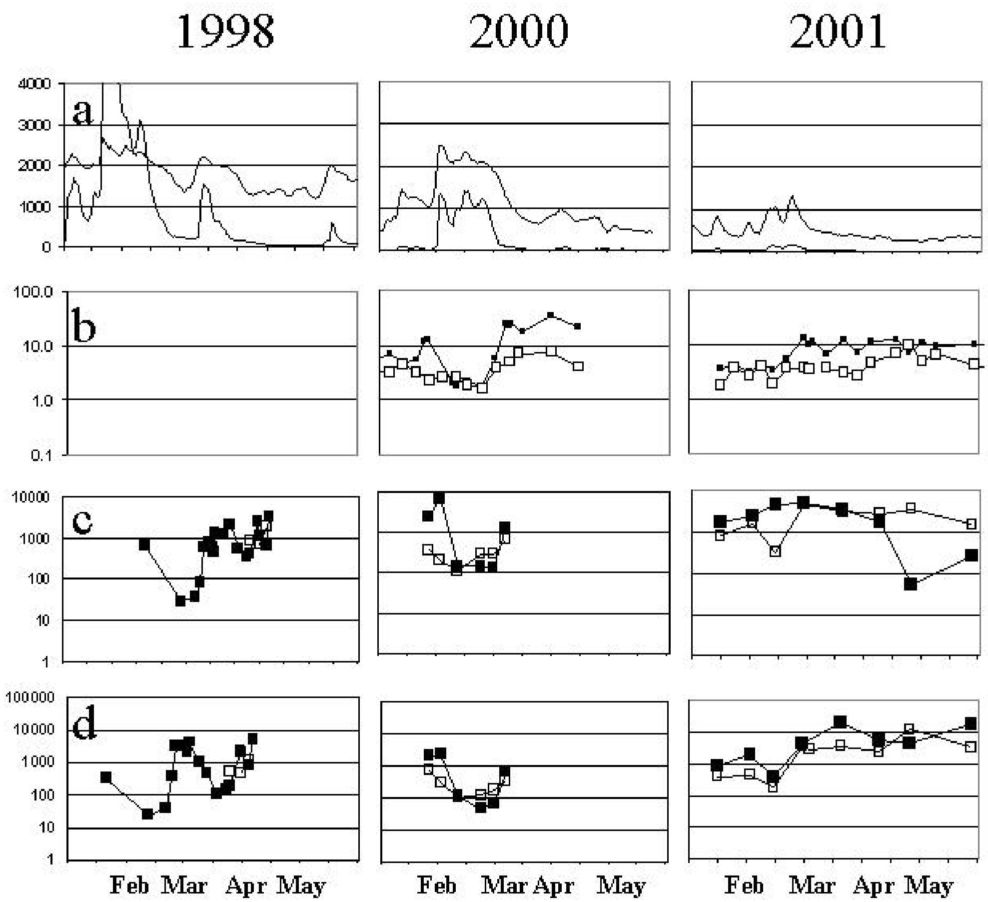
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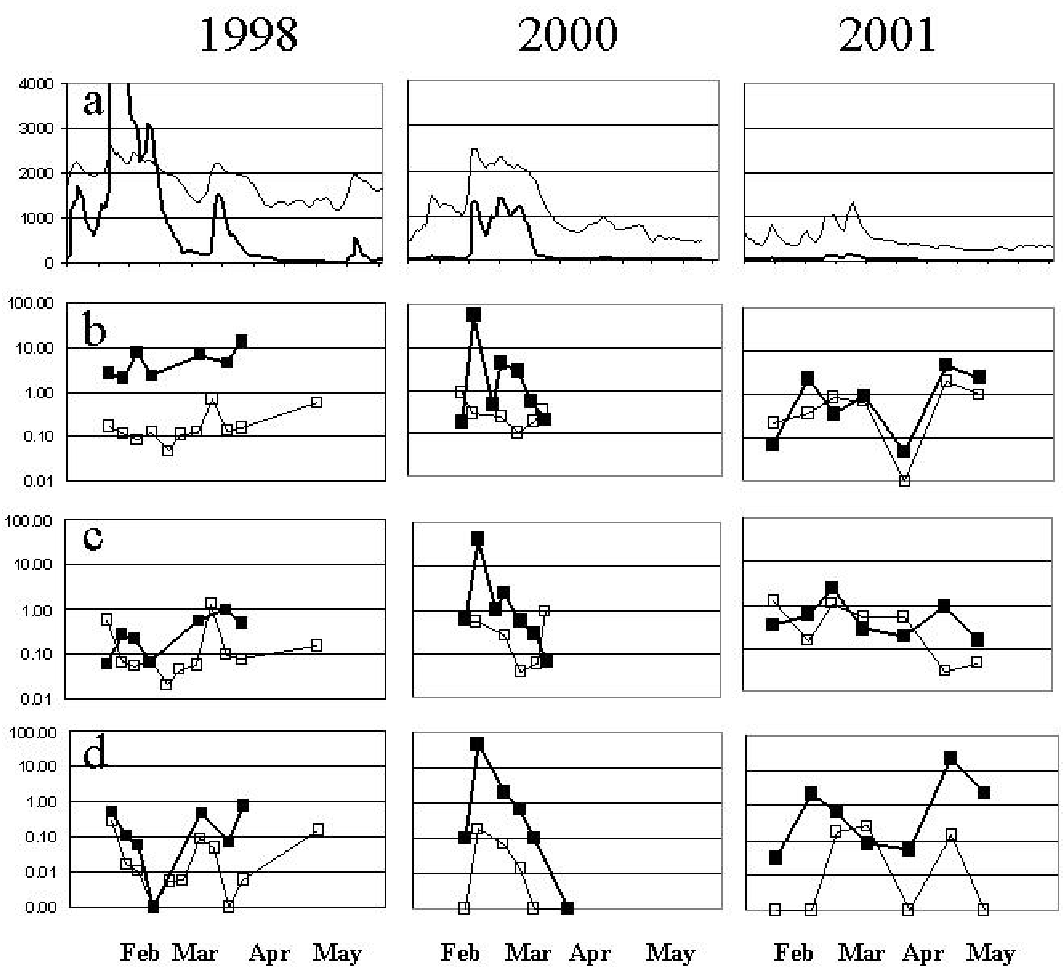
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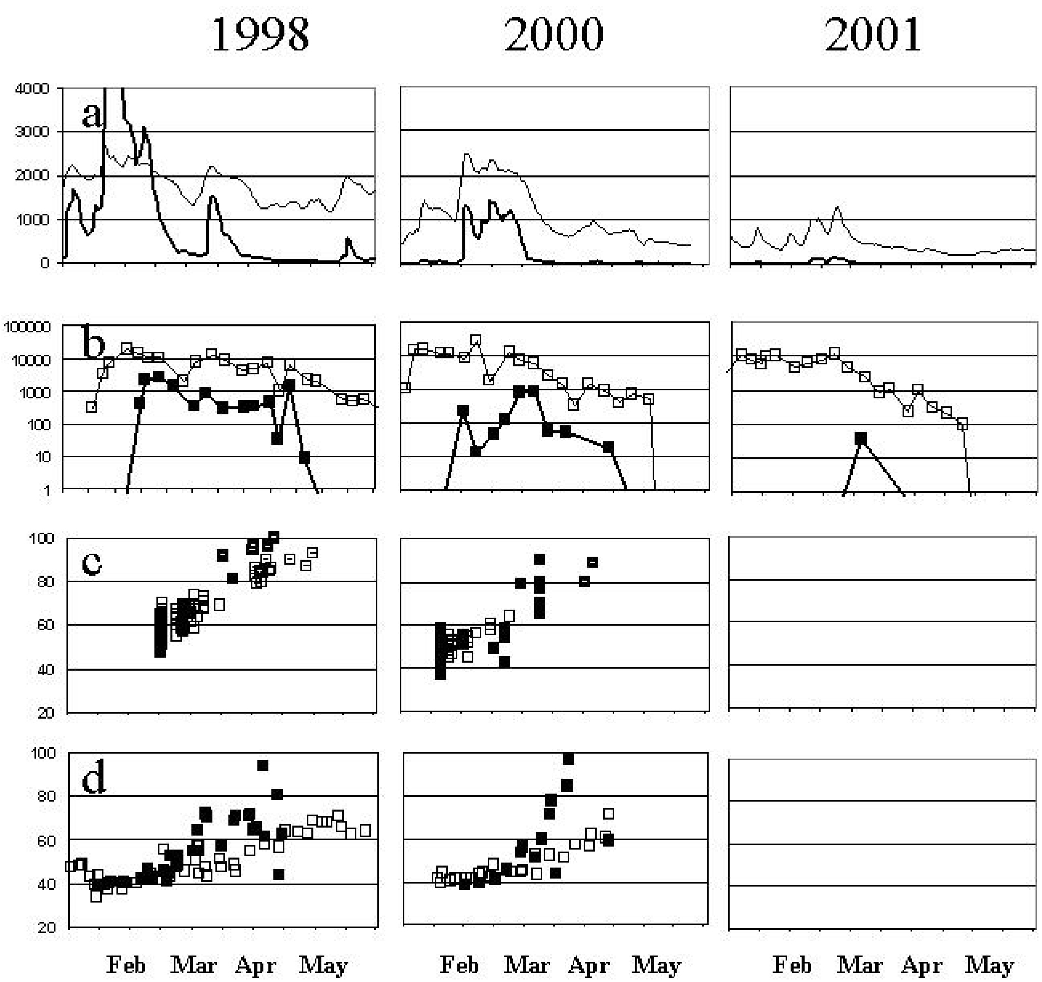
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APPENDIX E: EXPERIMENTAL STUDY REVIEW PAPER

Spawning and rearing of splittail in a model floodplain wetland

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NOTES

Spawning and Rearing of Splittail in a Model Floodplain Wetland

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Abstract.—The splittail *Pogonichthys macrolepidotus*, which has been listed as threatened by the U.S. government, does not produce strong year-classes unless it has access to the floodplain habitat of the San Francisco estuary and its tributaries. In this small-scale, single-year study, we tested the hypothesis that managed inundation of a floodplain can be used to support splittail reproduction in dry years, when this habitat type is not readily available. Adult splittails were captured on their 2001 upstream spawning migration and transferred to a 0.1-ha model floodplain wetland. Our results suggest that adults will successfully spawn if they are provided access to floodplain habitat in dry years. In snorkel surveys, progeny showed a significant association with the lower portion of the water column. Young splittails (15–20 mm fork length [FL]) concentrated in edge habitat near an inflow during the day but at night moved into deeper-water habitats, including open water and habitats with submerged vegetation. Larger splittails (28–34 mm FL) used a broad range of habitats both during the day and at night. Juveniles showed significant schooling behavior during the day, then dispersed at night. These observations have potential implications for the design of habitat restoration projects for the splittail, the last remaining representative of its genus.

The splittail *Pogonichthys macrolepidotus*, a native cyprinid, is perhaps the most floodplain-dependent fish in the San Francisco estuary (Figure 1; Sommer et al. 2001a). During high-flow periods in winter and spring, adult splittails migrate upstream into the Sacramento–San Joaquin delta and its tributaries (Daniels and Moyle 1983), where spawning activity is apparently concentrated on the seasonal floodplain (Sommer et al. 1997). Abundance is reduced in dry years, when splittails have little or no access to floodplain spawning and rearing habitat. Although the relatively long life span (frequently >5 years) and high fecundity of this species helps to buffer the population against low-outflow conditions, an extended drought during the 1980s and early 1990s led to a major decline in the production of young splittails (Meng and Moyle 1995; Sommer et al. 1997). This decline in abundance was the primary basis for the U.S. government's listing of the splittail as threatened in 1999 (USFWS 1999). Major declines have also been noted for several other native fish in the estuary, although the causes vary (Bennett and Moyle 1996). The splittail is the last surviving member of its genus; the only other species in the genus, the Clear Lake splittail *P. ciscoides*, became extinct sometime during the previous century (Moyle 2002).

Several restoration programs are underway to increase the fish populations of the estuary and its tributaries (Yoshiyama et al. 2000). Floodplain restoration has been identified as a potential way to support splittail and other species (CALFED 2000). One major restoration goal for the San Francisco estuary is to improve the connectivity between river and floodplain habitat, particularly in the Yolo Bypass, the largest remaining floodplain. As a result of the system of levees and weirs constructed around its perimeter, the Yolo Bypass typically floods only in above-normal water years (Sommer et al. 2001a). Here, we use a model floodplain wetland to test the hypothesis that managed inundation of floodplain habitat during lower-flow years can be used to support splittail spawning and rearing. An additional objective was to provide diel observations of juvenile splittails; the habitat

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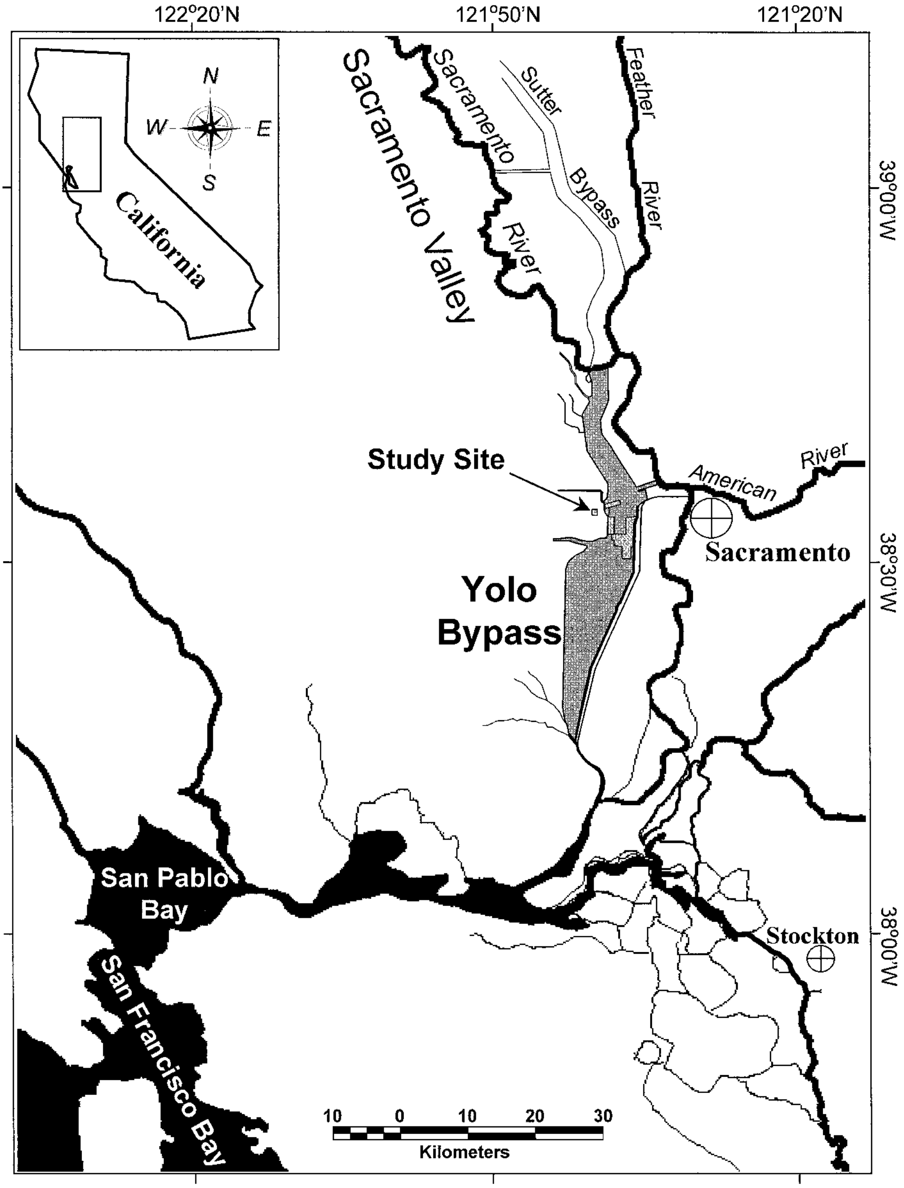

FIGURE 1.—Map showing the location of the Yolo Bypass (dark gray area). The San Francisco estuary includes the region from San Francisco Bay upstream to Sacramento. The Yolo Basin Wildlife Area is the light gray area within Yolo Bypass immediately southeast of the study site.

associations of this life stage are poorly understood because early juveniles typically occur during high-flow events, when high turbidity and extreme environmental fluctuations create major sampling problems. Young and Cech (1996) have described the physiological tolerances and requirements of young splittails in laboratory studies. However, little is known about the habitat preferences and distribution of early life history stages under natural conditions. Moreover, diel behavior has not been well studied for juvenile cyprinids (Garner 1996). This information is essential for the successful design and evaluation of splittail restoration projects.

Our basic approach was to capture adult splittails on their seasonal spawning migration during a dry year and relocate them to a model floodplain wetland. After successful spawning and hatching, we conducted intensive observations of the diel distribution of juveniles in relation to different habitat types. Use of a single model floodplain wetland is somewhat artificial and limited in scope; however, similar studies using captive fish in seminatural habitats have yielded useful biological data for other threatened North American cyprinids (Blinn et al. 1998). Our objective was to collect basic information on the spawning and rearing of splittails that could be used to generate hypotheses for more comprehensive field studies and habitat restoration projects.

Study Site

Our study was conducted with adult splittails collected from the Yolo Bypass, the largest floodplain of the San Francisco estuary (Figure 1). The estuary has been heavily modified by many factors, including levee construction, river channelization, draining of wetlands, diversions, and introduced species (Bennett and Moyle 1996). The 24,000-ha Yolo Bypass floodplain is dominated by agricultural uses, but there are also substantial ''natural'' habitats such as seasonal wetlands and riparian and upland habitats (Sommer et al. 2001a). The largest contiguous area of nonagricultural floodplain habitat is the Yolo Basin Wildlife Area, which is managed by the California Department of Fish and Game. The Yolo Bypass typically floods in about 60% of years, when high winter and spring floodwaters enter from the Sacramento River and several small streams. The floodplain is seasonally dewatered in summer and fall, except for perennial ponds and a single tidal channel. During extended droughts, such as that of 1987–1992, the floodplain is not inundated from its tributaries. Observational studies were conducted in a 0.1-ha floodplain wetland constructed at the Yolo Basin Wildlife Area headquarters, which is immediately adjacent to the Yolo Basin Wildlife Area.

The model floodplain was constructed in 1997, then planted with wetland vegetation and seasonally flooded during September–May over the next three years. At the time of the study (2001), approximately 10% of the wetland area was bordered by partially submerged terrestrial vegetation, primarily willows *Salix* spp., mule-fat *Baccharis salicifolia*, boxelder *Acer negundo*, and willow herb *Epilobium* spp. About 15% of the wetland was covered by dense beds of bermuda grass *Cynodon dactylon*, and the remaining 75% was lightly vegetated with cattails *Typha* spp. Swamp timothy *Crypsis schoenoides* was another major vegetation type in the wetland, but it was dormant during the study. The wetland was flooded in September 2000 before the initiation of the splittail study. Water surface elevations were maintained by inundating the wetland with well water for 4–6 h/d, which was supplemented by surface runoff from precipitation events. In addition to fresh flow from external water sources, a screened submersible pump was used to recirculate water from the outlet to the inlet at a rate of 100 L/min. The wetland was approximately oval-shaped and had a mean depth of 0.47 m during the study period. The depth profile from edge to center was gradual (8:1 slope) except for one side, which had a 2:1 slope.

There were several notable differences between the model floodplain wetland and the Yolo Bypass. Based on the mean depth, area, and recirculation rate, the mean hydraulic residence time (i.e., turnover rate) in the model wetland was approximately 1 d, about twice as fast as that estimated for peak natural flood events in the Yolo Bypass (California Department of Water Resources, unpublished data). The water levels in our model floodplain wetland had a standard deviation of 0.09 m during the observation period, compared with 0.20 m or more during recent long-duration (e.g., >30 d) Yolo Bypass flood events. Finally, water clarity was much higher in our model floodplain wetland. Visibility for divers (see below) was 2–5 m, while visibility during typical Yolo Bypass flood events (not actually measured) is typically on the order of less than 0.5 m.

Methods

During February 2001, we collected 14 adult splittails (320 ± 31 mm [mean ± SD] fork length [FL]) on their upstream migration using a 3-m-diameter fyke trap in the Yolo Bypass Toe Drain, a perennial tidal channel of the floodplain. As none of the fish were ''ripe,'' we were unable to determine the sex of the fish at the time of collection. The fish were transported immediately to the model floodplain wetland. No other fish species were present in the wetland before introduction of the splittail.

We considered a variety of shallow-water habitat sampling approaches, including seining, dipnetting, and electrofishing (Rozas and Minello 1997), to sample the distribution and habitat use of juveniles produced within the model wetland. We determined that these methods were not appropriate because they would have substantially disturbed the fish and their habitat and because their relatively poor resolution would have made it difficult to evaluate fine-scale distributions (e.g., water column position). As an alternative, we relied on snorkel observations, a ''passive'' approach. Although snorkel surveys have been used in many other studies to collect fine-scale data on habitat use (Helfman 1983), they may have somewhat altered the behavior of young fish. As recommended by Helfman (1983), we conducted our observations on habitat use and distribution from a distance of several meters to minimize behavioral effects. This was consistent with our initial observations on the responses of splittails to divers; the fish showed no obvious change in behavior (e.g., an increase in swimming speed or change in water column position) unless the observers moved to within 1 m of the fish.

Snorkel surveys were conducted by divers during two sampling periods, April 6–17, 2001 (period 1), and April 27−May 30, 2001 (period 2). For each sampling period, observations were made during the day (1–2 h after sunrise and at midday) and at night (1–2 h after sunset) to assess diel changes in distribution and behavior. A team of two divers surveyed the entire wetland, which was stratified into four habitat types: (1) open water (mud substrate with light vegetation; 74% of total wetland area); (2) submerged vegetation (dense beds of bermuda grass; 14% of total wetland area); (3) emergent vegetation (partially submerged terrestrial vegetation bordering the wetland; 10% of total wetland area); and (4) inflow (inflow area with vegetation similar to that of habitats 1 and 3; 2% of total wetland area). On two of the sampling days, only one of the two divers was used. Small dive lights were used for the night observations. A single observation was defined as a single fish or small aggregation or ''school'' (<25 individuals) within a 1-m^2 area. When larger schools were present, the observation represented the entire area covered by the school. For each observation, divers recorded the approximate number of fish, water column position (top, middle, or bottom third), and depth (actual depth for individuals, center of the school for groups). During the second sampling period, the water column position category for the bottom third of the water column was further subdivided into benthic (at or within 2 cm of the substrate) and pelagic observations. A sample of 27–50 fish was netted during each sampling period to measure mean fork length. Wetland depth was recorded 3–5 times each week, and water temperature was measured continuously using an Onset Optic Stowaway logger (Onset Computer Corporation, Bourne, Massachusetts) located at the outlet.

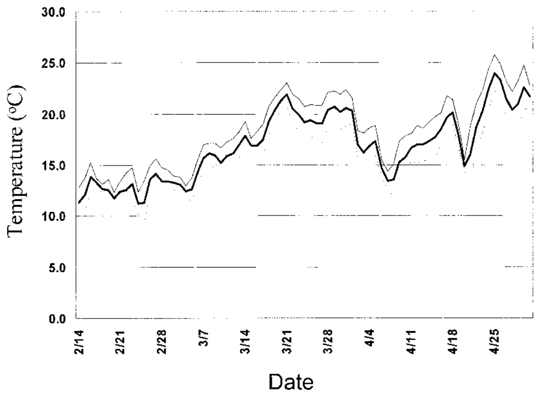

FIGURE 2.—Mean (thick line) and standard deviation (thin lines) of daily water temperature in the model floodplain wetland.

The observation data were summarized in three-way contingency tables using the following grouping variables: sampling period (1 or 2), time (day or night), and distribution (habitat type, depth, or water column position) or abundance (fish school size). We used three-way log-linear models to test the hypothesis that there were interactions between the categories of each of the contingency tables). Chi-square goodness-of-fit analyses were used to compare actual habitat use with the expected distributions based on the availability of each habitat type.

Results

Mean daily water temperatures ranged from 11°C to 24°C, with a gradual increase over the course of the study (Figure 2). The mean daily water temperature was 15–19°C during the first observation period and 21–23°C during the second. Larval splittails were first observed swimming at the edge of the wetland on April 3, 2001. The total number of observations varied somewhat among sampling periods: 63 and 74 for the day and night portions of period 1, respectively, and 52 and 78 for the day and night portions of period 2. However, the total number of fish observed was similar between periods for both day (286 ± 64 for period 1 and 241 ± 64 for period 2) and night (58 ± 1 for period 1 and 61 ± 2 for period 2). Fish densities were comparable to those in natural floodplain wetlands during previous high-flow years (California Department of Water Resources, unpublished data). The size range of young splittails collected with nets increased from 15–20 mm during the first sampling period to 28–34 mm during the second. The study was completed on May

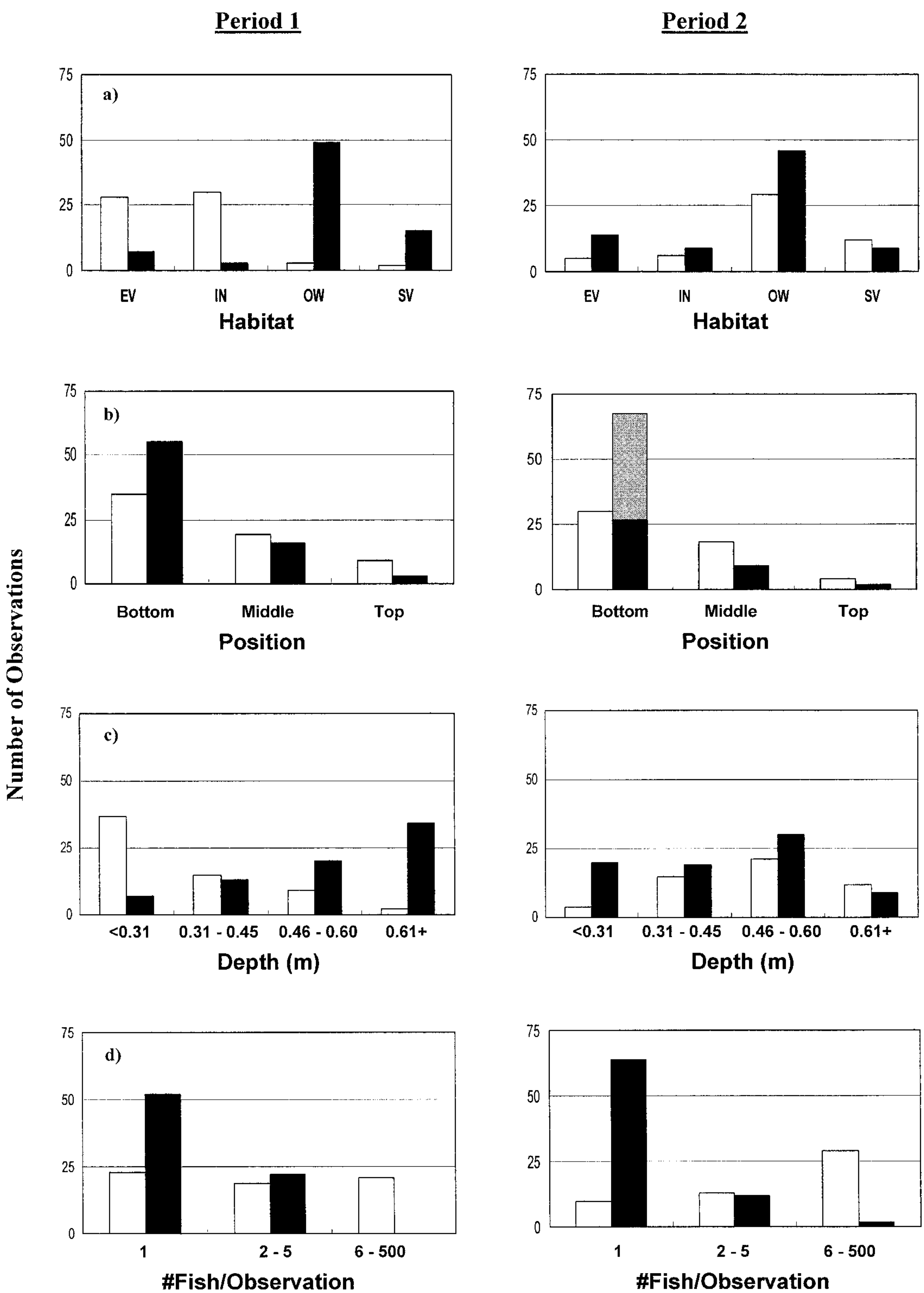

FIGURE 3.—Juvenile splittail habitat use during the day (open bars) and at night (solid bars) for two sampling periods. The *y*-axis for each variable indicates the total number of observations of one or more fish. Panels **(a)**

1–3, 2001, when the pond was drained and the fish removed. All of the original 14 adults were collected, along with 860 juveniles.

The snorkel surveys found young splittails in all habitat types (Figure 3a). Habitat use was significantly different from the expected distribution based on habitat availability during the day portions of periods 1 (χ^2 = 1,277; df = 3; $P < 0.001$) and 2 (χ^2 = 29; df = 3; $P < 0.001$) and the night portion of period 2 (χ^2 = 41; df = 3; $P < 0.001$), but not during the night portion of period 1 (χ^2 = 4.3; df = 3; $P > 0.05$). The log-linear analysis showed that there were statistically significant interactions between sampling period and habitat use ($P < 0.01$) and between time of day and habitat use ($P < 0.001$; Table 1). For period 1, there was a strong association with emergent-vegetation and inlet habitats during daytime (Figure 3a). At night and during period 2, there was increased use of open water and submerged-vegetation habitats.

Fish were most frequently observed in the bottom portion of the water column during all periods but showed an apparent shift towards the bottom at night (Figure 3b). During period 2, when we included ''benthic'' as an additional water column position, we found that 51% of all observations were made in benthic areas at night but that fish were entirely pelagic during the day. The diel shift in distribution was supported by log-linear analysis, which showed a significant ($P < 0.001$) interaction between time of day and water column position (Table 1).

The depth distribution of fish changed substantially between periods 1 and 2 (Figure 3c). During period 1, the majority of splittails were associated with very shallow (<0.40 m) edge areas of the wetland during the day but shifted to deeper water at night and at both times during period 2. Statistical analysis of the data indicated significant ($P < 0.001$) interactions between time of day and depth distribution and between sampling period and depth distribution (Table 1).

For both sampling periods, there were major changes in schooling behavior between day and night hours (Figure 3d). During the day, the majority of observations were of schools of 2–500 fish. At night the schools dispersed, and the majority of observations were of individual fish. These observations were reflected in the log-linear analysis, which demonstrated a significant ($P < 0.001$) interaction between time of day and school size (Table 1).

TABLE 1.—Results of three-way log-linear analyses of juvenile splittail distribution. Tests were performed for interactions between sampling period (1) or time of day (2) and distribution variables (3; habitat, water column position, and depth) and school size. The marginal χ^2 results are shown, with the degrees of freedom in parentheses; $P < 0.01$*, $P < 0.001$**.

Effect	Habitat	Water column position	Depth	School size
1 × 3	15.6 (3)*	2.9 (2)	16.0 (3)**	5.5 (2)
2 × 3	43.7 (3)**	18.0 (2)**	17.7 (3)**	95.0 (2)**

Discussion

Our results are most valid for a single year and location; they do not necessarily apply to all splittails in all restored and natural floodplain wetlands or to cyprinids elsewhere. However, we believe that the results have several implications for the biology and management of splittails. Our findings are consistent with previous evidence that floodplain habitat supports fish production in many locations, including tropical (Welcomme 1979; Junk et al. 1989) and temperate rivers (Bayley 1995; Gutreuter et al. 2000). At the regional level, the present study supports the conclusion of Sommer et al. (1997) that floodplain provides valuable spawning habitat for splittails. Flood events are known to be important for the spawning of several other federally listed cyprinids, including humpback chub *Gila cypha* (Kaeding et al. 1990) and Colorado pikeminnow *Ptychocheilus lucius* (Tyus 1991). Our data on juvenile distribution suggest that floodplains and perhaps other shallow-water habitats are also important for the early life stages of splittails. We found that the youngest splittails we studied (15–20 mm FL) were most abundant in the shallowest areas of the wetland with emergent vegetation, were associated with the lowest portion of the water column, and were largely benthic at night. As discussed in Sommer et al.

←

show habitat type (EV = emergent vegetation, IN = inlet, OW = open water, and SV = submerged vegetation), panels **(b)** water column distribution (during the second observation period, the ''bottom'' category was subdivided into ''pelagic'' [solid bar] and ''benthic'' [shaded bar]), panels **(c)** the depth of the water column, and panels **(d)** school size as measured by the number of fish in each observation.

(2001b), in dry years native fish are confined to the Sacramento River and similar channels that are deep (>5 m) and steep sided and have minimal shallow-water habitat or vegetation. This distribution contrasts with that of high-flow years, when the Yolo Bypass and other floodplains in the region are inundated, providing tens of thousands of hectares of shallow, vegetated habitat for rearing. The availability of shallow (Childs et al. 1998) and benthic (Glova and Jellyman 2000; Jakober et al. 2000) habitats is important for the rearing of many other freshwater fishes. Additional benefits of floodplain rearing include the enhanced availability of invertebrate prey relative to that in adjacent river channels (Junk et al. 1989; Sommer et al. 2001b).

We observed both diel and ontogenetic changes in splittail distribution, a common behavior in many freshwater fish (Matthews 1998). The diel behavior is consistent with preliminary laboratory studies showing that young splittails exhibit decreased swimming activity and rheotaxis at night (T. Swanson, University of California–Davis, unpublished results). Other studies on young cyprinids suggest that predation and food availability are the primary factors controlling habitat use (Rheinberger et al. 1987; Garner 1996). We did not collect data on food availability, so we do not know whether this factor was important for splittail distribution. The mean number of fish observed during the first and second sampling periods was similar, suggesting that predation mortality was not substantial. However, the presence of piscivores could have triggered changes in habitat use even if predation rates were relatively low (Carpenter et al. 1987). We were aware of only two potential predators in the demonstration wetland, adult splittails and great egrets *Casmerodius albus*. During our study, we observed feeding behavior by great egrets at edge areas in the floodplain wetland during daylight hours. Response to avian predators provides a poor explanation for the behavior of young splittails during period 1, when they showed a strong association with shallow, edge habitat during daylight hours. In other words, during the daytime the young splittails were in the same habitat as the avian predators; they did not move into deeper water until night, when the great egrets were not present. Adult splittails, the other potential predators in the pond, may occasionally be piscivores (Daniels and Moyle 1983). During period 1, the attraction of young splittails to shallow, edge habitat during daylight may have been a way to avoid the larger adults, which tended to aggregate in the deepest areas of the wetland. The observed shift into deeper water at night would be reasonable if the risk of predation by visual predators were substantially reduced. Diel shifts in habitat use are apparently used by other cyprinids as an antipredator behavior (Cerri 1983). The increased use of deeper water during period 2 may have reflected improved swimming ability and predator avoidance as the splittails grew larger.

The diel change in schooling provides additional support for the hypothesis that response to potential or actual predators was a major part of the behavior of young splittails. We observed that these fish showed the strongest schooling behavior during the daytime, a diel pattern that is consistent with the responses of other juvenile cyprinids to the presence of predators (Cerri 1983). Schooling is a common phenomenon in teleosts and may function to increase feeding success and reduce predation risk (Pitcher 1986). Cerri (1983) suggested that schools probably disperse at night because they lose visual cues to aggregate.

Our study data are insufficient to adequately address the causes of shifting habitat use and behavior in young splittails. Responses to predators are often highly complex, involving a balancing of the risks from terrestrial and aquatic piscivores (Power 1984) and resulting in species- or size-specific responses on the part of the prey (Brown and Moyle 1991). Alternatively, some of the temporal changes in splittail habitat use could be explained by environmental factors. For example, it is possible that juvenile splittails were attracted to shallow, edge habitat during period 1 because water temperatures were slightly higher there, providing a bioenergetic advantage given adequate food availability. Mean water temperatures were higher throughout the pond in period 2, so a broader range of habitats may have been within the preferred temperature range of splittails during that period. We did not specifically measure the spatial variability in water temperature during the study, but temperature effects are consistent with laboratory studies on young splittails. Young and Cech (1996) found that the final preferred temperatures and growth optima for splittails in a size range similar to that in our study were 22–24°C, depending on acclimation temperature. The mean daily water temperatures in period 2 (21–23°C) overlapped with this range, whereas those in period 1, when the fish showed a stronger association with shallow, edge habitat (Figure 2) were markedly cooler (15–20°C).

Although this investigation was limited to a single location and year, we believe that our results have potential management implications that warrant a more comprehensive series of studies. This small-scale study supports the idea that splittail reproduction could be improved through floodplain restoration (CALFED 2000), particularly if river–floodplain connectivity is improved in dry years. In the present study, splittails spawned after being transferred to a floodplain wetland, a largely inaccessible habitat type in dry years such as 2001. The flow fluctuations and turbidity levels in our model system were modest compared with those under natural conditions in Yolo Bypass, indicating that major flow variation and high turbidity events may not be critical requirements for restoration projects to support splittail spawning. We also observed ontogenetic and diel changes in habitat use by juvenile splittails, suggesting that restoration projects should incorporate multiple habitat types. The early life stages were associated with shallow habitat near sources of flow and emergent vegetation, while larger fish used deeper water in open and vegetated areas. It is unclear whether these distribution changes were primarily related to behavioral preferences, responses to predators, bioenergetics, or environmental variables. In any case, it seems prudent to provide a mosaic of floodplain habitat types in the design of initial restoration projects to ensure that the needs of different life stages are met. Subsequent monitoring of larger restoration projects will help to show whether our results are valid under ‘‘real-world’’ conditions, such as increased habitat variability and the presence of other fish species. We wish to emphasize, however, that our study does not provide sufficient evidence that floodplain restoration alone is adequate to restore the splittail to its historical abundance. The species resides in the San Francisco estuary, perhaps the most invaded estuary on the planet (Cohen and Carlton 1998). Splittails produced on seasonal floodplain habitat still face substantial obstacles from introduced competitors and predators and a radically altered food web.

Acknowledgments

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APPENDIX F: YOLO BYPASS HYDROLOGIC ANALYSIS

Flows and stages in all of the waterways entering the Yolo Bypass were evaluated to determine the suitability of each waterway as a source of flow to support fish passage and floodplain inundation. This appendix describes stage frequency in the Sacramento River at Fremont Weir, and flow variability in Yolo Bypass tributaries during the spawning and rearing season for splittail and other native fishes.

Datums Used for Elevations

Elevations are mentioned frequently in this hydrologic analysis. Historically, three different datums have been used to measure vertical elevation, and care must be taken to ensure that different sets of elevation data are converted to the same datum before they are compared. It was not practical to convert all elevation data to a single datum for this project, so conversions were done on a case-by-case basis for each part of the analysis. The applicable datum is indicated in the text, tables and figures to avoid confusion. Table F-1 shows how to convert elevations from each of the datums to any of the others:

Table F-1. Datum Conversion Table for Elevations

		To		
		NGVD 1929	U.S.E.D.	NAVD 1988
From	NGVD 1929		+3.00	+2.53
	U.S.E.D.	-3.00		-0.47
	NAVD 1988	-2.53	+0.47	

Stage Frequency Analysis of Sacramento River at Fremont Weir

Sacramento River stage at Fremont Weir is a critical factor for designing facilities to improve fish passage at the weir. This section describes a frequency analysis of river stage by month for wet and dry year types completed so that the hydraulic design of any new facilities can target an appropriate seasonal and year-type window.

Figures F-1 and F-2 show hydrographs of hourly stage readings at Fremont Weir during a sequence of three dry years (water years 1989–1991) and three wet years (water years 1997–1999). The period of record of readily available stage data for Fremont Weir is 1984 to the present. Unfortunately, that period of time contains mostly wet or dry years, with very few near-average years. As measured by the Four-Rivers Index, the period contains 7 wet, 2 above-normal, 3 dry and 4 critically-dry years. Rather than attempt to select a “representative” set of years, the present analysis shows stage frequencies for exceptionally wet and dry conditions, which bracket the range of variability. The 1989–1991 period contained one dry and two critically-dry years and was preceded by two dry years. The 1997–1999 period contained three

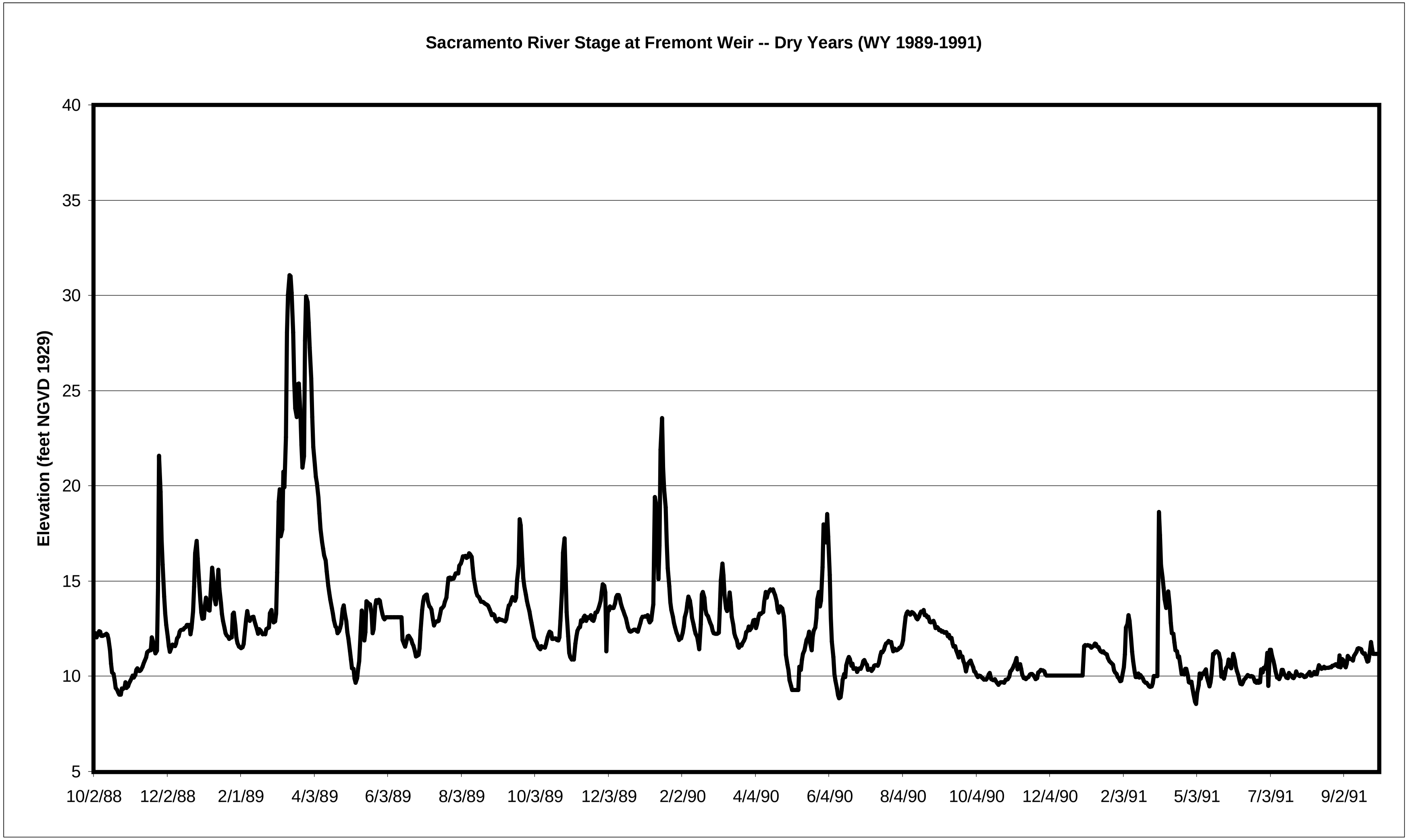

Figure F-1. Hourly Sacramento River Stage at Fremont Weir in Dry Years (1989-1991)

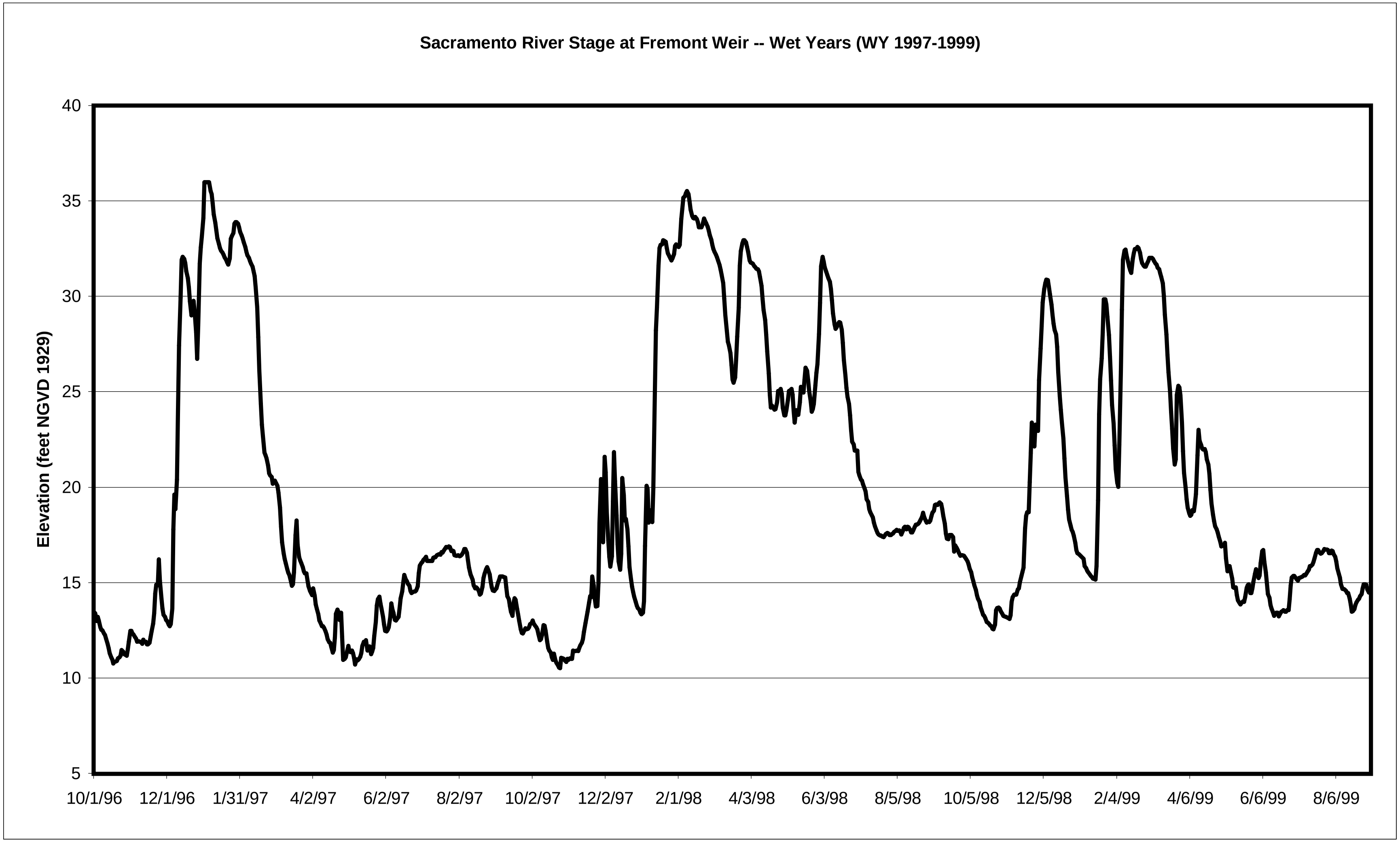

Figure F-2. Hourly Sacramento River Stage at Fremont Weir in Wet Years (1997-1999)

wet years preceded by two wet years. The antecedent conditions are relevant because of reservoir draining and refilling effects that follow a shift from dry to wet or wet to dry conditions.

The raw data available from the CDEC database contains many spurious measurements, which appear as upward or downward spikes in hydrographs. Most of these were filtered out for this analysis, but a few stray occurrences remain. The data were converted from the U.S.E.D. datum to the NGVD 1929 datum by subtracting 3.0 feet, and hourly values were consolidated into daily-average values using a utility program that ignored spurious or missing-value entries.

A comparison of Figures F-1 and F-2 shows pronounced differences between the stage regimes for dry and wet periods. During dry periods (Figure F-1), stage generally remains between 10 and 15 feet year-round, with infrequent brief spikes reaching 20–30 feet. During wet periods (Figure F-2), stage remains above 25 feet for prolonged periods (2–6 months) in winter and recedes to the 10- to15-foot range only briefly. During 1999, stage never fell below 13 feet.

Figure F-3a shows the frequency distribution of daily flows under dry conditions, by month, for the months of May through October. Each curve is a probability plot relating a given river stage to the fraction of time (or probability of occurrence) that that stage is exceeded in the indicated month (across all years in the data set). The curves are very flat, with stage in all months remaining between 9 and 14 feet 89 percent of the time. The curves for November through April are shown in Figure F-3b. Under dry conditions, even these typically rainy months rarely have stages greater than 15 feet (less than 20 percent of the time in all months except March). The conspicuously high curve for March reflects the largest flow event during the sample period, which occurred in March 1989. A larger sample of dry years would undoubtedly result in greater similarity among the curves for January, February and March.

Figure F-4a shows the monthly stage-frequency curves for May–October under wet conditions. The sample of years selected for analysis (1997–1999) included some significant runoff events in May and June that elevated the left end of the curves for those months. The rest of the time was characterized by baseflow, but the baseflow stage was 2–5 feet higher than under dry conditions throughout almost the entire range of probabilities. Thus, the typical stage range was 12–18 feet. The curve for October is considerably lower than the curves for the other months, which may reflect decreased water demand and associated decreases in reservoir releases.

Figure F-4b shows the frequency curves for November–April under wet conditions. In these months the difference between wet and dry conditions is much more pronounced. Stages are greater than or equal to 20 feet about 50 percent of the time in all months during December–April. For the selected period of years (1997–1999) the ranking of wet-season months from wettest to driest was February, January, March, December, April, and finally November. This sequence reflects relatively large amounts of rainfall runoff. Snowmelt might have a more pronounced effect in normal years and shift the wettest period to the late spring months (March–May).

If the objective of a fish passage channel is to allow flow by gravity from the Sacramento River to the Tule Canal most of the time during the target season and year type, then the required invert elevation at the up the channel can be estimated from the flow duration curves. For example, if the 80 percent exceedence level is selected to represent "most of the time", then the water surface at the upstream end of the channel would need to be between 16 feet for December–March in

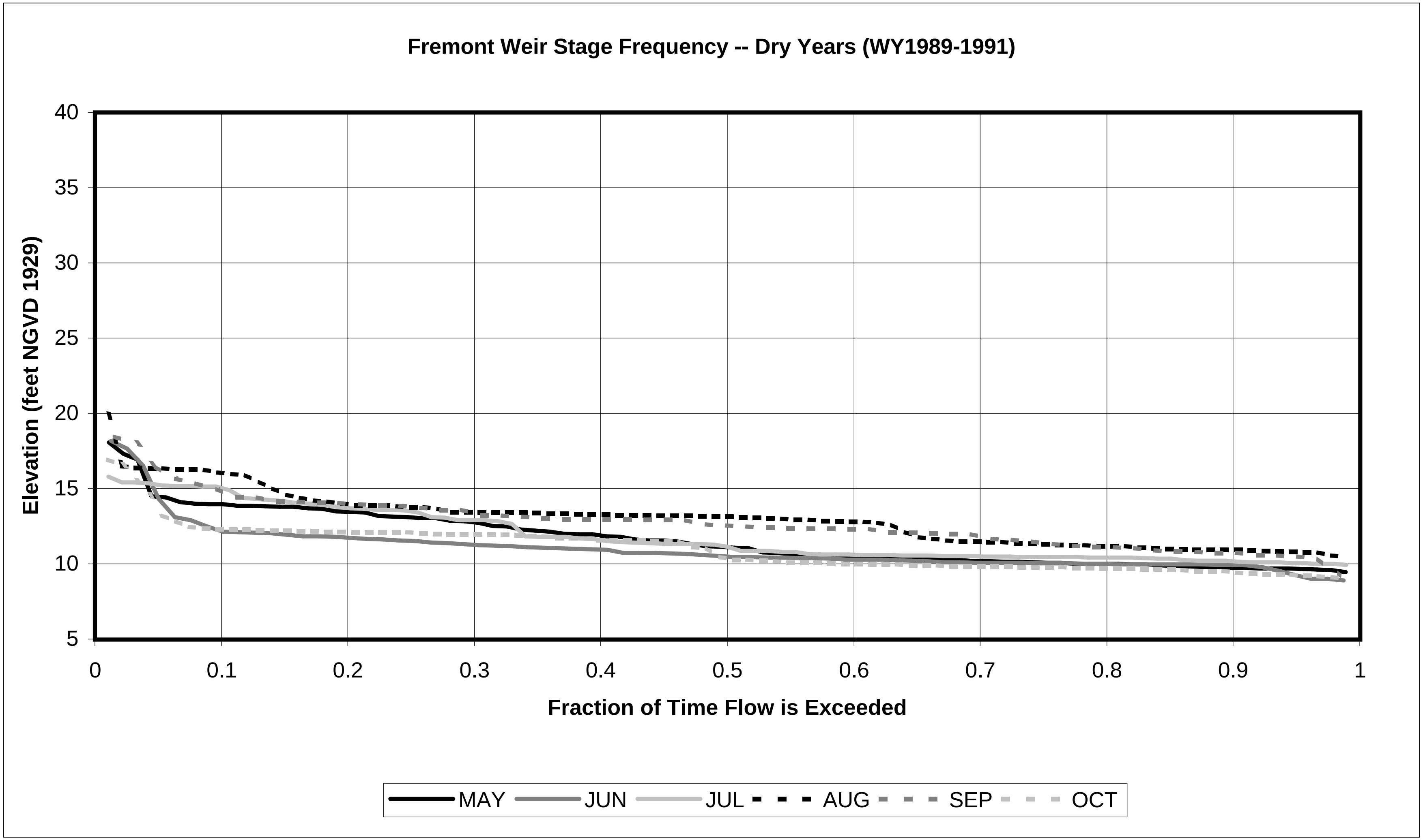

Figure F-3a -- Frequency Distribution of Daily Sacramento River Stage at Fremont Weir in Dry Years: May through October

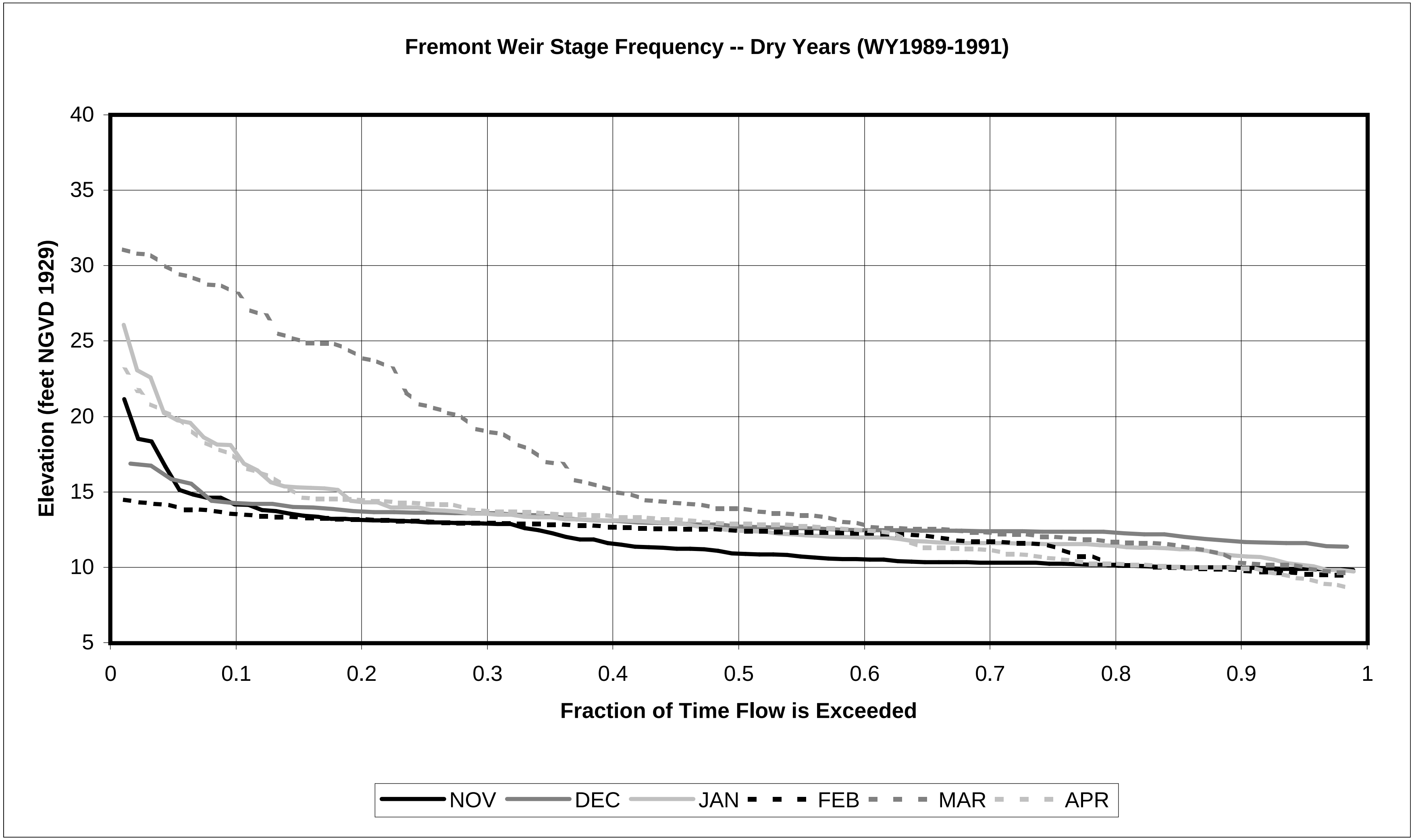

Figure F-3b -- Frequency Distribution of Daily Sacramento River Stage at Fremont Weir in Dry Years: November through April

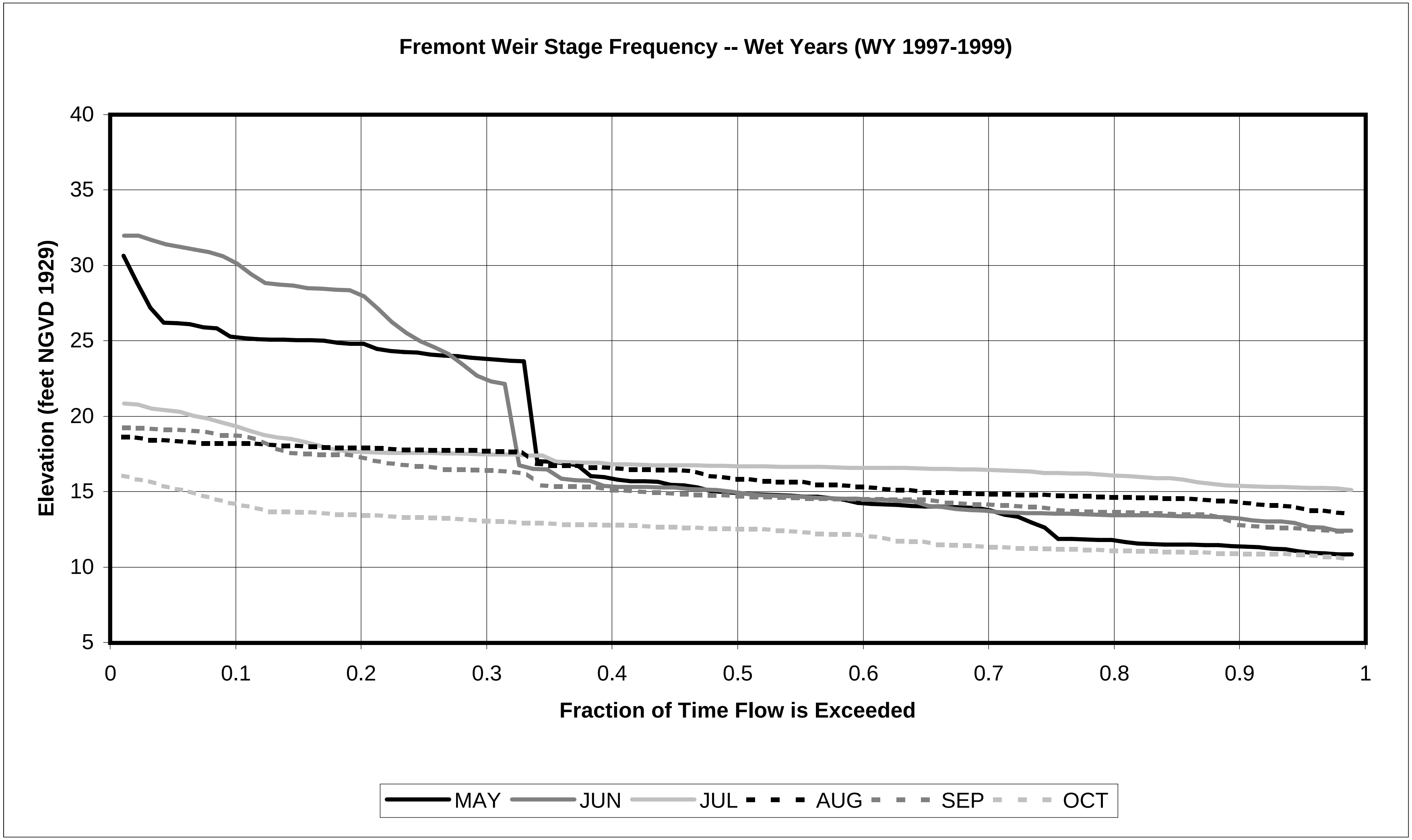

Figure F-4a -- Frequency Distribution of Daily Sacramento River Stage at Fremont Weir in Wet Years: May through October

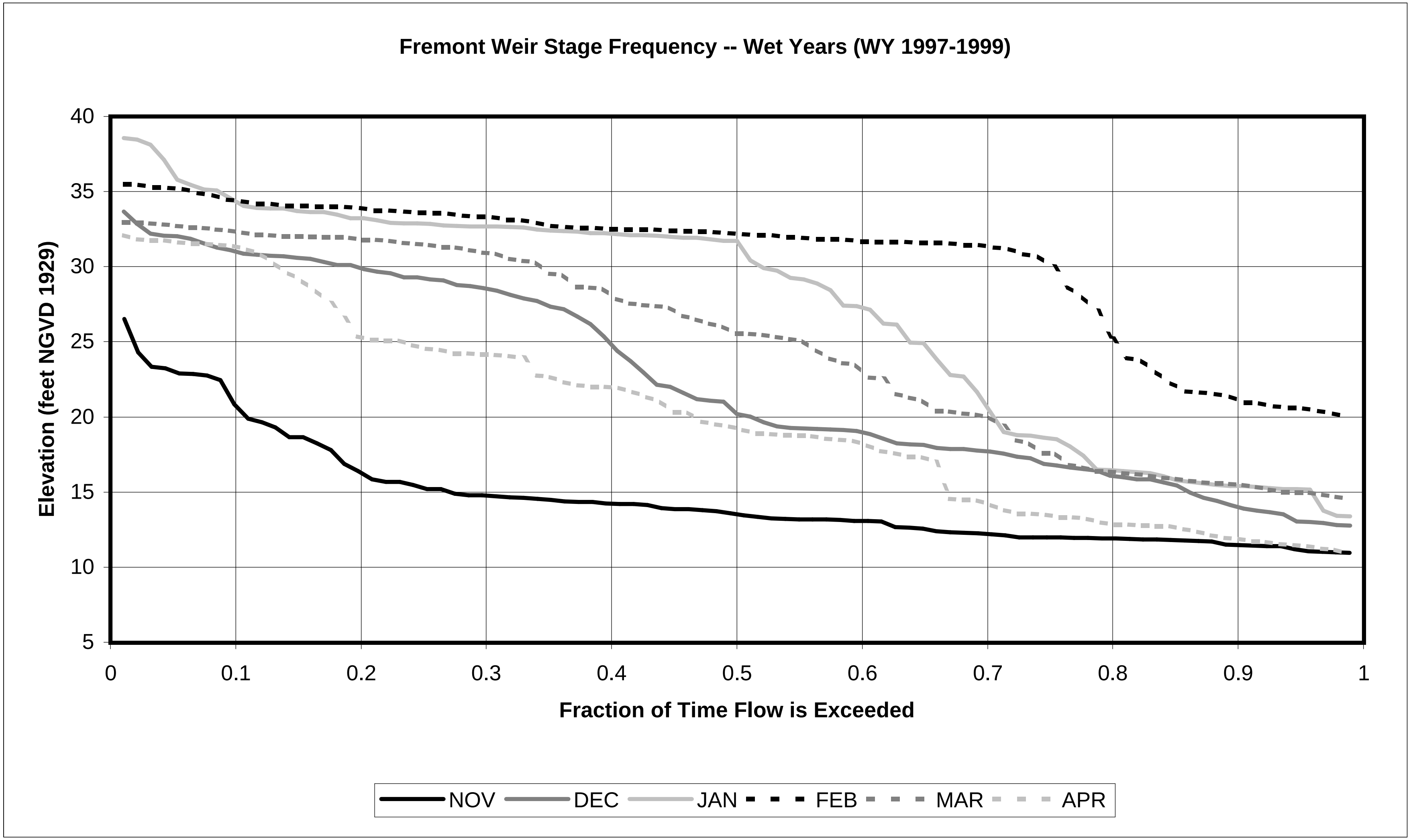

Figure F-4b -- Frequency Distribution of Daily Sacramento River Stage at Fremont Weir in Wet Years: November through April

wet years to as low as 9 feet for May–October in dry years. The channel invert elevation would need to be perhaps 3 feet lower than the water surface elevation, or between 6 and 13 feet above sea level.

Suitability of Yolo Bypass Tributary Inflows for Supporting Native Fish Spawning and Rearing Habitat

Successful spawning and rearing of splittail (*Pogonichthys macrolepidotus*) requires sustained inundation of floodplains along large lowland rivers, such as occurred under predevelopment conditions in California's Central Valley. Specifically, continuous and relatively stable inundation for a period of about 30 days is needed to complete the egg laying, incubation, hatching, and early growth phases of reproduction. After that period of time, fry are able to follow receding flood waters back into channels and sloughs that lead to the estuarine environment that is the normal habitat of splittail during non-reproduction periods. The most common season for spawning and rearing is between February 15 and May 15, although this seasonal window may vary from year to year depending on hydrologic conditions.

Creation or restoration of inundated floodplain habitat for splittail reproduction requires fairly sustained flow and water depth during the 30-day reproduction period. Under predevelopment conditions, the large drainage area of the Sacramento River system and the significant contribution of snowmelt to total runoff resulted in prolonged high flows in spring that were reliable and steady enough to support successful splittail reproduction. Flows in smaller watersheds dominated by rainfall runoff tend to be much more variable, and the associated floodplain inundation may not be steady enough to support splittail reproduction.

Short-term flow fluctuations are natural even in large rivers such as the Sacramento, and splittail are undoubtedly adapted to tolerate a certain level of fluctuation. However, exceptionally large upward or downward flow fluctuations could adversely affect reproductive success. High-flow events can potentially flush eggs or fry from the spawning area, although both of those life phases are probably adapted to avoid high-velocity conditions as much as possible. Of greater concern are downward fluctuations in flow and the associated risk of mortality from desiccation, stranding, or predation. Thus, sustained base flow during the spawning and rearing period is probably essential.

The Yolo Bypass is one of the largest contiguous floodplains accessible to native fishes such as splittail. Splittail reproduction is strong during wet years when overflow from the Sacramento River typically causes prolonged, widespread inundation of the Bypass. In normal-to-dry years, however, the only flows that presently enter the Bypass are from relatively small local tributaries, principally Putah Creek, Willow Slough, Cache Creek and Knights Landing Ridge Cut.

The variability of flows in each of the tributaries to the Yolo Bypass during the splittail spawning and rearing season was compared with the natural variability of Sacramento River flows absent the influence of reservoirs and flood Bypasses to determine the suitability of the tributary flow regimes for supporting splittail habitat. The predevelopment flow regime of the Sacramento River was used for comparison because it represents the flow regime to which splittail are adapted.

Data and Analysis Methods

Daily flows during water years 1968–1998 were estimated for all tributaries to the Yolo Bypass as part of a broader resource management planning effort funded by the CALFED Bay-Delta Program, and the estimates were reported in the Yolo Bypass Management Strategy (Yolo Bypass Working Group et al. 2001). The flow estimates were developed from a combination of correlation among gages, rainfall-runoff relationships, and weir operations. Complete data sets were developed for Putah Creek, Willow Slough and Cache Creek. Because of the limited periods of record for some of the underlying data sets used to estimate flows, Knights Landing Ridge Cut flows were only estimated for water years 1976–1998.

The low-flow regime of Putah Creek changed beginning in 2000 as a result of a settlement agreement regarding instream flows. A hypothetical set of Putah Creek flows under existing conditions was developed for water years 1971–1981 and 1984–1991 by modifying historical flow data to reflect the new instream flow criteria implemented according to the Lower Putah Creek Instream Flow Settlement Agreement (Yates 2001). This subset of the period of record was selected to represent long-term probabilities of spills from Lake Berryessa and curtailed instream flow releases during droughts. The variabilities of the historical and existing Putah Creek flows are characterized separately here. Note that this synthetic data set was a precursor to the data set developed for Chapter 5 of this report.

Gaged flows in the Sacramento River near Red Bluff during water years 1903–1934 were selected for this analysis to represent the natural variability of predevelopment Sacramento River flows. This station is upstream of the flood Bypass system, and the selected period of analysis predates the completion of Shasta Dam.

Flows for each tributary were normalized to eliminate the effects of watershed size and provide an indicator of flow variability that could be compared among the waterways. Daily flows during February 15 to May 15 of each year were divided by the average flow for that period of time to obtain a normalized, dimensionless indicator of flow variability. The standard deviation of flows during the February 15 to May 15 period was also calculated for each year. These data were displayed on two types of graphs for each tributary and for the predevelopment Sacramento River. The first graph type shows the ratio of the standard deviation of daily flows to the average daily flow value for each year of the analysis period. The second plot shows normalized daily flows (actual flow divided by the average flow) for 10 years of the period of record, to provide a visual impression of flow variability.

Nonparametric statistics were also tested and yielded qualitatively similar results. When the median daily flow and interquartile range were used in lieu of the average daily flow and standard deviation, the apparent variability of most of the Yolo Bypass tributaries increased while the apparent variability of the predevelopment Sacramento River flows remained about the same. The ratio of interquartile range to median could not be calculated in a number of cases because the median flow was zero. Although daily flows are probably not normally distributed, the parametric statistics are more complete and are adequate to illustrate the differences in flow variability among the different data sets. Accordingly, the parametric statistics are presented here.

Results

Figure F-5 shows the two graphs used to characterize flow variability in the Sacramento River under predevelopment conditions. Flow variability is small in every year of the analysis period, as indicated by ratios of standard deviation to average that are less than 1.0 (upper graph). Also of particular importance for splittail reproduction is that flows never dropped below about 50 percent of the average flow value during the reproduction period (lower graph). In other words, continuous baseflow sufficient to maintain a large inundated area was always present.

Figure F-6 shows the corresponding graphs for historical flows in Putah Creek. Note that the scale of the vertical axis is the same in each set of graphs to facilitate comparison among the tributaries and river. The ratio of standard deviation to the median often exceeded 1.0 during 1968–1998, reaching as high as 5.0 in one year. An important characteristic of the flow regime not revealed in the graphs is that the median flow was only 0–3 cfs in 8 of the 32 years evaluated, which would probably be too little flow to support an inundated floodplain. The hydrographs for ten sample years also exhibit considerably more variability than the predevelopment Sacramento River flows. In particular, daily flows commonly fall below 50 percent of the average flow and reach zero flow in a number of years. Also, high-flow pulses in response to rain storms are a much larger percentage of average flow than were the high-flow pulses in the Sacramento River under predevelopment conditions.

Synthesized Putah Creek flows under the existing flow regime were evaluated for water years 1971–1981 and 1984–1993, which was a collection of years selected in a previous study as representative of long-term average conditions. The results are shown in Figure F-7. The ratio of standard deviation to average flow is consistently smaller than for the corresponding historical Putah Creek flows, and values between 0.5 and 1.0 (the typical values for predevelopment Sacramento River flows) occur in 10 of the 21 years. This indicates that the sustained flow of 50 cfs for 30 days in spring required under the settlement agreement in most years provides a small but steady flow of water potentially suitable for splittail spawning. The flow would not be present under drought conditions that are defined in the Settlement Agreement and that are expected to occur on average in 25 percent of the years. This explains, for example, high ratios in water years 1991–1993. The sample hydrographs in the lower graph show that daily flows are still somewhat variable. Some high-flow events are proportionally still much larger than typically occurred in the Sacramento River prior to development, but there are fewer occurrences of complete flow cessation compared to the historical flows.

Flow variability in Willow Slough is shown in Figure F-8. Both graphs indicate that variability is substantially greater than for the predevelopment Sacramento River flows and somewhat greater than for historical Putah Creek flows. The ratio of standard deviation to average flow was greater than 2.0 in eleven of thirty years, and greater than 4.0 in four of those years. The magnitude and frequency of fluctuations in normalized daily flows (lower graph) are greater than for the historical and existing Putah Creek flows and much greater than for the predevelopment Sacramento River flows.

Overall, Cache Creek flows are fairly stable, perhaps intermediate in variability between historical and future Putah Creek flows. Figure F-9 shows that the ratio of standard deviation to average was typically between 1.0 and 2.0, with only two years where the ratio reached or

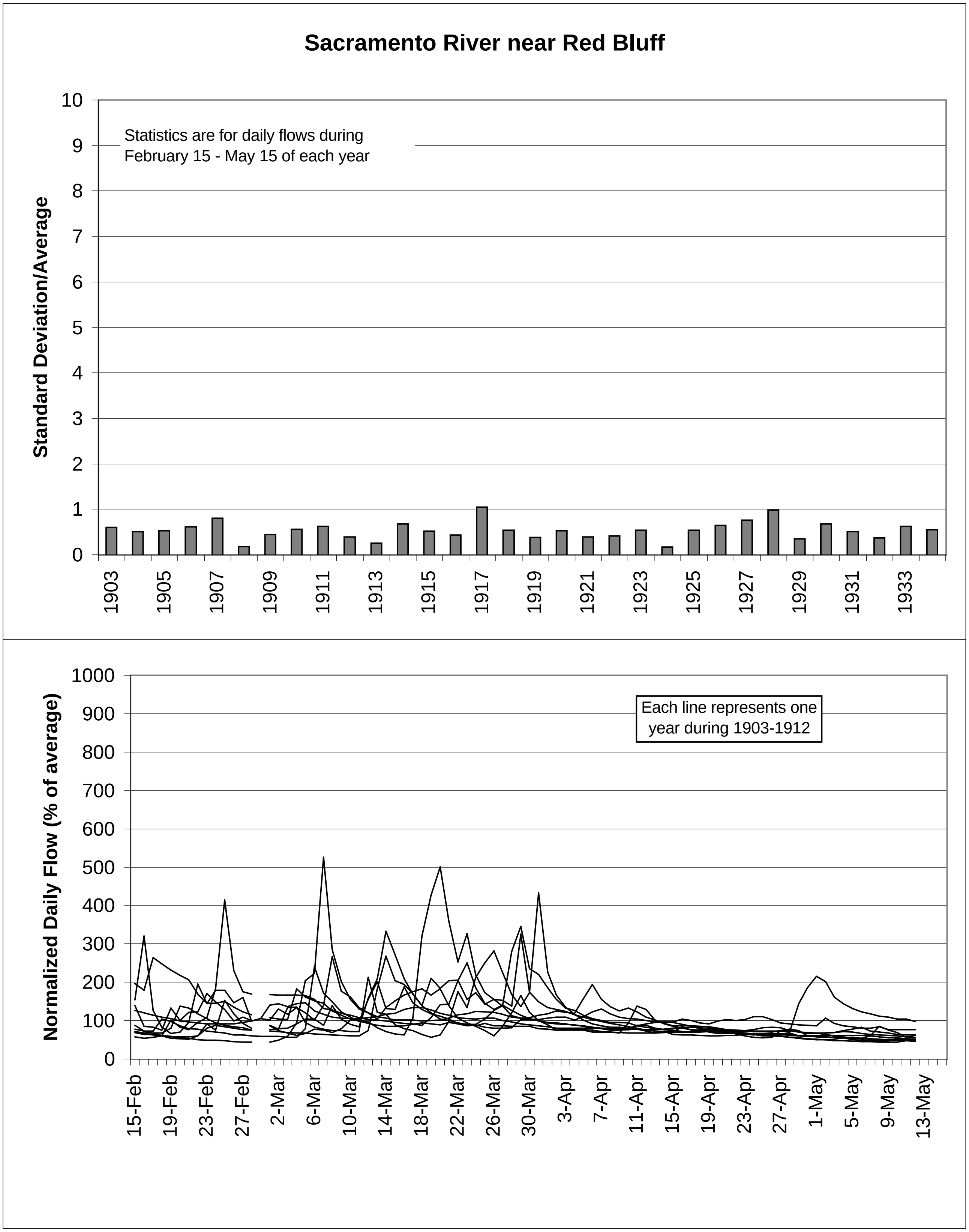

Figure F-5. Variability of Pre-Shasta Daily Flows in the Sacramento River during the Splittail Spawning/Rearing Season

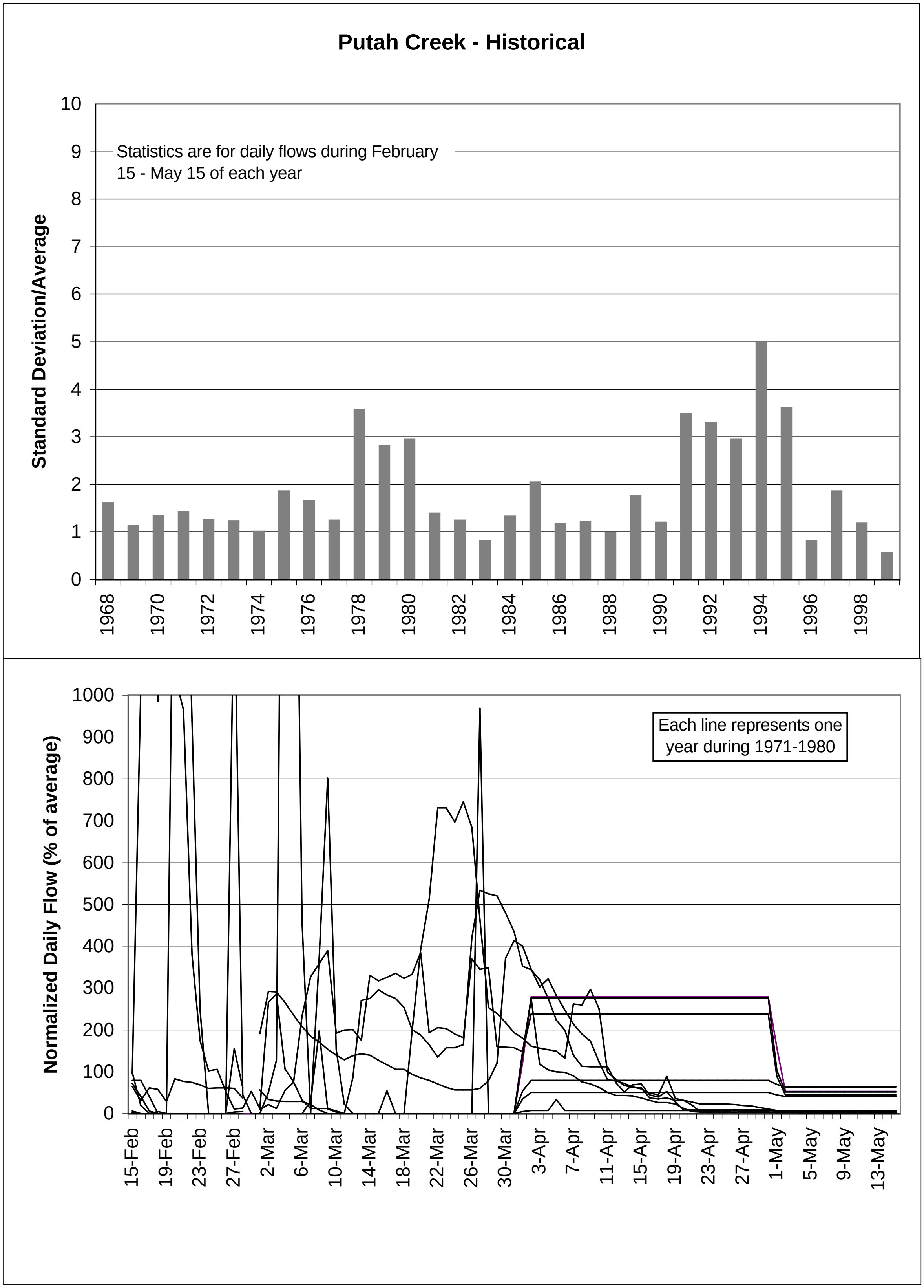

Figure F-6. Variability of Historical Daily Flows in Putah Creek during the Splittail Spawning/Rearing Season

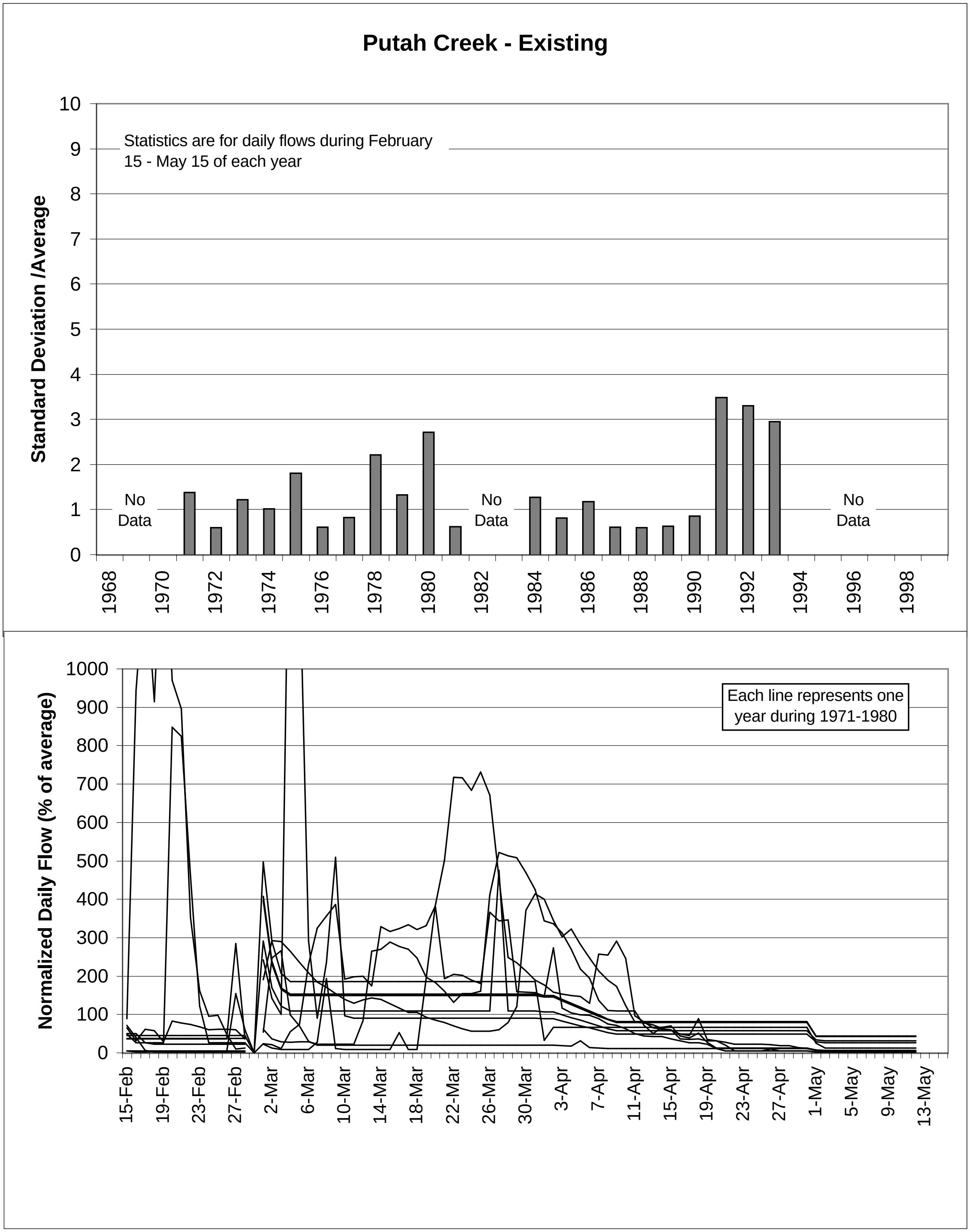

Figure F-7. Expected Variability of Existing Putah Creek Flows during the Splittail Spawning/Rearing Season, Pursuant to Settlement Agreement

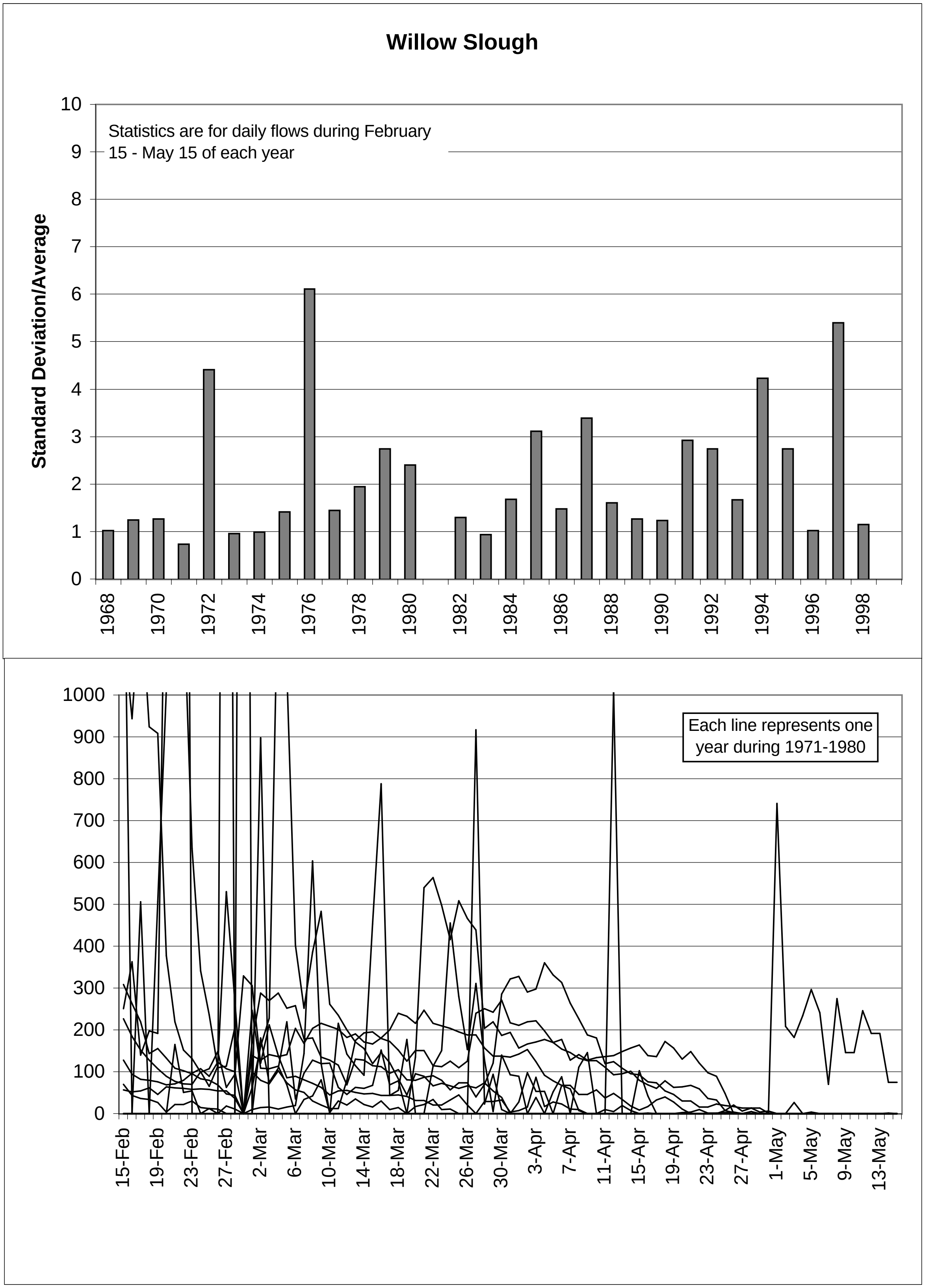

Figure F-8. Variability of Willow Slough Daily Flows during the Splittail

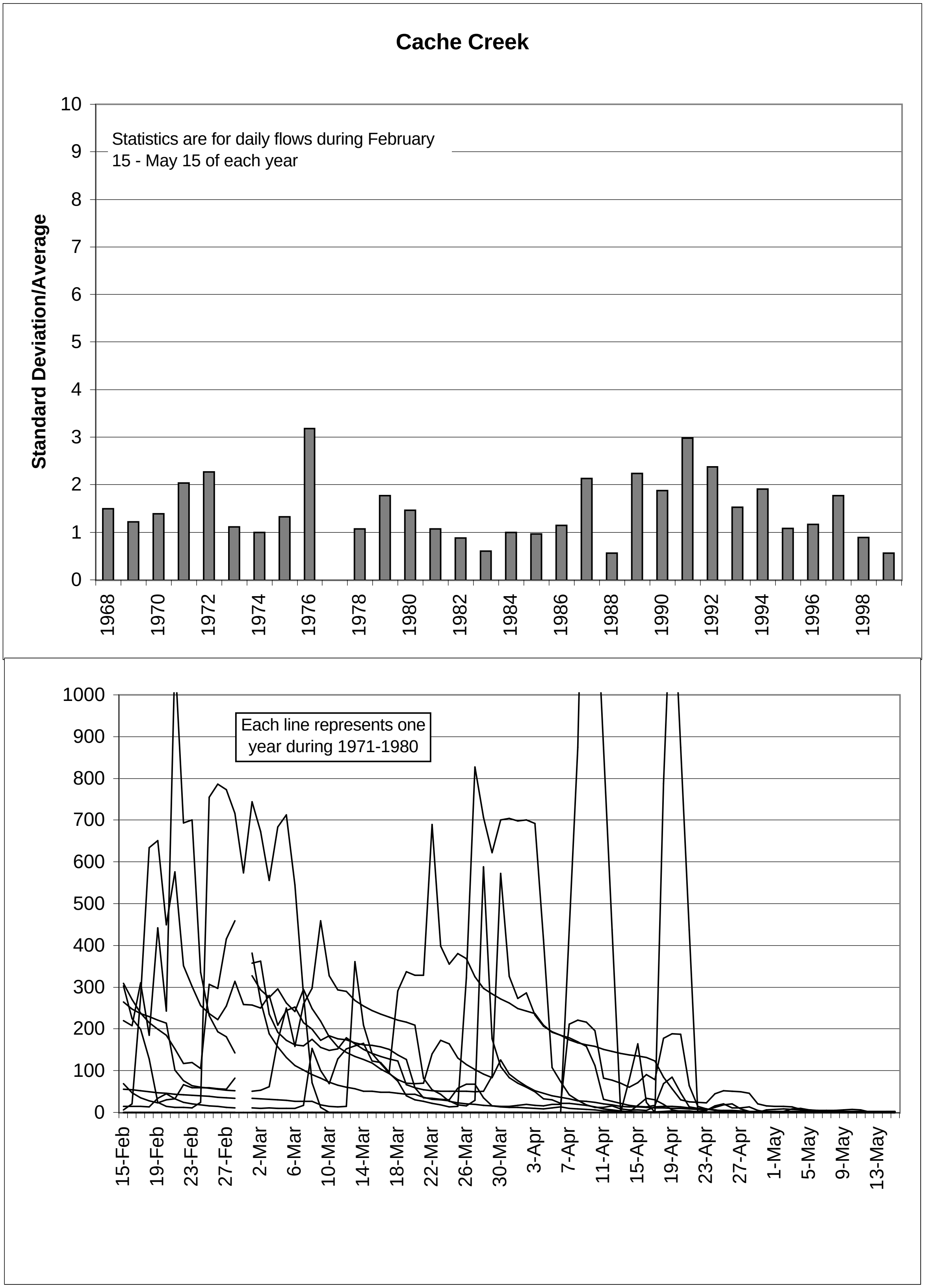

Figure F-9. Variability of Daily Flows in Cache Creek during the Splittail

exceeded 3.0. As with all of the tributaries, however, the sample of 10 years of normalized flow hydrographs (lower graph) shows that brief high flow events are not uncommon.

Knights Landing Ridge Cut is an overflow outlet at the lower end of Colusa Basin Drain. Flow in the Ridge Cut (Figure F-10) is highly irregular and episodic because low and moderate outflows from the Drain are shunted to the Sacramento River by gates located near Knights Landing. Flow through the Ridge Cut into the Yolo Bypass usually occurs only when Sacramento River stage is higher than the target water level for the Drain. Thus, inflow to the Bypass typically consists of brief pulses of high flow with no sustained base flow between pulses. This type of flow regime is much less suitable for splittail reproduction.

Conclusions

The flow regimes of all of the Yolo Bypass tributaries during the splittail spawning and rearing season are substantially more variable than the predevelopment flow regime of the Sacramento River, to which splittail are adapted. Daily flows in the tributaries often decrease to zero or near zero at some point during the spawning and rearing season, and high flows many times greater than the average flow are also common. These large flow fluctuations could adversely affect reproductive success by either dewatering eggs and fry or flushing them from the floodplain.

Among the Yolo Bypass tributaries studied, the new flow regime in Putah Creek appears to offer the greatest promise for supporting native fishes. Although, the spring flows released pursuant to the Settlement Agreement are small, they are relatively steady and reliable. An appropriately designed small floodplain area along Putah Creek where it crosses the Bypass could support successful splittail reproduction in most years. Cache Creek is the second most suitable tributary, with flows that are slightly more variable than the Putah Creek flows but relatively steady compared to the remaining tributaries. The sporadic nature of discharges from Knights Landing Ridge Cut render it unsuitable for supporting native fishes.

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Yates, Gus. 2001. Future Putah Creek flow regime for design of floodplain habitat enhancements along the Yolo Bypass reach of Putah Creek. March 14. Unpublished memorandum to Yolo Bypass Working Group steering committee, Davis, CA.

Yolo Bypass Working Group, Yolo Basin Foundation and Jones & Stokes, Inc. 2000. Yolo Bypass management strategy, Revision 3. November 16. Davis, CA. Prepared for CALFED Bay-Delta Program, Sacramento, CA.

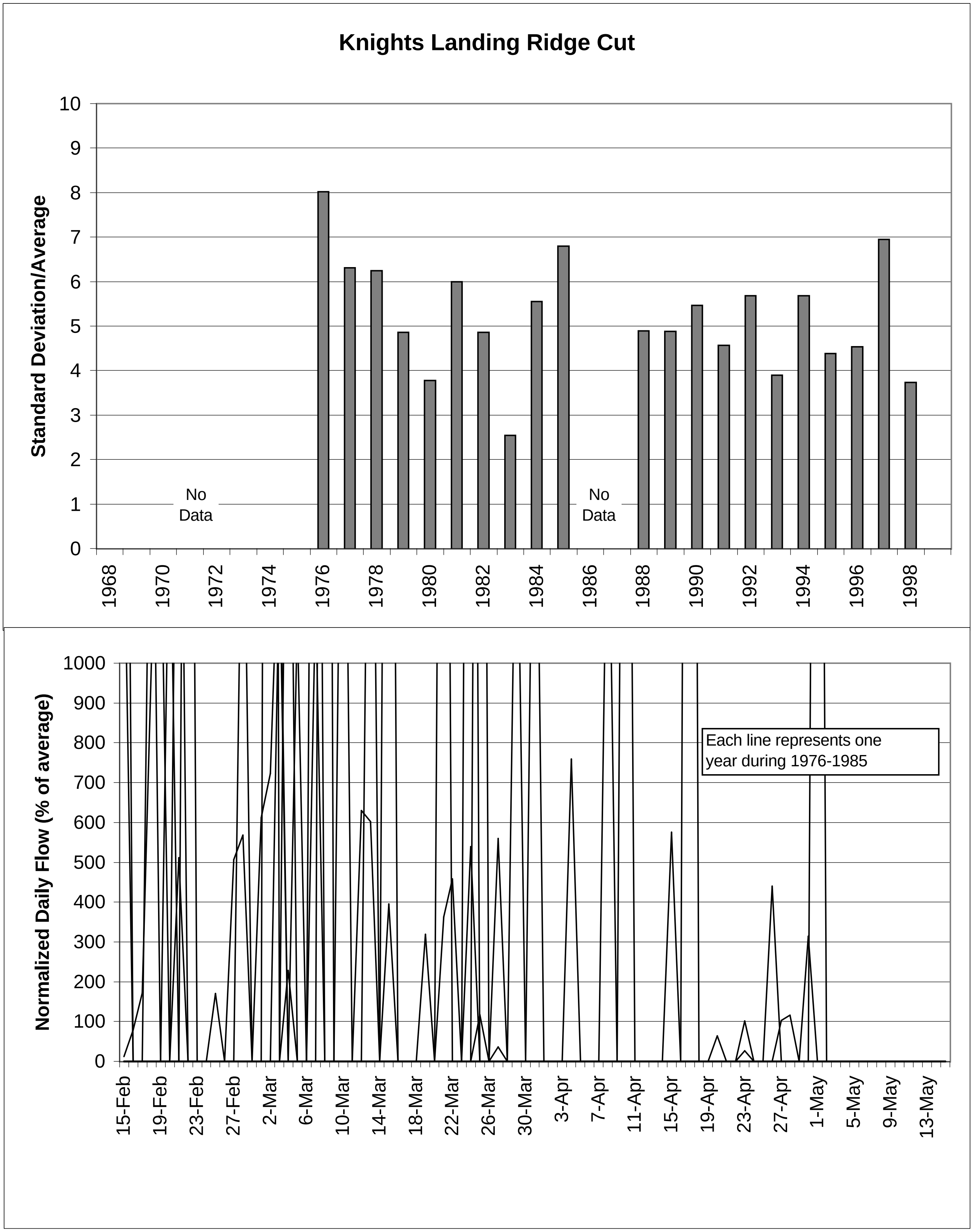


Figure F-10. Variability of Daily Flows Entering the Yolo Bypass from Knights Landing Ridge Cut during the Splittail Spawning/Rearing Season

APPENDIX G: DETAILS ON FREMONT WEIR ANALYSIS

Introduction

The Fremont Weir was identified as the best site to improve fish passage between the Yolo Bypass and the Sacramento River and to introduce regular flows from the Sacramento River into the Yolo Bypass (Chapter 4). A notch or opening in the weir was identified as one approach that could achieve both these objectives. This appendix examines the hydrology and hydraulics of such a structure, as part of evaluating its effectiveness in achieving the above objectives.

Weir and Canal Elevations

The crest elevation of the weir is at about 29 feet (NGVD 1929). The invert of the Tule Canal downstream of the weir is at about 12 to 13 feet (NGVD 1929). The canal starts about 5,000 feet downstream from the weir crest and a connection channel would be required to guide water from the river, through the weir, and into the Tule Canal.

Sacramento River Stages

Appendix F provides a stage frequency analysis for historic water levels recorded on the Sacramento River at Fremont Weir. Due to the short historic period available, analyses in Appendix F were limited to one exceptionally wet period (1997–99) and one exceptionally dry period (1989–91). Table G-1 summarizes the results from Appendix F for each month, showing median stages, the percentage of the month when stages were less than 13 feet and the percentage when they were greater than 30 feet.

Table G-1. Summary of the Stage Frequency for the Sacramento River at Fremont Weir [1]

	Wet Periods			Dry Periods		
Month	*Median Stage (ft) [2]*	*% Time less than 13 feet*	*% Time greater than 30 feet*	*Median Stage (ft) [2]*	*% Time less than 13 feet*	*% Time greater than 30 feet*
January	31.7	0%	52%	12.4	57%	0%
February	32.2	0%	75%	12.4	74%	0%
March	25.6	0%	35%	13.9	42%	5%
April	19.1	21%	13%	12.9	53%	0%
May	14.9	27%	2%	11.1	72%	0%
June	14.9	8%	10%	10.5	93%	0%
July	16.7	0%	0%	11.1	72%	0%
August	15.8	0%	0%	13.2	46%	0%
September	14.7	11%	0%	12.6	64%	0%
October	12.5	68%	0%	10.4	94%	0%
November	13.5	41%	0%	10.9	75%	0%
December	20.2	4%	20%	12.7	59%	0%

1. Stage frequency analysis summarized from Appendix F, Figures F-3 and F-4.

2. Elevations refer to the NVGD 1929 datum.

In the winter (November to April) of wet years, flows often overtopped the crest of the Fremont Weir and median stages were over 20 feet (NVGD 1929) in all months and over 25 feet from January through March (Table G-1). In these months only a relatively low notch would be required for continuous fish passage and to ensure continuous flow into the Yolo Bypass. In the summer (May to October) of wet years, median stages were around 15 feet and stages were less than 13 feet during much of September, October and November. Continuous fish passage could not be achieved with an opening through the weir—given existing Tule Canal elevations—and only small and discontinuous flows would be diverted into the Yolo Bypass in these months.

In dry periods, median stages in both winter and summer are often 13 feet or less and, during much of the year, stages are below the invert of the Tule Canal (Table G-1). During these dry periods, continuous fish passage could not be established and only very small and inconsistent flows would be diverted into the Yolo Bypass, even with a very wide opening at low elevations through the weir.

Figure G-1 provides a frequency analysis of all daily stages for the Sacramento River at Fremont Weir (January 1984 to October 2002) for the entire year, and for February to May and July to November. This analysis is intended to provide a rough indication of "typical" stages during various parts of the year. Figure G-1 indicates that median stages vary from 13 to 15 feet (NVGD 1929) depending on the period of the year, or less than two feet above the invert of the Tule Canal. February to May stages exceed 20 feet about 35 percent of the time and exceed 25 feet about 20 percent of the time.

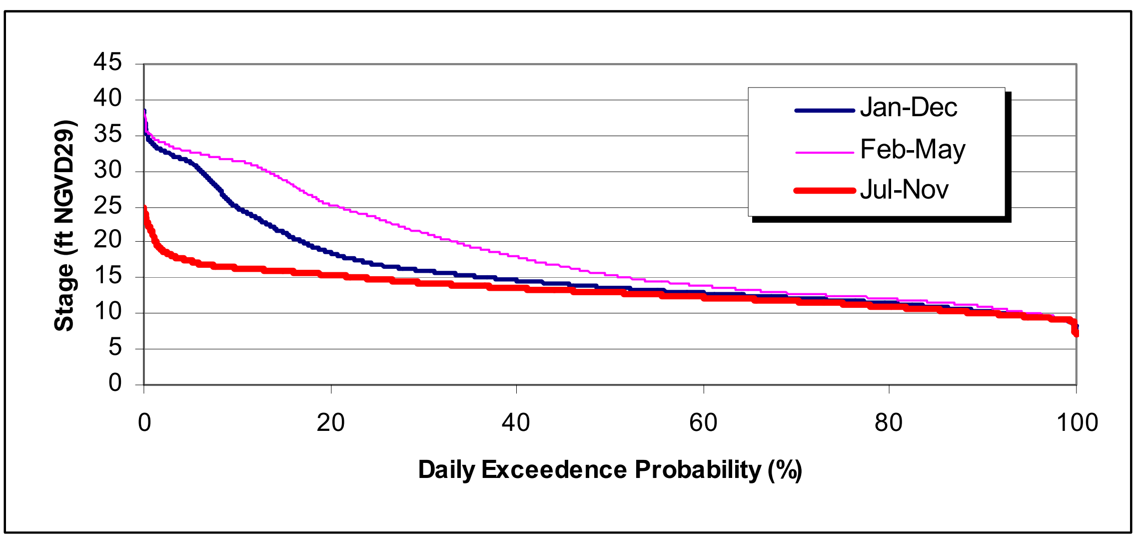


Figure G-1. Frequency Distribution of Daily Sacramento River at Fremont Weir Stages for All Years for Three Periods

Hydraulic Analysis of an Opening in Fremont Weir

Further analysis of the timing of fish movements in Yolo Bypass relative to stages in the Sacramento River would be required to select an appropriate design elevation for an opening through the Fremont Weir. The hydrologic analysis suggests that a shallow notch might be adequate to improve fish passage during wet years. However the above analysis also suggests that the bottom of an opening or notch would need to extend to the elevation of the invert of the Tule Canal in order to provide fish passage and inflows to the Tule Canal in typical years and that even such a deep notch would be of little benefit to fish passage and inflows in dry years.

We prepared a preliminary hydraulic analysis of a deep, narrow opening through the Fremont Weir to assess the potential to achieve flows adequate for floodplain inundation and to examine velocities for fish passage. The analysis was based on a low flow channel extending through the weir that was 4 feet wide by 3 feet deep with its invert at 13 feet (NVGD 1929) with a larger trapezoidal section with a base width of 10 feet and side slopes of 2:1 set above the low flow channel at an elevation of 16 feet (NGVD 1929). The invert of the low flow section is about 16 feet below the average elevation of the Freemont Weir and set to the approximate elevation of the invert of the Tule Canal, which begins about 4000 feet downstream. Such an opening represents only one of many alternatives that could be developed for hydraulic analysis.

The hydraulic characteristics of the opening and the connecting channel to the Tule Canal were analyzed with a steady-state HEC-RAS model of the Toe Drain and Tule Canal. The model extended from just below the Lisbon Weir north to the Sacramento River. Cross sections of the Tule Canal were estimated from USACE survey data, which marked the overbank areas of the canal, and a longitudinal bed profile surveyed in May of 2000. The assumed connecting channel and weir notch were added to the model. Roughness values in the channel were set at 0.04 for the main channel and 0.05 for the overbank areas. Discharges through the notch ranging between 100 and 2000 cfs were assumed to investigate the relationship between stage in the Sacramento River and hydraulic performance of the connection.

Figure G-2 presents the relationship between stage in the Sacramento River and discharge through the particular opening. For stages less than 20 feet in the Sacramento River, flows of less than 100 cfs would enter the Tule Canal and Yolo Bypass. Stages are less than 20 feet about 65 percent of the time from February through May. Flows of 500 cfs enter the Tule Canal and Yolo Bypass for stages greater than 25 feet. Such stages occur about 20 percent of the time from February through May but mostly in wet years. In dry years, stages exceeding 25 feet are only rarely reached. Further analysis of stages and inflows during specific sequences of years would be required to evaluate the potential effectiveness of a notch in the Fremont Weir in creating inundated floodplain habitat along the Yolo Bypass.

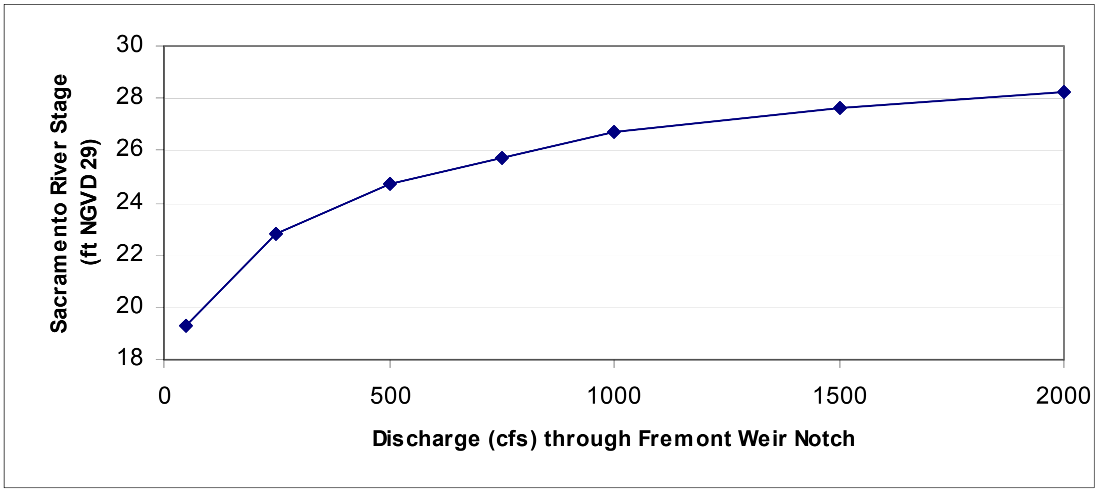


Figure G-2. Discharge through the Notch versus Stage in the Sacramento River at the Fremont Weir

Figure G-3 provides an analysis of maximum and average velocities through the opening and along the connecting channel for various discharges through the opening. For typical flows of less than 500 cfs through the opening, maximum velocities would average less than 4 feet/second. Such velocities are thought to be low enough for upstream adult fish passage for the target species (Chapter 1). Figure G-3 shows that high velocities develop at the Fremont Weir during high Sacramento River stages and large discharges through the notch. These high velocities are local to the weir and magnitudes quickly diminish downstream of the weir. Such velocities present a considerable threat to the opening through the weir and to the downstream side of the weir itself.

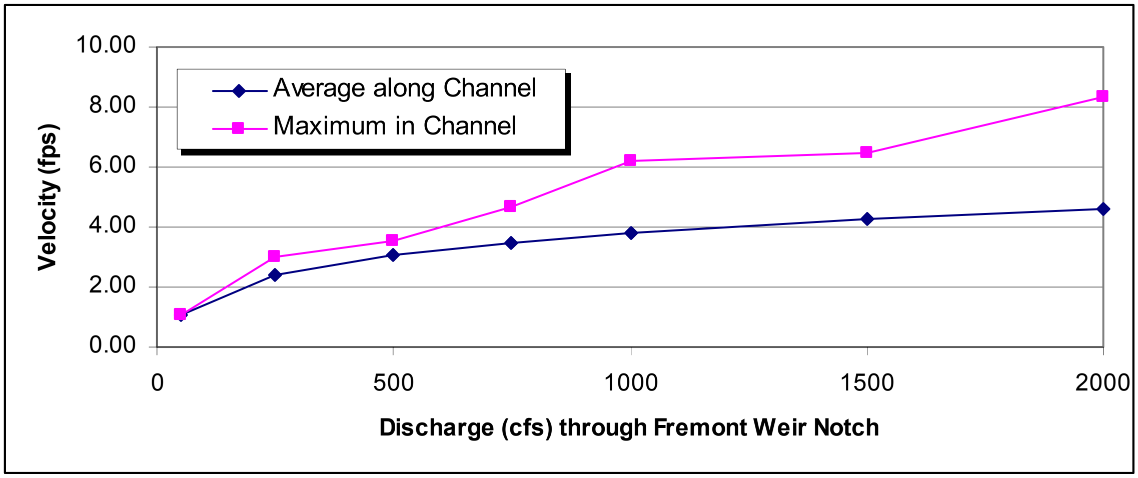


Figure G-3. Velocities through the Notch in Fremont Weir and along the Connecting Channel for Various Discharges through the Notch

The opening through the Fremont Weir described above would require engineering studies to ensure that the structure remains stable and numerical or physical modeling studies to ensure that the weir still functions as designed for flood control. These engineering studies are well beyond the scope of this study. The engineering feasibility studies, environmental compliance and permitting for such a project would likely require several years to complete.

APPENDIX H: 1962 FLOOD STRIP SITE ANALYSIS

A one-dimensional HEC-RAS model of the Tule Canal was developed to investigate water surface profiles near the 1962 Flood Strip, evaluate the potential for inundated floodplain habitat in the strip and evaluate the installation of an adjustable weir in the canal to inundate the site.

Geometry for the HEC-RAS Model

The geometry of the Tule canal from Lisbon Weir to Knights Landing was based on assumed trapezoidal cross sections and available survey and bathymetry data. Channel top widths were defined from cross sections of the Yolo Bypass developed by the USACE and channel inverts were estimated from a longitudinal profile of the canal surveyed in May of 2000 (Figure H-1).

The Tule Canal invert near the 1962 flood strip ranges from 5 feet to 8 feet (NVGD 1929) at the upstream end near the entrance to the flood strip and the elevation of the entrance to the 1962 Flood Strip area is estimated to range between 11 feet and 14 feet (NGVD 1929). The elevation of the levee separating the Tule Canal from the flood strip ranges between about 13 feet and 16 feet (NGVD 1929). Therefore, water in the canal would need to reach elevations of around 12 to 14 feet to flood the site.

Water Surface Profile Analysis

Figure H-1 presents water surface profiles along the Tule Canal for discharges of 100, 500 and 1,000 cfs. The profiles indicate that flows exceeding 500 cfs would be required to inundate the flood strip area and that depths over the entrance to the flood strip site would be shallow at these flows.

Figure H-2 presents profiles for the same three discharges but includes an adjustable weir with its crest at an elevation of 13 feet (NGVD 1929). The weir would extend to about 5 feet above the local streambed. Figure H-2 shows that installation of a weir in the canal would create a head difference of between 2 and 7 feet along the flood strip site, depending on flow. Thus, even at low discharges, the weir would direct flow into the flood strip and flow could be achieved. However, water depths in the habitat area would be variable, and may be less than half a foot when discharges through the canal are low. Conditions at the exit of the flood strip and potential access for splittail spawners could not be evaluated from the available information. The site would require grading and planting of vegetation to raise water levels as much as possible, reduce local velocities, and drain completely once the weir is lowered.

Installation of such a weir would raise other issues for the Tule Canal. First, flows in the Tule Canal are both low and seasonally sporadic and may not be adequate to provide suitable conditions along the site and avoid stagnant upstream pooling. Second, upstream fish passage might occur through the inundated flood strip but would need to be studied if such a structure was built in the Tule Canal.

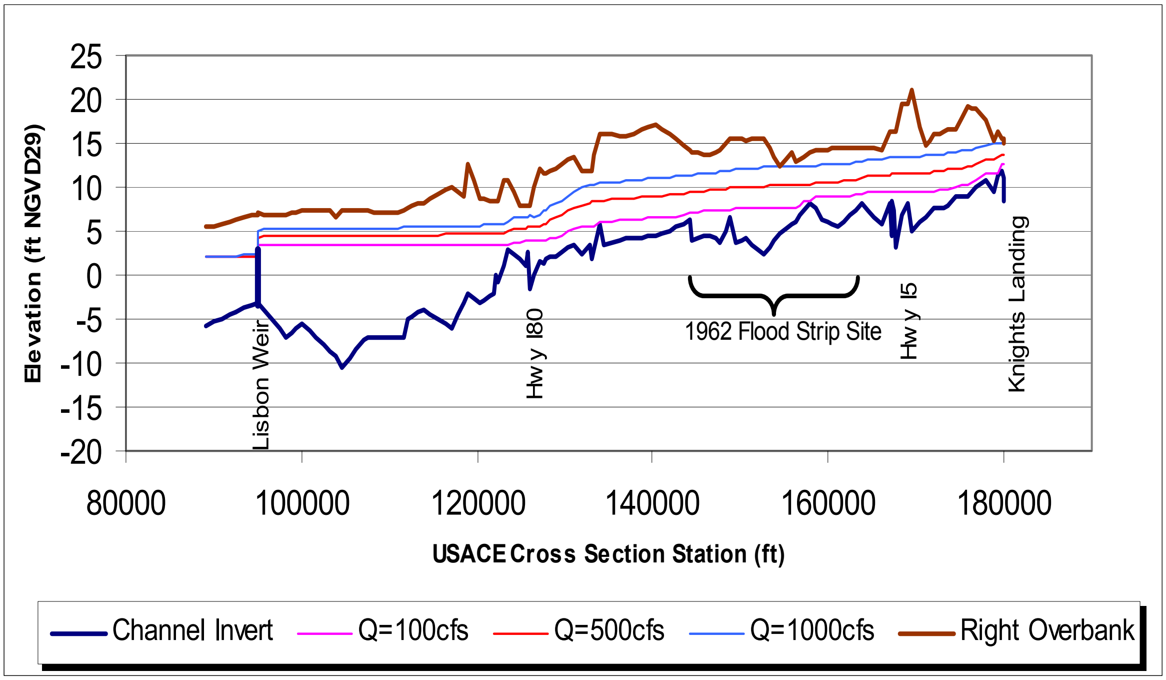


Figure H-1. Water Surface Profiles near the 1962 Flood Strip Site for Existing Conditions

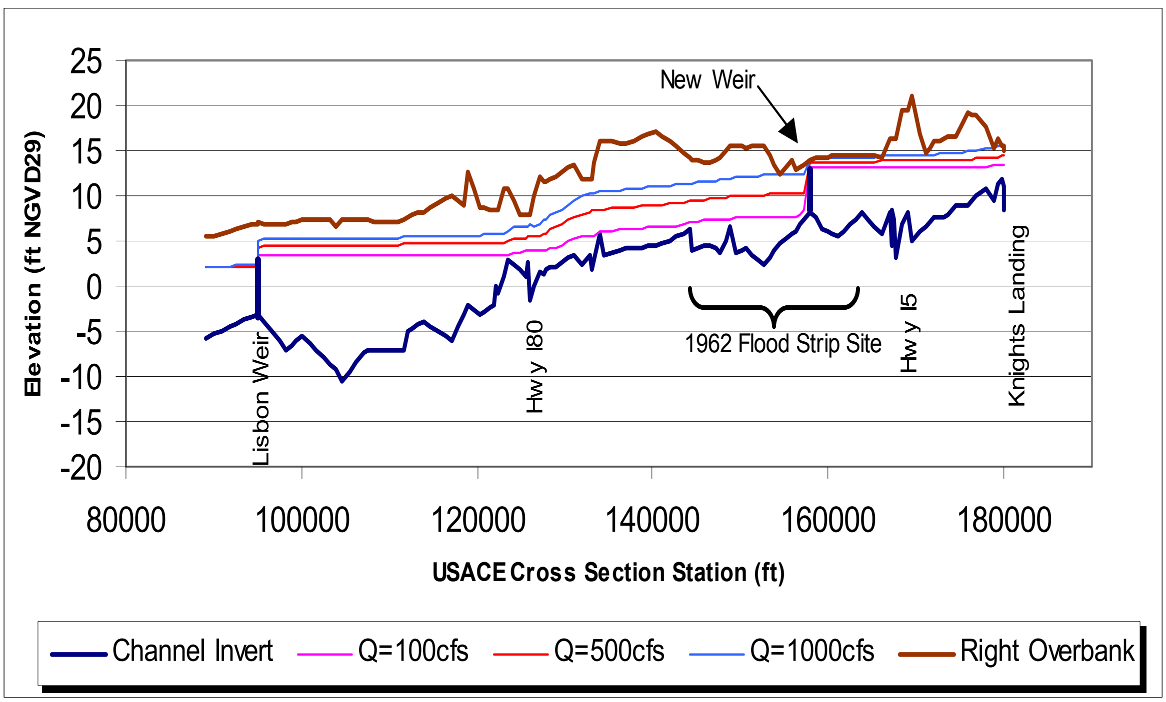


Figure H-2. Water Surface Profiles near the 1962 Flood Strip Site with an Adjustable Weir in the Tule Canal

APPENDIX I: PUTAH CREEK CROSS SECTIONS

These cross sections are a subset of the survey data that DWR collected along Putah Creek in spring 2002 to support restoration efforts in the Yolo Bypass.

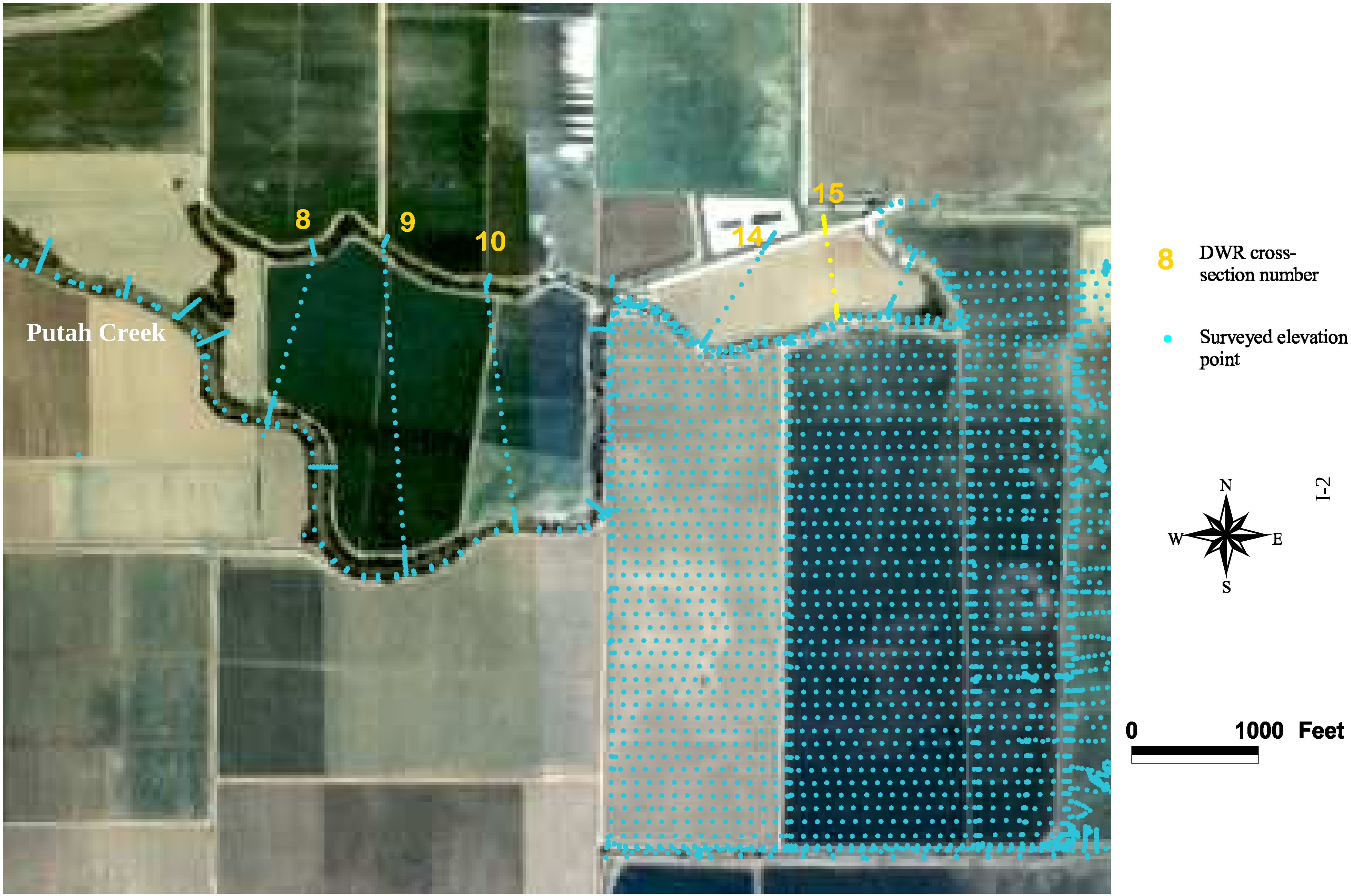
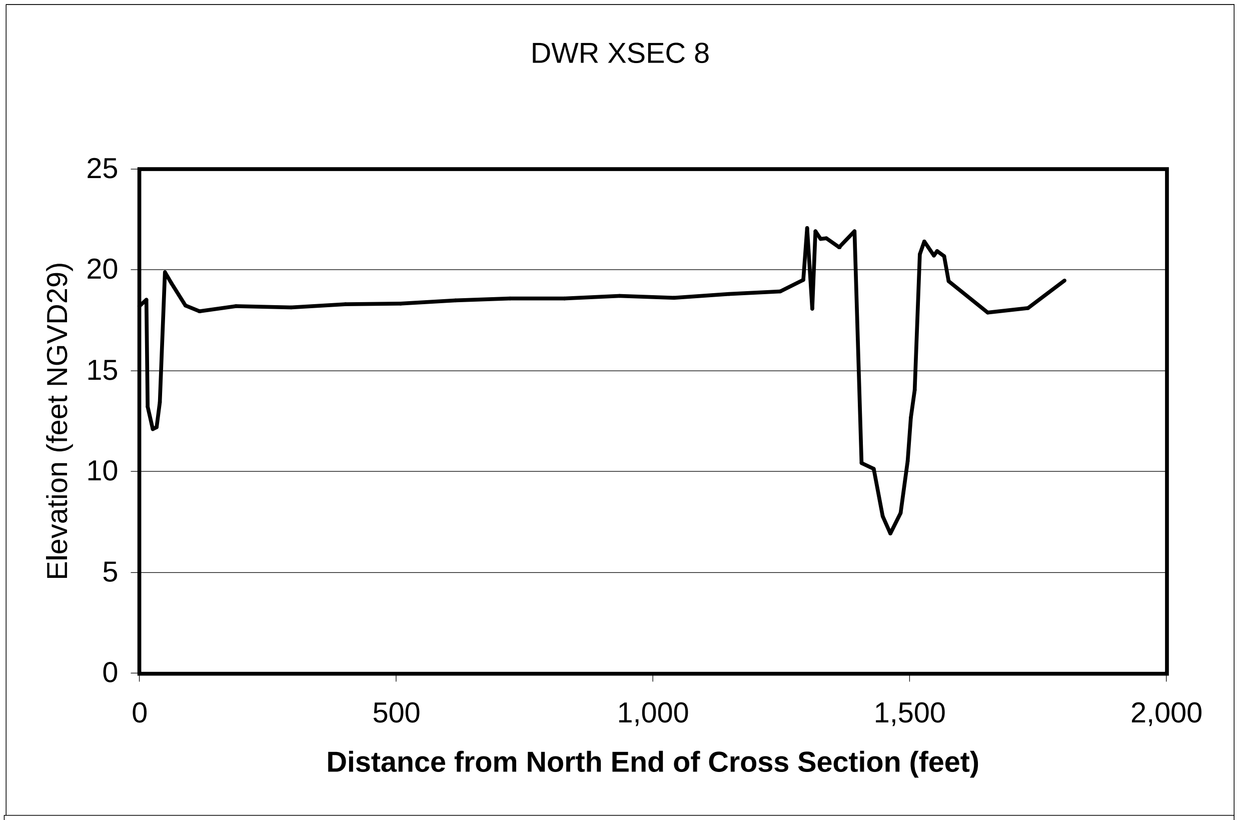


Figure I-1. Locations of Cross Sections that Include Split Channels of Putah Creek



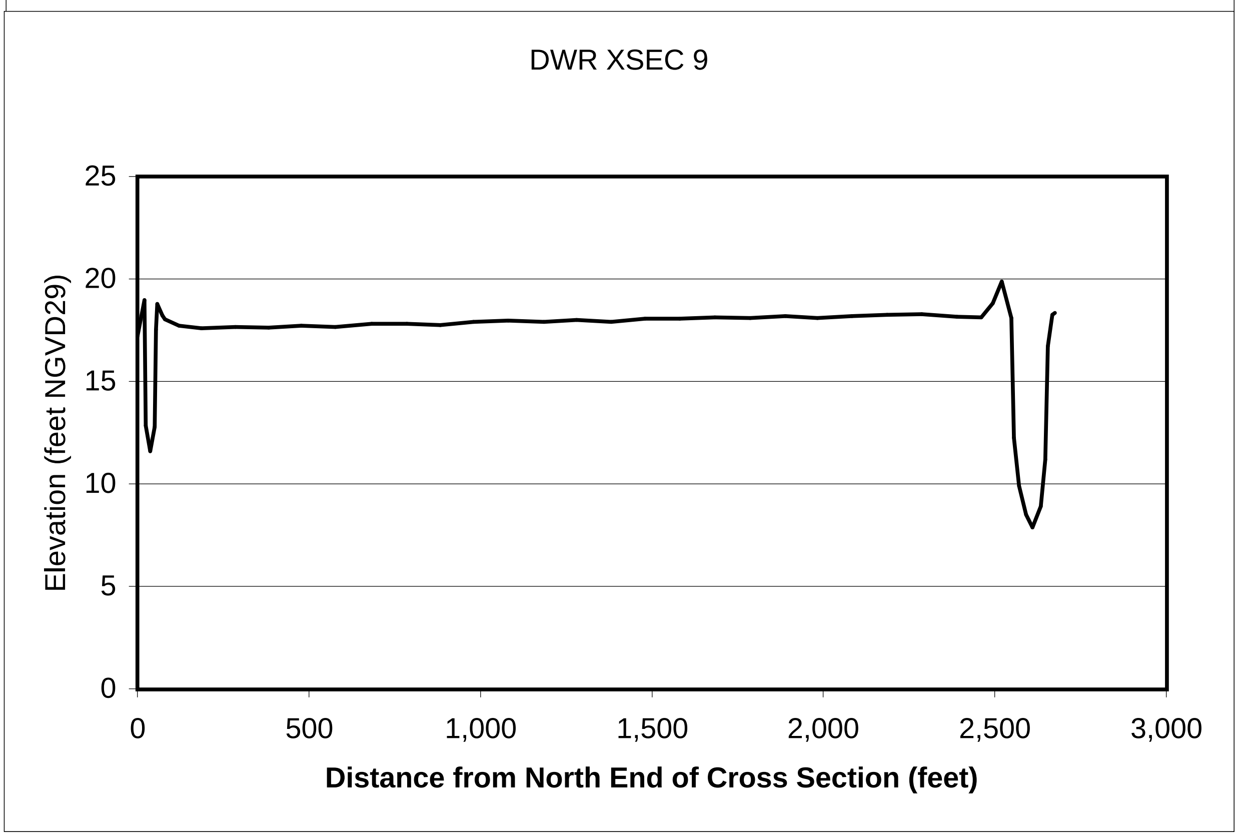
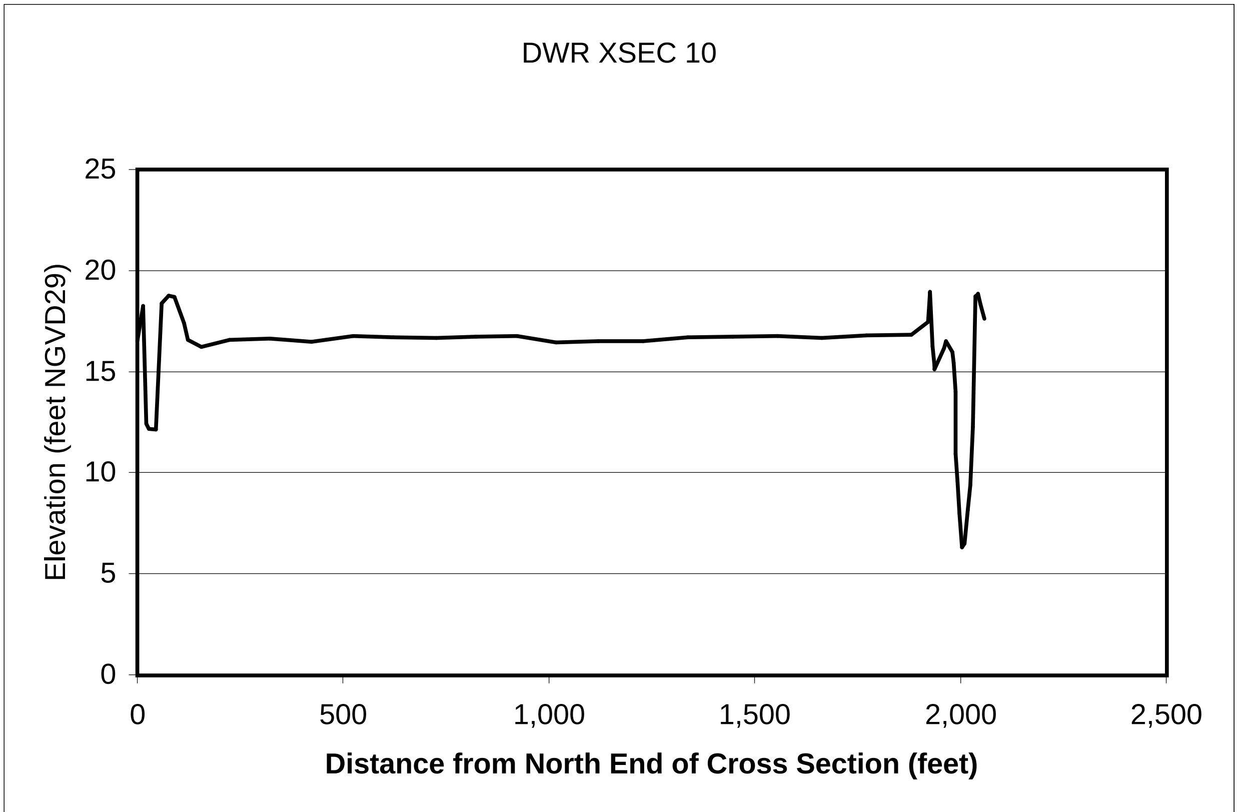


Figure I-2. DWR Cross Sections that Include Split Channels of Putah Creek



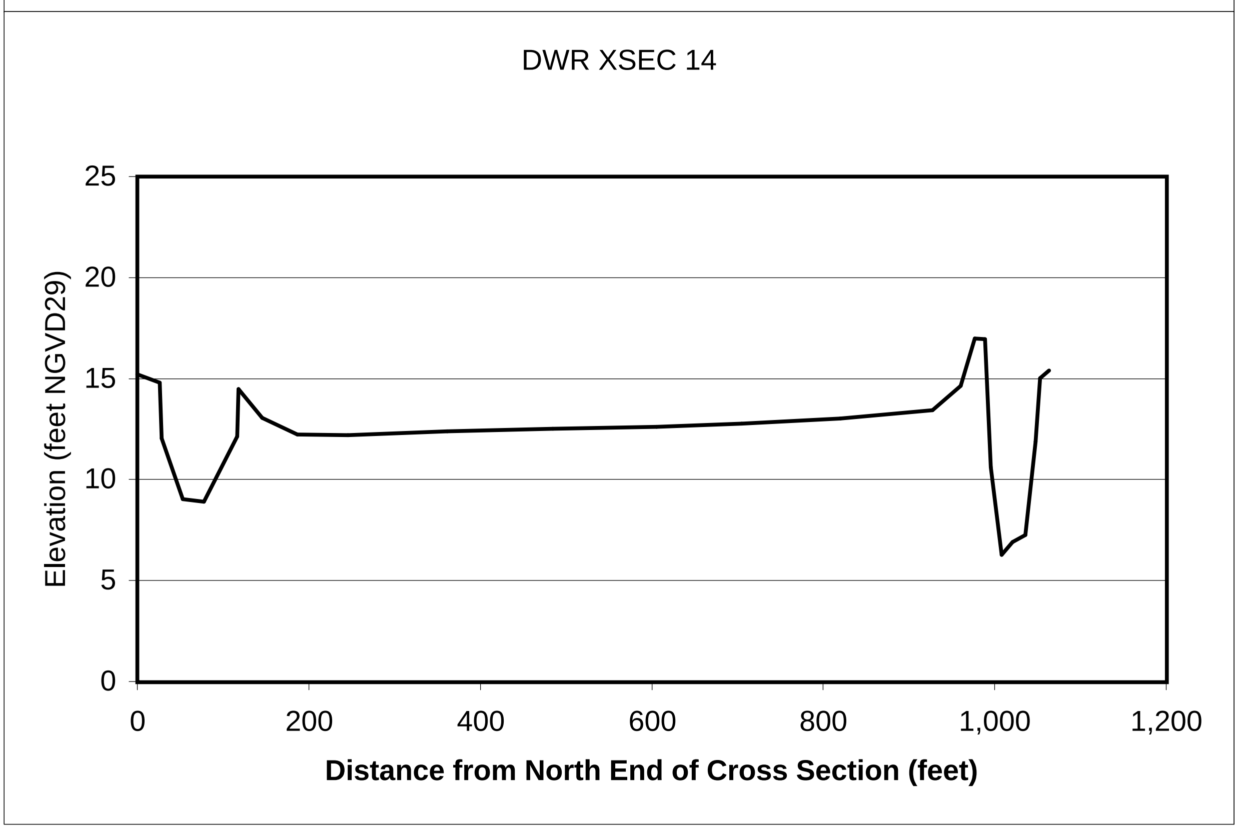


Figure I-2--Continued

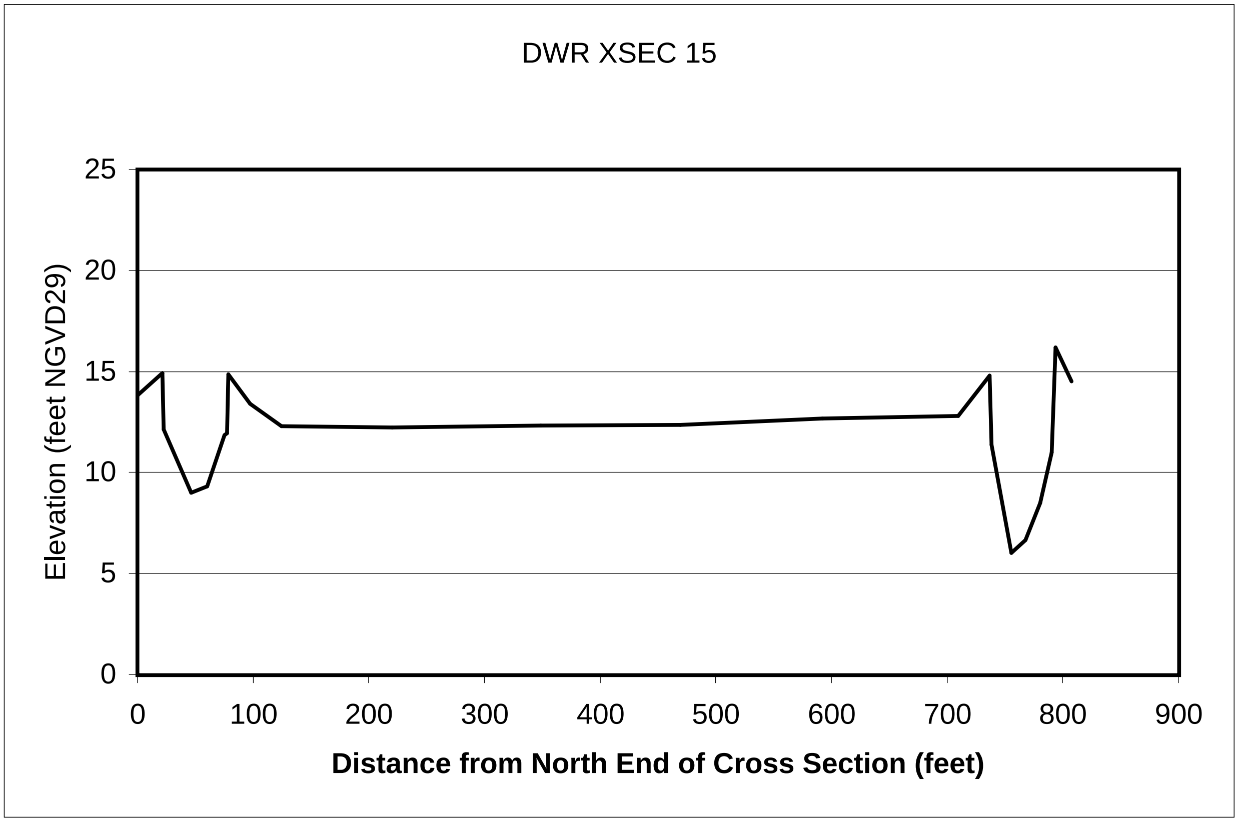


Figure I-2--Continued

APPENDIX J: PUTAH CREEK HYDROLOGY

<u>Putah Creek Flow Regime at the Yolo Bypass</u>

Characterization of the flow regime of lower Putah Creek is needed to design fish passage and floodplain habitat enhancements along the Yolo Bypass reach of the creek. The historical flow regime prior to construction of the Solano Project is needed to interpret geomorphic characteristics of the creek channel, and the existing flow regime is needed to estimate the availability of sustained low flows to supply the floodplain project and to estimate the magnitude of flood flows that could potentially damage channel features and structures built for the project.

For the present analysis, the flow regimes are characterized by exceedence probabilities, flow duration, and flood hydrographs. Exceedence probabilities are the probability that a given flow magnitude will be exceeded in any year and are used to characterize high-flow events. These are calculated for flows of various durations (instantaneous, 1-day, 5-day, 10-day, etc.) and for several seasonal windows (full year, January–April, etc.), resulting in families of curves. Flow duration is the complete frequency distribution of daily flows during the analysis period and is calculated here for various seasonal windows as well as for all months of the year. To further characterize Putah Creek hydrology, standard flood hydrographs were developed for historical and existing conditions, and the largest Putah Creek flood likely to occur in the absence of general Yolo Bypass flooding was estimated.

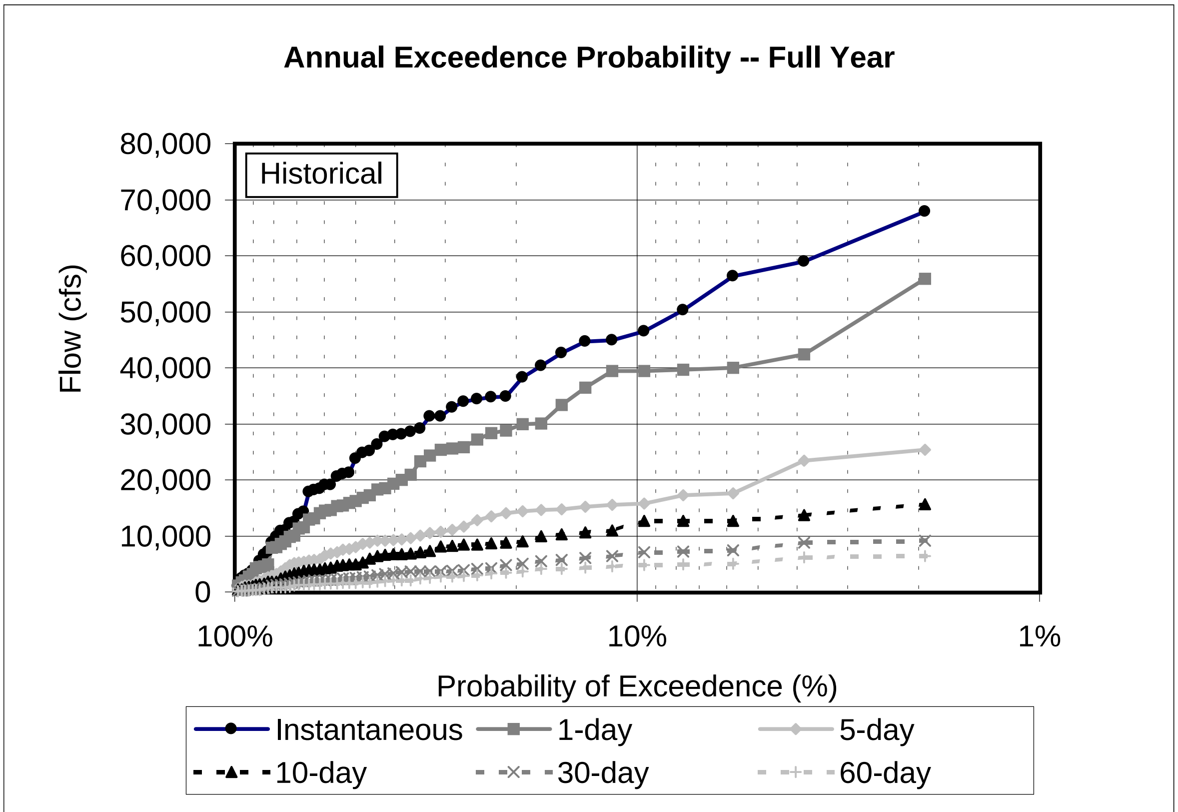
Before these statistics can be calculated, it is necessary to translate gaged flow records from locations at or above Winters to the west side of the Yolo Bypass by accounting for tributary inflows, diversions, evapotranspiration, seepage losses, and channel storage effects. The details and results for all of these calculations are described in the following sections of this appendix.

Historical Flow Regime

The flow regime in lower Putah Creek was radically altered by the construction of Monticello Dam in 1957 and the Putah Diversion Dam in 1959. Over 90 percent of the 633-square mile watershed is upstream of Monticello Dam, and the reservoir behind the dam (Lake Berryessa) has a capacity 4.4 times larger than the average annual runoff from the watershed. Consequently, the dam almost completely controls flows in lower Putah Creek. Flow data from before the construction of the dam were used to characterize the natural flow regime in the creek. The first gaging station on the creek was "Putah Creek at Winters" (U. S. Geological Survey [USGS] station number 11454500), which was in operation during water years 1906–1932 (water years begin in October of the preceding calendar year and end in September). Gaging station "Putah Creek near Winters" (USGS station number 11454000) is located about 1 mile below Monticello Dam. It began operation in water year 1932 and is still active. Daily flows and maximum annual peak flows for the water years 1906–1956 were compiled by combining data for the two gages.

<u>*Annual and Seasonal Exceedence Probability*</u>

Annual exceedence probability curves for instantaneous, 1-day, 5-day, 10-day, 30-day, and 60-day durations are show in the upper graph in Figure J-1. Data for the 51-year period of record are plotted on a semi-logarithmic plot using Weibull plotting positions and no assumptions regarding frequency distribution (e.g., Log Pearson III). Channel storage along the 20–25 miles



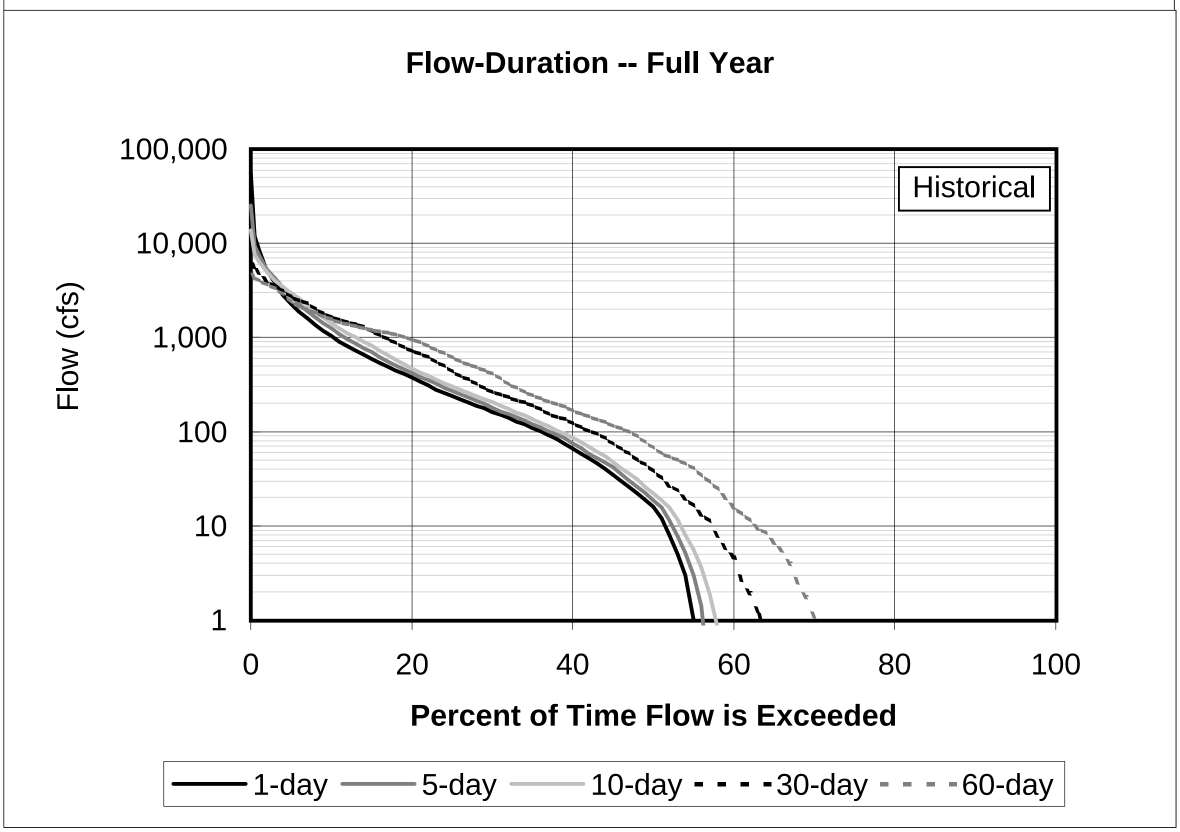


Figure J-1. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Historical Conditions -- Full-Year Data

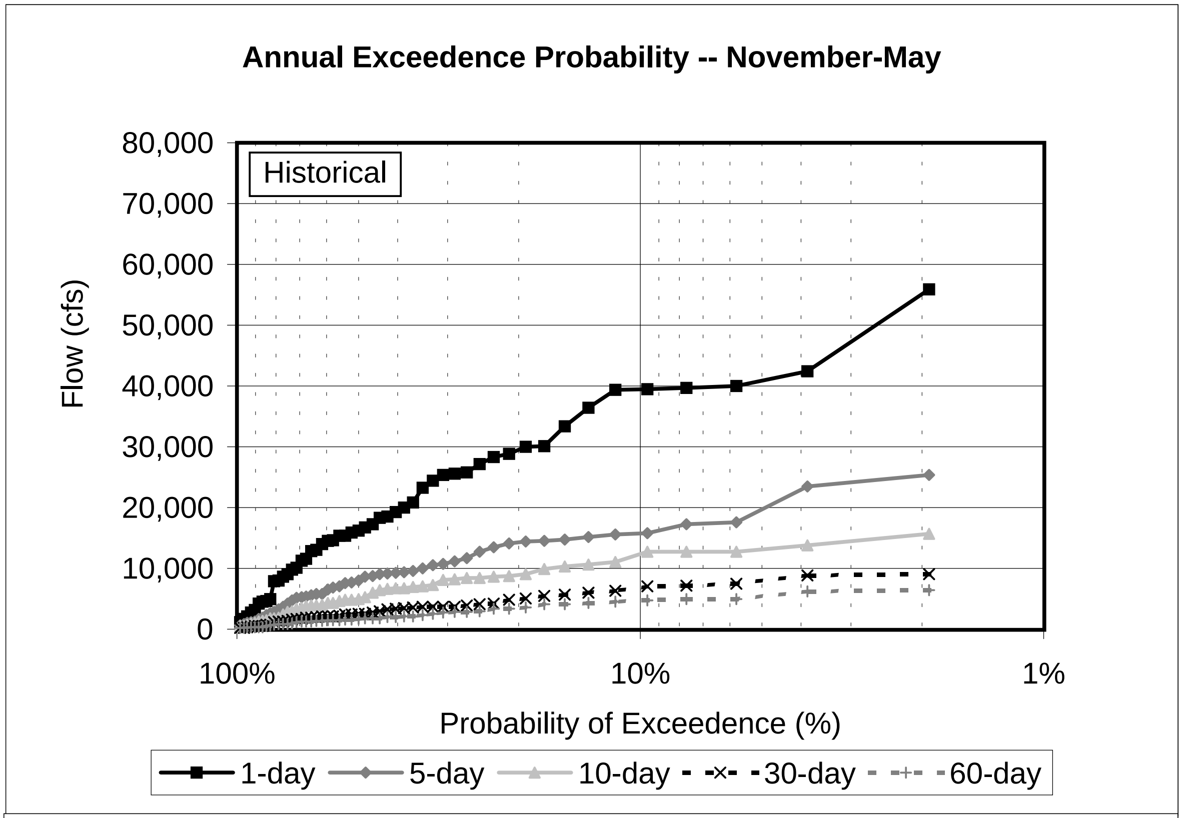
between the gage sites and the Yolo Bypass significantly attenuates flood peaks. Peak flows at the gage "Putah Creek near Davis" during water years 1949–1957 averaged 85 percent as large as the peaks at the "near Winters" gage. An exponential decay in peak magnitude with distance was assumed, and a decay rate of 0.992 per mile was calculated using the "near Davis" data. Projecting this decay rate to River Mile 0.0 at the western edge of the Yolo Bypass indicates that instantaneous peaks at the Yolo Bypass are 83.9 percent as large as at the "near Winters" gage. Larger peaks might experience less attenuation because of the larger volume of runoff. The instantaneous peak flows were not adjusted for tributary inflow from Dry Creek (the largest unregulated tributary below the gage) because it would be much smaller than the peak flow from the rest of the watershed and occur substantially in advance of it. Adjustments for seepage and diversions were also not made, as they would be negligible compared to the flood peak. The graph indicates that the 100-year peak flow at the Bypass was on the order of 72,000 cfs. The largest flood of record occurred during water year 1940 and peaked at 81,000 cfs at the "near Winters" gage.

Annual exceedence probability curves for the 1-day through 60-day durations were developed from daily flow data for the "at Winters" and "near Winters" gages. Time series of 5-day through 60-day durations were created from the daily flow time series by calculating n-day moving-averages. Note that the moving average includes daily values within the n-day window that are above and below the average. Thus, it does not indicate the minimum flow during that window, which could be of greater relevance to floodplain habitat. For the longer durations in particular, the moving average could conceal substantial short-term flow variability. Flow variability in Putah Creek is described in Appendix F "Yolo Bypass Hydrologic Analysis".

For the 1-day through 60-day curves, flow gains and losses between the gage locations and the Yolo Bypass were taken into consideration. Flows at the gages were translated to flows at the Bypass by adding estimated tributary inflow from Dry Creek to the "near Winters" data (the "at Winters" gage was below Dry Creek). Dry Creek is ungaged, and daily flows were estimated from the "near Winters" gage by multiplying those data by the ratio of the respective drainage areas and the ratio of the area-weighted average annual rainfall on the two drainage areas. The gaged flows were also adjusted by subtracting net flow losses due to seepage, evapotranspiration (ET), and diversions by riparian irrigators. Net flow losses between the gages and the Bypass for dry, normal and wet years were developed by the Putah Creek Council in the mid-1990s (unpublished data). The year types were assigned based on quartiles of annual rainfall, with the normal range including all years between the 25^{th} and 75^{th} percentile. Net losses ranged from 9 cfs in January of wet years to 66 cfs in July of dry years.

The resulting exceedence probability curves for 1-day through 60-day durations show that high flows in Putah Creek typically lasted only 1–5 days. Peak flows for large events (greater than a 5-year event) were 14–41 percent larger than the corresponding maximum 1-day flows, and the 1-day flows were slightly more than twice as large as the corresponding 5-day flows.

The exceedence probability analysis was refined by applying the calculations to selected seasons during the year: November–May (wet season), June–October (dry season), and January–April (splittail spawning and rearing season). The results are shown in the upper graphs in Figures J-2 through J-4. The Y-axis scale is the same for all of the graphs, to facilitate comparisons among them. Note that the instantaneous curve is not present in the seasonal graphs because the USGS peak flow data sets are for full years only. The seasonal graphs confirm the expected pattern of



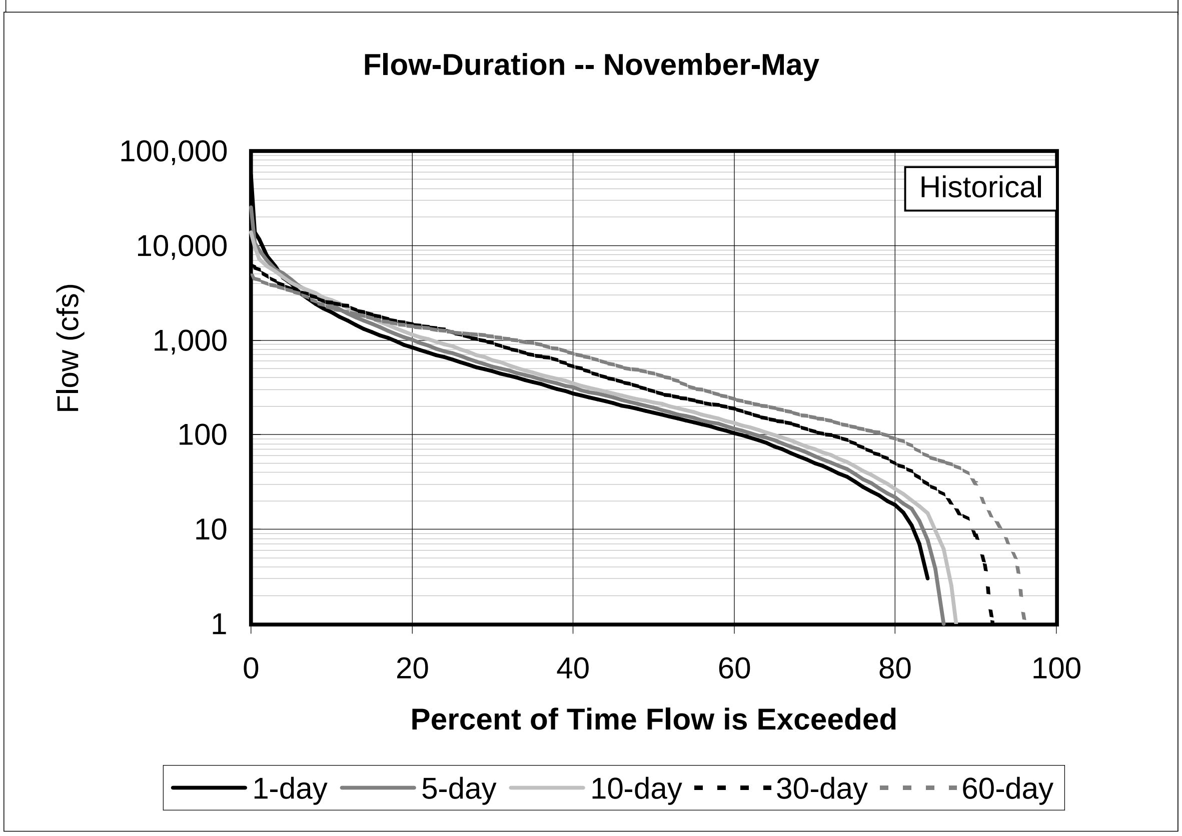
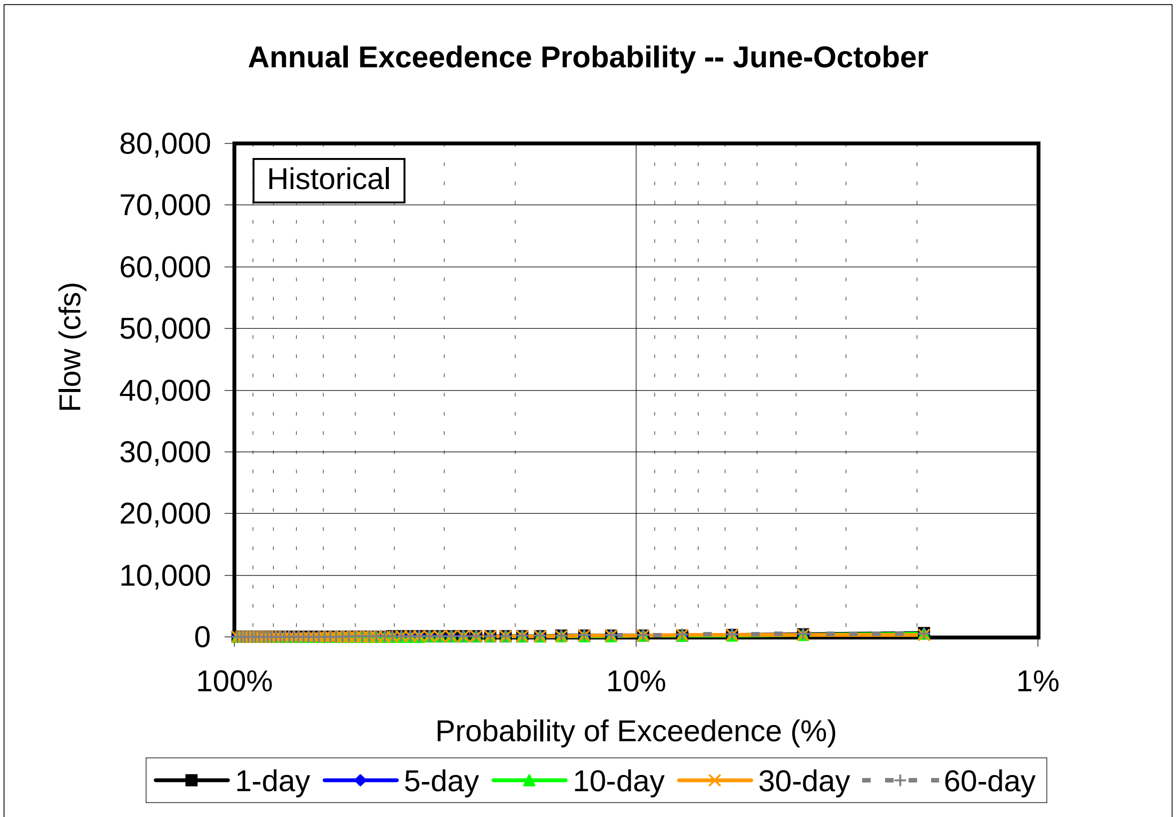


Figure J-2. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Historical Conditions -- November - May



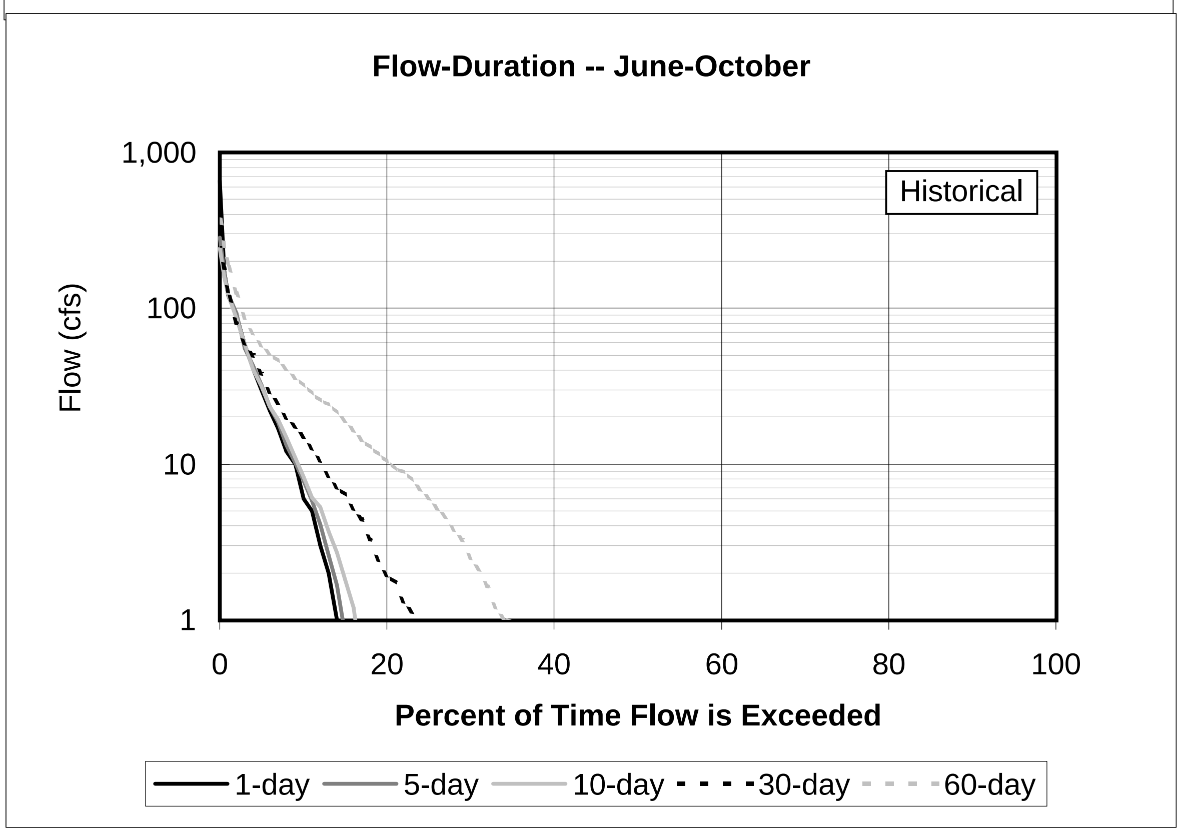


Figure J-3. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Historical Conditions -- June-October

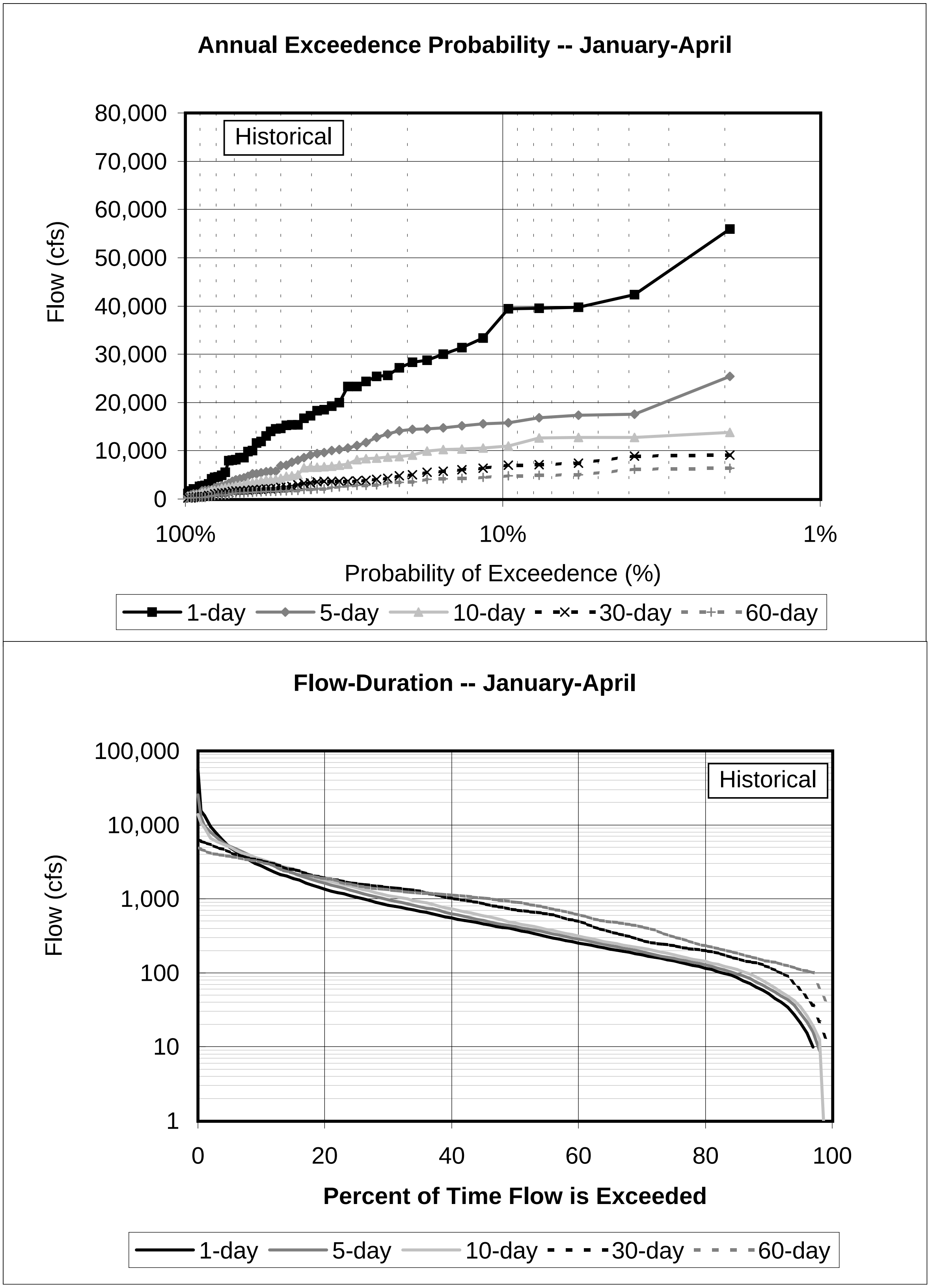


Figure J-4. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Historical Conditions -- January-April

flow seasonality. When the seasonal window is narrowed to November–May, the curves remain about the same as for the full-year data. When the seasonal window is further narrowed to January–April, there still is little change in the exceedence probability. In contrast, maximum flows during June–October are barely greater than zero. This simply confirms that the great majority of historical high flows occurred during January–April.

Annual and Seasonal Flow Duration

Flow-duration curves are a useful way to portray the full range of the flow regime, rather than just high flows. All daily flows at the Yolo Bypass location during water years 1935–1956 were ranked, and exceedence percentiles were calculated. This abbreviated historical period was used because of the array size limitation of one Excel spreadsheet function and because 21 years of record is more than sufficient to characterize the frequency of low to moderately high flows. It also matches the number of years used in the flow duration analysis of the existing flow regime. Flow duration curves for 1-day, 5-day, 10-day, 30-day and 60-day moving averages are shown in the lower graph in Figure J-1. These include data for all months of the year. The lower graphs in Figures J-2 through J-4 show the curves for the same seasonal windows used in the exceedence probability analysis.

The flow duration curves for full-year data (Figure J-1) show that there was no inflow to the Bypass much of the time prior to construction of Monticello Dam. For example, daily flows exceeded 1 cfs only 55 percent of the time. However, flows exceeded 100 cfs 36 percent of the time, and many of those days of high flows probably fell within the splittail spawning and rearing season. The seasonal flow-duration graphs confirm that flows were highly seasonal. During November–May, flow exceeded 1 cfs 85 percent of the time and exceeded 100 cfs 60 percent of the time. If the seasonal window is narrowed to include only the months of splittail spawning and rearing (January–April), those percentages increase to 98 percent and 81 percent, respectively. In contrast, flow exceeded 1 cfs only 14 percent of the time during the dry season (June–October).

Flood Hydrograph

A flood hydrograph is a detailed flow hydrograph during a flood event that uses short time steps to depict the rate of rise and fall before and after the peak flow. Often, time steps of only 1–2 hours are used. Although data for a particular historical flood events can be used for this purpose, a standard flood hydrograph is intended to be a generic representation of streamflow rise and fall during a flood of a specified magnitude.

Standard flood hydrographs for 100-year and 10-year events under historical conditions were developed by USACE for its reconnaissance study of flooding near Winters (USACE 1995). Because the watershed is large and high flows persist for several days, a 5-day hydrograph was developed from daily data, with refinement of the shape of the peak based on measured 15-minute data for the record flood of 1940. Daily inflow to Lake Berryessa during water years 1957–1994 was calculated from reservoir operations data and combined with gaged flows for the "at Winters" and "near Winters" gages to obtain almost 90 years of record of inflow to Lake Berryessa. The resulting flood hydrographs are shown in Figure J-5. The inflow to Lake Berryessa essentially represents historical conditions because the watershed upstream of the reservoir has no other major storage facilities.

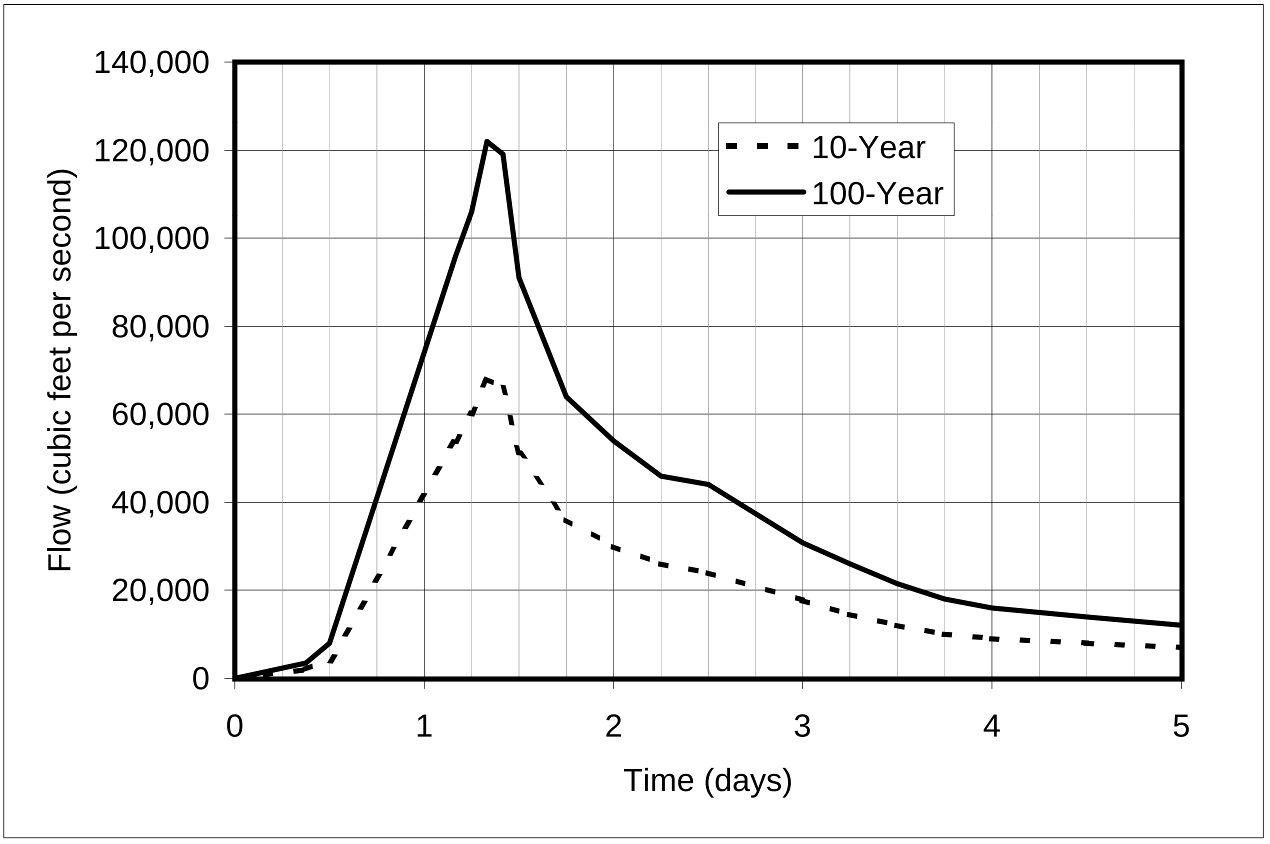


Figure J-5. Balanced Flood Hydrographs of Inflow to Lake Berryessa under Historical and Existing Conditions

The flood hydrograph at the Yolo Bypass would be attenuated relative to the hydrograph at Monticello Dam; that is, it would be slightly broader, flatter and delayed. For small floods, peak flow at the Yolo Bypass is approximately 80 percent as large as the peak at Monticello Dam, while the flow on the days preceding the peak are slightly higher (the total volume of flow for the 5-day hydrograph period remains approximately the same). The relative attenuation for larger floods is probably smaller because channel storage is smaller relative to the volume of flow. A channel hydraulics model could provide a quantitative estimate of hydrograph attenuation for a 100-year event.

Present Flow Regime

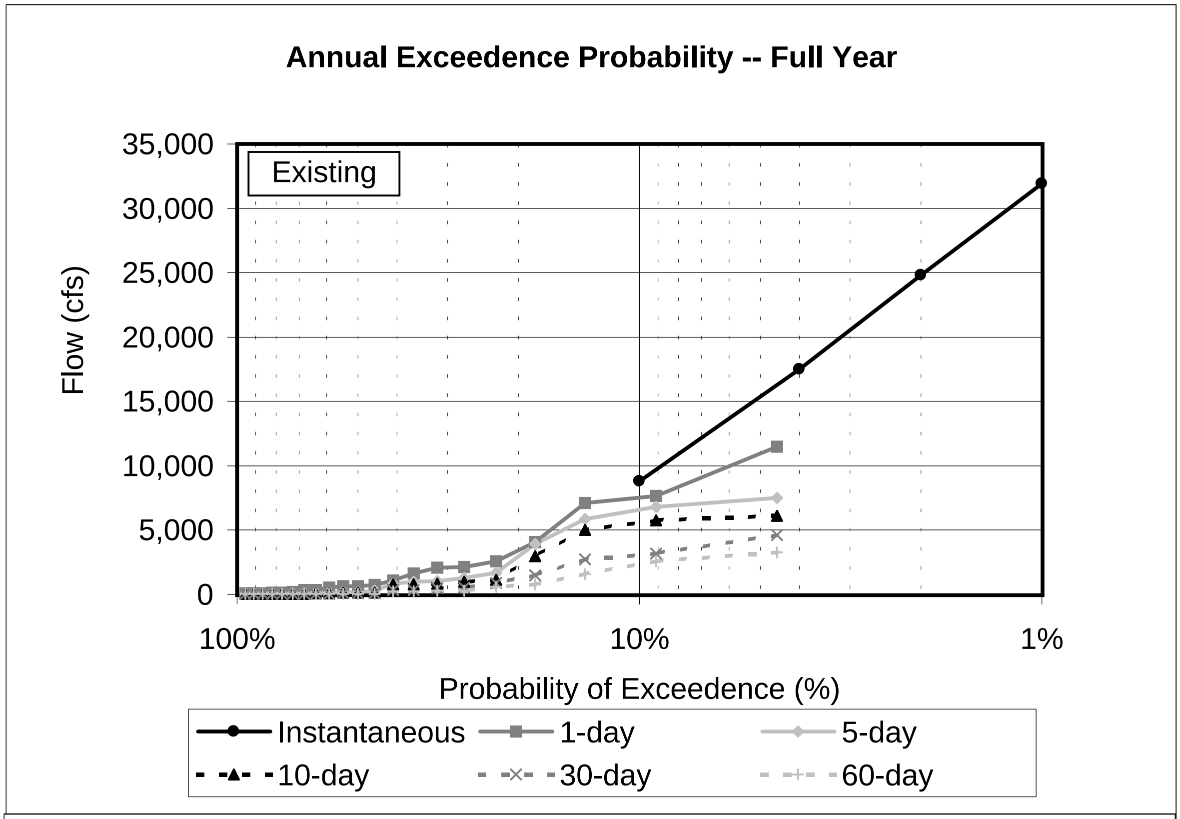
The present flow regime in lower Putah Creek is only 2 years old, because it was established in 2000 when the instream flow Settlement Agreement was adopted. For statistical analysis purposes, a longer record must be constructed that reflects the new regime. This was accomplished by modifying gaged flows at Putah Diversion Dam since 1970, which was when releases from the dam first began operating under a fixed monthly release schedule. The Settlement Agreement incorporates the 1970 release schedule as a minimum release to which other downstream criteria were added. Thus, the current flow regime has a general similarity to the regime that was in place during 1970–2000.

For flow frequency calculations, it is important that the period selected for analysis represent long-term average climatological conditions and the long-term average frequency of spills from Lake Berryessa. A 21-year data set consisting of water years 1971–1981 plus water years 1984–1993 was found to meet these criteria. For frequency analysis, it is not necessary that the data set consist of a continuous sequence of years.

The flow regime at Putah Diversion Dam was translated to the western edge of the Yolo Bypass by adjusting the daily flows to account for tributary inflows, flow losses along the channel between the Diversion Dam and the Yolo Bypass and additional flows now required to meet the instream flow criteria specified under the Settlement Agreement. The adjustment were similar but not identical to the basic monthly releases required, as explained below.

Annual and Seasonal Exceedence Probability

The 21-year data set for existing conditions is too short to reliably calculate the magnitudes of large, infrequent flood flows. Fortunately, USACE simulated these flows as part of its Winters and vicinity flood investigation (USACE 1995). Hydrographs for 10-year through 100-year peak inflows to Lake Berryessa were routed through the reservoir using a spillway hydraulics function. The resulting outflow hydrograph was then routed down the channel to the Yolo Bypass using a HEC-1 channel hydraulics model. The reservoir greatly attenuated the simulated peak outflow at the dam, even when the reservoir was assumed to be full at the beginning of the storm. Because the reservoir outflow hydrograph was already so flattened relative to the inflow hydrograph, there was less than 1 percent of additional peak attenuation as flow traveled down the channel to the Bypass. The resulting annual exceedence probability curve for peak instantaneous flows at the Yolo Bypass is shown in Figure J-6. A comparison of this graph with the graph for historical conditions (Figure J-1) shows that the reservoir decreased the 100-year peak flood flow from approximately 74,000 cfs to 32,000 cfs, or to 43 percent of its historical value.



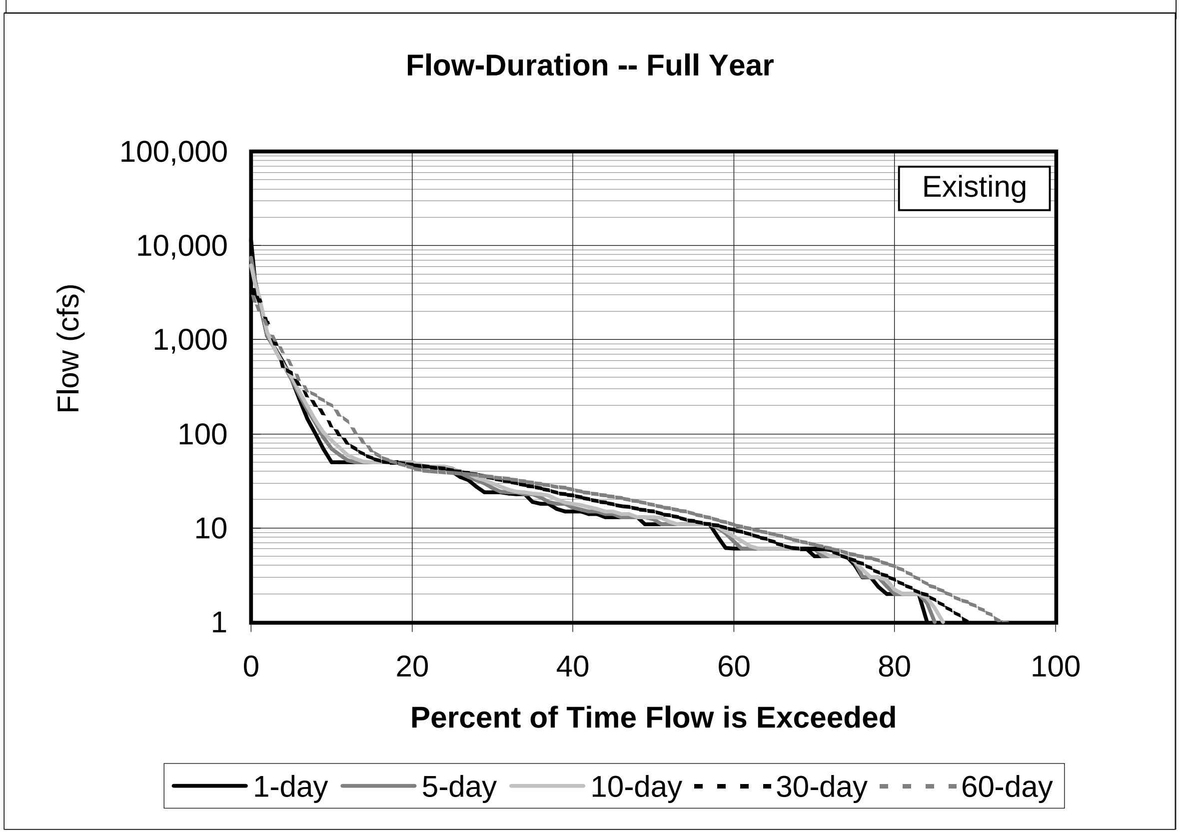


Figure J-6. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Existing Conditions -- Full-Year Data

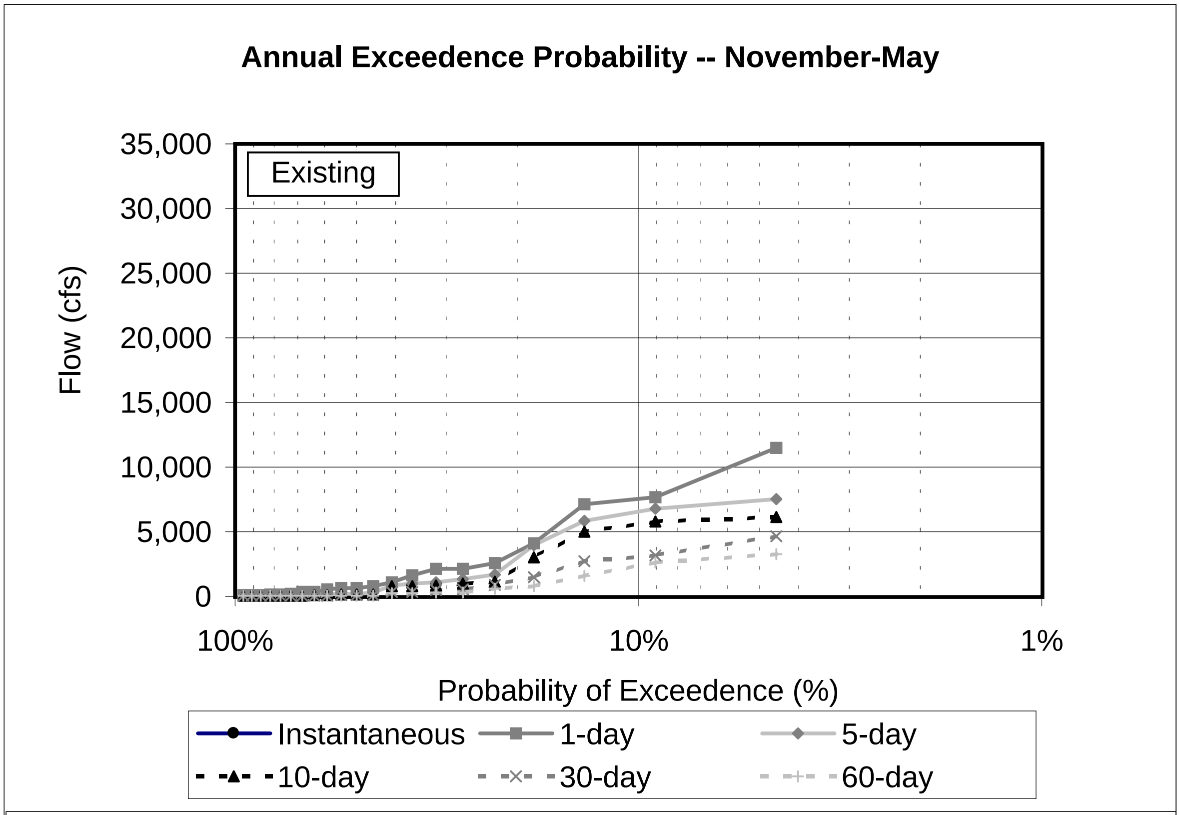
Exceedence probabilities for 1-day through 60-day durations were calculated from estimated daily flows at the Yolo Bypass location. These flows were estimated by a series of adjustments to gaged daily flows at Putah Diversion Dam. First, tributary inflow from Dry Creek (the largest unregulated tributary below the Diversion Dam), was estimated by correlation with runoff from tributaries along the interdam reach between Monticello Dam and Putah Diversion Dam. The interdam runoff flows were multiplied by the ratio of the two drainage areas and the ratio of their respective average annual rainfall amounts to obtain estimated flows in Dry Creek. Second, the same net flow losses to ET, seepage and diversions used for the historical analysis were used for the existing-condition analysis, applying dry, normal and wet year loss rates as appropriate. Finally, estimated daily flows at the Bypass were increased as needed to be consistent with the instream flow criteria. This last step was achieved by translating the I-80 criteria and the estimated flows at the west edge of the Yolo Bypass to the very end of the creek at the Toe Drain to account for flow losses along those reaches.

Because of the small number of years used in the analysis of existing conditions, exceedence probabilities only extend to a 21-year event (Figure J-6), although the curves can be extrapolated to slightly larger events based on the slope of the instantaneous probability curve. The probability curves for the various durations are of course much lower than under historical conditions, but the daily flows decreased by a greater percentage than 60-day flows (e.g., by 40 percent versus 71 percent for a 21-year event). This reflects the greater effect of the reservoir spillway on flood peaks than flood volume.

Exceedence probability plots for the seasonal windows (November–May, June–October, and January–April) are shown in Figures J-7 through J-9. These exhibit the same pattern evident in the historical flow regime. Namely, that high flows occur almost exclusively in the January–April period. Thus, the Solano Project has not significantly altered the timing of peak flows in lower Putah Creek. There probably is some decrease in high flows in the November–January period due to reservoir refilling effects, but this seasonal window was not separately evaluated.

<u>Annual and Seasonal Flow Duration</u>

The same procedure used to calculate annual and seasonal flow duration curve for the historical flow regime was also used for the existing flow regime, and the results are shown in the lower graphs in Figures J-6 through J-9. Several differences between the existing and historical flow duration curves are immediately obvious. First, the low-flow range of the existing regime is characterized by a stepped pattern that results from the scheduled monthly releases. Releases are held at approximately the same rate throughout each month, then adjusted to the designated level for the next month, resulting in a large number of days of flow at each of the scheduled release levels. Second, the creek is much more perennial at the Yolo Bypass location than it was under historical conditions. For example, considering data for all months, flow exceeds 1 cfs 84 percent of the time as compared to 55 percent of the time under historical conditions. The difference is most pronounced during the dry season (May–October), when flow exceeds 1 cfs 66 percent of the time versus 14 percent of the time under historical conditions. The duration of high flows has of course decreased by a proportionately greater amount, because average annual discharge down the creek under existing conditions is only about one-fourth the historical amount. For example, flow exceeds 50 cfs only 10 percent of the time (for all months combined) as opposed to 42 percent of the time under historical conditions.



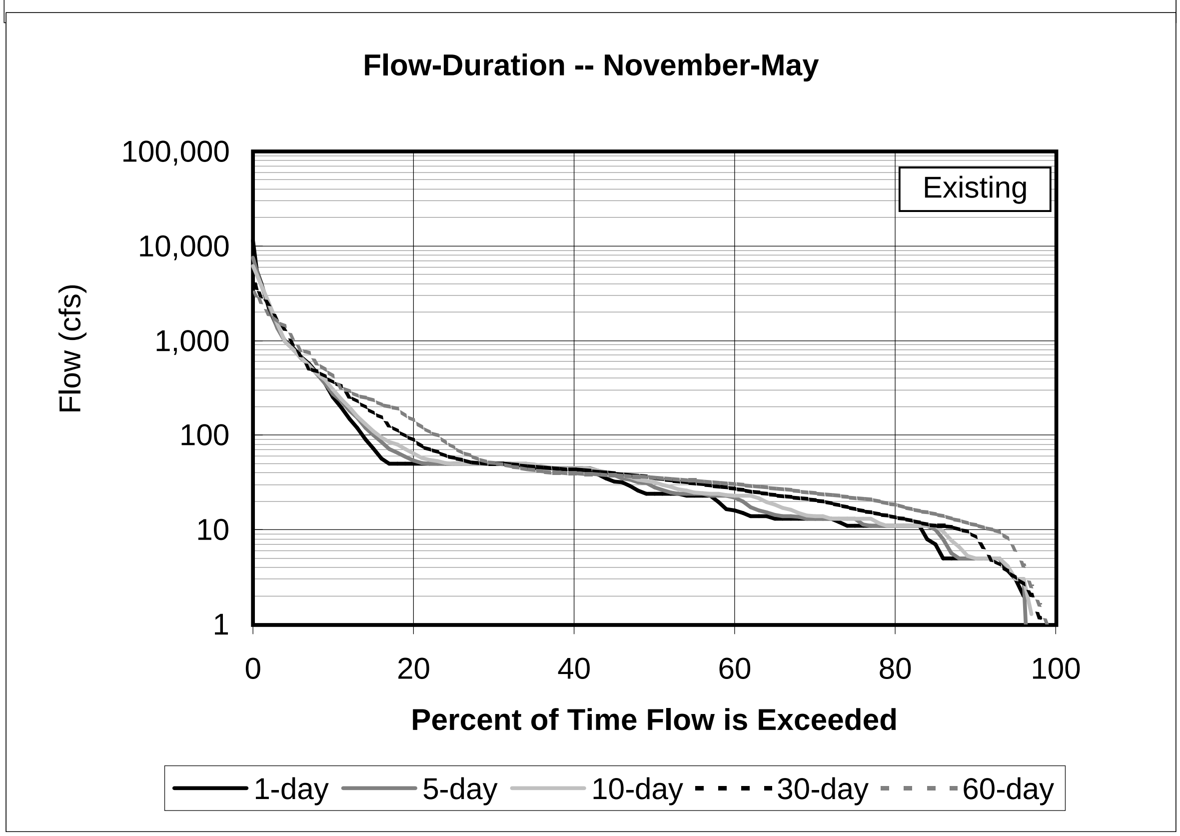


Figure J-7. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Existing Conditions -- November - May

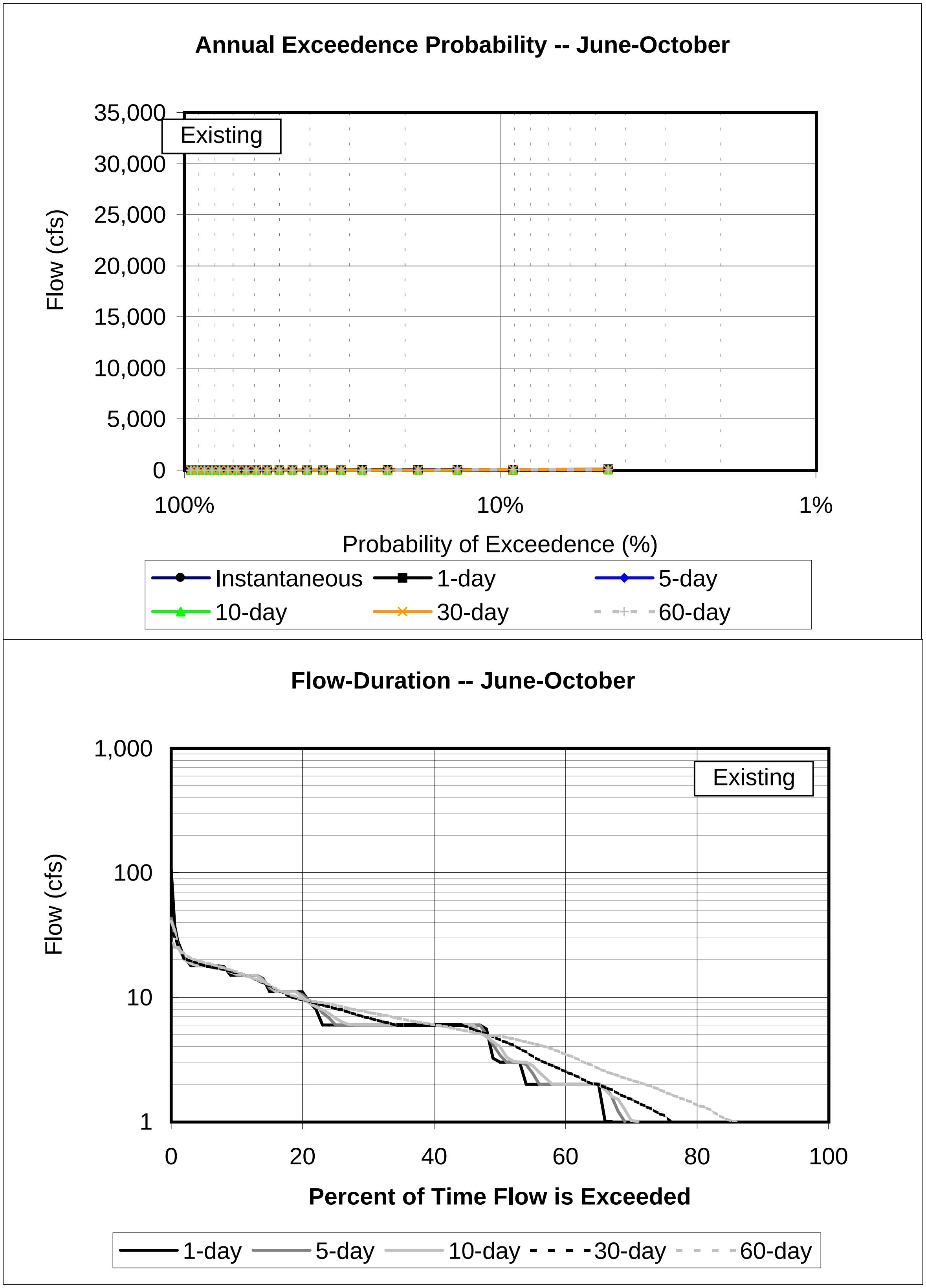


Figure J-8. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Existing Conditions -- June-October

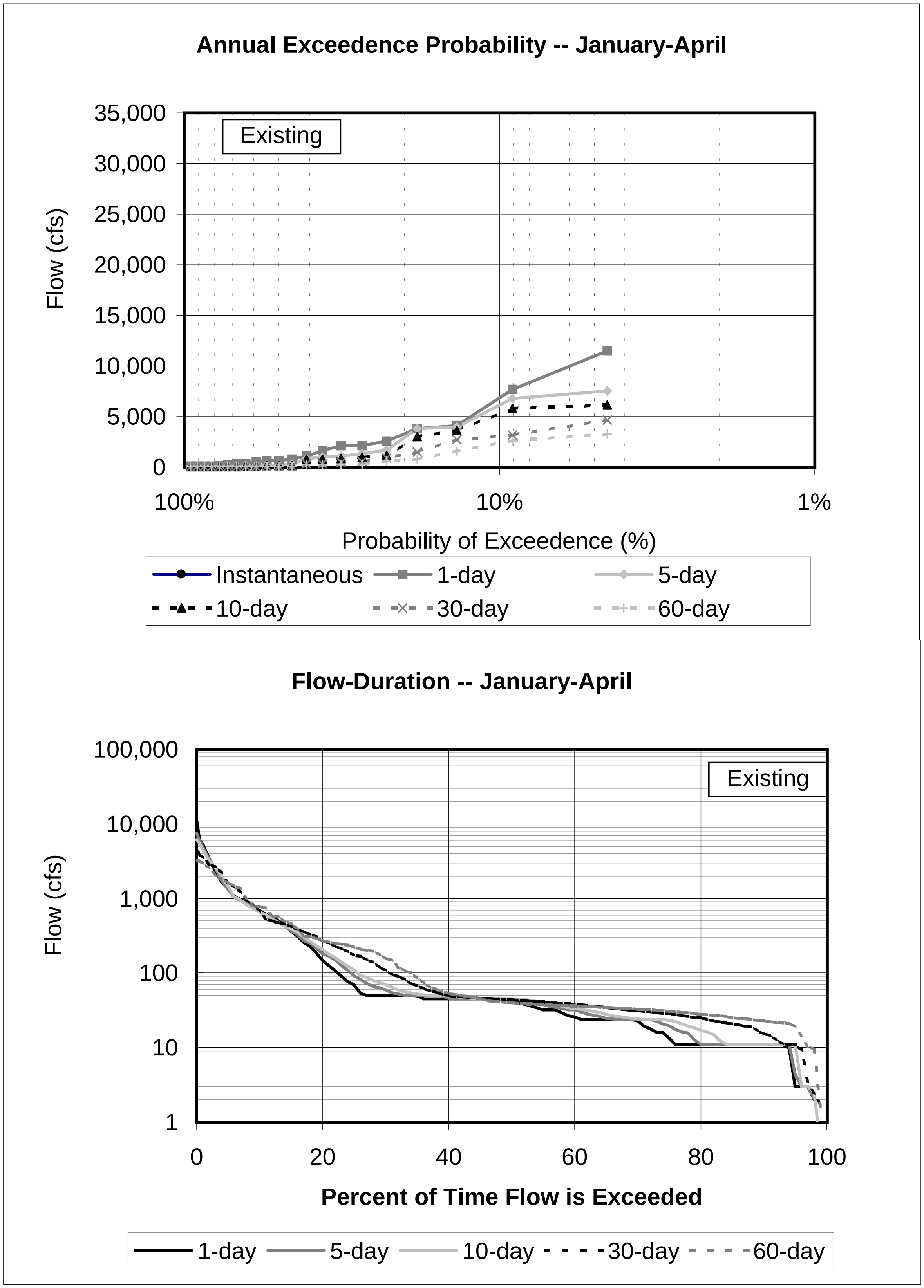


Figure J-9. Annual Exceedence Probability and Flow Duration Graphs for Putah Creek at the Yolo Bypass under Existing Conditions -- January-April

The flow-duration graph for the January–April period under existing conditions provides useful information for design of the floodplain restoration project. Assuming it is desirable to have a project that does not require supplemental water most of the time, the corresponding 30-day average flow curve can be used to identify the flow availability for any desired level of reliability. For example, the 75 percent exceedence level for the 30-day average flow is about 30 cfs. An analysis focused on the March–April period would show a higher flow at the 75 percent exceedence level because those are the months when the elevated spring release from Putah Diversion Dam is required.

Flood Hydrograph

USACE's flood study of the Winters area (USACE 1995) did not include a standard flood hydrograph for locations downstream of Monticello Dam. However, simulated peak flows at the Yolo Bypass for 10-year to 100-year events were reported. A standard hydrograph shape was developed by averaging the proportions of 10-day hydrographs for five of the largest flood events that have occurred since Monticello Dam was constructed. These are shown in the upper graph in Figure J-10. The ratio of the peak flow to the maximum daily flow for each event was noted, and the peak of the standard hydrograph was "sharpened" accordingly, while maintaining overall flood volume. This shape was then scaled to the 10-year through 100-year peak flows reported by USACE, resulting in the flood hydrographs shown in the lower graph.

Joint Occurrence of High Putah Creek Flows and Low Yolo Bypass Stages

Any structures or channel modifications along the Yolo Bypass reach of Putah Creek also need to withstand high flows. Very large flows in Putah Creek always coincide with spills at Fremont Weir and general inundation of the Bypass. Under those conditions, any structures and channel modifications near the lower end of the creek would already be under water and would not be subject to scouring flows from Putah Creek. Historical flows during 1984–2000 were examined to identify the largest Putah Creek flow that occurred in the absence of general inundation of the Bypass. This period was limited by the lack of readily available Yolo Bypass stage data prior to 1984. The maximum Putah Creek flow that occurs independently of Yolo Bypass flooding will be used as the design flow for ensuring that all structures and channel modifications can pass high Putah Creek flows without suffering damage or causing inadvertent inundation of nearby lands. Note that the conveyance capacity of the Putah Creek channel within the Yolo Bypass is only on the order of 1,000–2,000 cfs, even when the Los Rios Farms/CDFG check dam flashboards have been removed. Flows greater than this spill out of the low-flow channel at various locations between Road 106A and the check dam (see Appendix K "Putah Creek Geomorphology").

The Lisbon gage in the Toe Drain was selected to represent flood conditions in the Yolo Bypass. The gage is located about 3 miles south of the point where Putah Creek flows into the Toe Drain. Hourly stage data for the Lisbon gage were obtained for water years 1984–2000, which is the period of record for data available in electronic format. After eliminating erroneous data points and consolidating into daily average values, the stage data were plotted against the concurrent daily flow in Putah Creek as shown in Figure J-11. Points that plot in the upper left part of the graph correspond to high Putah Creek flows at low Yolo Bypass stages. Note that the California Department of Water Resources has traditionally used a stage of 11.5 feet U.S.E.D. (8.5 feet above NGVD 1929) as the threshold above which the Bypass can be considered inundated. The high-flow event of December 24–28, 1983 was the only event that reached significant flows

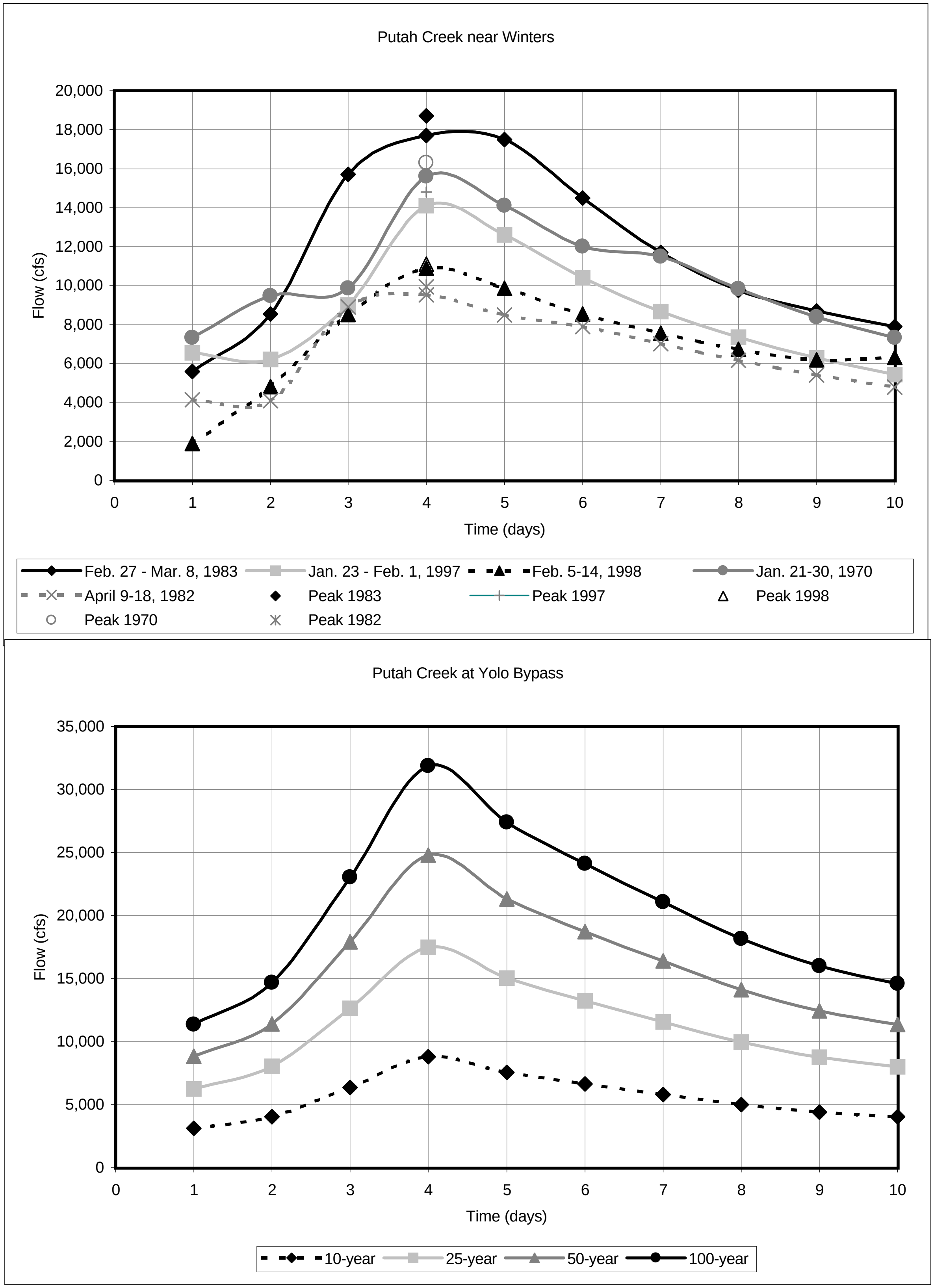


Figure J-10. Historical and Standardized Flood Hydrographs for Putah Creek at the Yolo Bypass under Existing Conditions

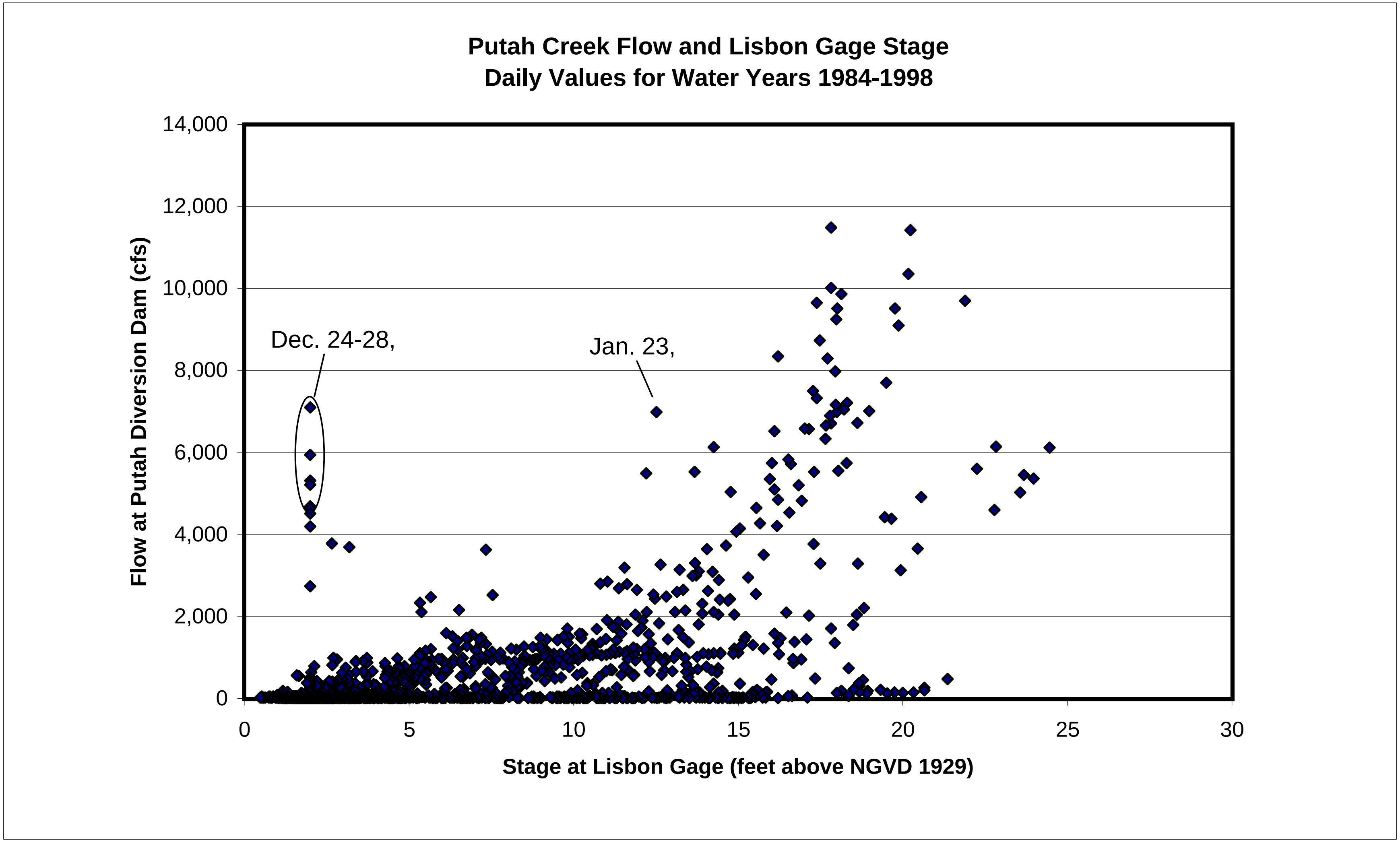


Figure J-11. Comparison of Daily Flows in Putah Creek with Concurrent Yolo Bypass Stage at the Lisbon Gage while the Lisbon gage stage was less than 8.5 feet above NGVD 1929. During this event, Putah Creek reached a maximum daily flow of about 7,000 cfs and remained above 4,000 cfs for 5 consecutive days. These flows included spills from Lake Berryessa. Closer examination of the two time series revealed that Fremont Weir had begun spilling slightly in November, but at relatively low rates (less than 90,000 cfs). The storm that generated the high flows in Putah Creek beginning on December 24 increased Sacramento River flows and Fremont Weir spills to much higher levels beginning on December 26. After a 2-day lag, those flows raised the stage at the Lisbon gage to above 8.5 feet.

A second high flow event on January 23, 1997 was also investigated because Putah Creek flow appeared to be higher than usual relative to stage at the Lisbon gage. Again, Fremont Weir was already spilling as a result of a prior high flow event (the New Year's 1997 flood), but the spill had receded to a relatively low level. A new storm starting January 22 increased Putah Creek flows faster than it increased Sacramento River flows, resulting in one day of high flows in the creek before a substantial increase in stage at the Lisbon gage. In this event, the high flows in Putah Creek also included spills from Lake Berryessa and also reached a maximum daily flow of about 7,000 cfs.

This analysis indicates that the coincidence of high flows in Putah Creek and low stage at the Lisbon gage is most likely to occur at the beginning of a major storm event. The faster arrival of runoff from the Putah Creek watershed compared to the Sacramento River watershed, combined with storage effects in the upstream part of the Yolo Bypass, provides a brief window of opportunity for high Putah Creek flows to occur before runoff from the same storm system swells the Sacramento River and inundates the entire Bypass.

Because of the small number of events available for analysis, it is possible that Putah Creek flows preceding Bypass inundation could exceed 7,000 cfs   Also, peak instantaneous flow could be somewhat larger than daily average flow, although flood hydrographs that include spills from Lake Berryessa are relatively flat compared to unregulated runoff hydrographs. A reasonable estimate of the maximum instantaneous flow entering the Yolo Bypass might be on the order of 10,000 cfs. Note that this greatly exceeds the existing low-flow channel capacity, which commonly spills over the north and south banks at several locations between Road 106A and the Los Rios Farms/CDFG check dam during high-flow events in Putah Creek.

With respect to the design of the floodplain enhancement project, it might not be necessary to design new structures and channels to withstand flows greater than 2,000 cfs because higher flows would already spill out of the channel farther upstream.

APPENDIX K: PUTAH CREEK GEOMORPHOLOGY

Introduction

Questions regarding stability of the new and old channels:

- Will the channel tend to meander or avulse (abruptly change course)?
- Will the channel tend to incise or fill with sediment?
- Will the old channel downstream of the diversion point to the new channel tend to fill in, and how fast?
- If the new channel is broad and shallow (to maximize floodplain area at relatively low flows), will it tend to reshape itself to a deeper, narrower box channel?

Answers to these questions can be inferred from the geologic setting of the lower end of Putah Creek and from changes in channel alignment and geometry in responses agricultural, flood-control and other human activities. Each of these variables and factors are considered in the following sections.

Geologic Setting

Over geologic time, Putah Creek has formed a broad, low-lying alluvial fan that spreads radially to the east and southeast from the point where the creek leaves the Coast Ranges and enters the Sacramento Valley, near Winters (Thomasson et al. 1960). Alluvial fans are depositional environments. Sediments are deposited along the channel and next to the channel during flood events. The channel eventually becomes higher than the surrounding alluvial plain and typically avulses, leaving its old course and switching to a new route along the lower ground. These avulsions range from minor channel splits and rejoins ("anabranching") to major changes in overall alignment. For example, a geologically recent former channel is still clearly recognizable on topographic maps, departing the present channel near Winters and heading south-southeast toward Dixon.

The alluvial fan extends eastward to the Yolo Basin, a topographically low area frequently inundated for prolonged periods by floodwaters from the Sacramento River, Putah Creek and other west side tributaries. The Yolo Basin also received perennial groundwater discharge, resulting in permanent wetland conditions supporting a vast tract of tules.

The surficial geology of the alluvial fan and the Yolo Basin are quite distinct. The channel deposits and alluvium on the alluvial fan consist of gravel, sand and silt, whereas the basin deposits consist of fine-grained silt and clay. A map of quaternary geology of the Sacramento River clearly shows the alluvial fan deposits along the South Fork Putah Creek channel protruding 3 miles eastward into the basin deposits, ending near River Mile 0.0 (Helley and Harwood, 1985). Another tongue of alluvial fan deposits extends a similar distance southeast into the basin deposits, departing the South Fork deposits near County Road 106A. The tongue of alluvial deposits along the South Fork of Putah Creek might be less than 120 years old, because the South Fork channel is an artificial alignment constructed in the late 1800s. By 1950, the creek had incised approximately 15 feet at the point of departure from the previous alignment (North Fork), located 9 miles upstream of the Bypass. The lobe of alluvium mapped in 1985 where the South Fork enters the Bypass could consist in part of sediments eroded during the down-cutting farther upstream.

Historical Modifications of Putah Creek

The depositional environment naturally present at the distal end of the Putah Creek fan appears to have changed as a result of historical modifications of the creek. The sequence of major alterations of the channel and flow regime along lower Putah Creek and their probable effects on geomorphic processes are described below.

South Fork Channel

In response to frequent flooding near Davisville (now Davis), residents began excavating a new channel (the South Fork) in 1871 using horse-drawn equipment. The channel split off of the original channel near what is now River Mile 8.0, about 4,000 feet upstream of I-80, and followed a relatively straight easterly course to the Yolo Bypass. The original channel is now referred to as the North Fork of Putah Creek. The channel was largely completed by the beginning of the 20th century, but excavation continued until the 1940s (Larkey 1969). Some downcutting of the channel occurred following construction of the South Fork, some of it by erosion during floods and possibly some by excavation. By 1950, the bottom of the creek channel at the split was about 18 feet below the former invert elevation at that location. The creek at that time was incised 35–40 feet below the surrounding valley flats from Winters to the North Fork split, decreasing to 20 feet at Mace Boulevard (Thomasson et al. 1960). However, the North Fork was incised nearly as much at Davis prior to construction of the South Fork. A description of the ditch pump used by Jerome Davis to irrigate his dairy pastures appeared in the 1858 edition of the Transactions of the State Agricultural Library (Larkey 1969). The vertical distance from the creek up to the valley flats was reportedly 20 feet at that time.

Flood Control Levees

In the late 1940s, the USACE constructed flood control levees along the north and south banks of Putah Creek from the North Fork split (River Mile 9) to the Yolo Bypass as part of the Sacramento Flood Control Project. The levee sealed off the North Fork so that it no longer received flow during flood events. The levees rise 7–12 feet above the valley flats and are spaced 500 feet apart at the upstream end, gradually increasing to 2,000 feet apart at the Bypass (Jones & Stokes 1992). By confining flood flows to a relatively narrow channel, the levees presumably increase the depth and velocity of flow, increase the shear stress and the ability of the creek to convey sediment. There does not appear to have been widespread downcutting or channel enlargement since then, however (see "Thalweg Profile" and "Channel Width and Depth" below).

The levees were constructed from earth excavated from terraces along the low-flow channel. The cut areas are indicated in the as-built cross-sections. These blueprints do not state the total volume of excavated material, but it can be estimated from the levee dimensions. The combined length of the north and south side levees is 15.4 miles, and the average height above the previous ground surface is about 10 feet. With a 20-foot crown width and 2:1 and 3:1 side slopes on the outboard and inboard sides, respectively, the total volume of levee material is 1,355,000 cubic yards. This is a large volume relative to recent sediment transport rates along lower Putah Creek.

For example, it is 242 times greater than the average annual sediment accumulation rate in Lake Solano (Northwest Hydraulic Consultants, 1998). This suggests that the levee project could have created a new or enlarged depositional zone along the leveed reach by widening the low terraces adjacent to the low-flow channel. If so, this could function as a sink for sediment that would otherwise enter the Bypass reach of Putah Creek and potentially fill in a newly aligned channel or a ponded reach between the split to a new channel and the check dam.

Solano Project

The U. S. Bureau of Reclamation built a major water-supply project on Putah Creek in the 1950s. The main facility is Monticello Dam, located about 10 miles upstream of Winters and completed in 1957. The reservoir impounded by the dam (Lake Berryessa) has a capacity of 1.6 million acre-feet, or about four times the average annual runoff in the creek. Water released from the dam flows 7 miles down Putah Creek to Putah Diversion Dam, where most of it is diverted into Putah South Canal for agricultural and municipal use in Solano County.

Because the capacity of Lake Berryessa is very large relative to average annual runoff, most high flows are captured entirely. A reservoir operations analysis showed that up to 25 years can elapse between spills (Conwell 1975). When spills do occur, peak flows are greatly diminished by storage effects as the reservoir surcharges above the spillway elevation. The 100-year pre-project peak flow of nearly 90,000 cfs has been decreased to 32,300 cfs (USACE 1995). Flow in lower Putah Creek below the Putah Diversion Dam consists of releases required under the Putah Creek Instream Flow Settlement Agreement, Berryessa spills and unregulated runoff below Monticello Dam. The average annual discharge is now approximately 90,000 acre-feet, or about one-fourth the pre-project amount.

The large decreases in peak flows and annual discharge have greatly decreased the sediment transport capacity of lower Putah Creek. Furthermore, 95 percent of the 633-square-mile watershed is upstream of Monticello Dam, which intercepts all of the sediment yield from the upper watershed. Thus, sediment influx and the capacity to transport sediment were simultaneously greatly decreased when Monticello Dam was constructed. The expected result from this combination of changes would be a relatively stable system with little geomorphic change. However, the present flow regime is still capable of transporting a significant amount of sediment and may be outpacing the sediment supply. This could explain the lack of unconsolidated bed material (sand and gravel) in many areas along the creek, where the creek bed consists of dense, tough clayey silt. The distribution of bed material types along the creek is described below (see "Bed Materials and Hydraulics").

Putah Diversion Dam also traps sediment derived from tributaries along the interdam reach, but not as completely as Monticello Dam traps sediment from the upper watershed. The lake formed by the Diversion Dam (Lake Solano) was completed in 1959 and was largely filled with sediment by the 1990s. A comprehensive investigation of sediment texture and accumulation rate at Lake Solano conducted in 1998 found that there has been a long-term average sediment accumulation rate of about 7 acre-feet per year, but also that some of the sediment accumulated in dry years is flushed out in subsequent wet years (Northwest Hydraulic Consultants, 1998). As would be expected where a creek enters a lake, sediment deposited at the upstream end of the lake was generally coarser (sands and gravels) than sediments near the dam (fine sand and silt). The sediment flushed out through the gates of the dam would consist primarily of the more easily suspendable fine material. Thus, the dam probably traps coarse sediment fairly completely and fine sediment only partially. This texture filtering may be of importance to replenishment of spawning gravels, but even the fine material would be capable of forming bars or filling in the pool behind the check dam in the Yolo Bypass if the material were transported that far.

Gravel Mining

Extensive gravel mining occurred along a 2-mile reach of Putah Creek immediately downstream of Putah Diversion Dam during the late 1950s and 1960s. Aerial photographs taken in 1966 show a broad swath of exposed gravel and little vegetation along this reach. Mining in this area was discontinued in 1969 as a result of environmental concerns (Jones & Stokes 1992). The University of California at Davis also mined gravel from the creek bed near Pedrick Road until the late 1970s. Vegetation recovered quickly in both locations following the cessation of mining. Records indicating the volume of material mined were not obtained for this study, but the likely geomorphic effect of the mining would be scour and downcutting immediately upstream of the excavated area and a tendency for the excavation to function as a sediment trap. In other words, the mining activities could have caused a lasting decrease in the amount of sediment reaching the Yolo Bypass reach of Putah Creek.

Channel Planform

Creek channels on alluvial fans tend to avulse rather than meander, but some meandering can occur. Any minor historical shifts in channel alignment could indicate active meandering processes that might disrupt a new channel alignment created along the lowermost reach of the creek. The deeply incised condition of the Putah Creek channel between Winters and Mace Boulevard tends to prevent meandering. From there to the Bypass, however, the channel is less incised and the levees are farther apart, so the potential for meandering is greater.

Historical changes in channel alignment were evaluated by comparing conditions in 1906 and 1997. The earliest U. S. Geological Survey topographic maps of the area were published in 1915–1916 at a scale of 1:31680 and showed topography surveyed in 1906. For this study, the Swingle and Lovdal quadrangles (corresponding approximately to the present-day Davis and Sacramento West 7.5-minute quadrangles) were scanned and georeferenced, and topographic features were digitized in a geographic information system (GIS) using ArcView software. Solid-line creek channels, dotted-line creek channels, linear depressions, canals and sloughs were digitized as separate line types in a polyline shapefile. These features were overlain on a georeferenced digital aerial photograph taken in 1997.

To confirm that the two data sets were correctly aligned, several cultural features visible in the quads and in the air photo were also digitized as registration points. It was immediately obvious that the registration points did not all line up and that the direction and amount of offset was not the same for all of the points. Neither rotation nor enlargement/reduction would have achieved perfect alignment. The discrepancies are probably the result of inaccuracies in the 1905 survey, which used more primitive methods and fewer regional benchmarks than are available today. Instead of a formal registration process, the 1906 main creek channel polyline was registered by eye as much as possible to the 1997 photo. This was possible because many channel bends and junctions had not changed in the intervening 92 years.

The 1906 channel alignment and 1997 aerial photograph are shown in Figure K-1. Several distinct bends in the creek appeared almost unchanged and were used to register the creek channel to the modern photo. These points are labeled with the letter A in the figure and include the sharp "elbow" in the creek alignment about 0.5 mile upstream of the check dam. In other locations where the alignment had changed, it is not certain which changes were artificial and which were the result of fluvial geomorphic processes. In locations where the shift was accompanied by channel straightening, it was assumed that the realignment was imposed by farmers desiring to achieve more rectilinear field boundaries and/or to construct agricultural levees along the bank of the low-flow channel. For example, this could likely be the case in the locations marked "B" in the figure. The most conspicuous change in alignment of the main channel is at location C, where the channel departed from its former easterly course to a southeasterly alignment that captured segments of two smaller drainages (near location D) and eventually turned north to rejoin its former channel. The change in alignment is much larger than the small discrepancies in other locations, so it can't be attributed to surveying error. Also, the new alignment does not appear to be artificial because it is curved and not aligned with property boundaries. Thus, this change in channel alignment is presumed to be the result of natural processes. The 1952 edition of the Davis quadrangle (based on aerial photographs taken in 1949) shows that the change in alignment occurred prior to 1949, when large flood flows still coursed down the creek.

Another indication that the present flow regime is not as likely to create channel avulsions as the pre-Solano-Project flow regime is that the channel has not changed its course to any of the several common overflow locations along the reach between Road 106A and the check dam. These locations are labeled 1 through 6 in Figure K-1. The capacity of the channel in this area is only 1,000–2,000 cfs, and higher flows spill out of the channel at these locations. Spills over the north bank occur at locations 1 and 4, and spills over the south bank occur at locations 1, 2, 3, 5 and 6. Broad overflows to the south at locations 1, 2 and between 4 and 5 were visible in an aerial photograph taken during a flood event in the late 1990s. The remaining overflow locations were reported by the Los Rios Farms manager (Schmid, pers. comm.). Flows in excess of 2,000 cfs occur on average about once every 3 years, yet the creek has not scoured out any of the overflow points to establish a new alignment.

The conclusions that can be drawn from the figure are that the channel alignment is generally quite stable. Even sharp bends can persist for almost a century with little change. One localized, abrupt change in alignment occurred prior to construction of the Solano Project, but the likelihood of such changes is now lower because of the greatly reduced magnitude and frequency of high flow events.

Thalweg Profile

The longitudinal elevation profile of the thalweg, or invert, of Putah Creek is another indicator of geomorphic change. Three sets of detailed channel surveys over a 55-year time span were obtained and plotted to determine whether there have been significant changes or trends in the thalweg profile or top-of-bank profile. The as-built drawings for the flood control levees built by USACE included maps, profiles and cross-sections surveyed in 1947. In the mid-1990s, USACE obtained detailed channel surveys done by the Yolo County Flood Control and Water Conservation District in 1994 to develop cross sections for a flood hydraulics model as part of a reconnaissance investigation of flood control needs near Winters (USACE 1995). Finally, DWR

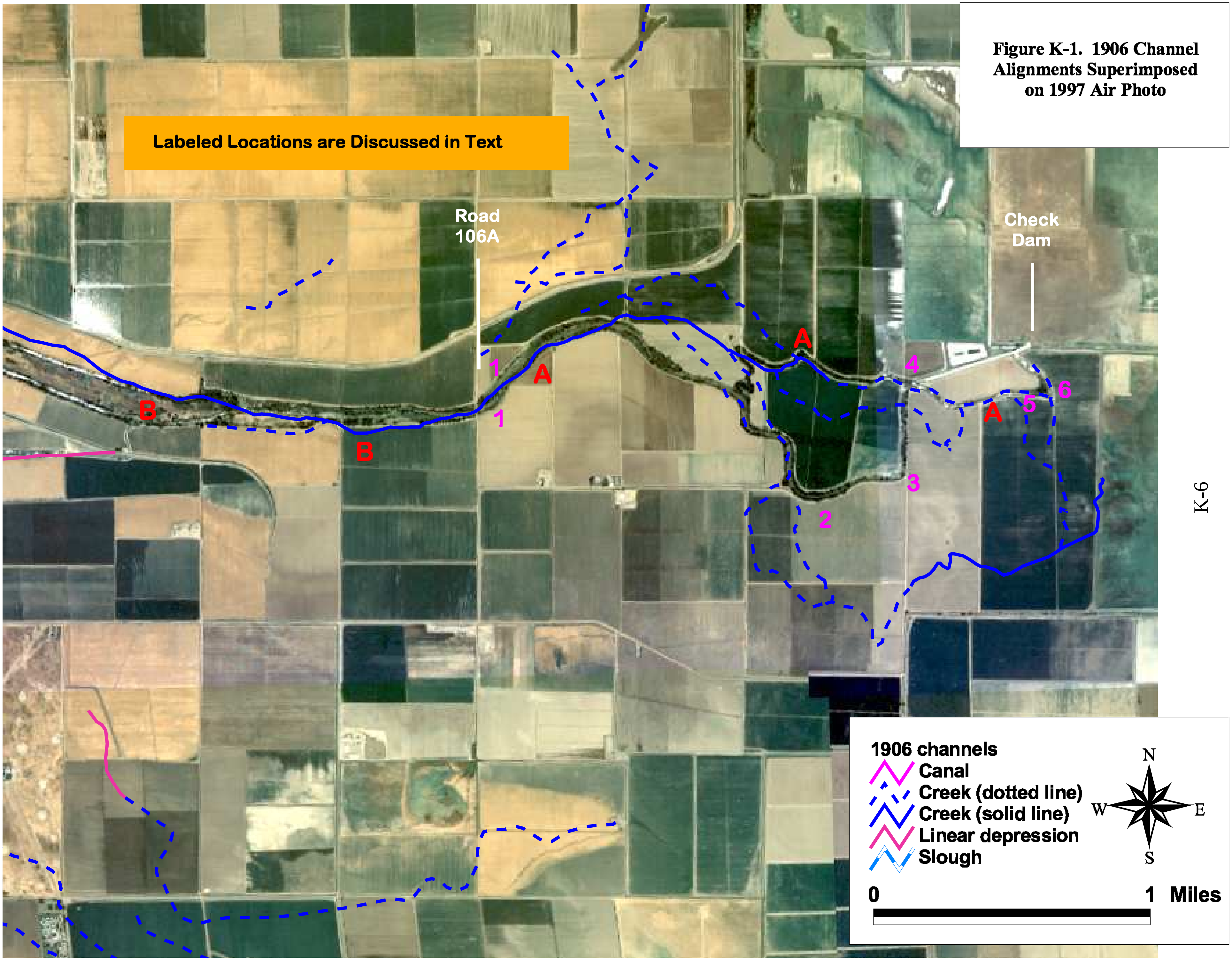


Figure K-1. 1906 Channel Alignments Superimposed on 1997 Air Photo

surveyed the reach between Road 106A and the check dam in spring 2002 for the present project. The three sets of profiles were converted to a common datum and plotted, as shown in Figure K-2.

The thalweg profiles differ in detail but not in general elevation and slope, and the same is true for the top-of-bank profiles. Of particular interest is the bulge in the thalweg profile between River Miles 3 and 0, which is evident in all three of the data sets. Because this bulge is located near the end of the south levee and at an elevation equal to high flood stages in the Yolo Bypass, it was initially surmised that it might consist of a large gravel bar deposited where stream velocities abruptly slowed. A canoe-based survey of channel substrate in 2002 revealed that the creek bottom is almost entirely dense clay-silt along that reach. Thus, it appears that the bulge is simply an outcrop of an older, less erodible, fine-grained layer in the Sacramento Valley alluvial deposits.

The stability of the thalweg profile of the creek over the past 55 years could indicate a strong tendency to maintain channel slope. Alternatively, it could simply indicate insufficient energy to adjust itself following construction of the Solano Project. These two possibilities have different implications for the stability of a new channel alignment. If the new channel were constructed at the approximate elevation of the valley floor in the Yolo Bypass (about eight feet higher than the present thalweg profile), there would be an abrupt step up in the profile where the creek exits the existing channel and enters the new channel. This vertical increment is equal to the amount of fall along 2.25 miles of channel at the current slope. To restore or at least smooth the profile, the creek would tend to erode the exit structure and upper end of the new channel segment. Perhaps more likely would be an avulsion to an entirely new alignment starting at some upstream location because of the increased water surface elevation during high flows. The most likely locations for an avulsion are the locations where high flows presently tend to spill out of the low-flow channel between Road 106A and the check dam (see Figure K-1).

Channel Width and Depth

On alluvial fans, it is common for the channel to branch into several smaller channels as it reaches the bottom margin of the fan. The width and depth of the low-flow channel was tabulated from the same data sets used for the thalweg profile analysis (i.e., data for 1947, 1994 and 2002) to see whether there was a trend along the length of the creek or a trend over time. Figure K-3 shows profiles of channel top width for those three years. The width is quite variable, although some of the variation could stem from incorrect identification of the low-flow channel bank in some cross sections. Nevertheless, channel width clearly decreases in the downstream direction in all three profiles, and the profiles are generally similar.

Channel depth was measured as the difference in elevation between the top of the bank and the thalweg. The product of top width and depth was used as a surrogate for more detailed conveyance area tabulations to determine whether the conveyance area also decreases in the downstream direction. Conveyance area could remain constant if the decrease in channel width is offset by an increase in channel depth. Figure K-4 shows that the product of width and depth decreased more clearly and uniformly than channel width by itself. Once again, all three profiles were similar in slope and magnitude.

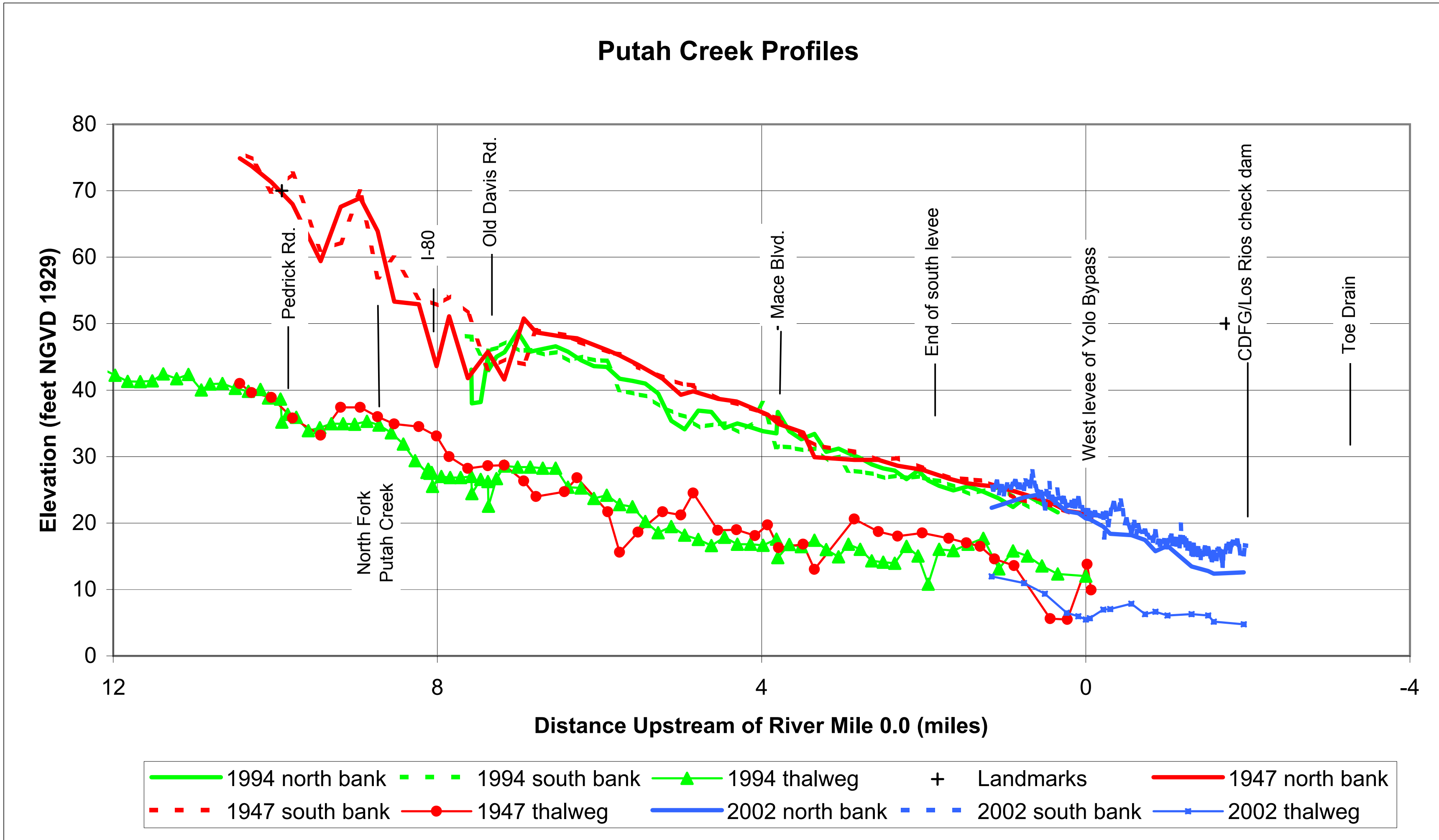


Figure K-2. Profiles of Thalweg and Top-of-Bank Elevations along Putah Creek between Pedrick Road and the Check Dam

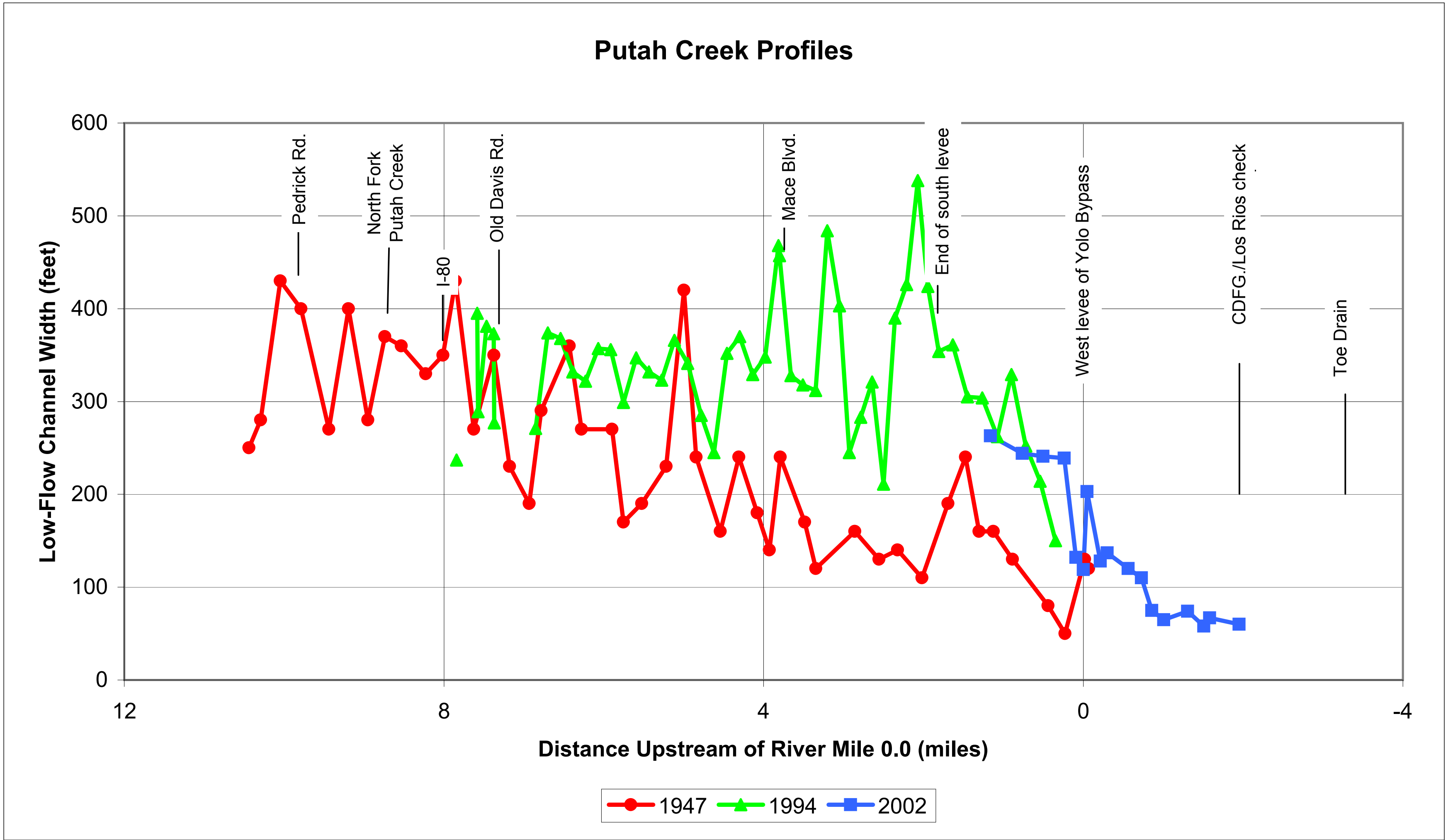


Figure K-3. Profiles of Low-Flow Channel Width along Putah Creek between Pedrick Road and the Check Dam

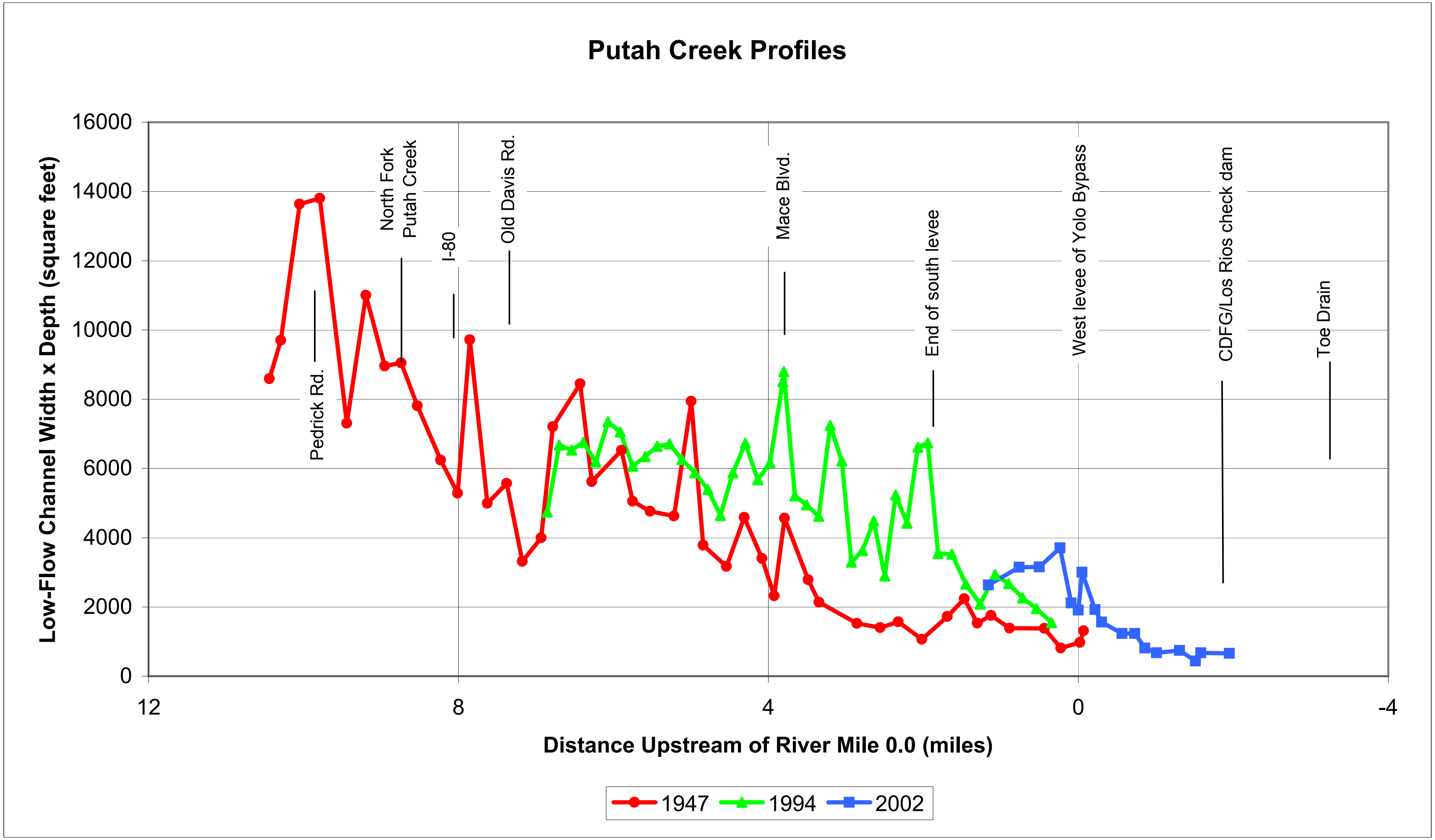


Figure K-4. Profiles of Low-Flow Channel Width times Depth along Putah Creek between Pedrick Road and the Check Dam

These channel geometry profiles confirm that conveyance area does decrease in the downstream direction, consistent with typical alluvial fan characteristics, and that overbank flows have probably always been common along the lower end of the creek. Furthermore, this pattern has not changed qualitatively or quantitatively in the last 55 years. Once again, it is difficult to determine whether this represents a strong resistance to change, or simply the lack of sufficient stream energy following construction of the Solano Project to reshape the channel.

Bed Material

Substrate materials along lower Putah Creek can be lumped into two general categories: unconsolidated silts, sands and gravels, and dense, tough, consolidated clayey silt. These two general categories have been present since before construction of the Solano Project (Thomasson et al. 1960). The type of substrate present at any given location provides some indication of whether that location is generally characterized by erosion or deposition. A canoe-based survey of channel substrate was completed in summer 2002. A GPS unit was used to record location, and an 8-foot-long, 3/8-inch diameter steel rod was used to determine substrate type based on the sound and ease of penetration when probed. Mapping units included "claypan" (the tough clayey silt), four types of unconsolidated sediments (mud, sand, sand and gravel, and gravel), and patchy occurrences of unconsolidated sediments on claypan. Stream segments as short as 50 feet were mapped.

The results of the survey are shown in Figure K-5. The 2-mile reach downstream of Mace Boulevard consists of claypan with a few segments of patchy unconsolidated material. This reach coincides with the bulge in the thalweg profile (see "Thalweg Profile", above) and confirms that the bulge is caused by a consolidated formation resistant to erosion rather than by accumulated deposits of unconsolidated sediments. Unconsolidated sands and gravels are common downstream of the claypan segment, however. Without corresponding data from the period prior to construction of the Solano Project, it is difficult to determine whether the claypan reach was covered with unconsolidated sediments at that time that have since been flushed away for lack of upstream replenishment, or whether unconsolidated sediments have always been transported across the claypan bulge with little deposition because of higher velocities in that reach. The sediments downstream of the bulge could be relicts from the high-energy flow regime prior to construction of the Solano Project, or they could be actively transported under the present flow regime. Casual observations of changes in gravel bar shape farther upstream after brief flows of only 100 cfs in 1989 and 1990 suggest that the materials in the Yolo Bypass reach are actively transported. If so, any slack water segments of the channel caused by leaving the check dam up year-round to facilitate diversion of flow into a new channel would probably fill in with sediment, at least immediately downstream of the split.

Hydraulics Model and Sediment Transport Capacity

An existing hydraulics model was modified and used to simulate water surface profiles and bed shear stress along lower Putah Creek under existing conditions and for Alternatives 1D, 2B and 3D. The two principal purposes of the simluations were to:

- Estimate the present channel capacity with the check dam flashboards up and down, the locations where water first overflows the channel, and the levee height that would

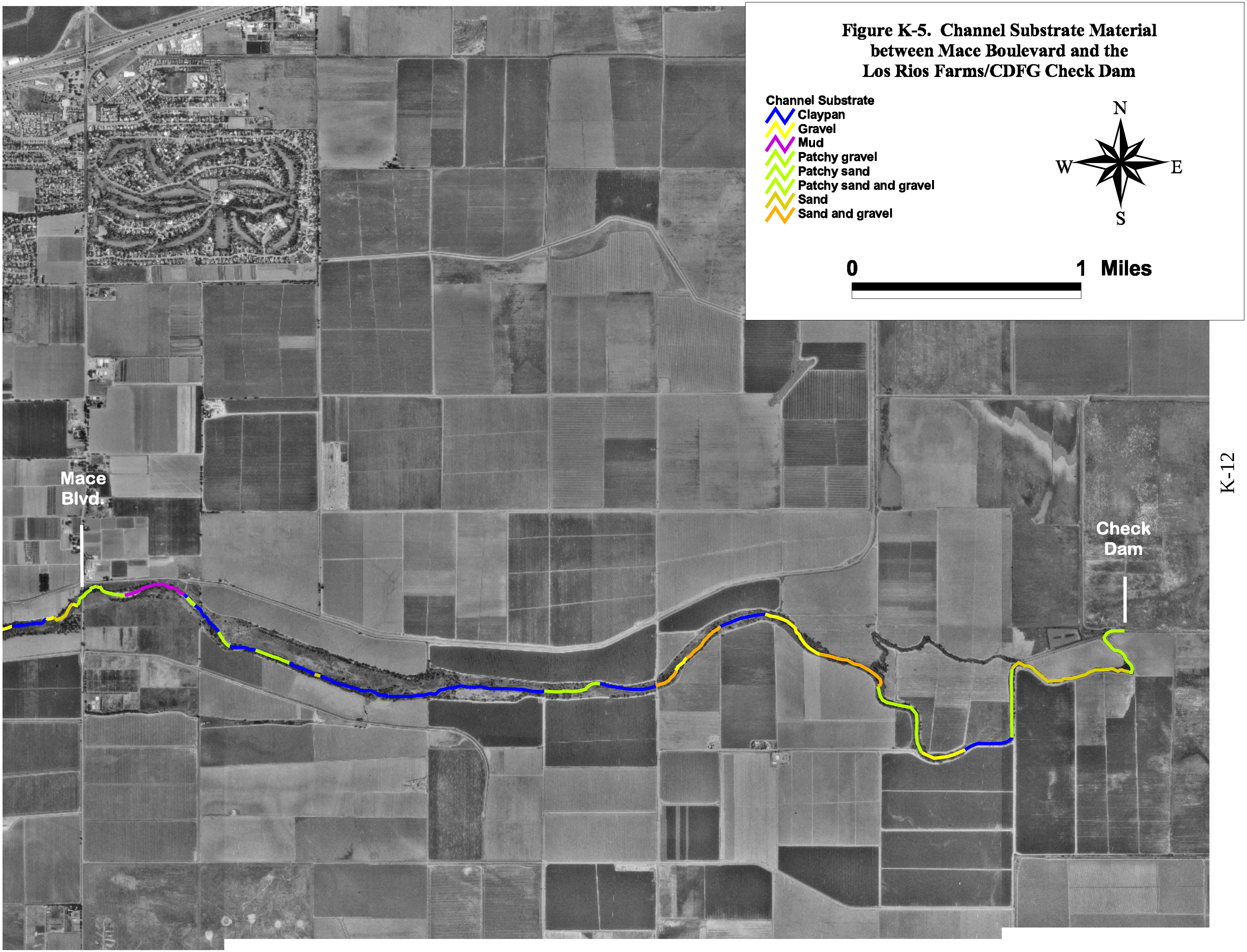


Figure K-5. Channel Substrate Material between Mace Boulevard and the Los Rios Farms/CDFG Check Dam be needed to contain the existing bankfull flow within the channel when the flashboards are up.

- Identify abrupt changes in bed shear stress along the channel, to estimate the tendency toward scour or erosion at those locations.

A HEC-RAS model of lower Putah Creek from Putah Diversion Dam to the western edge of the Yolo Bypass was developed by USACE for an evaluation of a proposed restoration project near Mace Boulevard (USACE 1996). Seventeen cross sections between Road 106A and the check dam surveyed by DWR in spring 2002 were imported into the model to update and extend the lower end of the model into the Yolo Bypass. The geometry of the check dam was measured, and the dimensions of the channel downstream of the check dam were visually estimated. The two split segments of the creek upstream of the check dam were also added to the model. A Manning's roughness coefficient of 0.045 was used for channel and overbank areas in all of the new cross sections.

A potential source of error in the model became apparent even before the first simulation. There are abrupt decreases in channel invert elevation at the start and end of the stream segment surveyed by DWR. These can be seen at Road 106A and the check dam in the profile plot shown in Figure K-6. For clarity, only the lowermost 11 miles of the creek are included in the figure. The abrupt changes in invert elevation are not thought to be the result of different datums, because the survey data had been transposed from NAVD 1988 to NGVD 1929 to match the datum of the existing model. It is quite possible that the abrupt shifts are real. The seasonal installation of an earth road crossing at Road 106A impounds a long pool that might tend to deposit sediment. There also is undoubtedly some road fill left behind in the channel when the crossing is removed each year, and over a period of years that might build up a high spot on the invert profile. At the downstream end of the DWR segment, there is a steep drop of several feet at the downstream end of the concrete apron of the check dam. The step in the invert profile and the resulting supercritical flow simulated at the check dam are quite likely real. Additional survey information at those two transition locations would eliminate this source of uncertainty in model results.

The approximate capacity of the creek channel under existing conditions with the check dam flashboards down was determined by finding the flow for which the simulated water surface elevation equaled the bank top elevation. Overflows onto the fields between the channel splits were ignored because only a small area is affected. The smallest flow at which water began spilling out of the channel was 1,300 cfs along the right (south) bank of the southern channel of the eastern split. Several other locations along that segment began to overflow at flows of 1,400–1,700 cfs. For comparative simulations of the alternatives, a channel capacity of 1,500 cfs was assumed. The water surface elevation for that flow appears as the solid black line in the profile plot (Figure K-6). Note that for all of the simulations described here, flow was constrained to the width of the channel by hypothetical vertical extensions of the bank tops. This maintained constant flow along the entire length of the channel. In reality, of course, flow in the channel is diminished downstream of overflow points.

Several of the alternatives proposed installing flashboards at the check dam earlier than usual – in March instead of April – to enable gravity diversion of about 40 cfs into an adjoining floodplain (e.g., Alternative 1D) or a new channel (e.g., Alternative 2B). High flows in Putah

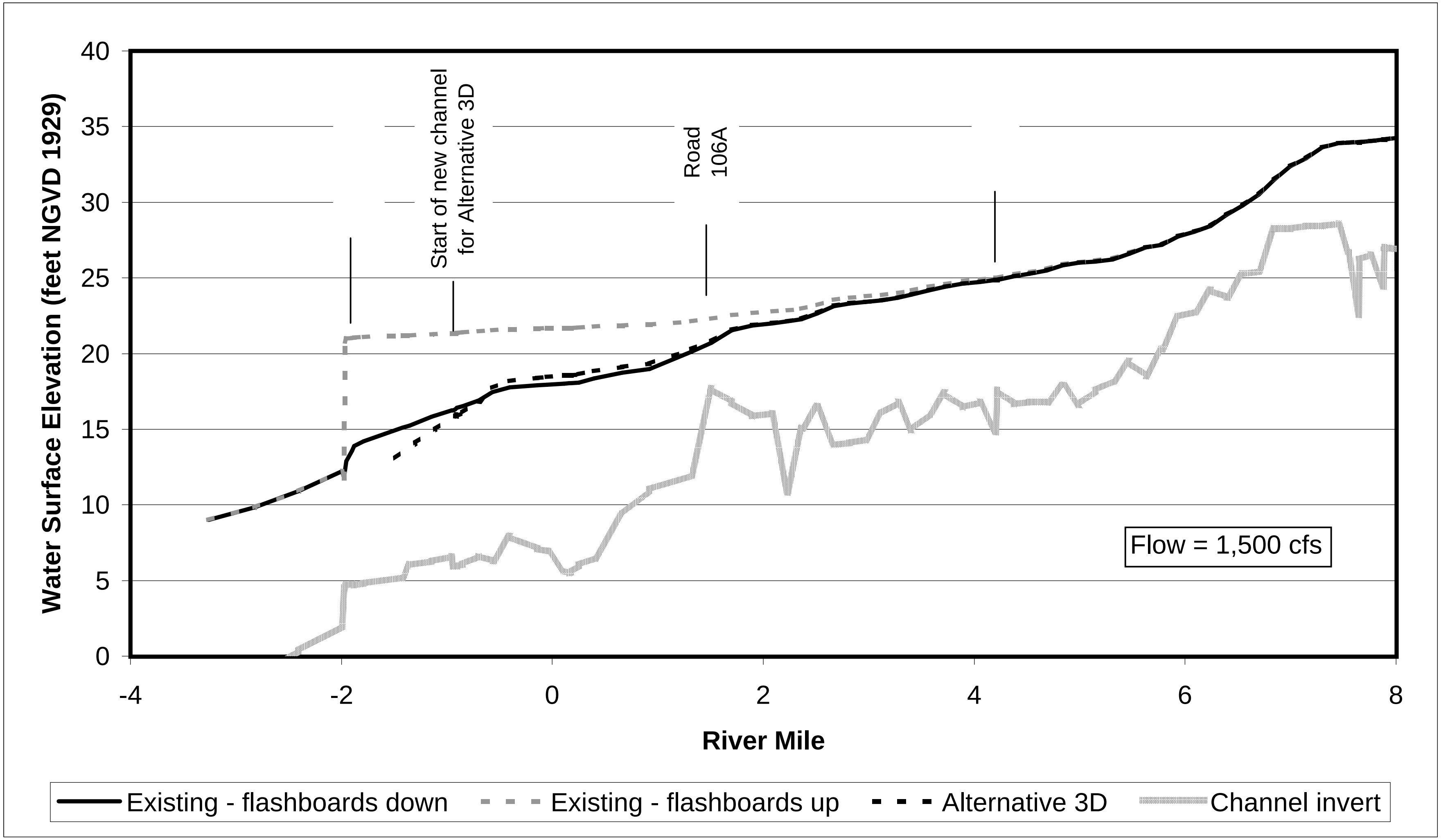


Figure K-6. Simulated Water Surface Profiles along the Lower End of Putah Creek under Existing and Alternative Conditions

Creek are considerably more common in March than in April, and a high-flow event with the flashboards up would cause much larger spills from the channel than would occur with the flashboards down. This condition was simulated by representing the check dam as a weir with a crest elevation of 13.47 feet (NGVD 1929). With the flashboards up, the channel upstream of the dam begins to spill at a flow of only 200 cfs. The spill location is the same as described earlier. Hypothetical levees were included along the banktops to determine the levee elevations that would be needed to contain a flow of 1,500 cfs within the channel when the flashboards are up. The profile for that simulation is shown as the dashed gray line in Figure K-6. A comparison of that profile with the existing banktop profiles (not shown in the figure) indicated that levees 3–5 feet high would be needed from the check dam up to the upstream end of the western split (River Mile 0.2), decreasing to 1–2 feet high between the split and Road 106A (River Mile 1.3).

Under Alternative 3D, all of the flow in the creek would be diverted into a new channel. For simulation purposes, this channel was assumed to leave the existing channel at the southern end of the north-south segment of creek in the western split, where the creek first reaches the Wildlife Area. Rather than turn abruptly north, flow was assumed to proceed east over the top of the bank into a new channel that then turns south. The top of the bank was assumed to be reshaped into a 300-foot-wide flat-bottomed notch with a bottom elevation of 13.47 feet (NGVD 1929). In the center of that broad gap was assumed to be a small low-flow notch 2.5 feet deep and10 feet wide at the base, with 2:1 side slopes. The new channel downstream of the exit point was assumed to retain this shape and have a slope equal to the general fall of the terrain (0.00088). For convenience, the channel was only simulated for the first 4,000 feet, and a rating curve was developed for the downstream boundary condition. The check dam was assumed to be up and to not pass any water. The north channel of the western split was also assumed to be ineffective and not convey any flow.

The simulated water surface profile for a flow of 1,500 cfs is similar to the profile under existing conditions with the flashboards down. This is because the large width of the new channel is able to convey 1,500 cfs with relatively little flow depth (about 2 feet). The water surface elevation along the abandoned channel between the exit point and the check dam was 15.9 feet, or only about 0.5 foot higher than the elevation at which water first spills out of the channel. Thus, with this exit design, berms along the channel would need to be raised only about 1 foot in a few places to prevent an increase in overflow frequency onto adjacent agricultural fields.

The second objective of the modeling was to identify the locations and magnitudes of changes in bed shear stress along the creek. Bed shear stress represents the ability of the creek to transport bed load material. Abrupt decreases in shear stress along the flow path indicate locations where deposition would be likely, and locations with high bed shear stress would be prone to scour. Profiles of bed shear stress for the three conditions just described are shown in Figure K-7. Simulated bed shear stress is quite variable, as indicated by the spikes and dips along the upstream part of all three curves. The differences between the curves shows the effects of leaving the flashboards up or of diverting all of the flow into a new channel. The pool impounded by the check dam creates a reach of low shear stress that extends to slightly above Road 106A. If the flashboards were left permanently up, this pool would gradually fill with sediment. Coarser material would be deposited near the upstream end, with progressively finer material settling out toward the dam. If the flashboards continued to be operated seasonally, as

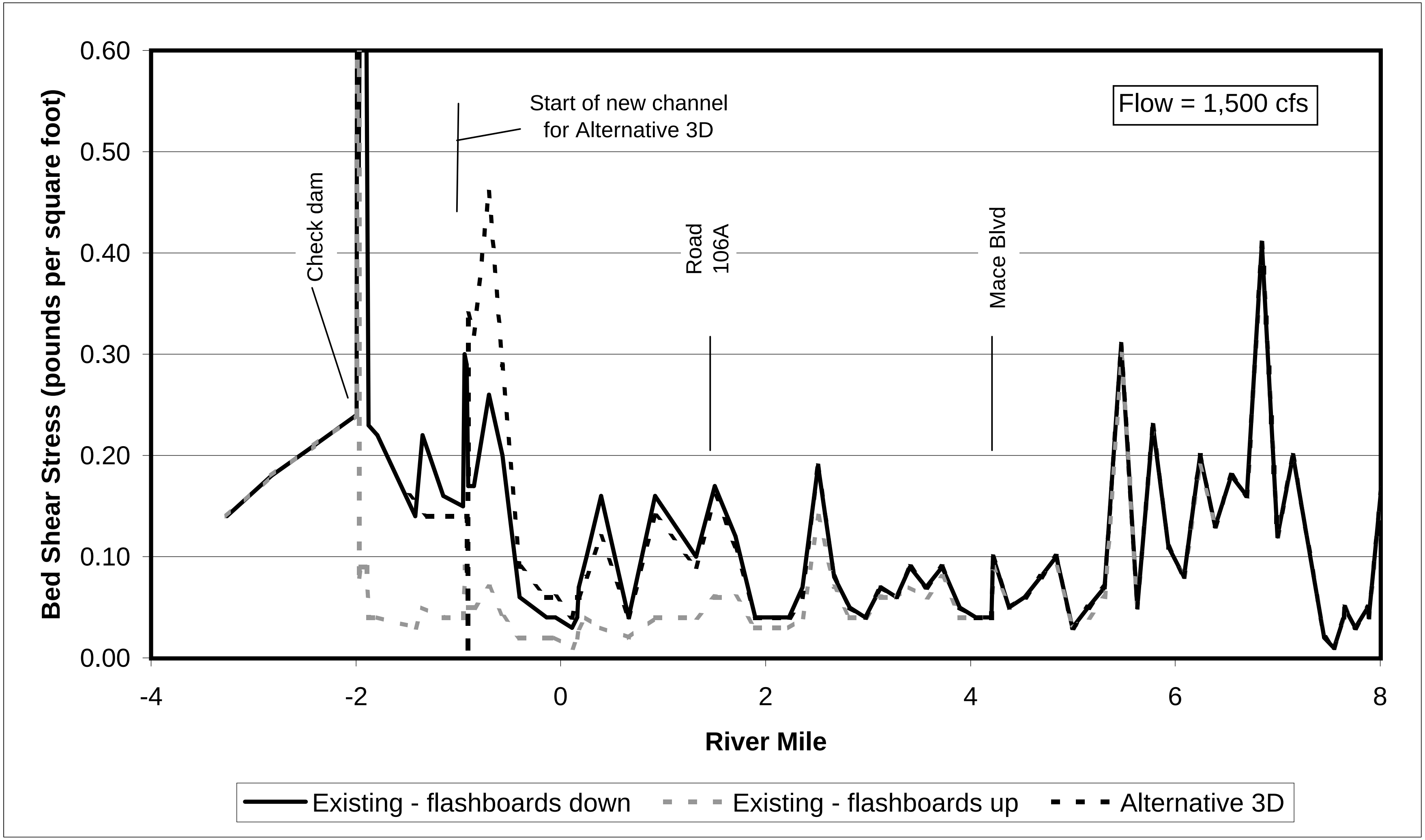


Figure K-7. Simulated Bed Shear Stress along the Lower End of Putah Creek under Existing and Alternative Conditions

contemplated under Alternatives 1D and 2B, any sediment accumulated during a high flow event in March would tend to be flushed out the following winter when the first high flow event occurred with the flashboards removed.

Alternative 3D has a much smaller effect because the pool impounded upstream of the exit point is much lower than the pool impounded by the check dam (15.9 feet versus 20.9 feet NGVD 1929) and consequently much shorter. In fact, markedly decreased shear is evident only immediately upstream of the exit point, where flow widens out and slows down as it approaches the weir-like start of the new channel. This is shown in the figure as the single downward spike near River Mile -0.9. This suggests that sedimentation would partially fill in the channel immediately upstream of the exit point, and a sandbar would form in the existing (non-flowing) channel immediately downstream of the exit point. With little or no flow continuing down the existing channel toward the check dam, sedimentation would be limited to the vicinity of the exit point to the new channel. The sandbar might need to be periodically dredged to maintain a modest conveyance capacity for irrigation flows in summer.

Summary and Conclusions

Almost all of the historical human-induced impacts to lower Putah Creek have tended to decrease the sediment transport capacity of the creek and the amount of sediment reaching the Yolo Bypass.

- Putah Creek flows across a low-lying alluvial fan, where sudden changes in alignment due to channel avulsion are more likely than gradual meandering.
- The creek channel was somewhat incised in the 1850s—at least near Davis—but the amount of incision increased following construction of the South Fork in the late 19th century.
- Construction of the Solano Project in the 1950s greatly decreased the flows in lower Putah Creek (peak flows and average annual discharge volume), and the decreased energy of the flow regime has tended to increase channel stability. There have been no natural changes in channel alignment since the project was constructed.
- Monticello Dam and to a lesser extent Putah Diversion Dam intercept almost all of the sediment supply that formerly entered lower Putah Creek. This has not resulted in a noticeable change in thalweg profile or cross-sectional area along the lower end of the creek, however.
- Sediment transport along lower Putah Creek appears to be active, but undoubtedly at a much lower rate than occurred prior to the Solano Project.
- Gravel mining and levee construction between 1945 and 1975 resulted in the removal of substantial volumes of sediment from the channel and adjoining terraces. These excavations might have created sediment traps that decreased the rate of sediment influx to the Yolo Bypass reach, but again, no obvious changes in thalweg profile or cross-sectional area have resulted.
- Hydraulics modeling indicates that the capacity of the existing channel between Road 106A and the Los Rios Farms/CDFG check dam with the flashboards down is about 1,500 cfs, with a water surface elevation of 13.9 feet (NGVD 1929) at the dam.

- With the flashboards up, a flow of 1,500 cfs would have a water surface elevation of 20.9 feet at the dam (several feet higher than the bridge and abutments). This condition could result from early installation of the flashboards under Alternatives 1D and 2B. Containing this flow within the channel would require levees 3–5 feet along about 2 miles of channel and levees 1–2 feet high along an additional 2 miles of channel.
- If a flow of 1,500 cfs is entirely directed into a new channel with a 300-foot-wide flat bottom at elevation 13.47 (NGVD 1929), the water surface upstream of the exit point is 15.9 feet, or only slightly higher than the overflow elevation of the existing channel. This condition would occur under Alternative 3D. Levees 1–2 feet high would be needed in only a few places to prevent an increase in upstream overflows.
- The long, slow pool created by routing high flows down the existing channel with the flashboards up (which could happen in March under Alternatives 1D and 2B) would tend to accumulate sediment. That sediment would likely be flushed out the following winter when the first high flow occurred with the flashboards down.
- If all flow is routed down a new channel (Alternative 3D), sedimentation would likely occur in the existing channel, but only in the immediate vicinity of the exit point to the new channel.

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APPENDIX L: RELEVANT CEQA CATEGORICAL EXEMPTIONS

All references are to Cal. Code Regs., tit. 14.

15304. Minor Alterations to Land.
Class 4 consists of minor public or private alterations in the condition of land, water, and/or vegetation which do not involve removal of healthy, mature, scenic trees except for forestry and agricultural purposes. Examples include but are not limited to:
a) Grading on land with a slope of less than 10 percent, except that grading shall not be exempt in a waterway, in any wetland, in an officially designated (by federal, state, or local government action) scenic area, or in officially mapped areas of severe geologic hazard such as an Alquist-Priolo Earthquake Fault Zone or within an official Seismic Hazard Zone, as delineated by the State Geologist.
b) New gardening or landscaping, including the replacement of existing conventional landscaping with water efficient or fire resistant landscaping.
(c) Filling of earth into previously excavated land with material compatible with the natural features of the site.
(d) Minor alterations in land, water, and vegetation on existing officially designated wildlife management areas or fish production facilities which result in improvement of habitat for fish and wildlife resources or greater fish production.
(e) Minor temporary use of land having negligible or no permanent effects on the environment, including carnivals, sales of Christmas trees, etc.
(f) Minor trenching and backfilling where the surface is restored.
(g) Maintenance dredging where the spoil is deposited in a spoil area authorized by all applicable state and federal regulatory agencies.
(h) The creation of bicycle lanes on existing rights-of-way.
(i) Fuel management activities within 30 feet of structures to reduce the volume of flammable vegetation, provided that the activities will not result in the taking of endangered, rare, or threatened plant or animal species or significant erosion and sedimentation of surface waters. This exemption shall apply to fuel management activities within 100 feet of a structure if the public agency having fire protection responsibility for the area has determined that 100 feet of fuel clearance is required due to extra hazardous fire conditions.

15313. Acquisition of Lands for Wildlife Conservation Purposes
Class 13 consists of the acquisition of lands for fish and wildlife conservation purposes including preservation of fish and wildlife habitat, establishing ecological reserves under Fish and Game Code Section 1580, and preserving access to public lands and waters where the purpose of the acquisition is to preserve the land in its natural condition.

See also CDFG CEQA regulations, § 757, subd. 13:
Class 13: Acquisition of Lands for Wildlife Conservation Purposes. Class 13 consists of the acquisition of lands for fish and wildlife conservation purposes including preservation of fish and wildlife habitat, establishing ecological reserves under Fish and Game Code Section 1580, and preserving access to public lands and waters where the purpose of the acquisition is to preserve the land in its natural condition.

§15316. Transfer of Ownership of Land in Order to Create Parks.
Class 16 consists of the acquisition, sale, or other transfer of land in order to establish a park where the land is in a natural condition or contains historical or archaeological resources and either:
(a) The management plan for the park has not been prepared, or
(b) The management plan proposes to keep the area in a natural condition or preserve the historic or archaeological resources. CEQA will apply when a management plan is proposed that will change the area from its natural condition or cause substantial adverse change in the significance of the historic or archaeological resource.

See also CDFG CEQA regulations, § 757, subd. 16.

§15317. Open Space Contracts or Easements.
Class 17 consists of the establishment of agricultural preserves, the making and renewing of open space contracts under the Williamson Act, or the acceptance of easements or fee interests in order to maintain the open space character of the area. The cancellation of such preserves, contracts, interests, or easements is not included and will normally be an action subject to the CEQA process.

See also CDFG CEQA regulations, § 757, subd. 17.

§15325. Transfers of Ownership in Land to Preserve Existing Natural Conditions and Historical Resources.
Class 25 consists of the transfers of ownership of interests in land in order to preserve open space, habitat, or historical resources. Examples include but are not limited to:
(a) Acquisition, sale, or other transfer of areas to preserve the existing natural conditions, including plant or animal habitats.
(b) Acquisition, sale, or other transfer of areas to allow continued agricultural use of the areas.
(c) Acquisition, sale, or other transfer to allow restoration of natural conditions, including plant or animal habitats.
(d) Acquisition, sale, or other transfer to prevent encroachment of development into flood plains.
(e) Acquisition, sale, or other transfer to preserve historical resources.

APPENDIX M: APPLICABLE MITIGATION STRATEGIES FROM CALFED BAY-DELTA PROGRAM PEIS/EIR

Applicable Mitigation Strategies for Conversion of Prime and Unique Agricultural Land

- Siting and aligning Program features to avoid or minimize impacts on agriculture.
- Examining structural and nonstructural alternatives to achieving project goals in order to avoid impacts on agricultural land.
- Supporting the California Farmland Conservancy Program in acquiring easements on agricultural land in order to prevent its conversion to urbanized uses and increase farm viability. Focusing on lands in proximity to where any conversion impact takes place.
- Restoring existing degraded habitat as a priority before converting agricultural land.
- Focusing habitat restoration efforts on developing new habitat on public lands before converting agricultural land.
- If public lands are not available for restoration efforts, focusing restoration efforts on acquiring lands that can meet ecosystem restoration goals from willing sellers where at least part of the reason to sell is an economic hardship (for example, lands that flood frequently or where levees are too expensive to maintain.
- Using farmer-initiated and developed restoration and conservation projects as a means of reaching Program goals.
- Where small parcels of land need to be acquired for waterside habitat, seeking out points of land on islands where the ratio of levee miles to acres farmed is high.
- Obtaining easements on existing agricultural land for minor changes in agricultural practices (such as flooding rice fields after harvest) that would increase the value of the agricultural crop(s) to wildlife.
- Including provisions in floodplain restoration efforts for compatible agricultural practices.
- Purchasing water for habitat purposes so that the same locality is not affected over the long term.
- Using a planned or phased habitat development approach in concert with adaptive management.
- Minimizing the amount of water supply required to sustain habitat restoration acreage.
- In implementing levee reconstruction measures, working with landowners to establish levee reconstruction methods that avoid or minimize the use of agricultural land.

- Working with landowners to establish levee subsidence BMPs that avoid impacts on land use practices. Through adaptive management, further modify BMPs to reduce impacts on agricultural land.
- Advising the Director of Conservation and the local governing body responsible for the administration of the preserve of a proposal, when it appears that land within an agricultural preserve may be acquired from a willing seller by a state CALFED agency for a public improvement as used in Government Code Section 51920.
- Limiting the number of acres that can be fallowed (in order to produce transferable water) in a given area (district or county) or the amount of water that can be transferred from a given area.

APPENDIX N: OUTLINE OF THE ACTION-SPECIFIC IMPLEMENTATION PLANS FOR CALFED ACTION COMPLIANCE WITH FESA, CESA AND NCCP

To fulfill the requirements of FESA Sections 7 and 10 and California Fish and Game Code Sections 2835 and 208 1, as applicable, each ASIP must adhere to the following outline:

- a detailed project description of the CALFED action or group of actions to be implemented, including site-specific and operational information;
- a list of evaluated species and any other special-status species that occur in the action area;
- an analysis identifying the direct, indirect, and cumulative impacts on the evaluated species, other special-status species occurring in the action area (along with an analysis of impacts on any designated critical habitat) likely to result from the proposed CALFED action or group of actions, as well as actions related to and dependent on the proposed action;
- measures the implementing entity will undertake to avoid, minimize, and compensate for such impacts and, as appropriate, measures to enhance the condition of NCCP communities and evaluated species, along with a discussion of:

  a plan to monitor the impacts and the implementation and effectiveness of these measures,

  the funding that will be made available to undertake the measures, and

  the procedures to address changed circumstances;
- measures the implementing entity will undertake to provide commitments to cooperating landowners, consistent with the discussion in Section 6.3.5 below;
- a discussion of alternative actions the applicant considered that would not result in take, and the reasons why such alternatives are not being utilized;
- additional measures USFWS, NMFS, and CDFG may require as necessary or appropriate for compliance with FESA, CESA, and NCCPA; and
- a description of how and to what extent the action or group of actions addressed in the ASIP will help CALFED achieve the MSCS's goals for the affected species (i.e., how the ASIP implements the MSCS).

APPENDIX O: BRIEF EXCERPTS OF U.S. ARMY CORPS OF ENGINEERS NATIONWIDE PERMITS

NW-01 **Aids to Navigation.** The placement of aids to navigation and Regulatory markers which are approved by and installed in accordance with the requirements of the US Coast Guard.

NW-02 **Structures in Artificial Canals.** Structures constructed in artificial canals within principally residential developments where the connection of the canal to navigable water of the US has been previously authorized.

NW-03 **Maintenance.** Activities related to: 1) the repair, rehabilitation, or replacement of any previously authorized structure; 2) discharges of dredged or fill material, including excavation, to remove accumulated sediments in the vicinity of existing structures or the placement of riprap to protect the structure; 3) discharges of dredged or fill material, including excavation, associated with the restoration of upland areas damaged by storm, flood, or other event, including the construction, placement, or installation of upland protection structures.

NW-04 **Fish and Wildlife Harvesting, Enhancement, and Attraction Devices and Actions.** Fish and wildlife harvesting devices and activities such as pound nets, crab traps, crab dredging, eel pots, lobster traps, duck blinds, clam and oyster digging; and small fish attraction devices such as open water fish concentrators (sea kites, etc.). This NWP authorizes shellfish seeding provided this activity does not occur in wetlands or sites that support submerged aquatic vegetation.

NW-05 **Scientific Measurement Devices.** Devices, whose purpose is to measure and record scientific data such as staff gages, tide gages, water recording devices, water quality testing and improvement devices and similar structures. Small weirs and flumes constructed primarily to record water quantity and velocity are also authorized provided the discharge is limited to 25 cubic yards and further.

NW-06 **Survey Activities.** Survey activities including core sampling, seismic exploratory operations, plugging of seismic shot holes and other exploratory-type bore holes, soil survey, sampling, and historic resources surveys.

NW-07 **Outfall Structures and Maintenance.** Activities related to: 1) construction of outfall structures and associated intake structures where the effluent from the outfall is authorized; 2) maintenance excavation, including dredging, to remove accumulated sediments blocking or restricting outfall and intake structures, accumulated sediments from small impoundments associated with outfall and intake structures, and accumulated sediments from canals associated with outfall and intake structures, provided that the activity meets certain criteria (see full text).

NW-08 **Oil and Gas Structures.** Structures for the exploration, production, and transportation of oil, gas, and minerals on the outer continental shelf within areas leased for such purposes by the DOI, Minerals Management Service (MMS). Such structures shall not be placed within the limits of any designated shipping safety fairway or traffic separation scheme, except temporary anchors that comply with the fairway regulations in 33 CFR 322.5(l).

NW-09 **Structures in Fleeting and Anchorage Areas.** Structures, buoys, floats and other devices placed within anchorage or fleeting areas to facilitate moorage of vessels where the USCG has established such areas for that purpose.

NW-10 **Mooring Buoys.** Non-commercial, single-boat, mooring buoys.

NW-11 **Temporary Recreational Structures.** Temporary buoys, markers, small floating docks, and similar structures placed for recreational use during specific events such as water skiing competitions and boat races or seasonal use provided that such structures are removed within 30 days after use has been discontinued. At USACE reservoirs, the reservoir manager must approve each buoy or marker individually.

NW-12 **Utility Line Activities.** Activities required for the construction, maintenance and repair of utility lines and associated facilities in waters of the US. (see full text)

NW-13 **Bank stabilization.** Bank stabilization activities necessary for erosion prevention provided the activity meets specific criteria. (see full text)

NW-14 **Linear Transportation Projects.** Activities required for the construction, expansion, modification, or improvement of linear transportation crossings (e.g., highways, railways, trails, airport runways, and taxiways) in waters of the US, including wetlands, if the activity meets the criteria. (see full text)

NW-15 **U.S. Coast Guard Approved Bridges.** Discharges of dredged or fill material incidental to the construction of bridges across navigable waters of the US, including cofferdams, abutments, foundation seals, piers, and temporary construction and access fills provided such discharges have been authorized by the USCG as part of the bridge permit. Causeways and approach fills are not included in this NWP and will require an individual or regional Section 404 permit.

NW-16 **Return Water From Upland Contained Disposal Areas.** Return water from upland, contained dredged material disposal area. The dredging itself may require a Section 404 permit (33 CFR 323.2(d)), but will require a Section 10 permit if located in navigable waters of the US. The return water from a contained disposal area is administratively defined as a discharge of dredged material by 33 CFR 323.2(d), even though the disposal itself occurs on the upland and does not require a Section 404 permit. This NWP satisfies the technical requirement for a Section 404 permit for the return water where the quality of the return water is controlled by the state through the Section 401 certification procedures. (Section 404)

NW-17 **Hydropower Projects.** Discharges of dredged or fill material associated with (a) small hydropower projects at existing reservoirs where the project, which includes the fill, are licensed by the Federal Energy Regulatory Commission (FERC) under the Federal Power Act of 1920, as amended; and has a total generating capacity of not more than 5000 kW; and the permittee notifies the District Engineer in accordance with the "Notification" General Condition; or (b) hydropower projects for which the FERC has granted an exemption from licensing pursuant to Section 408 of the Energy Security Act of 1980 (16 U.S.C. 2705 and 2708) and Section 30 of the Federal Power Act, as amended; provided the permittee notifies the District Engineer in accordance with the "Notification" General Condition. (Section 404)

NW-18 **Minor Discharges.** Minor discharges of dredged or fill material into all waters of the US if the activity meets all of the criteria.

NW-19 **Minor Dredging.** Dredging of no more than 25 cubic yards below the plane of the ordinary high water mark or the mean high water mark from navigable waters of the US (i.e., Section 10 waters) as part of a single and complete project. This NWP does not authorize the dredging or degradation through siltation of coral reefs, sites that support submerged aquatic vegetation (including sites where submerged aquatic vegetation is documented to exist, but may not be present in a given year), anadromous fish spawning areas, or wetlands, or the connection of canals or other artificial waterways to navigable waters of the US (see 33 CFR 322.5(g)). (Sections 10 and 404)

NW-20 **Oil Spill Cleanup.** Activities required for the containment and cleanup of oil and hazardous substances which are subject to the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR part 300) provided that the work is done in accordance with the Spill Control and Countermeasure Plan required by 40 CFR part 112.3 and any existing state contingency plan and provided that the Regional Response Team (if one exists in the area) concurs with the proposed containment and cleanup action. (Sections 10 and 404)

NW-21 **Surface Coal Mining Activities.** Discharges of dredged or fill material into waters of the US associated with surface coal mining and reclamation operations provided the coal mining activities are authorized by the DOI, Office of Surface Mining (OSM), or by states with approved programs under Title V of the Surface Mining Control and Reclamation Act of 1977.

NW-22 **Removal of Vessels.** Temporary structures or minor discharges of dredged or fill material required for the removal of wrecked, abandoned, or disabled vessels, or the removal of man-made obstructions to navigation.

NW-23 **Approved Categorical Exclusions.** Activities undertaken, assisted, authorized, regulated, funded, or financed, in whole or in part, by another Federal agency or department where that agency or department has determined, pursuant to the Council on Environmental Quality Regulation for Implementing the Procedural Provisions of the National Environmental Policy Act (NEPA) (40 CFR part 1500 et seq.), that the activity, work, or discharge is categorically excluded from environmental documentation, because it is included within a category of actions which neither individually nor cumulatively have a significant effect on the human environment.

NW-24 **State Administered Section 404 Program.** Any activity permitted by a state administering its own Section 404 permit program pursuant to 33 U.S.C. 1344(g):(l) is permitted pursuant to Section 10 of the Rivers and Harbors Act of 1899. Those activities that do not involve a Section 404 state permit are not included in this NWP, but certain structures will be exempted by Section 154 of Pub. L. 94-587, 90 Stat. 2917 (33 U.S.C. 591) (see 33 CFR 322.3(a)(2)). (Section 10)

NW-25 **Structural Discharges.** Discharges of material such as concrete, sand, rock, etc., into tightly sealed forms or cells where the material will be used as a structural member for standard pile supported structures, such as bridges, transmission line footings, and walkways or for general navigation, such as mooring cells, including the excavation of bottom material from within the form prior to the discharge of concrete, sand, rock, etc.

NW-26 **Reserved.**

NW-27 **Stream and Wetland Restoration Activities.** Activities in waters of the US associated with the restoration of former waters, the enhancement of degraded tidal and non-tidal wetlands and riparian areas, the creation of tidal and non-tidal wetlands and riparian areas, and the restoration and enhancement of non-tidal streams and non-tidal open water areas.

NW-28 **Modifications of Existing Marinas.** Reconfiguration of existing docking facilities within an authorized marina area. No dredging, additional slips, dock spaces, or expansion of any kind within waters of the US is authorized by this NWP. (Section 10)

NW-29 **Single-family Housing.** Discharges of dredged or fill material into non-tidal waters of the US, including non-tidal wetlands for the construction or expansion of a single-family home and attendant features (such as a garage, driveway, storage shed, and/or septic field) for an Individual Permittee provided that the activity meets all of the criteria.

NW-30 **Moist Soil Management for Wildlife.** Discharges of dredged or fill material and maintenance activities that are associated with moist soil management for wildlife performed on non-tidal Federally-owned or managed, state-owned or managed property, and local government agency-owned or managed property, for the purpose of continuing ongoing, site-specific, wildlife management activities where soil manipulation is used to manage habitat and feeding areas for wildlife.

NW-31 **Maintenance of Existing Flood Control Facilities.** Discharge of dredge or fill material resulting from activities associated with the maintenance of existing flood control facilities, including debris basins, retention/detention basins, and channels that meet certain criteria.

NW-32 **Completed Enforcement Actions.** Any structure, work or discharge of dredged or fill material, remaining in place, or undertaken for mitigation, restoration, or environmental benefit in compliance with specified terms.

NW-33 **Temporary Construction, Access and Dewatering.** Temporary structures, work and discharges, including cofferdams, necessary for construction activities or access fills or dewatering of construction sites; provided that the associated primary activity is authorized by USACE or USCG, or for other construction activities not subject to the USACE or USCG regulations.

NW-34 **Cranberry Production Activities.** Discharges of dredged or fill material for dikes, berms, pumps, water control structures or leveling of cranberry beds associated with expansion, enhancement, or modification activities at existing cranberry production operations provided that the activity meets all of the criteria.

NW-35 **Maintenance Dredging of Existing Basins.** Excavation and removal of accumulated sediment for maintenance of existing marina basins, access channels to marinas or boat slips, and boat slips to previously authorized depths or controlling depths for ingress/egress, whichever is less, provided the dredged material is disposed of at an upland site and proper siltation controls are used. (Section 10)

NW-36 **Boat Ramps.** Activities required for the construction of boat ramps provided:

NW-37 **Emergency Watershed Protection and Rehabilitation.** Work done by or funded by: a) The NRCS which is a situation requiring immediate action under its emergency Watershed Protection Program (7 CFR part 624); or b) The USFS under its Burned-Area Emergency Rehabilitation Handbook (FSH 509.13); or c) The DOI for wildland fire management burned area emergency stabilization and rehabilitation (DOI Manual Part 620, Ch. 3).

NW-38 **Cleanup of Hazardous and Toxic Waste.** Specific activities required to effect the containment, stabilization, or removal of hazardous or toxic waste materials that are performed, ordered, or sponsored by a government agency with established legal or regulatory authority.

NW-39 **Residential, Commercial, and Institutional Developments.** Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, for the construction or expansion of residential, commercial, and institutional building foundations and building pads and attendant features that are necessary for the use and maintenance of the structures.

NW-40 **Agricultural Activities.** Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, for improving agricultural production and the construction of building pads for farm buildings.

NW-41 **Reshaping Existing Drainage Ditches.** Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, to modify the cross-sectional configuration of currently serviceable drainage ditches constructed in waters of the US. The reshaping of the ditch cannot increase drainage capacity beyond the original design capacity. Nor can it expand the area drained by the ditch as originally designed (i.e., the capacity of the ditch must be the same as originally designed and it cannot drain additional wetlands or other waters of the US).

NW-42 **Recreational Facilities.** Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, for the construction or expansion of recreational facilities, provided the activity meets certain criteria.

NW-43 **Stormwater Management Facilities.** Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, for the construction and maintenance of stormwater management facilities, including activities for the excavation of stormwater ponds/facilities, detention basins, and retention basins; the installation and maintenance of water control structures, outfall structures and emergency spillways; and the maintenance dredging of existing stormwater management ponds/facilities and detention and retention basins, provided the activity meets certain criteria.

NW-44 **Mining Activities.** Discharges of dredged or fill materials into certain bodies of water.

APPENDIX P: EXCERPTS OF YOLO COUNTY FLOOD DAMAGE AND DEVELOPMENT PERMIT REGULATIONS

Yolo County Zoning Code, Chapter 3. Flood Damage Prevention

Sec. 8-3.401. Establishment of flood hazard development permit.

(a) A Flood Hazard Development Permit shall be obtained before any construction or other development begins within any area of special flood hazards established in Section 8-3.302. Application for a Flood Hazard Development Permit shall be made on forms furnished by the Floodplain Administrator and may include, but not be limited to: plans in duplicate drawn to scale showing the nature, location, dimensions, and elevation of the area in question; existing or proposed structures, fill, storage of materials, drainage facilities; and the location of the foregoing.

Sec. 8-3.506. Floodways.

Located within areas of special flood hazard established in Section 8-3.302 are areas designated as floodways. Since the floodway is an extremely hazardous area due to the velocity of flood waters which carry debris, potential projectiles, and erosion potential, the following provisions apply:

(a) Prohibit encroachments, including fill, new construction, substantial improvements, and other new development unless certification by a registered professional engineer is provided demonstrating that encroachments shall not result in any increase in the base flood elevation during the occurrence of the base flood discharge.

In addition to the requirements in Subsection (a), of this section, all new construction, substantial improvements, and other proposed new development shall comply with all other applicable flood hazard reduction provisions of this article.