SURFACE STORAGE INVESTIGATIONS PROGRAM

SACRAMENTO RIVER FLOW REGIME STATUS REPORT

ADMINISTRATIVE DRAFT

Prepared For:

NORTH-OF-THE-DELTA OFFSTREAM STORAGE INVESTIGATION

California Department of Water Resources
Division of Planning and Local Assistance
901 P Street
Sacramento, California 95816

Bureau of Reclamation
Mid-Pacific Region
Federal Office Building
2800 Cottage Way
Sacramento, California 95833

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This report was prepared under the direction of:

NORTH-OF-THE-DELTA OFFSTREAM STORAGE INVESTIGATION

California Department of Water Resources

Stephen Roberts, ... Chief, Surface Storage Investigations Branch

Sean Sou... Supervising Engineer, Surface Storage Investigations Branch

James Wieking .... Senior Engineer, Surface Storage Investigations Branch

U.S. Bureau of Reclamation

David Lewis ....

Michael Tansey ....

Ron Ganzfried

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EXECUTIVE SUMMARY

Introduction

The present investigations of new offstream water storage locations near the Sacramento River began in 1997 with funding from Proposition 204, *The Safe, Clean, Reliable Water Supply Act.* Early in the investigation, stakeholders' primary concern was identified as the Sacramento River flow regime and the potential impacts of diverting Sacramento River flows for a North-of-the-Delta Offstream Storage (NODOS) project. At the same time, initial NODOS conceptual plans were developed to improve the flow regime of the river for certain ecosystem processes. The CALFED Record of Decision (ROD) in 2000 identified a NODOS facility near Sites as one of the five storage investigations to be considered for further study. In 2001, the NODOS Project Management Team (PMT) requested establishing a Technical Advisory Group (TAG) to consider the flow regime of the Upper Sacramento River. TAG members are identified in Appendix A. The PMT specifically asked that the TAG help identify potential NODOS flow regime impacts and benefits, as well as improve the general understanding of the flow regime of the Sacramento River below Keswick Dam and related ecosystem processes.

Purpose of Status Report

The purpose of this Sacramento River Flow Regime Status Report is to share and document information related to the physical aspects of the flow regime of the Sacramento River and the resulting ecological responses. This report describes historic changes in the flow regime of the river and presents a few preliminary concepts that may contribute to improving the habitat and ecological processes of the river, with or without a new NODOS project. The report also identifies the need for additional studies related to flow regime and ecosystem processes. Information from this report will be used by the NODOS investigation to develop and evaluate alternatives and identify impacts and benefits of the NODOS alternatives on the Sacramento River system below Keswick Dam. Ultimately, the NODOS study team will develop environmental and feasibility documents that will include analysis of impacts and benefits associated with NODOS alternatives. This report will provide a background and foundation for that analysis.

Background

In 1986, Senate Bill 1086 called for an *Upper Sacramento River Fisheries and Riparian Habitat Management Plan*, to "protect, restore, and enhance wild strains of salmon and steelhead and maximize habitat restoration for naturally spawning salmon and steelhead, as well as preserve remaining riparian habitat and reestablish a continuous riparian ecosystem along the Sacramento River between the mouth of the Feather River and Keswick Dam." The federal Central Valley Project Improvement Act (CVPIA) and CALFED programs also have identified improvements in Sacramento River geomorphology, meander migration, fishery, and ecosystem health as important issues. As part of the CALFED program and the Integrated Storage Investigation, a report (*Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red Bluff, 2000 - also known as the "2000 Flow Regime White Paper"*) summarized information about the Upper Sacramento River and identified long-term studies to address the kinds of flow regime requirements between Red Bluff and Colusa to maintain or rehabilitate riparian and riverine habitat with respect to existing conditions and capability/constraints of infrastructure. This study also identified the need to consider changes in the flow regime and riparian habitat conditions before and after construction of Shasta Dam and the need to understand the capabilities and constraints of current infrastructure to develop an ecologically beneficial flow regime through modification of reservoir operations, flood bypass operations, and diversions. The results of the 2000 Flow Regime White Paper were considered during the preparation of the CALFED Programmatic Environmental Impact Statement/ Environmental Impact Report (EIS/EIR) (CALFED 2000a), specifically in the Ecosystem Restoration Program and the hydrologic/hydraulic modeling used in the impact analysis.

The *2000 North of the Delta Offstream Storage investigation Progress Report* (Progress Report) was prepared concurrently with the CALFED Programmatic EIS/EIR to evaluate several potential reservoirs on the western side of the Sacramento Valley, including Sites Reservoir. Following the completion of the CALFED PEIS/EIR and ROD, the results of the Progress Report were incorporated into the current NODOS program. The NODOS investigation is being completed by the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation) in partnership with local water interests and other State and Federal resources agencies. DWR and Reclamation are conducting a feasibility investigation with appropriate California Environmental Quality Act and National Environmental Policy Act compliance and documentation to support selection of a recommended plan for implementation. Draft and final Feasibility Report/EIS-EIR are planned for completion in Spring 2008 and Fall 2008.

Study Area Description

The watershed for the Sacramento River includes 6,649 square miles above Shasta Dam. The watershed increases to 8,900 square miles at Red Bluff and 12,100 square miles at Colusa. Unimpaired flows of the Sacramento River were characterized by high runoff rates during winter and early spring storms. Spring snowmelt occurred in the late spring and early summer months. Flows declined in the summer. Peak storm events generally occurred during the months of February, March, and April. In this area, peak tributary flows occur during and immediately following storm events.

The Sacramento River is contained between natural vertical banks between Shasta Lake and Red Bluff. Downstream of Red Bluff, the river migrates through alluvial deposits and coarse cobbles constrained by natural terraces to Woodson Bridge (a reach of 43 river miles). From Woodson Bridge to Colusa (57 river miles), the natural riverbed meanders through coarse gravels in an area somewhat constrained by intermittent natural levees on the west.

The flow regime of the Sacramento River has been modified since the late 1800s by dams and diversions, flood protection projects, and erosion control measures. More specifically, the magnitude, duration, timing and subsequent effects of flows in the river have been altered; peak winter flows have been reduced; snowmelt flows have been eliminated; and peak flow in the main stem has be desynchronized from peak tributary inflows. In recent years, several studies have described existing conditions, identified actions that modified the river, and considered concepts and programs that could improve fish, wildlife, and vegetation habitat conditions associated with the river. This document addresses pertinent highlights of such studies.

The TAG identified the following five historic flow regime changes and the general ecosystem functions that have been affected:

1. Reductions in the magnitude and duration of peak flows during late-winter and early-spring storms that disturbed the soil and contribute to in-channel and overbank habitat that also support processes such as seed germination.
2. Reduction or elimination of “snowmelt runoff” patterns (including appropriate recession rates) in spring that maintained adequate soil moisture for successful seed root growth, especially in the overbank areas.
3. Increased summer flows and abrupt reductions in mid-October following or during the fall-run Chinook salmon spawning period that desiccate some incubating eggs.
4. Sporadic and unsustained flows into the bypasses (including the Yolo Bypass) during peak flow events that strand fish, desiccate eggs, and lessen valuable spawning and rearing habitat for both Chinook salmon and Sacramento splittail.
5. Diversions from the Sacramento River that entrain or entrap juvenile fish.

Recent Investigations

This report also summarizes a variety of studies that focus on the history of recent channel formation on the Sacramento River, needs for additional information related to flow and channel formation, and concepts that could potentially be used to achieve restoration goals for the Sacramento River. Most of these studies have been limited in scope due to limited availability of long-term data and observations, and nearly all of them identified the need for additional studies. The study summaries are grouped into five categories, 1) Comprehensive Studies; 2) Flow, Sediment, and Channel Form Studies; 3) Riparian Vegetation Studies; 4) Recreation and Socioeconomic Studies; and 5) Land Management Program-related Studies.

NODOS Assumptions and Concepts

While a number of concerns have been considered during NODOS planning, operational assumptions for the NODOS program in the scenarios discussed with the TAG are that the reservoir would be located at Sites with storage of 1.8 million acre-feet. Potential diversions would occur at Red Bluff near the Red Bluff Diversion Dam, Hamilton City at the Glenn-Colusa Irrigation District diversion, and a new diversion near the Maxwell Irrigation Diversion site opposite Moulton Weir. One of the offshoots of the TAG process was the development of five preliminary flow and operation scenarios designed to improve environmental conditions along the Sacramento River. Generally the scenarios increased flows during peak storm events, increased spring flows to emulate a snowmelt flow pattern, stabilized fall flows, increased flow into the Yolo Bypass during some years, or reduced diversions at Red Bluff Diversion Dam and Glenn-Colusa Irrigation District during the spring.

There are several concepts being considered for the use of NODOS to improve Sacramento River flow regime. One of the concepts would increase the amount of flow in the river to improve conditions between Keswick and Colusa for channel formation, vegetation establishment, and fisheries. Water stored in Sites Reservoir could be used for a number of identified needs including flow regime modifications, other restoration scenarios, or other water use needs.

Diversion of water at any of the three river diversion locations (Tehama-Colusa Canal at Red Bluff, Glenn-Colusa Irrigation District Canal at Hamilton City, and a new pipeline opposite Moulton Weir) may be limited by the presence of suspended sediment. The primary downstream control point for flow associated with real-time Shasta Dam operations is Bend Bridge. Examples of flood operation constraints include maintenance of dedicated flood control capacity in Shasta Reservoir and maximum flood flow targets at specific river gage locations such as Bend Bridge.

Models Used to Simulate Conditions and Potential Effects

To better understand how interventions to historic, present, and future flow patterns of the Sacramento River have or will affect physical processes and ecological function, a set of conceptual models and a toolbox of potentially useful analytical models was assembled. These tools will assist in depictions and interpretation of the affects of flow regime modification scenarios.

NODOS Flow Regime Scenarios

The following five flow regime modification scenarios have been developed to improve habitat conditions along the Upper Sacramento River in support of restoring conditions related to the five historic flow regime changes as described above. (Note: Scenario 1 is intended to restore flow regime conditions that have been changed as described in the historic flow regime change 1 above) The scenarios are not NODOS alternatives, but may be used to develop NODOS alternatives during the investigation. The CALSIM modeling will help indicate the ability of NODOS to provide the specific flow regime conditions.

Scenario 1 - Increase flows during peak storm events in late winter and early spring - Red Bluff to Colusa

Scenario 2 - Modify spring flows into a snowmelt pattern in years with peak storm events in late-winter/early-spring - Red Bluff to Colusa

Scenario 3 - Stabilize fall flows to avoid abrupt reductions - Keswick to Red Bluff: from September through November

Scenario 4 - Increase flows (especially duration) diverted into Yolo Bypass in March and April during years with high flows in those months

Scenario 5 – Reduce late spring diversions at Red Bluff (to provide water into the Tehama-Colusa Canal) and at Hamilton City (to provide water into the Glenn-Colusa Irrigation District Canal).

This report has documented the status of the NODOS investigation related to flow regime of the Upper Sacramento River. Interest in the flow regime and the potential for NODOS to both support restoration scenarios and cause environmental effects remains high. This status report describes information and understanding gained from the Flow Regime Technical Advisory Group to date. In addition, this report documents potential flow regime-related analytical tools and conceptual understandings of flow regime and ecosystem function. With this foundational information, DWR and Reclamation plan to complete a feasibility investigation and a NEPA/CEQA environmental document. DWR and Reclamation would like to thank the members of the TAG for all of their input thus far and look forward to their continued input into improving the understanding of the Upper Sacramento River flow regime as well as advisory input into the NODOS project formulation and benefit and impact analysis.

CHAPTER 1. INTRODUCTION

The CALFED Bay-Delta Program represents an unprecedented effort for establishing a framework to manage California's most valuable natural resource: water. In developing the CALFED Programmatic Record of Decision (ROD, August 28, 2000), the CALFED Program, and the CALFED Agencies addressed the multitude of ecosystem health and water management issues from regional perspectives: asking, "What makes the most sense for the affected region?" The regions, including their respective watersheds, are the Sacramento Valley, the San Francisco Bay Area, the Delta, the Westside San Joaquin Valley, the San Joaquin River/South San Joaquin Valley, and Southern California. Of course, each region is beset with its own unique ecosystem and water management issues, but each area ultimately affects the health and functioning of the Bay-Delta system. None-the-less, the regional issues require local solutions that not only meet regional needs for ecosystem health and water management flexibility, but must also contribute to alleviation of problems manifest in the Delta as well.

The CALFED Preferred Program Alternative consists of a through-Delta conveyance approach, coupled with ecosystem restoration, water quality improvements, levee system improvements, increased water use efficiency, improved water transfer opportunities, watershed restoration, and additional surface water and groundwater storage. Sites Reservoir in the Sacramento Valley is identified in the CALFED ROD as a potential surface storage project requiring additional consideration (CALFED 2000a). Sites Reservoir is characterized as a potential project with a capacity of up to 1.9 million acre-feet of storage that could enhance water management flexibility in the Sacramento Valley. For example, by reducing water diversions on the Sacramento River during critical fish migration periods, a Sites Project could compensate diverters for the reduction in water diversions and greatly increase the reliability of water supplies for a significant portion of the Sacramento Valley (CALFED 2000a).

The storage component (including both surface water and groundwater), contained recommendations for further study and implementation of several programs. The following goals were identified for the storage component.

- Provide flexibility to improve water quality and support fish restoration efforts
- Capture water during peak flows and wet years and move into storage facilities
- Provide additional storage to serve future growth
- Implement concurrently with conservation and recycling

The *2000 North of the Delta Offstream Storage Investigation Progress Report* (Progress Report) evaluated several potential reservoirs on the western side of the Sacramento Valley, including Sites Reservoir (California Department of Water Resources 2000). Following the completion of the CALFED PEIS/EIR and ROD, the results of the Progress Report were incorporated into the current North-of-the-Delta Offstream Storage (NODOS) program. The NODOS investigation is being completed by the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation) in partnership with local water interests and other State and Federal resources agencies. DWR and Reclamation are preparing environmental documentation in compliance with the California Environmental Quality Act and National Environmental Policy Act and feasibility documentation to support selection of a preferred NODOS alternative.

The following goals identified in the CALFED ROD for Sites Reservoir are consistent with the current NODOS investigation.

- Enhance water management flexibility in the Sacramento Valley
- Reduce water diversions from the Sacramento River during critical fish migration periods
- Increase reliability of supplies for a significant portion of the Sacramento Valley
- Provide storage and operational benefits for other CALFED programs, including Delta Water Quality and the Environmental Water Account

Interest in the Sacramento River's flow regime has grown significantly over the last two decades. In recent years, several studies have been conducted to describe existing conditions, identify actions that modified the river, and consider concepts and programs that could improve fish, wildlife, and vegetation habitat conditions associated with the river. The flow regime of the Sacramento River has been modified since the late 1800s by dams and diversions, flood protection projects, land use practices, and erosion control measures. More specifically, the magnitude, duration, timing and subsequent effects of flows in the river have been altered.

In 1986, Senate Bill 1086 called for an *Upper Sacramento River Fisheries and Riparian Habitat Management Plan*, to "protect, restore, and enhance wild strains of salmon and steelhead and maximize habitat restoration for naturally spawning salmon and steelhead, as well as preserve remaining riparian habitat and reestablish a continuous riparian ecosystem along the Sacramento River between the mouth of the Feather River and Keswick Dam." The Central Valley Project Improvement Act (CVPIA) and CALFED programs also have identified improvements in Sacramento River geomorphology, meander migration, fishery, and ecosystem health as important issues. As part of the CALFED program and the Integrated Storage Investigation, a report titled *Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red Bluff, 2000* (CALFED 2000b) (also known as the *"2000 Flow Regime White Paper"*) was prepared to summarize information about the Sacramento River. The report identifies long-term studies to address the kinds of flow regime requirements between Red Bluff and Colusa to maintain or rehabilitate riparian and riverine habitat with respect to existing conditions. This study also identified the need to consider the flow regime and riparian habitat under conditions prior to and after construction of Shasta Dam and to understand the capabilities and constraints of current infrastructure to develop an ecologically beneficial flow regime through modification of reservoir operations, flood bypass operations, and diversions. The results of the 2000 Flow Regime White Paper were considered during the preparation of the CALFED Programmatic Environmental Impact Statement/Environmental Impact Report (EIS/EIR), specifically in the Ecosystem Restoration Program and the hydrologic/hydraulic modeling used in the impact analysis.

North of the Delta Offstream Storage (NODOS)

The ongoing investigation of offstream storage located near the Sacramento River began in 1997 with funding from *The Safe, Clean, Reliable Water Supply Act* (Proposition 204). Early in the

North-of-the-Delta Offstream Storage (NODOS) study, stakeholders identified the flow regime of the Sacramento River as a primary concern related to potential impacts of an offstream storage reservoir. At the same time, initial NODOS conceptual plans were developed to improve the flow regime of the river for specific ecosystem processes.

In 2001, the NODOS Project Management Team (PMT) requested that a Technical Advisory Group (TAG) be established to consider the flow regime of the Upper Sacramento River. The PMT specifically asked that the TAG help identify potential NODOS flow regime impacts and benefits, as well as improve the general understanding of the flow regime of the Upper Sacramento River and related ecosystem processes. Meetings of the Flow Regime TAG began in 2002 and continued through 2004 (See Appendix A for TAG accomplishments and membership).

> Early in the Progress Report phase of the NODOS investigation, stakeholder participants identified the flow regime of the Sacramento River as a primary concern related to potential implementation impacts. At the same time, initial conceptual plans conceived that the flow regime and associated ecosystem processes of the river could be improved with an offstream storage facility. In 2000, a Flow Regime White Paper (CALFED 2000b) was an important part of the initial investigation of westside Sacramento Valley reservoirs during the CALFED programmatic EIS/EIR efforts. This effort was explicitly commissioned to address issues related to flow regime associated with potential non-irrigation period diversions from the Sacramento River that would be part of an offstream storage facility such as Sites Reservoir. Subsequently, the NODOS project management team requested that a TAG be established to pick up many of the issues identified in the white paper as well as provide input related to impacts and benefits.

Operational assumptions for the NODOS investigation in the scenarios discussed with the TAG and presented in this report include a reservoir at Sites with storage of 1.8 million acre-feet. Potential diversions would occur at Red Bluff near the Red Bluff Diversion Dam, Hamilton City at the Glenn-Colusa Irrigation District diversion, and a new diversion near the Maxwell Irrigation District's diversion site opposite Moulton Weir. One of the products of the TAG process was the development of five preliminary flow modification scenarios designed to improve environmental conditions along the Sacramento River. Generally, scenarios increase flows during peak storm events, increase spring flows to emulate a snowmelt flow pattern, stabilize fall flows, increase flow into the Yolo Bypass during some years, or reduce diversions at Red Bluff Diversion Dam and Glenn-Colusa Irrigation District during certain times. The flow regime modification scenarios are discussed in detail in Chapter 7.

DWR and Reclamation are working in partnership with local, regional, State, and federal agencies, and stakeholders to study North-of-the-Delta Offstream Storage opportunities and associated potential effects. Scoping was completed in 2002. DWR and Reclamation are now developing Plan Formulation documents. An Initial Alternatives Information Report was completed May 2006. A Plan Formulation Report is scheduled to be completed Fall 2007. A Feasibility Report and EIS/EIR are scheduled to be completed Fall 2008.

PURPOSE AND SCOPE OF STATUS REPORT

The purpose of the Sacramento River Flow Regime Status Report is to provide the NODOS study team, with input from interested stakeholders, an early opportunity to share and document information related to the flow regime of the river. This report describes historic changes in the flow regime of the Sacramento River and presents a few preliminary concepts that may improve the habitat and ecological processes of the Sacramento River, with or without NODOS implementation. The report also documents the need for additional studies related to flow regime and ecosystem processes. Information from this report will be used by the NODOS investigation to develop and screen alternatives and identify impacts and benefits of the NODOS alternatives on the Sacramento River system. Ultimately, the NODOS study team will develop environmental and feasibility documents that will include analysis of impacts and benefits associated with NODOS alternatives. This report will provide a background and foundation for that analysis.

Much of the information presented herein was conveyed by members of the TAG, including members of the NODOS study team. As mentioned previously, the TAG was convened to consider methods to improve flow patterns in the Sacramento River and identify methods to reduce or avoid flow regime-related negative effects associated with potential NODOS operations. In addition, the TAG and this report were designed more generally to improve the understanding of the river's flow regime and related ecosystem processes.

To further the understanding of river dynamics, the TAG proposed five flow regime modification scenarios designed to restore ecosystem function. These scenarios and the offstream storage operation assumptions are described in Chapter 7. These scenarios are not NODOS alternatives, information from them may.be used to formulate NODOS alternatives during the investigation.

The NODOS study team and TAG anticipate that this general understanding of flow regime and related ecosystem processes will contribute toward the development of a regional ecosystem management plan for an area including the Sacramento River. It is not the intent, nor is it within the scope of the NODOS program to develop a regional ecosystem management plan for the Sacramento Valley. However, the NODOS study team and the TAG both recognize the need for a plan that would provide specific direction related to management of the Sacramento River below Shasta Dam.

Other Related Studies

The California Bay-Delta Authority (CBDA) has commissioned the development of a Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). This regional plan is the first of four regional plans intended to guide the implementation of the CALFED Bay-Delta Program's Ecosystem Restoration Program (ERP) element. The other CALFED regions intended to have regional ecosystem implementation plans include the Sacramento Valley, San Francisco Bay, and the San Joaquin Valley. The DRERIP will refine the planning foundation specific to the Delta, refine existing Delta specific restoration scenarios, and provide Delta specific implementation guidance, program tracking, performance evaluation, and adaptive management feedback. Preparation of the DRERIP is a collaborative effort involving the ERP implementing agencies: Department of Fish and Game, NOAA Fisheries, and the U.S. Fish and Wildlife Service, as well as the CBDA ERP and Science Program staff and the ERP Science Board.

The 2000 Flow Regime White Paper and this Sacramento River Flow Regime Status Report will support the eventual development of a Sacramento Valley Regional Ecosystem Restoration Implementation Plan.

The following evaluation tasks were originally recommended to the TAG by the Project Management Team, the NODOS study team and by TAG members:

- Identify Sacramento River flow regime characteristics necessary to support ecosystem processes (including channel migration, fish migration, and downstream habitat quality) and achieve relevant CALFED Ecosystem Restoration Program goals and objectives.

- Identify potential synergies and conflicts between desirable Sacramento River flow regime characteristics and potential NODOS operations in order to: 1) identify NODOS features and operations to assist in achieving relevant Ecosystem Restoration Program and other CALFED objectives; 2) identify alternatives to NODOS that may also achieve these objectives; and 3) accurately evaluate impacts of NODOS alternatives.

- Determine the Sacramento River's potential to achieve relevant Ecosystem Restoration Program objectives to maintain or enhance ecosystem processes (including meander channel formation and fish migration) under existing operational conditions and under assumptions for CALFED implementation of Ecosystem Restoration Program goals.

- Determine the potential effects to the ecosystem processes on the Sacramento River and downstream habitats (including floodplains, bypasses, and the Delta) of diverting water from the Sacramento River during defined higher flow periods for NODOS.

- Identify potential mitigation and strategies to offset potential impacts associated with NODOS and identify potential alternatives to avoid impacts but meet the associated CALFED goals.

- Determine potential benefits to the ecosystem processes and downstream habitat that may be derived from NODOS.

- Determine specific conditions (season, frequency, duration, temperature, water quality, and flows), if any, when diversions from the Sacramento River can be made with minimal adverse impacts to the ecosystem processes, including meander channel formation, fish migration, and downstream habitat.

- Coordinate flow regime studies and findings with associated programs including SB 1086 Program, CVPIA programs, Corps of Engineers Comprehensive Study, and Ecosystem Restoration Program.

- Provide information, analysis, and tools that will assist the SB 1086 Program to meet goals to preserve remaining riparian habitat and to reestablish a continuous riparian ecosystem along the river.
- Coordinate with the CALFED Science Program to allow scientific peer review of the tools, evaluations, and conclusions developed by the NODOS Project Management Team and its member entities relative to the Flow Regime Evaluation.

Ecological Values of the Sacramento River

The Sacramento River flows more than 300 miles from Lake Shasta to Collinsville in the Delta, where it joins the San Joaquin River. It is a major river of the western United States and the largest and most important riverine ecosystem in the State of California. Some of the environmental attributes associated with the Sacramento River below Keswick Dam include ecological processes; diversity of habitats for fish and wildlife; and a multitude of dependent fish, wildlife, and plant species (CALFED 2000b).

Significant physical processes that help to shape the ecosystem include streamflow, sediment supply, stream meander, and natural floodplain and flood processes. Habitats include riparian and riverine aquatic habitats and freshwater fish habitats. Important species include green sturgeon, white sturgeon, Sacramento River winter-run Chinook salmon, fall-run Chinook salmon, spring-run Chinook salmon, late-fall-run Chinook salmon, steelhead, striped bass, American shad, western yellow-billed cuckoo, valley elderberry longhorn beetle, numerous other species of neotropical migrant birds, and a diversity of plant species and communities (CALFED 2000b).

The Sacramento River Conservation Area (SRCA), established in May 2000, extends along 222 miles of the main stem between Keswick Dam and Verona. The forum handbook identifies four distinct reaches, three of which are between Keswick Dam and Colusa. These reaches are: (1) Keswick to Red Bluff, (2) Red Bluff to Chico Landing, and (3) Chico Landing to Colusa (Sacramento River Conservation Area Forum 2003). Each reach is unique in terms of geomorphology, biology, and human interventions. The Keswick-Red Bluff reach is characterized by relatively stable geologic formations which confine the river and a narrow band of riparian vegetation. In the Red Bluff-Chico Landing reach, the river meanders over a broad alluvial floodplain and encompasses a large system of tributary watersheds which connect the river with the upland areas. In the Chico Landing-Colusa reach, the topography changes such that only Stony Creek provides tributary inflow to the mainstem river. This reach has an extensive system of setback levees and weirs, which control the release of floodwaters into the overflow basin through a system of bypasses and weirs (Resources Agency 2002).

A significant challenge for the NODOS Program will be integrating the growing body of riverine science (both physical and biological) in the development and evaluation of alternative river management interventions in a manner consistent with ongoing restoration programs such as the federal CVPIA Anadromous Fish Restoration Program, CALFED’s Ecosystem Restoration Program, and endangered species recovery programs implemented by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service.

Major Geological and Hydrological Characteristics

The watershed for the Sacramento River extends from above Shasta Dam to Colusa, as shown in Figure 1-1. There are about 6,649 square miles in the Upper Sacramento River watershed above Shasta Dam, including the Sacramento, Pit, and McCloud rivers, that are characterized by steep mountains and canyons that originate at high elevations. This part of the upper watershed is characterized by volcanic rock formations. During the fall and spring, rain enters the soils more slowly than in alluvial soils in the valley, and therefore quickly causes peak flows in these upper watershed streams. Spring snowmelt causes high flows in late spring and early summer. In some of the upper tributaries, water is seasonally stored in the shallow volcanic soils and seeps slowly into the upper reaches of the Sacramento River through the late summer and fall. Water from the snowmelt and high-elevation volcanic rock seeps is relatively cold and provided favorable water temperatures for Chinook salmon. Most of the precipitation in this area of the watershed occurs as snow.

The Sacramento River enters the Redding Plain near Keswick. The river flows through a well-defined trough along the Redding Plain and enters another incised reach near Iron Canyon. This reach continues to about Bend Bridge where the river enters the Central Valley trough. In the Iron Canyon area, upstream of Bend Bridge, the riverbed is characterized by gravel and sand. Downstream of Bend Bridge to Butte City, the riverbed is generally characterized by coarse/medium/fine sand lain over fine/medium gravels. This reach includes active meandering with braiding and straight sections. Generally, the point bars consist of areas of gravels inter-mixed with areas of sand and silts. Between Butte City and Colusa, the riverbed becomes a sand bed that is located near and crosses the Willow Fault. The channel narrows near Colusa to about 14 percent of the width near Butte City. This channel narrowing causes the water to backwater upstream and increases the frequency and extent of overbank flows and sediment deposition into the adjacent Butte Basin and Sutter Basin.

Channel Characteristics of the Sacramento River below Keswick Dam and Recent Studies

The Sacramento River channel was formed by a combination of hydrology, erosion and deposition, sediment generation from tributaries within the watershed, and vegetation. Changes in hydrology and land use resulted in changes in erosion, sediment generation and deposition, and vegetation that are described in this section. Portions have been affected by human activities to control flows for navigation, agriculture, flood damange reduction, flood plain management, and ecosystem restoration.

The riparian corridors in the northern valley troughs consist of several zones. The riverbed is generally an active channel with sand and gravel bars, meandering and braiding. When this channel is flowing full, the condition is generally known as "bankfull discharge." The floodplain adjacent to the riverbed was generally formed during high flows when suspended sediment was deposited during overbank flows. The sediment usually was fine sand, silt and clays that were transported by the laterally spreading floodwaters. Initially, the overbank floodplains were generally flat.

FIGURE 1-1. Sacramento River Watershed.

With a complex microtopography resulting from the formation of distributary channels. As vegetation established, the floodplain became rougher as sediment became trapped in the vegetation. The current floodplain is often located in areas historically occupied by the river channel.

Studies completed by the U.S. Fish and Wildlife Service, DWR, and U.C. Davis have described historical riparian vegetation extending up to 4 to 5 miles from each side of the river and flanked with numerous wetlands. Willow and cottonwood occurred on the sand/gravel banks and point bars adjacent to the channel. The fine sediments deposited in the overbank areas support oaks, sycamore, box-elder, elderberry, and Oregon ash in mixed riparian forests. Under high flow conditions, highly sinuous bends of the channel were "cutoff" resulting in the formation of long sloughs from the former river channel that over time evolved into oxbow lakes and finally to terrestrial mixed riparian forests. Following a cutoff event, additional bank erosion formed new point bars along the river corridor. On portions of the newly formed point bar, shallow slopes near the water’s edge allowed willow/cottonwood vegetation to colonize in a process known as “primary succession.” Over time, as the point bar evolved, other plant species subsequently replaced these initial pioneer species to create mixed riparian forests. In addition, older trees from the riparian forests fell into the active channel and formed areas with "large woody debris” that contributes to fish habitat along riparian corridor.

In the latter part of the 1880s, agricultural activities removed the wide riparian forests in the floodplains. Diversions were constructed in the early 1900s and Shasta Dam was constructed in the 1940s. Following construction of Shasta Dam, flood potential was reduced and agricultural activities extended towards the river channel. Wetland areas, including oxbows, were drained and filled to provide fertile land for agriculture. Bank armoring (rip-rapping) started in the early 1900s; however, the large-scale levee projects began in the 1960s. As diversions, dams, levee construction, and bank armoring (or rip-rapping) were implemented, flow patterns and sediment sources were modified. The extent of the riverbed was constrained, and the aquatic and terrestrial diversity of the meander channel was reduced. The channels and floodplains have been invaded by non-native species such as giant reed (*Arundo donax*), salt cedar (*Tamarix parviflora*), Himalaya berry (*Rubus procerus*), fig (*Ficus carica*), and California black walnut (*Juglans californica* var. *hindsii*), as described in the 2000 Flow Regime White Paper (CALFED 2000b) that is summarized later in this report.

Many reports indicate that it is difficult to predict how the Sacramento River corridor will change in the future. Flow, sediment grain size and deposition, channel erosion, and geologic characteristics can vary across the width and along the main channel of the Sacramento River. Due to the complexity of the present system, it is difficult to use historical patterns on the Sacramento River, or similar rivers, to predict future channel formation patterns. The CALFED report on flow regime requirements discusses several approaches that can be used to evaluate channel formation characteristics, including qualitative and statistical methods.

Mainstem and Tributaries of the Sacramento River between Keswick and Colusa

Following is a short geo-physical description of the Sacramento River watershed.

The Sacramento River originates in the Klamath Mountains west of Mt. Shasta City. The McCloud and Pit rivers flow into the Sacramento River upstream of Lake Shasta. Unimpaired flows of the Sacramento River reflected the runoff patterns primarily associated with winter and early spring precipitation in steep, rocky canyons. Spring snowmelt continues into the late spring and early summer months. Flows decline in the summer into late fall months. Peak unimpaired flows generally occur during January, February, and March. The average annual runoff from the area above Shasta Lake is about 5.9 MAF. The average unimpaired flow in summer and fall months of about 3,000 to 4,000 cfs is caused by groundwater seeping from the volcanic rocks in the upper watershed.

Vertical banks characterize the Sacramento River between Shasta Lake and Red Bluff. Downstream of Red Bluff, the river becomes a meander channel for about 98 miles. The river migrates through alluvial deposits and intersects the tributaries described below. The river channel primarily consists of coarse cobbles between Red Bluff and Woodson Bridge (a reach of 43 river miles). This reach is somewhat constrained by natural terraces. From Woodson Bridge to Colusa (57 river miles), the natural river bed consists of coarse gravels and is somewhat constrained by intermittent natural and constructed levees on the west and Moulton Weir, which diverts floodwaters into the Butte Basin, on the eastern side of the river.

Flow data and watershed size for tributaries to the Sacramento River between Keswick Dam and Colusa were examined to provide additional context for main stem flow patterns. The tributaries discussed in the following sections were selected because flow records were available. In general, most of the unimpaired flow contribution of the Sacramento River occurred in response to the winter flow events.

Some notable tributaries are not included in the discussion as historical flow data are not available. Toomes Creek is one example of a tributary that may provide significant inflow during storm events, but is not described because historical flow records are unavailable.

Major Tributaries between Keswick and Red Bluff

Clear Creek: This watershed is about 228 square miles, west of the river, and the average unimpaired flow of Clear Creek is 302,000 acre-feet/year. Clear Creek enters the Sacramento River at river mile (RM) 290R. Whiskeytown Lake is located on Clear Creek. The Saeltzer Dam was located downstream of Whiskeytown Dam until 2000 when the dam was decommissioned. Immediately following construction of Whiskeytown Dam, flows increased as water was conveyed from Trinity River to the Sacramento River. However, following construction of the conveyance from the Trinity River to Keswick Reservoir, the annual flows in Lower Clear Creek declined to 112,000 acre-feet/year.

Clear Creek supports fall-, late-fall-, and spring-run Chinook salmon and steelhead. In addition to the removal of the diversion dam, there are several other restoration programs that are being completed or have recently been completed on Lower Clear Creek through several agencies, including the Western Shasta Resources Conservation District. These projects include a Vegetation Management Project in 1996, Spawning Gravel Injection Project in 1996, Hubbard Mine Reclamation Project in 1997, and Floodway Rehabilitation Project to reduce impacts of gravel mining on fisheries in 2002.

Cow Creek and Bear Creek: These eastside watersheds are about 425 and 76 square miles, respectively, and provide about 7 percent of the unimpaired Sacramento River flow at the confluence with Bear Creek (RM 278L). There are 13 seasonal gravel diversion dams on tributaries of Cow Creek and other seasonal gravel dams on Bear Creek during the irrigation season. Both creeks support fall- and spring-run Chinook salmon and steelhead.

Cottonwood Creek: The three tributaries of Cottonwood Creek drain about 927 square miles west of the Sacramento River and enter at RM 273R. A portion of this watershed extends to about 4,000 feet elevation, and therefore is influenced by snowmelt. The Cottonwood Creek watershed does not absorb large amounts of rainfall, and is prone to flash flooding. Cottonwood Creek contributes about 7 to 8 percent of the unimpaired flow in the Sacramento River at Bend Bridge. The creek supports fall- and spring-run Chinook salmon and steelhead.

Battle Creek: This 360 square-mile watershed is east of the river and the largest spring-fed tributary of the Upper Sacramento River. Flows continue in the summer and fall months at about 50 percent of the winter and spring flows. Battle Creek contributes about 5 percent of the unimpaired flow in the Sacramento River at Bend Bridge. Battle Creek enters the Sacramento River at RM 271L. Improved fish passage is the theme of the Battle Creek Salmon and Steelhead Restoration Project which is considering a Five Dam Removal Alternative, that would remove Wildcat, South, Soap Creek Feeder, Lower Ripley Creek Feeder, and Coleman Diversion Dams. In addition, fish screens and fish ladders would be installed at North Battle Creek Feeder, Eagle Canyon, and Inskip Diversion Dams. Prior to construction of structures that blocked fish passage, Battle Creek supported fall-, late-fall-, winter-, and spring-run Chinook salmon and steelhead.

Paynes Creek: This creek originates in a series of small lava springs northeast of Red Bluff. The creek flows through a watershed of 93 square miles and enters the Sacramento River north of Red Bluff at RM 253L. Several agricultural diversions occur along the creek. The stream supports fall-run Chinook salmon and steelhead.

Major Tributaries between Red Bluff and Chico Landing

Antelope Creek: This creek originates in the Lassen National Forest northeast of Red Bluff. The creek flows through a watershed of 123 square miles and enters the Sacramento River south of Red Bluff at RM 235L. The average flow is 92 cubic feet/second (cfs) between April and October. Water rights have been issued for up to 120 cfs. Therefore, lower Antelope Creek is generally dry in the summer and early fall. The stream supports fall- and spring-run Chinook salmon and steelhead.

Elder Creek: This 142 square-mile watershed is located west of the Sacramento River and the creek enters the Sacramento River south of Red Bluff at RM 230R. Peak wet weather flows can exceed 11,000 cfs. However, the stream is intermittent in late summer and early fall due to several small diversions. The creek has provided for sporadic populations of fall-run Chinook salmon in the past, but presently does not support adult anadromous fish.

Mill Creek: This creek is a major tributary to the Sacramento River, flowing south and west from the southern slopes of Mount Lassen and entering the Sacramento River north of Hamilton City at RM 230L. The volcanic ash from the Mount Lassen area causes high silt loads during relatively higher runoff periods. The upper watershed is located at 8,000 feet elevation and therefore the 134 square-mile watershed hydrology is dominated by snowfall. The stream supports fall- and spring-run Chinook salmon and steelhead. There are three dams on the lower 8 miles of the 60-mile creek to serve irrigation users: Upper Diversion Dam, Clough Dam, and Ward Dam. Clough Dam was damaged in the 1997 floods. During the summer of 2002, the remnants of Clough Dam were removed and a 30" diameter inverted siphon was installed under Mill Creek to provide diversions to private landowners. Ward Dam was rebuilt in 1997 with a fish ladder and resting pool. Fish screens and a new diversion structure were constructed by Los Molinos Mutual Water Company at the Upper Diversion Dam. Several programs are being completed or have recently been completed on Mill Creek. Lower Mill Creek Riparian Restoration Project was undertaken by the Mill Creek Conservancy and The Nature Conservancy. The Deer and Mill Creek Watershed Conservancies have developed and are implementing watershed plans that focus on the protection of spring-run Chinook salmon habitat. The Deer, Mill, and Antelope Creeks Stabilization Project was initiated by CALFED in 1997 to reduce fine sediment generation. The Mill Creek Water Exchange Program has been implemented to allow conjunctive use of surface water and groundwater in the watershed to increase instream flows during critical migration periods for spring-run Chinook salmon.

Thomes Creek: This creek flows from the west and enters the Sacramento River north of Corning at RM 226R. The creek drains a 203 square mile watershed. There are several small irrigation diversions on Thomes Creek. Lower Thomes Creek is generally dry during late summer and early fall. The creek has provided for sporadic populations of fall-run Chinook salmon in the past. The creek presently does not support sustainable populations of anadromous fish, though a single spring-run Chinook was observed in 1998

Deer Creek: This creek flows from the east on the southern slopes of Butt Mountain, and enters the Sacramento River near Vina at RM 220L. The creek drains a 229 square mile watershed. There are three irrigation diversions on Deer Creek. Because of these diversions, lower Deer Creek is generally dry from summer through early fall. The stream supports fall-run and spring-run Chinook salmon and steelhead. Several of the programs listed above under Mill Creek include efforts on Deer Creek.

Major Tributaries between Chico Landing and Colusa

Big Chico Creek: This creek drains 72 square miles and flows from the west entering the Sacramento River near Chico at RM 193L. Big Chico Creek originates from a series of springs, at an elevation of about 5,400 feet, northeast of the City of Chico on the southwest flanks of Colby Mountain. The watershed also encompasses three smaller drainages to the north:

Sycamore, Mud, and Rock creeks. The average yearly precipitation varies from 70-80 inches at Colby Mountain to about 20 inches at the Sacramento River. Big Chico Creek is a free flowing stream, down to Five-mile dam in Bidwell Park.

Stony Creek: This creek drains a 738 square-mile watershed and flows from the west to the Sacramento River south of Hamilton City at RM 190R. Flows in Stony Creek are controlled by East Park Dam on Little Stony Creek, Stony Gorge Dam on Stony Creek and then at Black Butte Dam on Stony Creek east of Orland. East Park and Stony Gorge reservoirs store surplus water for irrigation deliveries near Orland and are operated by Reclamation independently of the CVP. Black Butte Dam and Reservoir were constructed by the Corps of Engineers. The reservoir provides flood control and irrigation supply and is operated cooperatively by COE and Reclamation. The Stony Creek Task Force is currently evaluating methods to improve fisheries habitat on this tributary. The creek supported small populations of fall-run Chinook salmon in the past, but presently does not support adult anadromous fish

CHAPTER 2. SUMMARY OF HISTORIC CHANGES TO UPPER SACRAMENTO RIVER FLOW CONDITIONS

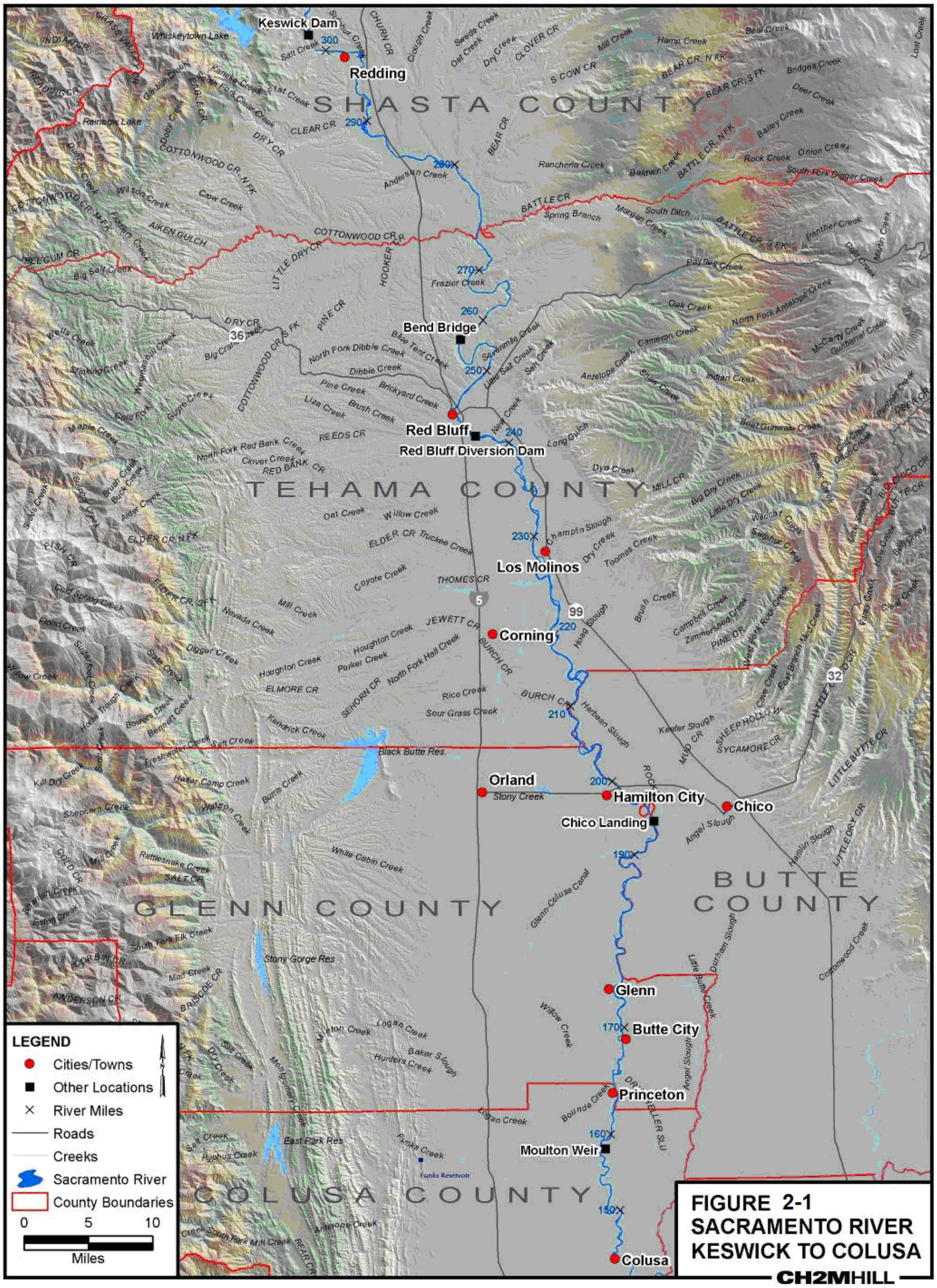
This section describes the apparent historical changes in flows and associated water management actions on the Sacramento River between Keswick Dam and Colusa, as shown on Figure 2-1. Improved understanding of the manner in which the Sacramento River's flow regime has changed over the previous century is an important first step to consider how future interventions might influence river dynamics and its ecological health. Discussions at the Flow Regime TAG meetings indicated that the relationships between river management actions and the flow regime of the Sacramento River were not well understood. More specifically, most generally recognized that the construction of Shasta Dam had a relatively large effect on Sacramento River flow regime when compared to other water management actions. However, the cumulative effects of many other actions were less clearly recognized or acknowledged. The development of this chronology shows that many other actions have affected the flow regime of the river. The understanding of the relationship between the river's flow regime and ecosystem processes has clearly been improved with recent work. However, the mechanisms of the river's flow regime evolution over the last century associated with specific water supply, environmental and flood management actions as described below further improves the general understanding of the Sacramento River flow regime.

To provide a framework to improve understanding of the consequences of historic changes, a chronology of water management actions that appear to have caused a noticeable effect on the river's altered hydrology was prepared. For the subsequent discussions, the Sacramento River is the 158-mile long river section from Keswick Dam (River Mile [RM] 302) downstream to Colusa (RM 144). Note that this presentation is not comprehensive and does not consider factors that are not directly related to water management. For example, the flow regime of the river has also been affected by land use and land management changes, both adjacent to the river and in the tributary watersheds. In addition, changes in climate obviously affect flow regime, but are not described here. Finally, this summary does not attempt to assign relative importance of specific actions to flow regime changes. However, the following chronology does indicate a complex and dynamic evolution of the Sacramento River’s flow regime over the last 120 years.

Chronology of Historical Management Changes on the Sacramento River

This chronology was developed to provide a foundation to understand the relationship between water management actions associated with the Sacramento River and historical streamflow data. This evaluation is not quantitative and is primarily observational based on inspection of annual hydrographs. As an initial listing of water management actions was compared to streamflow data, apparent effects upon the flow regime of the river became discernable. Ultimately, hundreds of annual, monthly, and daily storm hydrographs were compared to gain a sense of the effect of specific actions that have occurred since 1892, the beginning of the daily streamflow records. The reader should note that this is not a statistical analysis of the Sacramento River's hydrology. For a statistical analysis comparing hydrology before and after just two management actions, see the discussion in Chapter 5 of the Indicators of Hydrologic Alteration (IHA) analysis

FIGURE 2-1. Upper Sacramento River Between Keswick Dam And Colusa.



completed by DWR (2002). By contrast, this observational approach relies upon recognition of apparent changes in flow regime effects and subsequent attempts to correlate those observed effects with known water management actions. More than 30 actions have been identified for evaluation using this approach. Because changes from actions have occurred fairly frequently over the streamflow period of record, comparisons of flow regime before and after an action sometimes consist of just a few years. A number of water management actions took place at virtually the same time. Separating multiple-action changes in the flow regime may not be possible, but the cumulative effect of those changes can usually be recognized.

Sources of Streamflow Data

Historical changes in Sacramento River flows have been evaluated in this report based upon historical gauge flows at three locations in the Upper Sacramento River (Table 2-1). Although numerous gauging stations along the Sacramento River have been installed and abandoned during the past century, the following gauges were selected for their long periods of record and their coverage of significant river reaches. The gauge locations are (1) Keswick Dam at River Mile (RM) 302 (USGS# 11370500), (2) Bend Bridge at RM 258 (USGS# 11377100), and (3) Butte City at RM 169 USGS# 11389000). The gauge data for these locations were compiled by DWR as part of the NODOS program. All the flow records are from USGS water supply papers. The period of record for the daily gauge data is presented below with the major inflows and diversions.

Changes in water management that affected the flow regime monitored at these gauges are summarized in Table 2-2.

Evaluation Parameters

The flows have been evaluated with respect to seasonal flow patterns in October, winter flow patterns for November through March, spring flow patterns in April, May, and June, and summer flow patterns in July, August, and September. Additionally, low flows in each season, peak flow events occurring between November and May, and snowmelt are identified. This information can be used as a basis to compare flow regimes prior to and following construction and operation of most water supply management facilities as well as management actions that influence the magnitude and duration of flows in the Sacramento River between Keswick and Colusa.

To assess responses to storm events, a flow of 90,000 cfs at Keswick, Bend Bridge, or Butte City was selected to characterize larger flow events that typically were related to winter storms (Table 2-3).

Streamflow Evaluation Intervals

To provide a more comprehensive discussion of flow changes over time, the flow data were grouped into shorter periods based on water development actions and other water management changes in the system. For example, most recently, new water quality requirements and operational changes due to biological opinions modified the flow regime of the river between 1993 through the end of the period of record.

TABLE 2-1. Location And Related Information For Flow Gauge Data.

Sacramento River below Keswick Dam (River Mile 302) (gauge data 1939 - 1998)
(USGS #11370500)

- Inflow to Shasta Lake from the Upper Sacramento, McCloud, and Pit rivers
- Inflow from Trinity River imports through Keswick Reservoir
- Diversions upstream of Keswick Reservoir to CVP Water Service Contractors: Shasta Dam and Summit City public utility districts, Mountain Gate and Clear Creek community services district, and Bella Vista Water District

Sacramento River at Bend Bridge (River Mile 258) - approximately 15 miles upstream of Red Bluff (River Mile 245) (gauge data 1892 - 1998)
(USGS #11377100)

- Flows as measured at Keswick (as described above). Corps of Engineers estimates typical travel time between Keswick and Bend Bridge at 10 hours.
- Inflows from Clear, Churn, Cow, Bear, Cottonwood, and Battle Creeks
- Inflow from Trinity River imports through Clear Creek
- Diversions between Keswick and Bend Bridge to Water Rights Settlement Contractors: City of Redding, Shasta County Water Agency, and Anderson-Cottonwood Irrigation District

Sacramento River at Butte City (River Mile 169) - approximately 36 miles downstream of Glenn-Colusa Irrigation District Intake (River Mile 205) and 10 miles upstream of Moulton Weir (River Mile 159) (gauge data 1939 - 1998)
(USGS #11389000)

- Flows as measured at Bend Bridge (as described above). Corps of Engineers estimates typical travel time between Keswick and Butte City as 36 hours, and Bend Bridge to Butte City as 26 hours.
- Inflows from Red Bank, Antelope, Mill, Thomes, Deer, Big Chico, and Stony creeks
- Diversions between Bend Bridge and Butte City to Water Rights Settlement Contractors: Glenn-Colusa Irrigation District, Roberts Ditch Irrigation Company, Provident Irrigation District
- Diversions between Bend Bridge and Butte City to CVP Water Service Contractors: Tehama-Colusa Canal and Corning Canal users
- Diversions between Butte City and Colusa to Water Rights Settlement Contractors: Princeton-Cordura-Glenn Irrigation District

This analysis has divided the available streamflow data into 6 intervals for discussion (Table 2-3). The intervals used for the daily flow analysis follow:

1892 – 1938. Prior to construction of Shasta Dam
1939 – 1944. During construction of Shasta Dam, without storage operations at Shasta Dam
1945 – 1964. The initial phases of CVP operations that provided water to water rights holders along the Sacramento and San Joaquin rivers and water contractors in Shasta and Contra Costa counties and along the San Joaquin River
1965 – 1970. Increased deliveries to CVP water service contractors along the Tehama-Colusa, Corning, and San Luis canals and areas near Redding
1971 – 1992. Increasing deliveries to water service contractors along the Cross Valley Canal and in the San Felipe Unit. CVP operations modified to include Trinity River diversion via Keswick Reservoir and inclusion of operational requirements to protect Sacramento River winter-run Chinook salmon and Delta water quality.
1993 – 1998. Following adoption of water quality requirements and biological opinions that modified the pattern of releases from Shasta Dam and reduced amounts of water imported from the Trinity River.

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
Prior to 1886	Water Rights diversion near Keswick for City of Redding	Reduces flow downstream of Keswick	Data not available	Not applicable
"Early 1900s"	Water Rights diversion dams built on Pit and McCloud Rivers above Keswick	Modifies flow regime at Keswick	Data not available	Not applicable
1911	Construction of Yolo Bypass	Indirect – Downstream of Colusa	Not applicable	Not applicable
1915	Water Rights diversion downstream of Keswick and upstream of Bend Bridge for Anderson Cottonwood Irrigation District and Redding Diversion Dam for agricultural users	Modifies flow regime at Bend Bridge and Butte City in summer	Data not available	Not applicable
1916	Water Rights diversion downstream of Bend Bridge for Glenn-Colusa Irrigation District for agricultural users	Modifies flow regime at Butte City in summer	Data not available	Not applicable
1930s	Construction of Sutter Bypass	Indirect – Downstream of Colusa	Not applicable	Not applicable
1939 - 1945	Construction of Shasta and Keswick Dams, 4.5 million acre-feet of storage	Reduces the peak winter storm flows and increases flows in river following storms as part of Sacramento River flood management operations	Not applicable	Not applicable
1945 - 1946	Water Rights deliveries from Shasta Lake to serve City of Redding, Anderson Cottonwood Irrigation District, and other Sacramento River water rights holders that diverted or could have diverted water without construction of Shasta Dam for agricultural purposes The Settlement Contractors are located along the Sacramento River from Redding to West Sacramento	Shasta Dam allowed storage of water in the wet season for diversion later in the summer. These contract amounts are delivered each year, except extreme drought when 75% of contract amounts are delivered 1 percent of released flows diverted upstream of Keswick, 10 percent diverted between Keswick and Bend Bridge, and 61 percent diverted between Bend Bridge and Butte City	Water Rights Settlement Contracts = 1,940,000 af <u>Including:</u> 21,000 af upstream of Keswick 185,000 af between Keswick and Bend Bridge 1,179,500 af between Bend Bridge and Butte City	Not applicable
1948 - 1970	Corps of Engineers constructs flood management systems downstream of Butte City RM 170	May influence flood management decisions related to Shasta Dam operations	Not applicable	Not applicable

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
1950	Completion of Keswick Dam	Reduces hourly flow fluctuations in Sacramento River caused by hydropower operations at Shasta Dam.	Not applicable	Not applicable
1946 - 1955	Modification of Shasta Lake Operations to serve water rights holders along the San Joaquin River. This water was provided in exchange for water diverted by CVP on the upper San Joaquin River to serve the Friant Unit	Summer flows released from Shasta Lake further increased as water released for agricultural uses by the water rights exchange contractors These contract amounts are delivered each year, except extreme drought when 75% of contract amounts are delivered All of these flows pass Keswick, Bend Bridge, and Butte City	Delta-Mendota Water Rights Exchange Contracts: 880,000 af	Not applicable
1946 - 1955	Modification of Shasta Lake Operations to serve agricultural water to CVP contractors located near Shasta Lake, in Contra Costa County, and along the Delta-Mendota Canal	Summer flows released from Shasta Lake for agricultural uses by the CVP contractors. 1 percent released upstream of Keswick and 99 percent pass Keswick, Bend Bridge, and Butte City	Not applicable	Shasta Unit = (Shasta Dam and Summit City public utility districts, and Mountain Gate Community Services District) 3,635 af Contra Costa Water District = 195,000 af Delta-Mendota Contractors = 75,400 af prior to 1964

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
1958 - 1985	Channel protection installed Red Bluff to Chico Landing (including the Bend Bridge to Butte City reach)	Reduces or eliminates bank erosion and sediment generation, reduces or eliminates the formation of oxbows (See Chapter 5)	Not applicable	Not applicable
1963	Black Butte Reservoir completed on Stony Creek	Modifies flows from Stony Creek into Sacramento River Changed flow regime downstream of Hamilton City	Not applicable	Not applicable
1963 - 1964	Whiskeytown Dam, Lewiston Dam (Trinity Lake), and Clear Creek Tunnel completed in 1963. Trinity Dam completed in 1964, and water diverted to Sacramento River through Clear Creek	Increases tributary inflows between Keswick and Bend Bridge Available water varies from less than 100,000 to more than 1,800,000 af/year	Not applicable	Not applicable
1964	Red Bluff Diversion Dam and Corning Canal completed Modification of Shasta Lake Operations to serve agricultural water to CVP contractors along the Corning canal	Summer releases from Shasta Lake further increased to serve the agricultural uses by CVP contractors 100 percent of these flows passed by Keswick and Bend Bridge, and diverted upstream of Butte City	Not applicable	Corning Canal Contractors = 43,800 af
1966	Wintu Pumping Plant completed downstream of Keswick to deliver water through Bella Vista Conduit	Primarily summer flows from Shasta Lake further increased for agricultural users with some municipal users	Not applicable	Shasta Unit = released immediately downstream of Keswick increased from 3,635 af (see 1946) to 49,445 af
1967	Whiskeytown Conduit completed	Allowed water from Trinity River to be delivered into Sacramento River via Clear Creek or Keswick Reservoir	Not applicable	Not applicable

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
1967	State Water Project (SWP) Banks Pumping Plant and California Aqueduct and SWP/CVP San Luis Reservoir completed	Summer flows from Shasta Lake further increased for CVP water service contractors in San Luis Unit	Not applicable	San Luis Unit = 1,4366,000 af
1971	Tehama-Colusa Canal initial reaches completed	Summer flows from Shasta Lake further increased for CVP water service contractors served by Tehama Colusa Canal	Not applicable	Tehama Colusa Canal users = 322,000 af
1960s	Uses in Contra Costa Canal Unit is modified from agricultural to municipal uses	Flows that used to be delivered primarily in summer, now delivered all year long	Not applicable	No change in contract amount
1970s	Additional CVP contractors are connected to Delta Mendota Canal San Luis Reservoir came into service	Flows from Shasta Lake further increased for CVP water service contractors served by Delta-Mendota Canal. Primarily agricultural contracts and 10,000 af to serve City of Tracy	Not applicable	Delta Mendota Canal Unit = increased from 75,400 af (see 1946) to 237,500 af
1971	State Water Resources Control Board (SWRCB) adopts Water Rights Decision 1379 to establish water quality standards	Summer flows from Shasta Lake further increased to reduce salinity when water is exported from Delta	Not applicable	Not applicable
1975	Cross Valley Canal completed	Summer flows from Shasta Lake further increased to serve agricultural users in southern San Joaquin Valley Deliveries through SWP facilities and occur only when capacity available in Banks Pumping Plant and California Aqueduct	Not applicable	Cross Valley Canal users = 176,500 af
1978	SWRCB adopts Decision 1485 to increase requirements to meet Delta water quality	Flows from Shasta lake further increased to reduce salinity when water is exported from Delta Releases reduced water available to CVP water service contractors	Not applicable	Not applicable

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
1981	Secretary of the Interior established minimum instream flows in Trinity River and initiated studies to protect anadromous fish in Trinity River	Flows into Sacramento River reduced, especially in drier years The reductions in exports reduced water available to CVP water service contractors	Not applicable	Not applicable
1984	Rice farmers in northern Sacramento Valley begin to flood fields to improve air quality	Flows from Shasta Lake are released in October and November for "rice inundation"	Part of existing contracts	Part of existing contracts
1987	San Felipe Unit completed - water not delivered until early 1990s due to drought	Flows from Shasta Lake further increased throughout the year to serve municipal and agricultural users in Santa Clara and San Benito counties	Not applicable	San Felipe Unit = 196,300 af (35 percent agricultural and 65 percent municipal)
1990-1993	National Oceanic and Atmospheric Agency (NOAA) Fisheries and SWRCB established requirements for late summer and fall flow releases to reduce temperatures for winter-run Chinook salmon	Flow requirements upstream of Bend Bridge required increased flows from Shasta Lake from about August through early October, To maintain cold water pool to protect winter-run Chinook salmon, CVP water contract deliveries were reduced when storage in Shasta Lake was low If possible, water was diverted by downstream users	Not applicable	Not applicable
1991	Secretary of the Interior increased Trinity River minimum instream flow in drier years	Further reduced flows diverted from Trinity River into Sacramento River in drier years The reductions in exports reduced water available to CVP water service contractors	Not applicable	Not applicable
1991	State legislature passes Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991	Additional flows from Shasta Lake are released in October and November for rice stubble flooding and decomposition (see also 1984)	Part of existing contracts	Part of existing contracts

TABLE 2-2. Summary Of Water Management Activities That Affected Upper Sacramento River Flows.

Year	Activity	Related Effect in Sacramento River: Keswick to Colusa	Water Right Amounts for Delivery from CVP - including Shasta Lake	CVP Contract Amounts for Delivery - including Shasta Lake
1992	PL 102-575, including Title 34: Central Valley Project Improvement Act, signed by President Bush	Provisions reduced amount of water available for delivery to CVP water service contractors and increased amounts of water delivered to refuges and used for environmental restoration (including water provided under Section 3406(b)(2))	Not applicable	CVP Contract amounts not reduced Level 2 Refuge Water Supply = 653,600 af
1993	U.S. Fish and Wildlife Service issued restrictions on CVP and SWP operations to protect Delta smelt	Reduced periods when water released from Shasta Lake to be exported from Delta	Not applicable	Not applicable
1994	Bay-Delta Plan Accord signed	The accord did not specifically change operations but led to changes in requirements	Not applicable	Not applicable
1995	SWRCB adopts Water Rights Order 95-01 that modified Delta water requirements for CVP and SWP	Flows from Shasta lake further increased to reduce salinity when water is exported from Delta and increased releases from Shasta Lake in winter and in spring following storm periods to reduce Delta salinity to protect habitat Releases reduced water available to CVP water service contractors	Not applicable	Not applicable

TABLE 2-3. Peak Flows For Major Storm Events In Upper Sacramento River.

(Storms with peak daily flows in excess of 90,000 cfs measured at Keswick, Bend Bridge or Butte City)

Water Year (Oct-Sept)	Storm Dates	Peak Flows (cfs) [1]		
		Keswick	Bend Bridge	Butte City
1892 through 1938: Period Prior to Construction of Shasta Dam: During this period, major diversions constructed in 1915 -1916 to serve upper Sacramento River water rights users and a drought occurred 1928 – 1934. Keswick and Butte City flows were not recorded during this period.				
1893	December 24- 27, 1892	No Data	156,000	No Data
	March 11, 1983		90,900	
	April 6, 1893		118,000	
1894	January 15, 1894		150,000	
1895	December 21, 1894		108,000	
	January 4, 1895		106,000	
	January 22-23, 1895		117,000	
1896	January 17-18, 1896		122,000	
	January 20- 21, 1896		115,000	
	January 27- 28, 1896		128,000	
1900	January 2-3, 1900		96,600	
	March 7, 1900		123,000	
1901	February 19, 1901		102,000	
1902	February 9-11, 1902		140,000	
	February 23- 26, 1902		151,000	
1903	November 9, 1902		118,000	
1904	January 24-25, 1903		119,000	
1904	November 20-21, 1903		119,000	
	January 21, 1904		109,000	
	February 15, 1904		177,000	
	February 21, 1904		108,000	
	February 23-24, 1904		98,800	
	March 7-8, 1904		147,000	
	March 15-19, 1904		101,000	
	March 28, 1904		91,300	
1905	January 22, 1905		108,000	
1906	January 18, 1906		136,000	
	March 30, 1906		137,000	
1907	February 1- 4, 1907		134,000	
	March 17- 22, 1907		184,000	
1909	January 7-8, 1909		111,000	
	January 14- 17, 1909		181,000	
	January 19-21, 1909		168,000	
	January 25, 1909		94,800	
	February 1- 4, 1909		232,000	
1910	December 9, 1909		90,800	
1911	March 7, 1911		130,000	
1914	December 31, 1913 - January 3, 1914		145,000	
	January 21- 22, 1914		122,000	
	February 20- 22, 1914		153,000	
1915	February 1- 3, 1915		228,000	
1916	February 11, 1916		91,300	
1917	February 25- 26, 1917		176,000	
1919	February 11, 1919		118,000	
1921	November 19, 1920		104,000	

[1] USGS water supply papers are the source of flow data.

TABLE 2-3. Peak Flows For Major Storm Events In Upper Sacramento River.

(Storms with peak daily flows in excess of 90,000 cfs measured at Keswick, Bend Bridge or Butte City)

Water Year (Oct-Sept)	Storm Dates	Peak Flows (cfs) [1]		
		Keswick	Bend Bridge	Butte City
	January 30, 1921		96,000	
1925	February 11- 12, 1925		115,000	
1927	February 21- 22, 1927	No Data	137,000	No Data
1928	March 27, 1928		140,000	
1933	September 19, 1933		92,700	
1935	April 8, 1935		98,200	
1936	January 15, 1936		110,000	
	February 22, 1936		120,000	
1938	November 20, 1937		91,100	
	December 11-12, 1937		103,000	
	February 8- 10, 1938		113,000	
	March 20, 1938		92,500	
	March 23- 24, 1938		113,000	
1939 through 1944: Period During Construction of Shasta Dam				
1940	January 26-27, 1940	33,700	77,600	91,400
	February 28-29, 1940	160,000	261,000	162,000
	March 30 - April 1, 1940	95,200	149,000	136,000
1941	December 24-25, 1940	64,700	104,000	114,000
	December 27-28, 1940	62,400	105,000	114,000
	January 14-15, 1941	30,200	67,000	99,000
	January 25-26, 1941	62,400	109,000	110,000
	February 11-12, 1941	54,100	114,000	147,000
	March 1-2, 1941	66,100	129,000	147,000
	April 4-6, 1941	69,300	114,000	135,000
1942	December 16-17, 1941	65,400	80,000	96,100
	January 25-26, 1942	53,200	91,100	121,000
	January 27-28, 1942	66,900	100,000	126,000
	February 6-7, 1942	78,400	181,000	166,000
1943	January 22- 25, 1943	44,200	105,000	141,000
1945 through 1964: Period Following Construction of Shasta Dam Delivery of Sacramento River Water Rights Settlement and Delta-Mendota Water Exchange Contacts, CVP Water Service Contracts to areas near Redding and along Contra Costa and Delta-Mendota canals				
1946	December 28-29, 1945	8,000	64,000	112,000
1952	December 27-29, 1951	7,140	87,800	102,000
1953	January 13-15, 1953	61,700	75,100	104,000
	January 16-18, 1953	69,100	85,700	98,800
	January 21-22, 1953	61,200	83,000	101,000
1956	December 22-24, 1955	29,800	88,500	130,000
	January 15-16, 1956	26,300	107,000	145,000
	February 22-23, 1956	48,600	80,200	115,000
	February 24, 1956	51,200	68,900	103,000
1958	February 4-6, 1958	42,700	79,300	117,000
	February 12-13, 1958	56,800	85,800	118,000
	February 18- 23, 1958	75,800	125,000	158,000
	February 24-26, 1958	51,100	93,900	146,000
1963	April 13-16, 1963	41,900	66,800	94,800

TABLE 2-3. Peak Flows For Major Storm Events In Upper Sacramento River.

(Storms with peak daily flows in excess of 90,000 cfs measured at Keswick, Bend Bridge or Butte City)

Water Year (Oct-Sept)	Storm Dates	Peak Flows (cfs) [1]		
		Keswick	Bend Bridge	Butte City
1965 through 1970: Period of Expansion of CVP Deliveries Additional deliveries to CVP Water Service Contractors along Tehama-Colusa, Corning, and San Luis canals and areas near Redding. CVP operations modified to include storage in San Luis Reservoir and initial flows from Trinity River via Clear Creek				
1965	December 22-24, 1964	40,500	101,000	122,000
	December 27-28, 1964	52,900	71,000	99,800
	January 6-7, 1965	53,400	96,600	120,000
1967	January 31 - February 1, 1967	42,500	77,400	97,000
1969	January 13-14, 1969	5,880	80,000	114,000
	January 21-22, 1969	52,600	81,100	111,000
	January 26-27, 1969	52,600	71,500	95,200
	February 13, 1969	41,700	55,000	92,000
	February 16, 1969	41,700	59,800	99,000
1970	January 27-28, 1970	36,200	83,100	123,000
	January 24-25, 1970	77,200	123,000	146,000
	January 27-28, 1970	75,800	127,000	123,000
1971 through 1992: Period Following Expansion of CVP Deliveries Additional deliveries to CVP Water Service Contractors along Cross Valley Canal and in San Felipe Unit. CVP operations modified to fully use Trinity River flows via Keswick Reservoir and to incorporate operational requirements to protect winter-run Chinook salmon and Delta water quality. Major droughts occurred in 1977-78 and 1987-1992.				
1973	January 18-19, 1973	40,600	64,000	94,200
1974	January 16-18, 1974	43,200	107,000	130,000
	March 31 - April 1, 1974	79,700	119,000	124,000
1978	January 16-17, 1978	20,100	64,800	116,000
1980	January 15- 16, 1980	37,000	64,200	92,000
1983	March 1-2, 1983	50,700	88,400	151,000
1982	December 21, 1981	36,700	56,000	92,800
1983	January 27- 29, 1983	56,600	76,000	123,000
	March 1-2, 1983	23,900	123,000	151,000
	March 7-8, 1983	60,900	87,800	104,000
	March 12-13, 1983	57,900	86,100	115,000
1984	December 11-12, 1983	37,200	66,700	93,500
	December 24-26, 1983	25,100	85,100	127,000
1986	February 17-19, 1986	69,700	108,000	142,000
	March 10-11, 1986	52,300	77,700	99,200
1993 through 1998: Period Following Major Modifications to CVP Operations CVP operations modified to reflect requirements to protect endangered and threatened fisheries species, improve Delta water quality, and increased diversions by upstream water rights holders				
1993	January 22, 1993	3,530	35,900	91,800
1995	January 9, 1995	5,400	94,500	
	March 15, 1995	51,800	107,000	
1997	December 31, 1996 - January 4, 1997	66,700	103,000	

Streamflow Evaluations 1892 through1998 (non-statistical)[2, 3]

1892 through 1938 Streamflow Evaluation Interval

The period of 1892 through 1938 characterizes Upper Sacramento River flows prior to the construction of Shasta and Keswick Dams. The analysis of this period is based upon an evaluation of daily flow data for the Sacramento River at Bend Bridge. The period of gauge record is 1892 through 1938.

Water Management Facilities or Operations that Changed from 1892 through 1938. The Anderson-Cottonwood Irrigation District diversion dam was operational by 1916 to serve agricultural users located south of Redding. The diversion dam was constructed with flashboards that were installed during April and remained in place through October. The City of Redding also constructed a diversion at this time near Keswick. As described below, the combination of these diversions decreased the flows between July and September by about 500 to 1,000 cfs after 1916.

Seasonal Flow Patterns. Flow patterns at Bend Bridge were evaluated for the period 1892 to 1938.

- **October Flow Patterns**. The non-storm daily October flows generally range from 4,000 to 8,000 cfs in this period. October storm events occur infrequently but cause flows that range from less than 10,000 cfs to more than 40,000 cfs.

- **Winter Flow Patterns (November through March)**. Non-storm daily flows in these months generally range from 3,000 to 12,000 cfs. Storms generally occurred during the November through May period. Flows during most storm events ranged from 15,000 cfs to 140,000 cfs. In the 1890s, flows increased and declined rapidly with peak flows of 100,000 to 150,000 cfs. From 1900 to 1927, the duration of the high flow events increased as compared to the previous period. The peak flows also increased during storm events to more than 150,000 cfs. One of the largest storms in the record occurred on December 11, 1937 with a peak flow of 225,000 cfs.

During this period, there was a "Record Drought for the Sacramento Valley" between 1928 and 1934. This period was used as the design drought conditions for the Central Valley Project and State Water Project facilities. Storm events during the drought were short-term in duration and peak flows were generally less than 50,000 cfs.

Storms that caused flows in excess of 90,000 cfs occurred in Water Years 1893, 1894, 1895, 1896, 1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907, 1909, 1910, 1911, 1914, 1915, 1916,

2 This evaluation is primarily observational. As an initial listing of water management actions were compared to streamflow data, apparent effects upon the flow regime of the river became discernable. Ultimately, hundreds of annual, monthly, and daily storm hydrographs were compared to gain a sense of the effect of specific actions that have occurred since 1892.

3 The IHA analysis which is described in Chapter 6 provides a statistical analysis of flow change over time.

1917, 1919, 1921, 1925, 1927, 1928, 1935, 1936, and 1938, as summarized in Table 2-3 and below.

The average monthly flow patterns for this period were evaluated for years from 1892 to 1927 and 1935 to 1938. The drought period of 1928 to 1934 was separated for this evaluation. Average monthly flow patterns for November and December vary from 3,300 to 43,000 cfs. Flows are generally similar during the 1928 to 1934 drought, with daily flows ranging from 3,400 to 15,700 cfs.

Average monthly flows for January, February, and March from 1892 to 1902 are generally similar to those from 1916 to 1928 and 1935 to 1938. Flows from 1903 to 1915 reflect a generally wetter period.

- **Spring Flow Patterns (April through June)**: Non-storm daily spring flows generally range from 6,000 to 20,000 cfs. Spring storms generally result in short-term flow increases of 10,000 cfs to 30,000 cfs.

Flow response to snowmelt generally starts in April-May and continues through June. During this period, the flows typically decrease from about 20,000 cfs to less than 6,000 cfs.

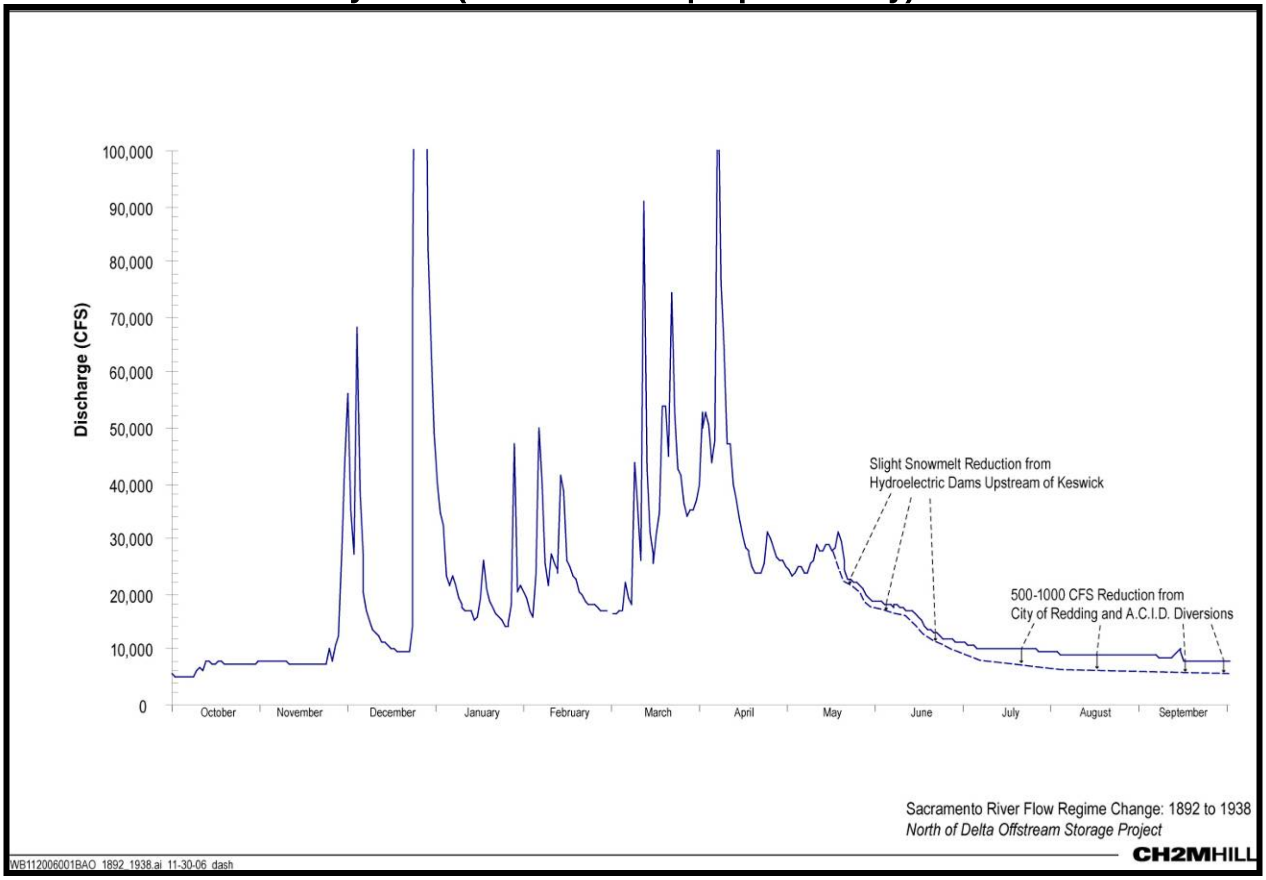
Average monthly flows for April and May range from 3,000 to 38,700 cfs. During the 1928 to 1934 drought, the flows range from 3,100 to 19,600 cfs.

- **Summer Flow Patterns (July through September)**: Average monthly flows during this period range from 2,900 to 10,200 cfs. During the 1928-34 drought, the flows range from 2,500 to 5,800 cfs. The average daily flows generally appear to decrease by about 500-1,000 cfs after 1915 and would be consistent with initial use of the Anderson-Cottonwood Irrigation District intake. Late-September flows throughout the entire period generally appear to increase. This may occur because upstream diversions, including diversions that were constructed prior to 1892 (such as City of Redding and local irrigation districts) are decreased or eliminated following harvest periods.

Summary of Flow Regime Changes from 1892 to 1938. These years included a relatively wet period (1903 to 1915) and an extremely dry period (1928 to 1934). In addition, average daily summer flow (June through September) appear to decrease by about 500 to 1,000 cfs beginning in 1916. The Anderson-Cottonwood Irrigation District intake, located upstream of Bend Bridge, was first operated in 1916 and probably caused part of this change in the flow regime.

The "base" hydrograph depicted in Figure 2-2 is from Water Year 1893 and represents annual flow fluctuations typical of the period prior to the construction of Shasta Dam. The changes shown as dotted lines in subsequent hydrographs illustrate how significant changes in flow management on the Sacramento River have affected annual flow fluctuations. It is important to note that the changes shown are for illustrative purposes only and do not accurately show the magnitude of change to flows for all water year types. Nonetheless, these hydrographs do illustrate the major changes that have occurred to the Sacramento River flow regime between 1892 and 1938 that are the focus of the NODOS investigations (Figure 2-2).

FIGURE 2-2. Base hydrograph from 1892 and conceptual changes that occurred by 1938 (for illustrative purposes only).



1939 through 1944 Streamflow Evaluation Interval

This period encompasses Upper Sacramento River flows during construction of Shasta and Keswick Dams. The period of gauge record is 1939 through 1944.

This is a very short time period for a hydrologic analysis. However, it was selected because this period of record uniquely allows comparison of relatively "unimpaired" storm flows between Keswick, Bend Bridge, and Butte City, as described below.

The analysis of this period is based upon an evaluation of daily flow data for the Sacramento River at Keswick, Bend Bridge, and Butte City. The daily flow patterns in this period were dampened by coffer dams. However, because the storage facilities were not operational, all of the flow was passed into the river within a slight time delay.

Water Management Facilities or Operations that Changed from 1939 through 1944. Prior to this period, diversions were constructed between Bend Bridge and Butte City for the Glenn-Colusa Irrigation District and several other water rights users. The primary changes during this period are associated with construction of Shasta and Keswick dams.

Seasonal Flow Patterns. Flow patterns at Bend Bridge during this period were similar to those that occurred in 1892 to 1938. The flow patterns in this period are described below. However, due to the short period described in this section, the data were not evaluated for changes within this period.

- **October Flows**: The non-storm daily October flows generally range from 4,000 to 6,000 cfs in this period at Keswick, Bend Bridge, and Butte City. Storm events occur infrequently.

- **Winter Flows (November through March)**: Non-storm daily flows in these months generally range from 3,000 to 20,000 cfs. During most of the non-storm periods, Keswick flow range from 30 to 60 percent of flows at Bend Bridge and 25 to 60 percent of flows at Butte City.

  Storms generally occurred December through May. Flows during most storm events range from 70,000 to 130,000 cfs. On February 28, 1940, the largest storm in the period of record occurred with peak flows at Bend Bridge of 261,000 cfs. (Note: gauge data indicates a smaller peak flow downstream at Butte City than at Bend Bridge associated with this end-of-February storm. Flood documents report that numerous levee breaks occurred on the Upper Sacramento River because of this storm and may explain this apparent inconsistency in the data.)

  During the storm events, the storm flows at Keswick ranged from 45 to 69 percent of storm flows at Bend Bridge and Keswick flows ranged 29 to 59 percent of the flows at Butte City (based on the volume of flow during the storm events). Peak flows at Butte City occurred one to two days following peak flows at Keswick and Bend Bridge. During most storms, flows at all gauge stations increased over a 2 to 3 day period and declined over a 3 to 5 day period. Flows during 1940 and 1942 were high and halted construction of Shasta Dam.

  In December 1940/January 1941/early February 1941, the storm patterns were slightly different from other periods. During the storms, the Keswick flows do not increase as compared to increased flows at Bend Bridge and Butte City. The increase in Keswick flows was more apparent in the later February 1941 and March/April 1941 storms.

  The availability of flow data from three gauges provides an opportunity for indication of the percentage of flows at Butte City originate upstream of Keswick and from Keswick to Bend Bridge and Bend Bridge to Butte City. These results will be compared to flow ratios following construction of Shasta Lake, as described in the next subsection. Flow dampening occurs during this period due to use of cofferdams or other means to allow construction of the dam, and therefore, the data from 1940 storms may be more useful than data from 1944 storms. The large storm events that produced flows of at least 90,000 cfs occurred in 1940, 1941, 1942, and 1943 (Table 2-2).

- **Spring Flows (April through June)**: Non-storm daily spring flows generally range from 4,000 to 12,000 cfs. Spring storms in this period generally resulted in lower peak flow values than winter storm with peak flows from 25,000 cfs to 40,000 cfs.

  Snowmelt generally starts in May and continues through June. During this period, flows at Keswick typically decrease from about 12,000 cfs to less than 4,000 cfs. It appears that the snowmelt flows are stored in Shasta Lake and do not increase flows in the Sacramento River.

  In 1944, flows at Keswick do not reflect the snowmelt pattern and decrease in March to less than 1,000 cfs. Flows at Bend Bridge and Butte City decrease to 3,000 cfs by mid-April. Flows at all three gauges increase in late-April to 5,000-6,000 cfs. This flow pattern reflects releases from Shasta Dam to provide water to agricultural users.

- **Summer Flows (July through September)**: Daily flows during this period generally range from 4,000 to 6,000 cfs. Summer flows at Butte City are generally 1,500-2,000 cfs less than flows at Bend Bridge or Keswick until late September. This reflects the diversions between Bend Bridge and Butte City.

Summary of Flow Regime Changes from 1939 through 1944. The most notable change in this period is the change in summer flows in 1944 which eliminated the historic snowmelt pattern and increased flows in mid-April as stored water was released for downstream agricultural diversions.

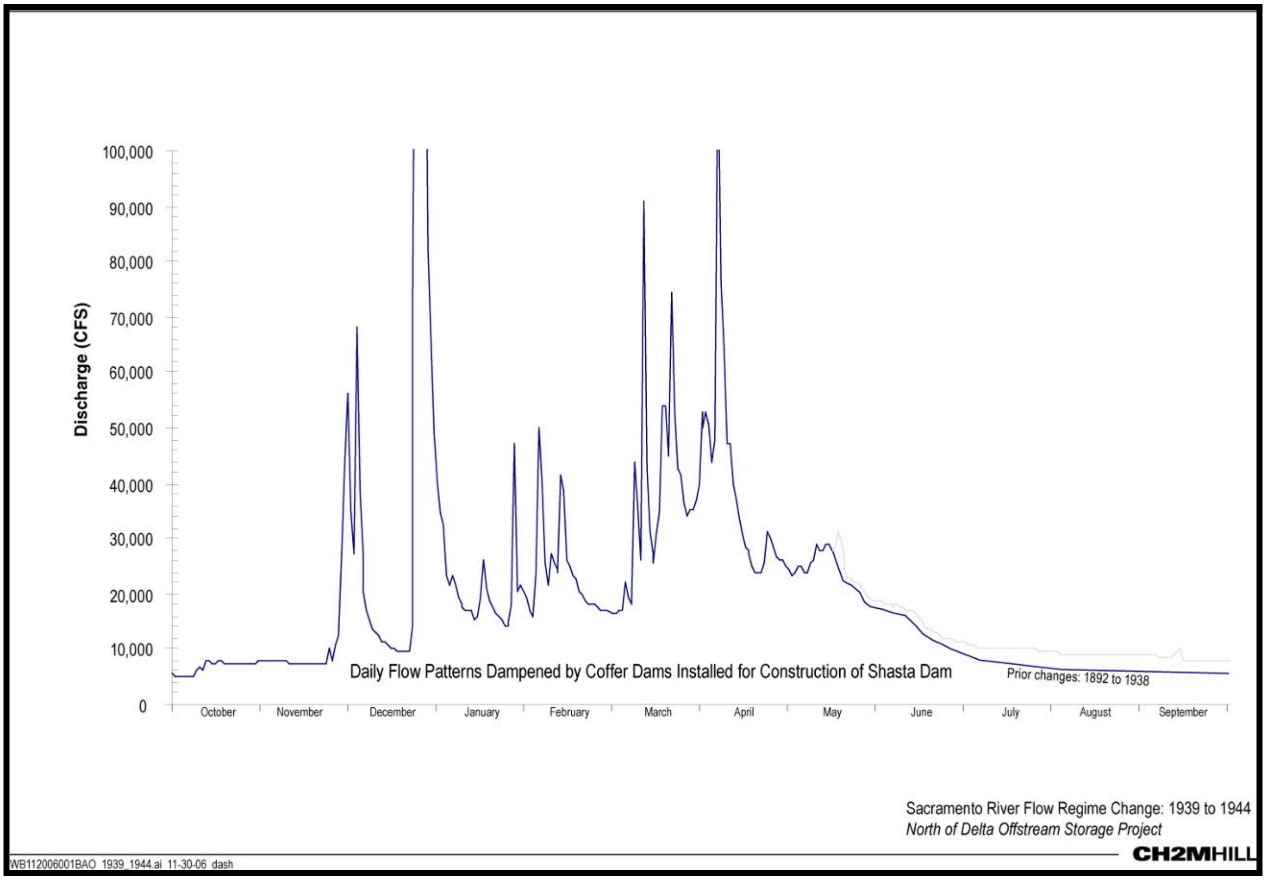
The "base" hydrograph in Figure 2-3 depicts changes that occurred from 1893 to 1938 and changes that occurred from 1939 to 1944. It shows changes reflected by the installation of coffer dams for the construction of Shasta Dam. The changes shown as dotted lines in subsequent hydrographs illustrate how significant changes in flow management on the Sacramento River have affected annual flow fluctuations. It is important to note that the changes shown are for illustrative purposes only and do not accurately show the magnitude of change to flows for all water year types. Nonetheless, these hydrographs do illustrate the major changes that have occurred to the Sacramento River flow regime between 1892-1938 and 1939-1944 (Figure 2-3).

1945 through 1964 Streamflow Evaluation Interval

This period includes Upper Sacramento River flows following construction of Shasta and Keswick Dam and during implementation of Shasta Division, Sacramento River Water Rights Contractors, Contra Costa Canal Unit, and Delta-Mendota Canal Unit. Period of gauge record is 1945 through 1964.

The analysis of this period is based upon an evaluation of daily flow data for the Sacramento River at Keswick, Bend Bridge, and Butte City following construction of Shasta and Keswick

FIGURE 2-3. Base hydrograph from prior changes from1892 through 1938 and changes that occurred from 1939 through 1944 (for illustrative purposes only).



dams. The flow patterns also reflect delivery of water to Sacramento River Water Rights Settlement Contractors, Delta Mendota Water Rights Exchange Contractors, and CVP municipal and agricultural contractors served by the Shasta Division, Contra Costa Canal, and Delta-Mendota Canal. The water right settlement and exchange contract amounts are made available for delivery in all water years except extremely dry years, as defined by the "Shasta Index." In these driest years, 75 percent of the water right contracts are delivered. These deliveries are based on water rights and have higher priorities than CVP water service contracts. Although the CVP water service contracts provided for reductions in deliveries, there was adequate water in storage to meet water demands under the contracts during this period.

Water Management Facilities or Operations that Changed from 1945 through 1964. During this period, releases from Shasta Lake were primarily used to meet prior water rights holders’ requirements in the Upper Sacramento Valley and along the San Joaquin River, and to a lesser extent, to municipal water service contractors near Redding and agricultural water users along the Contra Costa and Delta-Mendota canals. Many of the CVP contractors had not fully implemented water management facilities to divert water from the Sacramento River or CVP canals. Shasta Lake was operated in coordination with Folsom Lake releases to meet the demands located downstream of the confluence between Sacramento and American rivers.

Seasonal Flow Patterns. Flows during this period were analyzed to determine the specific changes that occurred following construction of Shasta and Keswick dams.

- **October Flows**: The non-storm daily flows generally range from 3,000 to 12,000 cfs. There was a slight increase in flows during the fall. This could be due to the availability of water to be used by agricultural users.

- **Winter Flows (November through March)**: Non-storm daily flows in these months generally range from 6,000 to 12,000 cfs. Storms generally occurred December through May. Flows during most storm events range from 20,000 cfs to 120,000 cfs. Storms that caused flows in excess of 90,000 cfs occurred in Water Years 1946, 1952, 1953, 1956, 1958, and 1963, as summarized on Table 2-2. There were several years in this period characterized by a series of storms that maintained moderate flows in the river for a long period, in some instances up to 12 weeks.

  During this period, many of the high flow events were caused by a series of two to three storms. However, the storm of December 20 to 26, 1955 included ten peak flow events. In general, flows at Keswick contributed 11 to over 50 percent of the peak flows at Bend Bridge. Flows at Bend Bridge contributed from 13 to 60 percent of the peak flows at Butte City. In late December 1951/January 1952, Keswick flows did not appear to increase at a high rate as compared to flows at Bend Bridge and Butte City. The Bend Bridge and Butte City flows are more significantly influenced by tributary inflows. Peak flows at Butte City continued to occur one day following peak flows at Bend Bridge and Keswick.

  The average monthly flow patterns at Bend Bridge for this period were compared to average monthly flows for the periods from 1892 to 1927 and 1935 to 1938. The average winter flows are comparable through January. However, average flow rates in February and March are 25 to 50 percent lower following construction of Shasta Dam as compared to years prior to and during the construction. Prior to construction of Shasta Dam, Keswick flows contributed 45 to 69 percent of flows at Bend Bridge. During the 1945-1964 period, average monthly flows exceeded 40,000 cfs in only three years (1953, 1956, and 1958) as compared to fourteen years in the 53 years prior to construction of the dam.

- **Spring Flows (April through June)**: Non-storm daily spring flows generally range from 3,000 to 10,000 cfs. Spring storms generally result in short-term increases of flows with storm flows ranging from 60,000 cfs to 140,000 cfs.

  The spring flows do not reflect snowmelt characteristics due to storage of the snowmelt flows upstream of Keswick. However, flows increase in May or June due to releases from Shasta Lake to serve downstream water users. Flows increase in late spring at Keswick, Bend Bridge, and Butte City to about 10,000 cfs (as compared to pre-Shasta Dam flow patterns that decreased in spring).

- **Summer Flows (July through September)**: Daily summer flows generally range from 9,000 to 11,000 cfs at Keswick and Bend Bridge. In late June, Butte City flows decrease by 3,000 to 4,000 cfs below flows at Keswick and Bend Bridge. This is probably caused by flows diverted to serve the Water Rights Settlement Contractors upstream of Butte City.

Summary of Flow Regime Changes from 1945 through 1964. The primary changes in this period are related to reductions in peak flows during late winter/early spring months, loss of snowmelt flows in May and June, and increased flows in the summer. The high storm flows occurred with lower peak flow values and less frequently at Keswick. The duration of the peak flow events became longer due to the releases from Shasta Dam following a storm event. This change in flow patterns reduced the potential for channel formation, as described in Chapter 7.

The "base" hydrograph in Figure 2-4 depicts changes that occurred from 1893 to 1938 and changes that occurred from 1945 to 1964. It shows reduction in peak winter flows and loss of snowmelt flows. The changes shown as dotted lines in subsequent hydrographs illustrate how significant changes in flow management on the Sacramento River have affected annual flow fluctuations. It is important to note that the changes shown are for illustrative purposes only and do not accurately show the magnitude of change to flows for all water year types (Figure 2-4).

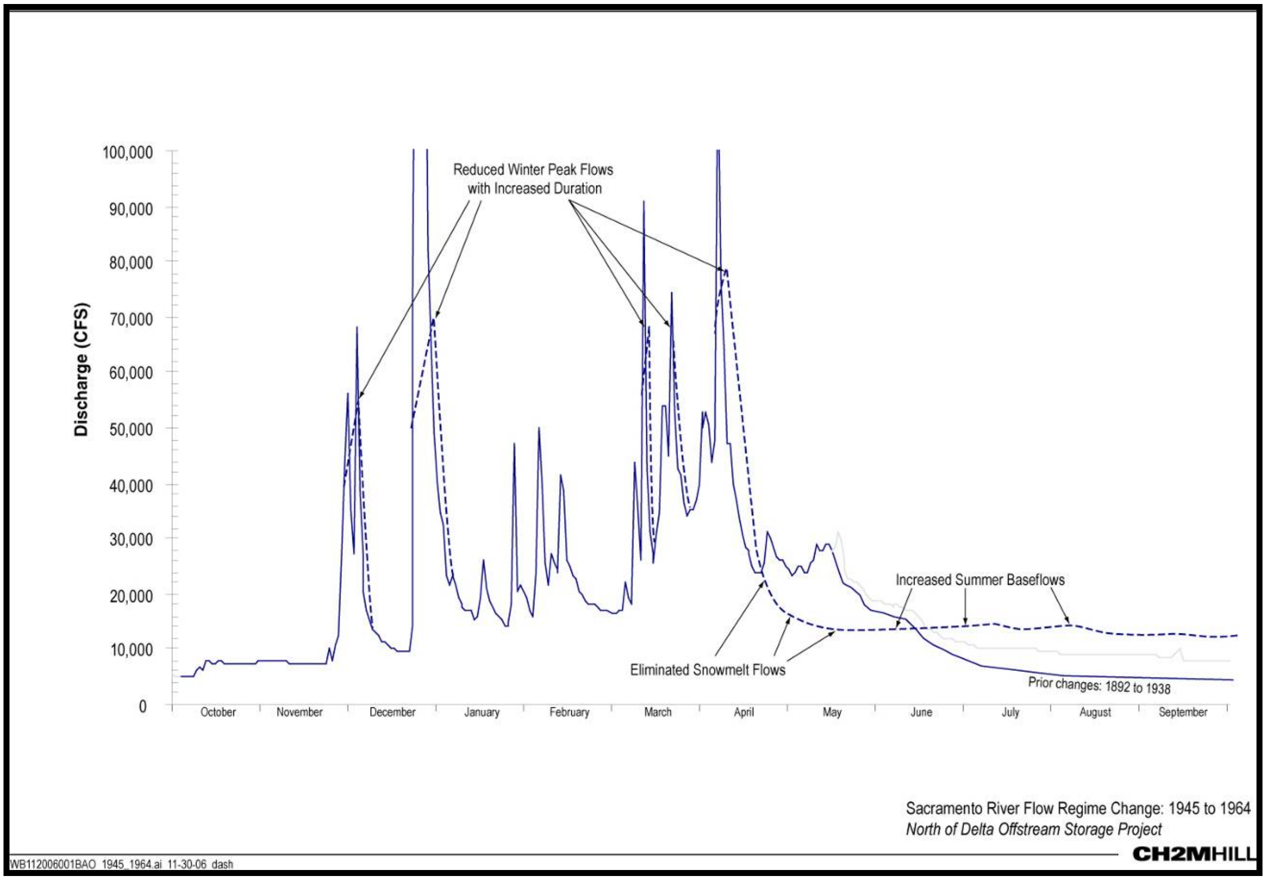
1965 through 1992 Streamflow Evaluation Interval

This period includes Upper Sacramento River Flows following implementation of the Tehama-Colusa Canal and Corning Canal Units, importation of water from Trinity River, and implementation of the State Water Project and San Luis Unit. The period of gauge record is 1965 through 1992.

The analysis of this period is based upon an evaluation of daily flow data for the Sacramento River at Keswick, Bend Bridge, and Butte City during and following expansion of CVP operations and flood management facilities on the Sacramento River.

Water Management Facilities or Operations that Changed from 1965 through 1992. One of the most significant water management events that occurred during this period was implementation of the State Water Project. This action required joint operation of the Sacramento River and the Delta by the CVP and SWP under water rights requirements and eventually the Coordinated Operations Agreement. Prior to this period, releases from Shasta Lake were primarily used to meet prior water rights holders' requirements in the Upper Sacramento Valley and along the San Joaquin River, and to a lesser extent, to municipal water service contractors near Redding and agricultural water service contractors along the Contra Costa and Delta-Mendota canals. Shasta Lake was operated in coordination with Folsom Lake releases to meet the demands along the Contra Costa and Delta Mendota canals.

FIGURE 2-4. Base hydrograph from 1892 through 1938 and changes that occurred from 1945 through 1964 (for illustrative purposes only).



During this period, water demands increased for the CVP water service contractors to include Tehama-Colusa and Corning canal users, Cross Valley Canal users (southern San Joaquin Valley), San Luis Unit (western San Joaquin Valley), and the San Felipe Unit to serve Santa Clara and San Benito counties. During this period, CVP operations also were modified to incorporate imported flows from Trinity River and modifications of flows from Stony Creek following construction of Black Butte Reservoir. However, the amount of water available from the Trinity River system was reduced several times during this period to reduce adverse impacts to fish in the Trinity River.

Shasta Lake and other CVP operations were modified during this period to reduce adverse impacts to habitat and fisheries resources in the Delta. This led to changes in flow release patterns from Shasta Dam.

Another critical set of activities during this period was the completion of new additional bank protection actions along the Upper Sacramento River and implementation of flood management requirements for Shasta Dam operations.

Seasonal Flow Patterns. Flows during this period were analyzed to determine the specific changes that occurred following full implementation of the CVP facilities. This period included two droughts of record: 1977-1978 and 1987-1992.

- **October Flows**: The non-storm daily flows generally range from 3,000 to 10,000 cfs. The patterns change in 1964 as compared to previous years. In 1964 through 1984, the flows decline in many years during the first week of October. The decline is about 2,000 to 3,000 cfs. From 1984 through 1998, the flows do not decline until the second week of October in most years.

- **Winter Flows (November through March)**: Non-storm daily flows in these months range from 6,000 to 12,000 cfs. Storms generally occurred December through May. Flows during most storm events range from 20,000 cfs to 140,000 cfs. Storms that caused flows in excess of 90,000 cfs occurred in Water Years 1965, 1967, 1969, 1970, 1973, 1974, 1978, 1980, 1982, 1983, 1984, and 1986, as summarized on Table 3-2. There were several years in this period characterized by a series of storms that maintained moderate flows in the river.

  This was the first period since construction of Shasta Dam that the effects of flood control criteria at Shasta Dam are evident both during and after the peak flow events. In 1964, and most of the following years in the period of record, flows did not increase at Keswick during the peak flow events at Bend Bridge or Butte City. Sometimes the flows never increased. However, in wet periods, flows were released from Shasta Dam following the storm event with lag times of up to 1 to 2 weeks after major storm events. If the initial storm was followed by additional storms, the peak flows at Bend Bridge and Butte City do not decrease. The flows from Keswick cause a new "base flow" and the peak flows from the tributaries are added to the base flow in the Sacramento River channel. This occurs in Water Year 1965, 1973, 1974, 1980, 1983, 1984, and 1986.

  Peak flows do not occur at Keswick during peak events at Bend Bridge and Butte City in Water Year 1967, 1970, January 1974 (March 1974 patterns are similar to pre-Shasta Dam conditions), and 1978.

  The Keswick flow patterns are probably due to Shasta Dam operations in accordance with flood control criteria developed by the Corps of Engineers and Section 7 of the 1944 Flood Control Act.

  The average monthly winter flows are comparable through the period in January (compared to years prior to and during the construction of Shasta Dam). However, average flow rates in February and March are 25 to 50 percent lower following construction of Shasta Dam. Prior to construction of Shasta Dam, Keswick flows contributed 45 to 69 percent of flows at Bend Bridge. During the 1945-1964 period, average flows exceeded 40,000 cfs in three years (1953, 1956, and 1958) as compared to fourteen years in the 53 years prior to construction of the dam.

- **Spring Flows (April through June)**: Non-storm daily spring flows generally range from 5,000 to 10,000 cfs. Spring storms generally result in short-term increases of flows with storm flows ranging from 60,000 cfs to 140,000 cfs.

  The spring flows do not reflect snowmelt characteristics due to storage of the snowmelt flows upstream of Keswick. However, flows increase in May or June due to releases from Shasta Lake to serve downstream water users. Flows increase in late spring at Keswick, Bend Bridge, and Butte City to about 10,000 cfs (as compared to pre-Shasta Dam flow patterns that decrease in spring).

- **Summer Flows (July through September)**: Daily summer flows generally range from 9,000 to 11,000 cfs at Keswick and Bend Bridge. However, in late June, Butte City flows decrease by 2,000 to 3,000 cfs below flows at Keswick and Bend Bridge to about 7,000 to 8,000 cfs. This is probably caused by flows diverted to serve agricultural users in the Upper Sacramento River.

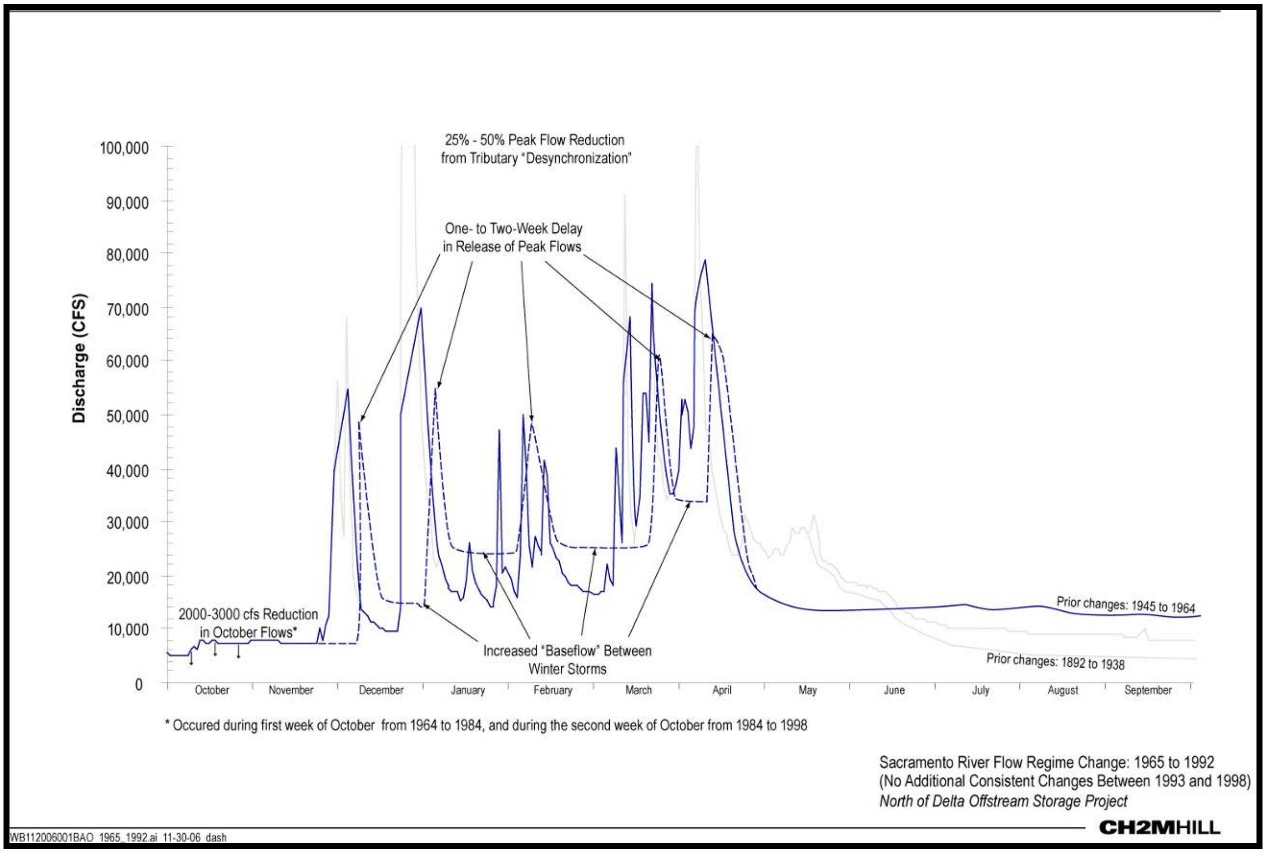
Summary of Flow Regime Changes from 1965 through 1992. The primary hydrologic changes in this period are related to increased long-duration peak flow events. Flows were not released from Shasta Dam until after the storm event, frequently 1 to 2 weeks following large storm events. This action created a high "base flow" following storm events and provided for peak flows similar to those prior to construction of Shasta Dam, however, the peak flow event frequently occurs over a week or more as compared to two to three days prior to Shasta Dam.

Another flow regime change that occurred in this period was an increase in flows during March. This could be related to conveying water to the Delta for export to San Luis Reservoir. There were no other noticeable changes in summer flows associated with implementation of the San Luis Unit. Tracy Pumping Plant was already operating at maximum flow of 4,600 cfs prior to the implementation of the San Luis Unit in the summer. Therefore, there was no additional capacity at the pumping plant or need to increase releases from Shasta Dam to serve San Luis Unit in the summer.

Many of the changes in CVP operations in this period occurred due to the need to coordinate Sacramento River and Delta operations with the SWP. There were also increased releases from Shasta Dam in the summer to serve the Tehama-Colusa and Corning canal users. However, these flows were diverted between Bend Bridge and Butte City.

The "base" hydrograph in Figure 2-5 depicts changes that occurred from 1893 to 1938 and changes that occurred from 1965 to 1992. It shows reduction in peak flows from tributary desynchronization. The changes shown as dotted lines in subsequent hydrographs illustrate how significant changes in flow management on the Sacramento River have affected annual flow fluctuations. It is important to note that the changes shown are for illustrative purposes only and do not accurately show the magnitude of change to flows for all water year types (Figure 2-5).

FIGURE 2-5. Base hydrograph from 1892 through 1938 and changes that occurred from 1965 through 1992 (for illustrative purposes only).



1993 through 1998 Streamflow Evaluation Interval

This period includes Sacramento River flows following implementation Bay-Delta Plan Accord, CVPIA, and the SWRCB Water Quality Control Plan. The period of gauge record is 1993 through 1998.

The analysis of this period is based upon an evaluation of daily flow data for the Sacramento River at Keswick, Bend Bridge, and Butte City in 1993 and 1994 and at Keswick and Bend Bridge from 1995 through 1998.

Water Management Facilities or Operations that Changed from 1993 through 1998. The CVP facilities and contractors were not expanded during this period. However, flow releases from Shasta Dam were changed. The CVPIA required the CVP to provide water to over 15 refuges at a priority provided to water rights holders. In addition, up to 800,000 acre-feet of CVP water was dedicated to environmental purposes, including meeting the Delta water quality requirements as well as stabilizing and improving instream flows of the Sacramento River.

During this period, Shasta Dam operations were modified to provide a cold-water pool from which cold water could be released to meet temperature requirements downstream of Keswick. This requirement of 56 degrees Fahrenheit to protect winter-run Chinook salmon reduced releases for CVP water service contractors during the spring and summer. A temperature control device (TCD) was installed on Shasta Dam to allow selective withdrawal of water that also facilitated hydroelectric power generation. Use of the TCD also has affected release patterns to the river.

Requirements to protect delta smelt and Delta water quality necessitated releases in many years during January through June from Shasta Dam to increase Delta outflow. This reduced the amount of water available for use by CVP water service contractors, environmental uses, and other project purposes.

The SWRCB Water Quality Control Plan and CVPIA provisions also required significant pumping restrictions in the Delta from mid-April through at least mid-May. This further reduced the amount of water released for CVP water service contractors (except the users on the Tehama-Colusa Canal), environmental uses, and other project purposes.

In this period, minimum instream flows for the Trinity River also were increased. This action also reduced flows released from Shasta Dam to serve CVP water service contractors, environmental uses, and other project purposes.

Seasonal Flow Patterns. Flows during this period were analyzed to determine the specific changes that occurred following modification of CVP operations.

- **October Flows**: The non-storm daily flows generally range from 3,000 to 8,000 cfs. The October flow patterns in this short period do not appreciably change from prior to 1992. Flows decline after October 15 and Keswick flows are frequently 1,000 to 2,000 cfs less than flows at Bend Bridge.

- **Winter Flows (November through March)**: Non-storm daily flows in these months generally range from 6,000 to 10,000 cfs. Storms generally occurred December through May. Flows during most storm events range from 20,000 cfs to 90,000 cfs at Bend Bridge. Storms that caused flows in excess of 90,000 cfs occurred in Water Years 1995 and 1997, as shown in Table 2-2. Flow values for these storms at the Butte City gauge were not available. The storms in this period were more similar to those that occurred prior to 1964 when Keswick flows were either not released or released during the storm event. Therefore, the high "base flows" that occurred in the 1960s through 1980s did not occur and the present flow patterns do not exhibit the many short-duration peaks that occurred in the pre-Shasta era.

- **Spring Flows (April through June)**: Non-storm daily spring flows range from 3,000 to 10,000 cfs. Spring storms generally result in short-term increases of flows with total flows ranging up to 40,000 cfs. Flow patterns are similar to the 1964 to 1992 period with increases in May or June due to releases from Shasta Lake to serve downstream water users. There does not appear to be any changes in Keswick flows following the adoption of the Water

Quality Control Plan or its predecessor regulations in the spring and summer flows, except in 1997, when flows remain constant from March through May. This could have been related to new Delta outflow requirements adopted in 1995.

- **Summer Flows (July through September)**: Daily summer flows generally range from 9,000 to 15,000 cfs at Keswick and Bend Bridge. In late June, Butte City flows decrease by 3,000 to 4,000 cfs below flows at Keswick and Bend Bridge. This is probably caused by flows diverted to serve the Water Rights Settlement Contractors upstream of Butte City and Tehama-Colusa and Corning canal users. Note that with the adoption of the Water Quality Control Plan (WQCP) in 1995, the CVP's access to the Banks pumping plant for the Joint Point of Diversion changed. The WQCP also affected the ability of the CVP to export as much water at Banks and in the same pattern as prior to 1995 which likely affected Shasta Reservoir releases. The release from Keswick may be lower now than before 1995 in the August to November period.

Summary of Flow Regime Changes from 1993 through 1998. Due to the modifications in water quality and habitat improvements that occurred in this period, there were no consistent changes in flow patterns as compared to the 1964 to 1992 period.

CHAPTER 3. RELATIONSHIP OF CENTRAL VALLEY PROJECT OPERATIONS AND UPPER SACRAMENTO RIVER FLOW REGIME

During the Flow Regime TAG meetings, members of the group asked that staff consider methods to modify flow regime using non-structural methods. A number of concepts related to the potential of using non-structural approaches were discussed at the Flow Regime TAG meetings. However, most of these methods were related to changes in Central Valley Project (CVP) operations. Therefore, as part of the meetings, a description of CVP operations was presented. This chapter describes the operational requirements for the CVP.

Central Valley Project Operations

CVP facilities, including Shasta Dam, are operated to provide water to CVP water service contractors (among other purposes previously noted) under a water right granted by the State Water Resources Control Board to the U.S. Department of the Interior. The U.S. Bureau of Reclamation operates the CVP facilities and is also required by the water rights orders and decisions to provide water to users that hold senior water rights on rivers impacted by CVP facilities and to meet requirements to protect water quality and specific threatened or endangered species that could be affected by CVP operations.

The water needs and requirements that lead to the Shasta Dam flow releases were described in Section 3 in relationship to historical changes in the flow regime of the Upper Sacramento River. The discussion presented in this section provides a consolidated description of the requirements and the feasibility of modifying operations. This discussion is limited to CVP operations related to water flows in the Sacramento River and includes discussions about the Shasta/Sacramento River Divisions, Trinity River Division, and Delta water rights order and decision requirements adopted by the SWRCB.

Shasta and Sacramento River Divisions

The Shasta Division of the CVP includes facilities that conserve water on the Sacramento River for flood control, navigation maintenance, conservation of fish in the Sacramento River, protection of the Delta from intrusion of saline ocean water, irrigation and municipal and industrial (M&I) water supplies, and hydroelectric generation. The Shasta Division includes Shasta Dam, Lake, and Power Plant; Keswick Dam, Reservoir, and Power Plant; and the Toyon pipeline. The Sacramento River Division, which was authorized after completion of the Shasta Division, includes facilities for the diversion and conveyance of water to CVP contractors on the west side of the Sacramento River. The division includes the Sacramento Canals Unit, which was authorized in 1950 and consists of the Red Bluff Diversion Dam, the Corning Pumping Plant, and the Corning and Tehama-Colusa canals.

Water in Shasta Lake is released through or around the Shasta Power Plant to the Sacramento River, where it is re-regulated downstream by Keswick Dam. A small amount of water is diverted directly from Shasta Lake for M&I use by local communities. Keswick Reservoir serves as an afterbay for releases from Shasta Dam and Spring Creek Power Plant. The Temperature Control Device (TCD) at Shasta Dam was completed in 1997 to allow greater flexibility in the management of cold water reserves in Shasta Lake to meet downstream temperature requirements while still allowing continued operations to meet other CVP purposes.

Fish and Wildlife Requirements on the Sacramento River

Reclamation operates the Shasta, Sacramento River, and Trinity River divisions of the CVP to meet, to the extent possible, the provisions of SWRCB Order 90-05, the NOAA Fisheries winter-run Chinook biological opinion, and the new OCAP (Operations Criteria and Plan) for the CVP and SWP dated June 30, 2004 including June 30, 2004 and October 2004 Biological Opinions. Flow objectives in the Sacramento River had been previously established in an April 5, 1960 Memorandum of Agreement (MOA) between Reclamation and Department of Fish and Game. SWRCB subsequently modified Reclamation's water rights for the Sacramento River several times. The orders include temperature objectives for the Sacramento River and state that Reclamation shall operate Keswick and Shasta dams and the Spring Creek Power Plants to meet a daily average water temperature objective of 56 degrees Fahrenheit in the Upper Sacramento River during critical periods when a higher temperature would be harmful to the fishery.

The NOAA Fisheries winter-run biological opinion was issued in 1993 and amended in 1995. The opinion sets a water temperature of 56 degrees Fahrenheit between April 15 and October 21 generally at Bend Bridge during wetter years and Jelly's Ferry during periods with low carryover storage in Shasta Lake. The opinion also requires a minimum end-of-September storage of 1.9 million acre-feet in Shasta Lake. If it is not possible for Reclamation to meet this requirement, re-consultation with NOAA Fisheries is required. Under the current requirements, Reclamation must disclose to the CVP water service contractors a conservative-based forecast of water availability by February. Reclamation then announces updates to the initial allocation monthly, as necessary. This avoids the risk of over-committing water to the contractors and not providing adequate water for cold water reserves in Shasta Lake.

Minimum flow requirements were also established in the MOA and subsequent SWRCB orders as well as the NOAA Fisheries winter-run Chinook salmon biological opinion. The biological opinion requires minimum release of 3,250 cfs at Keswick Dam and Red Bluff Diversion Dam from September through the end of February in all water years. The MOA and SWRCB Order 90-05 requires minimum flows of at least 2,300 cfs in April and May in all years; and 3,900 cfs in September in all but critical dry years and 2,800 cfs in September in critical dry years. The following ramping rates also were required except during flood control releases.

- Change releases between sunset and sunrise
- If Keswick releases are 6,000 cfs or greater, rate of reduction cannot exceed 15 percent/night or 2.5 percent/hour
- If Keswick releases are 4,000 to 5,999 cfs, rate of reduction cannot exceed 200 cfs/night or 100 cfs/hour
- If Keswick releases are 3,250 to 3,999 cfs, rate of reduction cannot exceed 100 cfs/night.

Releases from Shasta and Keswick dams are gradually reduced in September and early October during the transition from meeting Delta export and water quality demands to operating the system for flood control from October through December.

Recreation

Although not an authorized purpose, recreational use of Shasta Lake is important with the prime recreation season extending from Memorial Day through Labor Day. It is desirable to have Shasta Lake full by Memorial Day and no less than elevation 1,017 feet on Labor Day. This elevation corresponds to a drawdown of 50 feet below the top of the conservation pool and is just below the bottom of the flood control storage envelope. The drawdown rate varies but is typically high during July in response to irrigation demands and during August in response to irrigation demands and temperature control operations.

The seasonal operation patterns at Keswick Dam typically are sufficient to satisfy river recreation needs. During flood control operations, little recreational use occurs along the river. In the spring and fall, marinas in the Sacramento area have occasionally reported shallow water problems at low flows.

Flood Control

Flood control objectives for Shasta Lake require that releases be restricted to quantities that will not cause downstream flows or stages to exceed specified levels. These include:

- 79,000 cfs at the tailwater of Keswick Dam
- Stage of 39.2 feet in the Sacramento River at Bend Bridge (approximately 100,000 cfs)

Flood control operations are based on regulating criteria developed by the Corps of Engineers pursuant to the provisions of the Flood Control Act of 1944 and a Flood Control Diagram to provide storage space in Shasta Lake below elevation 1,067 feet. Maximum flood space reservation is 1.3 million acre-feet, with variable storage space requirements based on the current flood hazard.

The most critical CVP flood forecast for the Sacramento River is that of local runoff entering the Sacramento River between Keswick Dam and Bend Bridge. The travel time required for release changes at Keswick Dam to affect Bend Bridge flows is approximately 8 to 10 hours. If flow at Bend Bridge is projected to exceed 100,000 cfs, the release from Keswick Dam is decreased so that the 100,000 cfs flow at Bend Bridge is not exceeded. As the flow at Bend Bridge is projected to recede, the Keswick Dam release is increased to evacuate water stored in the flood control space at Shasta Lake. Changes to Keswick Dam releases are scheduled to minimize rapid fluctuations in the flow at Bend Bridge. In addition, flows at Keswick in excess of 36,000 cfs begin to cause flooding in Redding.

Flood control criteria also require Keswick releases to not be increased more than 15,000 cfs or reduced by more than 4,000 cfs in any 2-hour period, unless in critical flood operations.

Navigation Minimum Flow

Historical commerce on the Sacramento River resulted in the requirement to maintain minimum flows of 5,000 cfs at Chico Landing to support navigation. There is currently no commercial traffic between Sacramento and Chico Landing. However, over time, water users diverting from the river have set their pump intakes just below this level. Some diverters have reported cavitation at flows below 5,000 cfs. During critical dry periods, Reclamation has reduced flows to less than 5,000 cfs.

Red Bluff Diversion Dam Operations

The Red Bluff Diversion Dam that diverts water into the Tehama-Colusa and Corning canals operates as a gated structure across the Sacramento River. The closed gates create Lake Red Bluff and block fish access, except through fish ladders, in the Sacramento River at Red Bluff. The NOAA Fisheries winter-run Chinook salmon biological opinion requires that the gates be raised between September 15 and May 14 to reduce fish passage impacts.

Trinity River Division

The Trinity River Division, completed in 1964, includes facilities to collect and regulate water in the Trinity River, as well as facilities to transfer portions of the collected water to the Sacramento River Basin. Specific facilities in the Trinity River Division include Trinity Dam and Power plant; Clair Engle Lake; Lewiston Dam, Lake, and Power plant; Clear Creek Tunnel; Whiskeytown Dam and Lake; Spring Creek Debris Dam and Reservoir; and the Cow Creek Unit. All releases from Trinity Dam are re-regulated downstream at Lewiston Lake to meet downstream flow, in-basin diversion, and downstream temperature requirements. Lewiston Reservoir provides a forebay for the trans-basin transfer of water through the Clear Creek Tunnel and the Judge Francis Carr Power plant into Whiskeytown Lake on Clear Creek. Water stored in Whiskeytown Lake includes exports from the Trinity River as well as runoff from the Clear Creek drainage area. Releases from Whiskeytown Lake are either passed through the Spring Creek Power plant and discharged into Keswick Reservoir on the Sacramento River, or released to Clear Creek to meet downstream flow and diversion requirements.

Diversions from the Trinity River Basin to the Sacramento River Basin are dependent upon the amounts and timing of Trinity River in-basin needs, carryover storage, and Sacramento River temperatures. During spring and early summer months, the exported water can be cooler than water released from Shasta Lake. However, during late summer and fall months, temperature of Trinity River exports can increase in Whiskeytown Lake. Reclamation also releases water through Whiskeytown to Clear Creek to provide 6,000 acre-feet/year to Townsend Flat Water Ditch Company and provide 900 acre-feet/year for CVPIA 3406(b)(2) requirements. This water was provided as part of the agreement to remove the McCormick-Saeltzer Dam on Clear Creek under the CVPIA Anadromous Fish Restoration Program.

Fish and Wildlife Requirements on the Trinity River

In December 2000, U.S. Fish and Wildlife Service adopted the Trinity River Mainstem Record of Decision that required a minimum instream flow in Trinity River between 369,000 to 815,000 acre-feet/year depending upon water year type. The Record of Decision has been the subject of litigation and further evaluation. A preliminary injunction directed Reclamation to release

368,600 acre-feet/year during critical Trinity River inflow years and 452,000 acre-feet during all other conditions. SWRCB Order 90-05 also established temperature objectives for the Trinity River. Between Lewiston Dam and Douglas City Bridge, the daily average temperature cannot exceed 60 degrees Fahrenheit from July 1 to September 14 or 56 degrees Fahrenheit from September 15 to October 1. From October 1 to December 31, the average daily temperature cannot exceed 56 degrees Fahrenheit between Lewiston Dam and the confluence of the North Fork Trinity River.

Fish and Wildlife Requirements on Clear Creek

Water Rights permits issued by SWRCB for diversions from Trinity River and Clear Creek specify minimum downstream releases from Lewiston and Whiskeytown dams, respectively. Three water rights agreements on Clear Creek govern releases from Whiskeytown Lake.

- A 1960 Memorandum of Agreement (MOA) with Department of Fish and Game establishing the following minimum flows to be released to Clear Creek at Whiskeytown Dam.

January 1 through February 28/29	50 cfs
March. 1 through May 31	30 cfs
June 1 through September 30	0 cfs
October 1 through October 15	10 cfs
October 16 through October 31	30 cfs
November 1 through December 31	100 cfs

- A 1963 release schedule from Whiskeytown Dam developed and implemented (but never formalized) with the Service to enhance fishery and recreational values for the Whiskeytown National Recreation Area.

January 1 through October 31	50 cfs (normal year), and 30 cfs (critical year)
November 1 through December 31	100 cfs (normal year), and 70 cfs (critical year)

- A 1980 agreement between Reclamation and Department of Fish and Game to increase the water surface elevation of Whiskeytown Lake by 1 foot between November 15 and March 31 to aid in passage of trout through the Whiskey Creek culvert.

Instream flows in Clear Creek downstream of Whiskeytown Dam are provided in accordance with CVPIA 3406(b)(2) operations to provide spawning flows for fall-run Chinook salmon and cooler temperatures for steelhead and spring-run Chinook salmon.

Hydropower

Power production as a result of cross-basin diversion of Trinity River water through Trinity power plants is approximately three to five times as efficient as power production at Shasta and Sacramento River Division power plants. The CVP system place a premium on power produced during the July-through-October period. Therefore, Clair Engle Lake is operated to reach its greatest storage level at the end of June annually, so that the maximum volume and head possible can be used too generate power at the Trinity, Carr, and Spring Creek power plants when it is most needed. This operation affects releases into Keswick Reservoir and therefore also affects

Shasta operations because the highest priority of Northern CVP operations is to manage the water resources for public health and safety and water supply while meeting the temperature objectives of the upper Sacramento River.

Recreation

Though not an authorized purpose of the Trinity Division, recreational use of Clair Engle Lake, Lewiston Reservoir, and Whiskeytown Lake, and Trinity River is important. Recreational considerations are factored into operational decisions that may result in abnormal reservoir levels or river flows. In general, the use of recreational facilities is typically constrained during dry or critically dry conditions only.

Flood Control

Flood control is not an authorized purpose of the Trinity River Division, although flood control benefits are provided through normal operations. Trinity Dam was not authorized for flood control and has limited release capacity below the spillway crest elevation. Studies completed by Corps of Engineers in 1974 and Reclamation in 1975 showed that the spillway and outlet works at Trinity Dam are not sufficient to safely pass the inflow design flood. Therefore, Safety of Dams criteria stipulate that drawdown and controlled filling of Clair Engle Lake are necessary to keep the storage from exceeding the total storage capacity. The regulation of storage is accomplished with releases that are within Trinity and Carr power plant capacities and by minimizing releases to the Trinity River that exceed the requirements for fisheries.

A minimum storage reservation of 348,000 acre-feet is maintained in Clair Engle Lake from November through March. During a major flood, releases from Trinity Dam are restricted to the combined capacity of the power plant and outlet works until a spill occurs. The release to the Trinity River at Lewiston Dam is reduced by diversions through Clear Creek Tunnel to Whiskeytown Lake, unless flood conditions on Clear Creek or on the Sacramento River require the diversion to be suspended.

Whiskeytown Lake is operated to maintain approximately 35,000 acre-feet of storage space during the flood season. Whiskeytown Lake operations during major floods are complicated by its relationship with the Trinity, Shasta, and Sacramento River operations. A number of specific operating guidelines have been developed to guide operations during this period.

Delta Operations Requirements That Effect Upper Sacramento River Operations

The operation of the CVP is, and has historically been, affected by the provisions of several regulatory requirements and agreements. Prior to the passage of CVPIA in 1992, the operation of the CVP was affected by SWRCB Decision 1485 (D-1485), the Coordinated Operations Agreement (COA), SWRCB Orders 90-05 and 91-01, Winter-Run Chinook Salmon Biological Opinion, and the delta smelt Biological Opinion. In May 1995, SWRCB adopted the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (SWRCB Order 95-1). Some of the regulations developed in the initial requirements remain in subsequent regulations, and some have been modified.

Protection of Beneficial Uses in the Delta

In 1978, the SWRCB adopted D-1485 for protection of beneficial uses in the Delta and to outline responsibilities of the two largest exporters in the Delta, the CVP, and the SWP. The SWRCB concurrently issued a Delta Water Quality Control Plan (Delta Plan). The basis for the D-1485 and the Delta Plan was that water quality was to be maintained at least to a level that would have existed if the CVP and SWP were not implemented. D-1485 included flow, water quality, and export standards to protect the beneficial uses in the Delta. Because of the hydraulic characteristics of the Delta, some D-1485 standards were managed more efficiently through export curtailments, while others were managed more efficiently through flow increases. These standards were implemented by the SWRCB by including them in the water rights permits of the CVP and SWP. These requirements were subsequently modified by SWRCB Order 95-1 and Decision 1641. However, the premise of protecting water quality was established in D-1485. These requirements and subsequent orders require that Delta outflow be increased during specific periods to maintain water quality.

Coordinated Operations Agreement

In 1986 Reclamation and the State of California Department of Water Resources (DWR) agreed upon the COA to establish the rationale for the coordination of reservoir releases and Delta exports between the CVP and SWP. The COA defines conditions under which existing in-basin and in-Delta demands are met, and establish shared responsibilities of the CVP and SWP in meeting these requirements to establish "balanced conditions." The purpose of the COA is to ensure that each project receives its share of the available water supply and bears its share of the joint responsibilities to protect beneficial uses. The COA was established based on the water quality objectives specified in D-1485, and serves as technical reference for review and modification of sharing principles as requirements are modified by the SWRCB.

Balanced water conditions are defined in the COA as periods when the two projects agree that releases from upstream reservoirs plus unregulated flows approximately equal the water supply needed to meet Sacramento Valley in-basin uses plus exports. During balanced conditions, the two projects share in meeting in-basin uses. Two sharing arrangements are possible under the COA, depending on whether water from upstream CVP/SWP storage is required to meet Sacramento Valley in-basin uses, or if water associated with non-CVP/SWP regulated flow plus unregulated flow into the Delta is available for export. When water must be withdrawn from reservoir storage to meet Sacramento Valley in-basin requirements, 75 percent of the water is provided by the CVP, and 25 percent is provided by the SWP. When waters from non-CVP/SWP sources and unregulated flow into the Delta are available for export in the Delta, the sum of CVP storage gains, SWP storage gains, and the available flows for export in the Delta are apportioned on a 55 percent to CVP and 45 percent to SWP basis. The COA further specifies that if one party cannot use its share of available water, the other party may use the available water. When the Delta is out-of-balance, i.e., the Delta has excess water under the COA, there is, by definition, sufficient water to meet all Delta beneficial use standards. The COA provides that under these conditions the CVP and SWP can store and export as much water as possible within physical and contractual limits.

The COA will be modified in the future to accommodate differences in sharing percentages that are required under subsequent regulations and CVPIA implementation actions.

CVPIA Anadromous Fish Restoration Program and CVPIA Dedication of CVP Yield to Fish and Wildlife ("3406(b)(2) water")

The CVPIA Anadromous Fish Restoration Program (AFRP) goal is to double the natural production of five anadromous species of fish – steelhead, Chinook salmon, American shad, striped bass and sturgeon, per the law. To achieve this goal, Reclamation and the Service are evaluating programs to improve instream flow patterns and quantities, modify operations that contribute to predation or entrainment/entrapment, and improve habitat conditions including temperature, flow fluctuations, and riparian vegetation that provide food web support. The Comprehensive Assessment and Monitoring Program (CAMP) was established under CVPIA to develop a monitoring program for actions considered by AFRP.

Reclamation and the Service have been working with stakeholders and regulatory agencies to develop a "3406(b)(2) water" program that defines how the 800,000 acre-feet can be used and accounted. Initial proposals were challenged in Federal court, and subsequent to findings by the court, are currently being redefined. The current proposal includes a list of actions contributing to the CVPIA goals.

State Water Resources Control Board Order 95-01 and Decision 1641

Subsequent to adoption of CVPIA, winter-run Chinook salmon biological opinion, and delta smelt biological opinion, the SWRCB adopted parts of the Bay-Delta Plan Accord and the 1995 Draft Water Quality Control Plan (WQCP) in SWRCB Order 95-01, which superseded D-1485. Decision 1641 (D-1641) was adopted in 1999 and superseded Order 95-01.

The WQCP included water quality goals and beneficial use objectives for the Sacramento, Stanislaus, and San Joaquin rivers and the Delta, as well as Delta operational restrictions to protect fish and wildlife including instream habitat and stream flows. The WQCP also modified definitions to the water year type indices for the Sacramento and San Joaquin valleys to more accurately reflect unimpaired runoff conditions associated with Wet, Above Normal, Below Normal, Dry, and Critical water year types that are used to trigger water quality and flow requirements.

This water rights order includes measures that regulate salinity within the Delta to protect drinking water quality at the Contra Costa Canal, agricultural diversions in the western and southern Delta, and fish and wildlife uses in Suisun Marsh. To meet the western Delta water quality standards and objectives that vary monthly and in association with water year types, flows are released from CVP and SWP reservoirs on the Sacramento River to increase freshwater Delta outflow and reduce salinity intrusion. Salinity standards in the southern Delta are primarily maintained by releases from New Melones Reservoir and are used to both manage salinity due to seawater intrusion, especially near the export pumping plants, and salinity from return flows discharged into the San Joaquin River.

One of the most critical issues included in Order 95-01 is the establishment of Delta Outflow Objectives. A minimum monthly Net Delta Outflow Index was established to require a minimum flow in all months in all water year types. The requirements range from July through January from 3,000 to 8,000 cfs depending upon month and water year type. From February through June, the Delta Outflow is based upon a "2.64 EC (2 ppm) Criteria." This criteria is based on the location of "X2" (i.e., 2 parts per thousand salinity, or approximately 3,000 microsiemens EC, measured one meter above the channel bottom) as measured at Chipps Island and Roe Island. The standard specifies the number of days in each month from February through June when the maximum daily average EC at Chipps and Roe islands must be less than 2.64 mmhos/cm. This criterion is reduced in May and June drier years. In other years, minimum Delta outflows are determined by an equation that considers the X2 position in the previous month and current month Delta outflow. Therefore, if the previous month Delta outflow is relatively high due to storm events or reservoir releases, the subsequent month Delta outflow requirement will continue the relatively high flows. This requirement was established to allow maturity of organisms that become established in brackish water in the western Delta during the initial high flow event, and could be compromised if higher salinity water is present in the western Delta and Suisun Bay prior to maturity. The maximum required monthly outflows are 29,200 cfs at Roe Island, 11,400 cfs at Chipps Island, and 7,100 cfs at the confluence of the rivers. The triggers for X2 flows can change within days following a high flow event, and can require freshwater releases from CVP and SWP reservoirs in the Sacramento River. Because Folsom Lake is the closest reservoir to the Delta, frequently water is released from Folsom Lake for several days or a week until waters released from Oroville Reservoir and Shasta Lake can flow into the Delta.

Order 95-01 also includes minimum flow requirements in the Sacramento River at Rio Vista that vary from 3,000 cfs to 4,500 cfs from September through December depending upon water year type. These flow requirements occur in different months than the X2 flows, and therefore may require additional releases from CVP and SWP reservoirs.

Delta Cross Channel gates are regulated to prevent fish from wandering into the interior Delta where they could be entrained in the export pumps. The gates are closed for 45 days from November through January, totally from February 1 to May 20, and for 14 days from May 21 to June 15 based upon the need to protect fish.

Delta Export ratios are specified as a percentage of total Delta inflow in all months. The ratio can range from 35 to 65 percent depending upon month. Between April 15 and May 15, exports are further limited to 1,500 cfs or 100 percent of the San Joaquin River flow at Vernalis (whichever is greater). Between April 1 and 15 and May 16 and May 31, export/import ratios are 35 percent or exports are limited to pumping capacity at Tracy and Banks pumping plants, whichever is less. Export limitations have been reduced for longer periods of time when fish are present near the pumps to avoid "take" of threatened and endangered species. Following adoption of SWRCB Order 95-01, NOAA Fisheries amended the winter run Chinook salmon biological opinion to include export/inflow Delta ratios. Some of the sharing agreements are difficult to meet with the new regulations. There are future plans to reconsider sharing agreements based upon other regulatory changes.

The SWRCB adopted Decision 1641 (D1641) on December 29, 1999 and a revised D1641 on March 15, 2000. The decision and its revision are to allocate flow and operations-related obligations under the 1995 Water Quality Control Plan and are based on more than two months of testimony before the SWRCB and its staff. D-1641 includes specific minimum instream flows for the Sacramento River at Rio Vista from September through December that are based on water year type; salinity requirements similar to Order 95-01 for San Joaquin River at Vernalis, increased pulse flows April 15 to May 16 for San Joaquin River at Vernalis in accordance with the Vernalis Adaptive Management Program, modifications to X2 operations and other Delta operations, and interim obligations to meet Lower American River flow standards established under CVPIA, as described in the following section. D-1641, subject to terms and conditions, allows DWR/Reclamation to petition for changing points of diversion in the Delta, Reclamation to petition for change in places and purposes of use for the CVP and, for the San Joaquin River Agreement that obligates Reclamation and DWR to meet the San Joaquin River portion of Delta outflow requirements.

CALFED Environmental Water Account

Order 95-01 requires reductions in exports in the late winter and spring months, as described above, to protect fish in the Delta. This reduction in export capacity correspondingly reduces available CVP and SWP water supplies for users located south of the Delta. A portion of the reduction in the water supply to CVP users is accounted for as "3406(b)(2) water." However, CALFED recognized that a method needed to be developed to provide additional water to protect fish populations. To meet this need, the CALFED Record of Decision (ROD) included the Environmental Water Account (EWA). The ROD stated that EWA was to provide "sufficient" water with the Ecosystem Restoration Program and regulatory baseline requirements to meet CALFED fishery protection and restoration/recovery needs. The ROD further states that EWA will include acquisition of "alternative sources of project water supply," or "assets," to increase instream flows and replace project water supply that was impaired by changes in operations to accommodate fishery needs, such as reduced export pumping when endangered species are within the vicinity of the export pumps.

Future EWA programs could affect the Upper Sacramento River flows in two ways. First, water rights holders and CVP Water Service Contractors could sell their water to EWA. Second, EWA assets could be used to meet instream flows and Delta outflow requirements. Operations with these assets would affect stream flow patterns in Sacramento River and could affect storage volumes in Shasta Lake.

Biological Opinion to Protect Delta Smelt

In 1993, the Service issued a biological opinion with restrictions to protect Delta smelt and associated habitat of operational actions by the CVP and SWP. The biological opinion was amended in 1994 and in 1995. The 1995 Delta Smelt Biological Opinion provides for export curtailments for a 30-day period in April and May beyond that specified in Order 95-01. The export restriction is based upon the San Joaquin pulse target flow at Vernalis as specified through the Vernalis Adaptive Management Program. Reductions in water supply to users located south of the Delta have been allocated to "3406(b)(2) water" for CVP users and to EWA assets for CVP and SWP users. The additional export restrictions further complicate the operational criteria for CVP integrated operations, including the associated operations for Shasta Lake.

CVP WATER SUPPLY DEMANDS

As indicated in the previous discussion, the CVP was constructed after many of the major water rights in the Central Valley had been established. In the development of the CVP, Reclamation entered into long-term contracts with some of these existing water right holders to establish water delivery requirements. Therefore, CVP is operated to satisfy downstream water rights, meet the obligations of the water rights contracts, and deliver project water to CVP water service contractors. The CVP water service contractors include users in the Sacramento Valley, Bay Area, westside of San Joaquin Valley, and eastside of San Joaquin Valley.

Many of the CVP water rights originated from applications filed by the State in 1927 and 1938 to advance the California Water Plan and build the CVP. After the State recognized it could not build the project due to fiscal constraints, the federal government was authorized to build the CVP and the water rights were transferred to Reclamation. Reclamation then made applications for additional water rights needed for the project. In granting water rights, the SWRCB sets certain conditions within the permits to protect prior water rights, fish and wildlife needs, and other prerequisites it deems in the public interest. Permits for CVP facilities include conditions requiring minimum flow below dams, and specify periods of the year when water may be directly diverted and periods when water may be stored at CVP facilities.

The water supply demands that have been established through contracts and water rights, including water service contracts in the eastside of the San Joaquin Valley are presented in Table 3-1. Water rights and contract amounts for the eastside of San Joaquin Valley are included in Table 3-1.

As indicated in Table 3-1, 3,350,000 acre-feet is provided by CVP operations to water rights holders located North and South of the Delta (not including water rights holders located in the Eastern San Joaquin Valley). The CVP also provides 653,600 acre-feet to the refuges. Both of these types of water users receive full amounts of water except during extremely dry water years, and then these users receive 75 percent of the full amount. The CVP provides 2,550,000 acre-feet to Agricultural Water Service Contractors and 615,000 acre-feet to Municipal Water Service Contractors located North and South of the Delta. The water service contractors are subject to reductions in most water year types. The agricultural water service contractors will be subject to reductions earlier and to a greater extent than municipal water service contractors. Overall, the CVP has obligations to deliver 7,196,600 acre-feet/year for the area located North and South of the Delta, not including Eastern San Joaquin Valley. About 55 percent of that amount is delivered to water rights holders and refuges and that are not subject to reductions except hydrologic reductions in extremely dry years. The remaining 45 percent is subject to reductions due to the need for the CVP to meet obligations of water rights holders, refuges, and environmental and water quality requirements; limitations of pumping facilities; and hydrologic limitations.

TABLE 3-1. WATER RIGHTS AND CONTRACT OBLIGATIONS SERVED BY CENTRAL VALLEY PROJECT

Water Users	Existing Contract Amounts (1,000 acre-feet)
North of the Delta	
Sacramento River Water Rights Contractors	1,940
Other Municipal/Industrial Water Rights Holders	530
Sacramento Valley Refuges (Level 2 Supplies, only)	210.6
CVP Agricultural Water Service Contractors	570
CVP Municipal/Industrial Water Service Contractors	455
Water Rights Holders and Reclamation Water Service Contractors served by Stony Creek	4
South of the Delta	
San Joaquin River Exchange Contractors	880
San Joaquin Valley Refuges (Level 2 Supplies, only)	250-280
CVP Agricultural Water Service Contractors	1,980
CVP Municipal/Industrial Water Service Contractors	160
Eastern San Joaquin Valley - Stanislaus River	
CVP Water Rights Holders served by Goodwin Dam	600
Other Riparian Water Rights Holders on Stanislaus River	48
CVP Water Service Contractors (all contracts)	155
Eastern San Joaquin Valley - Friant Division	
Madera Canal CVP Water Service Contractors	490
Buchanan and Hidden Unit CVP Water Service Contractors	50
Friant-Kern Canal Agricultural CVP Water Service Contractors	1,720
Friant-Kern Canal Municipal/Industrial Water Service Contractors	65

Sacramento River Water Rights, San Joaquin River Exchange Contractors, and Refuges

Sacramento River Water Rights Contractors are contractors who for the most part claim water rights on the Sacramento River. With the control of the Sacramento River by Shasta Dam, these water right claimants entered into contracts with Reclamation. Most of the agreements established a quantity of water the contractor is allowed to divert from April through October without charge and provided a supplemental CVP supply allocated by Reclamation.

San Joaquin River Exchange Contractors are CVP contractors who receive Project water from the Delta at the Mendota Pool. Under the Exchange Contracts, the parties agreed to not exercise their San Joaquin River water rights in exchange for a substitute Project water supply from the Delta. These exchanges allowed for water to be diverted from the San Joaquin River at Friant Dam under the water rights of the United States for storage at Millerton. The amount of water to serve these contractors cannot be provided from Friant Dam without further environmental documentation and modification of the Congressional authorizations.

Wildlife refuge contracts provide water supplies to specific managed lands for wildlife purposes. Based upon the requirements of the CVPIA, the CVP must provide "Level 2 Refuge Water Supplies." This water supply was defined in the 1989 Refuge Water Supply Study completed by Reclamation as the average amount of water provided to specific Federal and state refuges in the Sacramento and San Joaquin valleys between the years 1977 to 1984 plus average amounts of water to establish and maintain refuges that were initiated in response to contamination mitigation for Kesterson National Wildlife Refuge in the late 1980s. The Level 2 amount includes conveyance losses that are incurred as the water flows from CVP facilities or the rivers to the refuges. Subsequent amounts of water to improve wildlife management within existing managed areas or increase wetland and irrigated areas are provided for under CVPIA as "Level 4" water supplies that can be acquired but are not a mandated demand of the CVP.

Shortage conditions for providing water to the Sacramento River Water Rights Contractors, San Joaquin River Exchange Contractors (including the Mendota Pool Contractors), and refuges are based on the “Shasta Criteria”. The Shasta Criteria is used to establish when a water year is considered critical, based on inflow to Shasta Lake. As defined by the Shasta Criteria, when inflows to Shasta Lake fall below defined thresholds, water year is defined as critical, and water deliveries to these contractors may be reduced up to 75 percent of their contracted or settlement amount. A critical single-year deficit is defined as one in which the full natural inflow to Shasta Lake for the current water year (October 1 of the preceding calendar year through September 30 of the current calendar year) is equal to or less than 3.2 million acre-feet. A critical year with multiple drier years is defined as one in which the accumulated difference (deficiency) between 4 million acre-feet and the full natural inflow to Shasta Lake for successive previous years, plus the forecasted deficiency for the current water year, exceeds 800,000 acre-feet.

CVP Water Service Contracts

CVP water service contracts are between the United States and individual water users or districts and provide for an allocated supply of CVP water to be applied towards a beneficial use. The purposes of a water service contract are to stipulate provisions under which a water supply is provided, to produce revenues sufficient to recover an appropriate share of capital investment, and to pay the annual operations and maintenance costs of the project.

The criteria used to establish annual delivery amounts to CVP contractors served by the Sacramento River, American River, Delta, West San Joaquin, and San Felipe divisions is uniform based upon the water rights assigned to the Federal government on the Sacramento, American, and Trinity Rivers and in the Delta. CVP water allocations are different for CVP contractors in the Eastern San Joaquin Valley (Friant and East Side Divisions).

When water is available and facility capacity is available, the CVP makes available the amounts of water specified in the terms of the water service contracts in the CVP North and South of the Delta systems. Water availability for delivery to CVP water service contractors during periods of insufficient water supply is determined based on a combination of operational objectives, hydrologic conditions, and reservoir storage conditions. The decision-making process for allocating the water supply available to CVP contractors involves comparing the forecasted conditions of reservoir storage and allocated water supply for the current year with the risks of potential impacts in the following water years.

In the late fall and early winter, potential allocations are forecasted based on a range of assumed hydrologic and operations conditions. By February 15, forecasts are made based on year-to-date precipitation, water content in the snowpack, and runoff. The forecasts are updated at least monthly until May. If additional precipitation occurs, the allocation may be increased. The NOAA Fisheries biological opinion for winter-run Chinook salmon requires Reclamation to use a conservative forecast (with a probability of at least 90 percent) as the basis for allocations and for Reclamation to determine how the allocations will affect Sacramento River temperatures. The allocation process includes calculations to provide adequate water for water rights holders (as described above) and environmental requirements including instream flows in Trinity River, temperature requirements for winter-run Chinook salmon, Delta outflow and water quality requirements, refuge water supplies, and 3406(b)(2) water.

Allocations are also made for users south of the Delta based upon conveyance and storage limitations at the Tracy Pumping Plant due to the SWRCB water rights orders. Therefore, CVP water service contractors located south of the Delta may have more stringent allocations than the hydrologic allocations imposed on all water service contractors.

During periods when the Shasta Criteria is invoked, the Sacramento River Water Rights Contractors, San Joaquin Valley Exchange Contractors, and refuge water supplies receive 75 to 100 percent of their water contract amounts. The amounts for other environmental uses, including 3406(b)(2) water, are also generally reduced in critical dry years. However, to make this water available during the drier years, Reclamation reduces available supplies to water service contractors in many years considered to be "below normal" or even "normal" to provide adequate carryover storage to meet required uses if several consecutive dry years occur. During periods of reduction, water supplies are first reduced to agricultural water service contractors until a shortage of 25 percent occurs, then supplies to municipal/industrial water service contractors are reduced too. Based upon these assumptions, recent reports by Reclamation indicate that within the next 25 years, full contract amounts will be provided to all water service contractors less than 10 percent of the time (assuming hydrologic conditions that occurred between 1922 and 1994), and agricultural water service contractors may experience reductions of more than 50 percent more than 40 percent of the time.

CHAPTER 4. GENERALIZED ECOSYSTEM FUNCTION MODELS FOR THE UPPER SACRAMENTO RIVER

Introduction

The TAG was convened to provide advice on Sacramento River flow regime issues and related ecological values (Appendix A). Relevant suggestions from the TAG indicated a need for conceptual models related to the flow regime and the associated physical and ecological processes of the Sacramento River below Keswick Dam.

The conceptual models are valuable tools to present clear visions of our understanding of the functioning of the main stem Sacramento River ecosystem and to present how the system might function after implementation of management interventions such as flow modification.

This section is the initial summation and consolidation of a diverse group of conceptual models that address geomorphology and hydrology, riparian, and fishery resources.

What are Conceptual Models?

A conceptual model documents hypotheses about how ecological systems function (Murphy 2005). The formulation of a conceptual model should include the combinations of physical and biological parameters that are believed to drive the ecological system. However, there is no set pattern for developing a conceptual model (CALFED 2000a). Rather, useful conceptual models are those that provide an explanation of a particular situation, problem or hypothesis regarding the manner in which the ecosystem functions or is expected to respond after some type of intervention is implemented such as modifying a hydrologic pattern, installing or removing rip rap, or setting back a levee to increase floodplain/river interaction. Conceptual models may assume a variety of forms. They can be narratives that describe the understanding of the system, or the models can be stick and box diagrams, drawings, or any medium capable of depicting how the system previously functioned, presently operates, or will operate in the future. Ideally, the conceptual models would be developed for a specific purpose and contain only those elements that are relevant to answering specific questions. In addition, conceptual models can be qualitative or quantitative in nature depending on the level of understanding of the system.

Healey et al. (2004) contributed to the overall rationale to develop conceptual models for ecosystem restoration projects in the Central Valley and proposed an approach that viewed several styles of models of increasingly finer focus. Generally, conceptual models are representations of physical processes or ecosystem functions to allow evaluation of consequences or identification of uncertainty for specific management actions.

Many resource managers, scientists, and stakeholders interested in the restoration and management of the Bay-Delta ecosystem have an understanding about how the ecosystem functions, how it has been altered or degraded, and how various actions might improve conditions in the system. That is, these informed individuals have simplified mental pictures

Developing Conceptual Models (CALFED 2000b)

Conceptual modeling: the process of articulating implicit models (simplified mental illustrations about the most critical cause-and- effect pathways) to make them explicit.

- summarize knowledge and hypotheses about ecosystem structure and function
- highlight key uncertainties where research or adaptive probing might be necessary

Exploratory Simulation Modeling: to allow explicit exploration of the main pathways of causal interaction and feedback processes in the conceptual models

- greatly simplified, clear caricature of the system
- provide preliminary predictions of the consequences of different management actions

Quantitative Modeling: to refine conceptual models or simulation models themselves when a more detailed evaluation of potential alternatives is required.

about the most critical cause-and-effect pathways. At its basic level, conceptual modeling is the process of articulating these implicit models to make them explicit (CALFED 2000a).

Conceptual models can provide several benefits. The knowledge and hypotheses about ecosystem structure and function summarized in conceptual models can lead directly to potential restoration actions. They can highlight key uncertainties where research or adaptive probing might be necessary. Alternatively, competing conceptual models can illustrate areas of uncertainty, paving the way for suitably scaled experimental manipulations designed to both restore the system and explore it. Competing conceptual models provide a means for verifying the modeling inputs and parameters when multiple models have similar outputs or answers. Conceptual models can also help to define monitoring needs, and they can provide a basis for quantitative modeling. Articulating conceptual models can also facilitate dispute resolution since differences between implicit conceptual models often underlie disagreements about appropriate restoration actions (CALFED 2000a).

Conceptual models often suggest many possible restoration actions. In evaluating alternative actions, it is usually very helpful to conduct exploratory simulation modeling based on the conceptual models. These simulations are not intended to capture the full complexity and richness of ecological processes, but to capture the essential elements of ecological structure and function that underlie management decision making. They are greatly simplified, clear caricatures of the system, just as the conceptual models are clear caricatures. Their purpose is to allow explicit exploration of the main pathways of causal interaction and feedback processes in the conceptual models and provide preliminary predictions of the consequences of different management actions. The simple simulations can aid the decision-making process in many ways. For example, simulation modeling can:

- identify logical inconsistencies in the conceptual models,
- clarify where the nodes of greatest uncertainty are in the conceptual models and where new information would be most useful to decision making,
- allow comparison of the benefits and costs of alternative models of the system and alternative management actions,
- provide a basis for determining how much of a particular kind of restoration action will be required to achieve measurable benefits within a specified period of time,
- provide a basis for determining the value to the ecosystem of new information that might be obtained through adaptive experimentation, and
- help communicate to a broader audience the current understanding of the problem and the explicit rationale for particular restoration measures of targeted research.

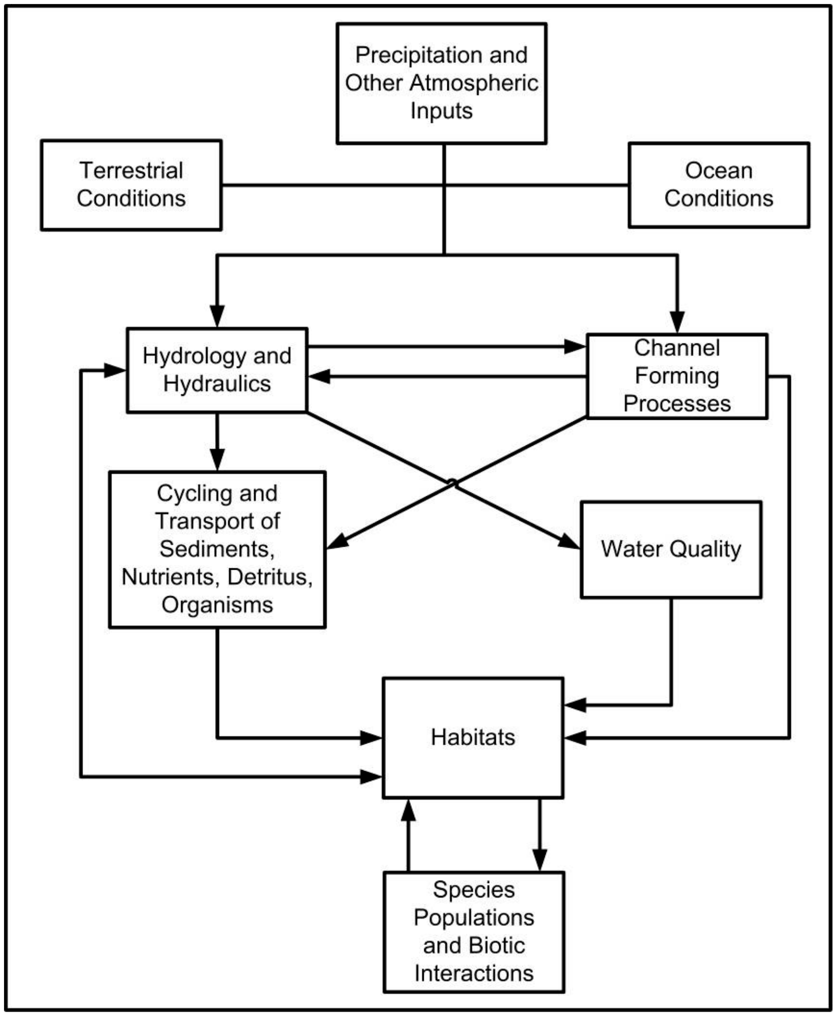
Quantitative modeling may also be a helpful tool to refine conceptual models or simulation models themselves when a more detailed evaluation of potential alternatives is required (CALFED 2000a).

Simplified Conceptual Models

One approach to synthesizing information about an expansive ecosystem is to develop models at various scales. At the landscape scale, only the most important ecosystem inputs and functions are identified. In the following landscape-level model, the major inputs and influences on the system include precipitation and terrestrial and ocean conditions, all of which can influence hydrology, channel forming processes, nutrient processing and water quality of the system. These factors in turn influence the quality and quantity of habitats for aquatic and terrestrial species and other biotic interactions (Figure 4-1).

A toolbox of quantitative models for potential use by the NODOS investigation is found in the following chapter.

FIGURE 4-1. Generalized landscape-level conceptual model.



While the generalized landscape-level model helps to define some of the ecological/ environmental boundaries, it is too broad to describe effectively the main stem Sacramento River. A more refined conceptual model that can be applied to the main stem Sacramento River is the generalized landscape-level lowland river floodplain model (Figure 4-2).

This conceptual model provides a more detailed understanding of specific ecosystem functions associated with the Sacramento River. Regulated lowland rivers situated below major impoundments typically are significantly influenced by reservoir operations. Except during extreme hydrologic conditions (e.g., large flood flows), reservoirs typically modify water quality, hydrology, sediment supply, and nutrient supply. In addition, dams can prevent the migration of fish and other aquatic species. These alterations to system inputs in turn affect fluvial processes, instream habitats, riparian habitats, floodplain habitats, and even upland habitats. The condition or reliability of the various habitats exerts influences on resident and migratory aquatic and terrestrial species and other biotic interactions. Finally, the outputs of this conceptual model, which are delivered to the Delta, are variants of the initial inputs including water quality, hydrology, sediment supply, nutrients, and biotic communities and individual species.

This conceptual model helps to frame the types of questions that need to be posed and answered related to offstream storage in the Sacramento Valley. More specifically, we can begin to see that modifications to existing hydrology will influence fluvial processes, which in turn affect instream, riparian, and floodplain habitats, resident and migrating species and other biotic interactions.

The Golet et al. (2003) model (Figure 4-3) was initially developed to help define indicators of ecosystem health. The model is also useful as a tool to identify, organize, and evaluate a suite of conceptual models for the Sacramento River. For example, in the Golet model, water is a major watershed input to the system and is an important driver for fluvial processes and habitat complexity and connectivity. To understand better the complexity of fluvial geomorphic processes, models that address sediment transport, deposition, and scour; channel migration and bank erosion; floodplain dynamics; and surface–ground water interactions would be very useful.

Additional information on the Sacramento River system can be derived from conceptual models that address habitat, especially riparian, shaded riverine aquatic, and inundated floodplain habitats. Biotic responses to the fluvial processes and habitats can be understood better by a series of conceptual life history models for specific aquatic and riparian species.

Generally, the Golet model suggests that to improve understanding of a riverine ecosystem, it is necessary to understand the relationships of watershed inputs, the manner in which fluvial geomorphic processes respond to the watershed inputs, and how geomorphic attributes influence habitat structure and complexity and the response of dependent biotic species. All of these are influenced by human-induced and natural disturbances.

FIGURE 4-2. Generalized landscape-level model of lowland river floodplain systems.

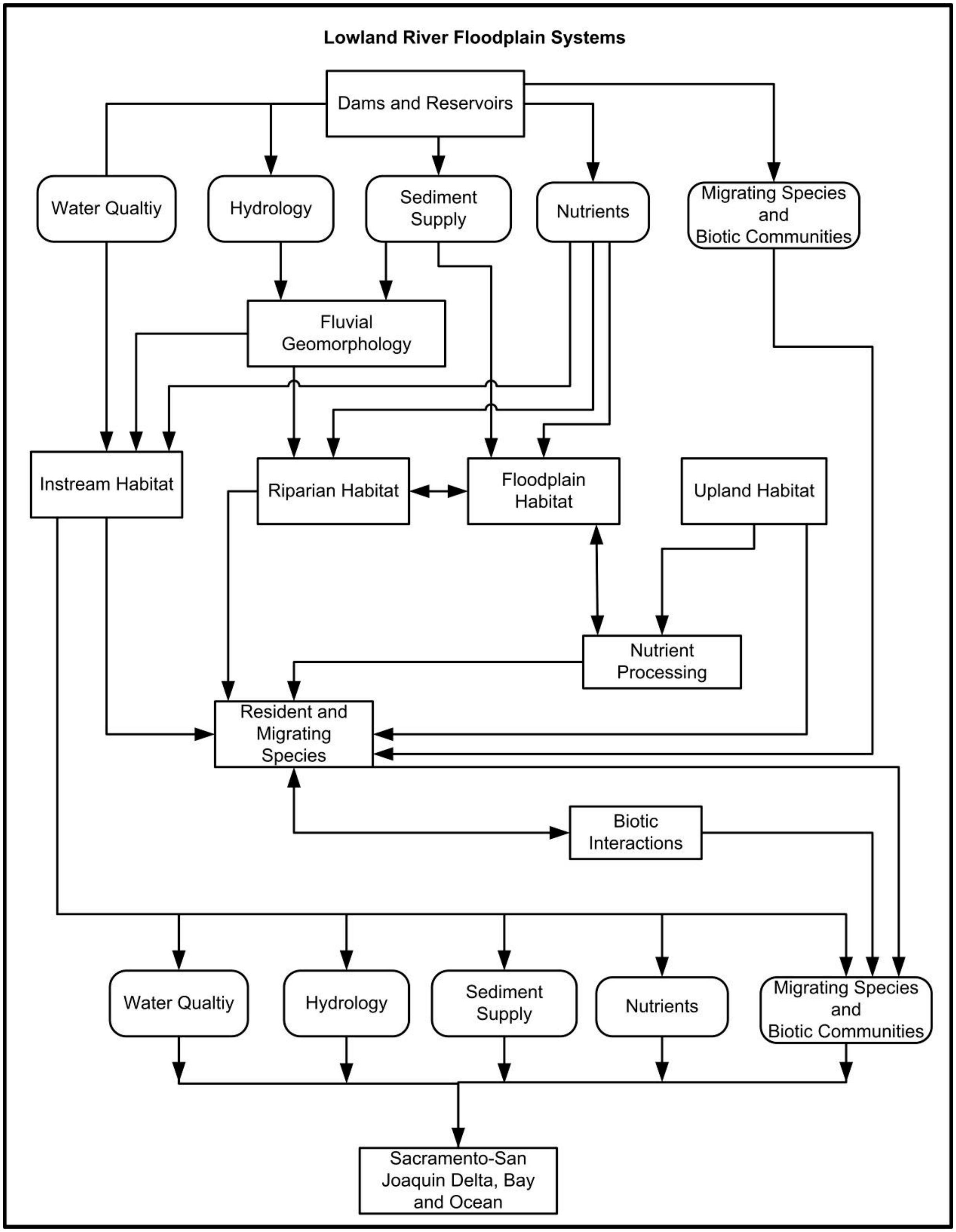
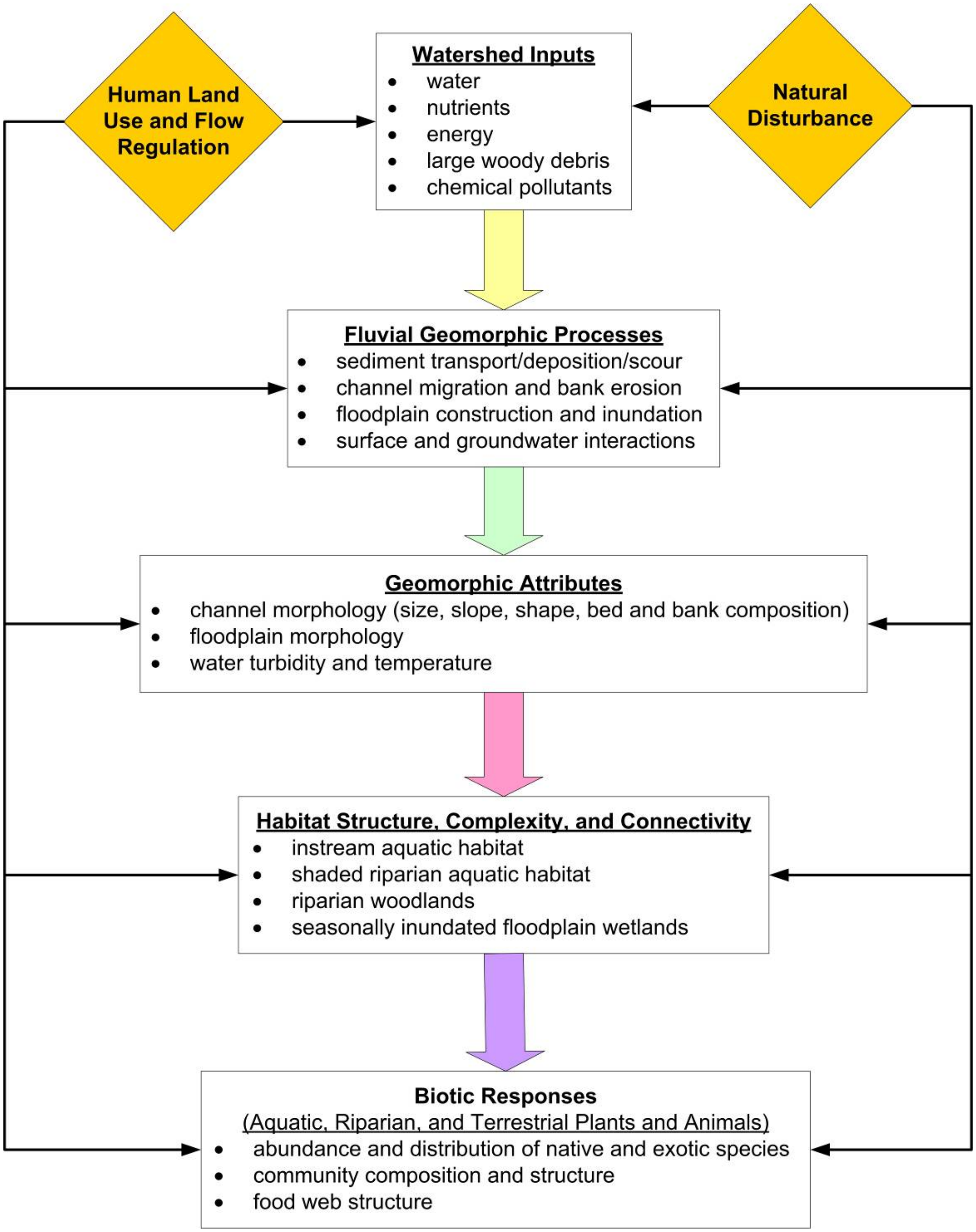


FIGURE 4-3. A Simplified Conceptual Model Of The Physical And Ecological Linkages Used In Developing Biotic Response Indices Of River Ecosystem Health (Golet et al. 2003).



Generalized River Restoration Conceptual Model

Another example of a conceptual model is the generalized conceptual model of Sacramento River restoration (Figure 4-4). This model is an adaptation of the general ecosystem model presented in a paper developed by Michael Healey and other members of the CALFED Bay-Delta Authority's Ecosystem Restoration Program Science Board[4]. In this example, land management, water management, and fish and wildlife management policies drive the manner in which the system is managed or operated. For example, water management policies influence the timing, magnitude, and duration of most flow events. Likewise, land management or fish and wildlife management policies also influence how flow patterns are manipulated, where habitat restoration projects are located, and which species are the beneficiaries of the flow/habitat interventions.

This model is relevant to management of the main stem Sacramento River and identifies the roles that some of the state, federal and local agencies play in river management. This identification helps to provide additional perspectives regarding off stream storage in the Sacramento Valley. Additional storage will need to consider the various land, water, and fish and wildlife management policies in defining an off stream storage program.

This particular model depicts and differentiates between policy, action, response and benefits by utilizing different shaped boxes while the direction of the arrows indicate the direction of influence exerted by the policies, actions and responses.

Management policies are at the highest level and depicted as round-cornered rectangles. The policies include land management, water management, and fish and wildlife management. At the next level, depicted in square-cornered rectangles, are actions to implement the relevant policies. The response to the policies and actions are depicted as circles. System response and ecosystem benefits are depicted as hexagonal figures.

Land management policies could lead to actions such as purchasing lands, relocating levees, allowing or expanding Sacramento River meander, expanding the floodplain of the Sacramento River or increasing the frequency of flood flows into the bypass system including the Yolo Bypass. Water management policies, likewise, could lead to actions such as acquiring water rights, modifying spring or fall flows, and storing additional water.

Fish and wildlife management policies could lead to actions such as improving fish habitat, restoring cottonwood forests, modifying diversions along the Sacramento River, and improving fish passage at diversion structures.

Many of the hypothesized ecosystem responses are influenced by more than one policy. For example, augmenting spawning gravel is a response to fish and wildlife, water, and land management policies.

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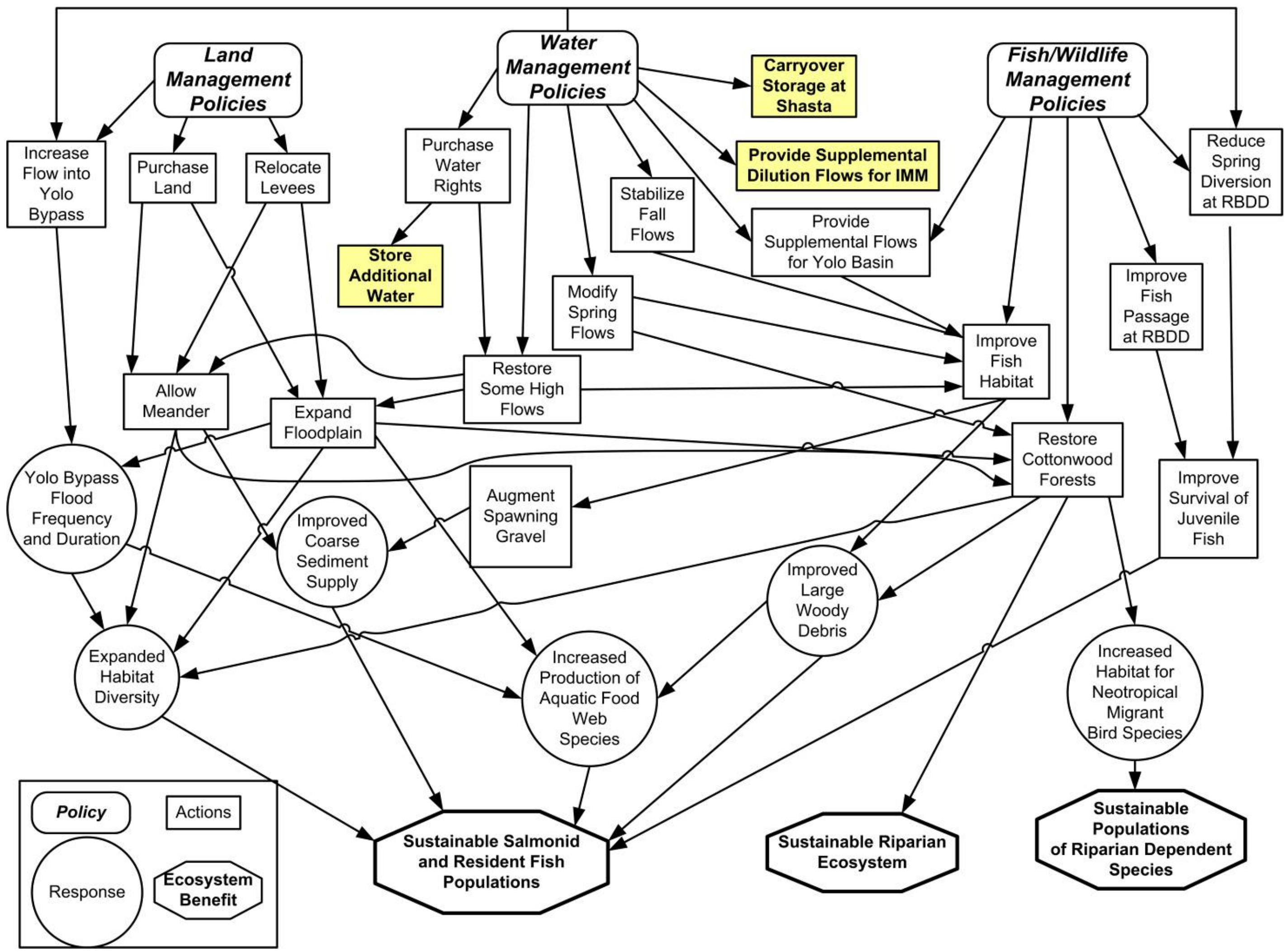
4 This paper is still in draft form and is titled "Conceptual Models and Adaptive Management in Ecological Restoration: The CALFED Bay-Delta Ecosystem Restoration Program."

FIGURE 4-4. General Ecological Model of Sacramento River Restoration Illustrating The Linkage Between Management Policies, Action Implementation, System Response, And Ecosystem Benefits (Adapted From Healey et al. 2004).



Examples of Additional Conceptual Models Relevant to the Sacramento River

Many conceptual models can be used to understand better the unique dynamics of the ecological processes, habitats, and species of the main stem Sacramento River below Keswick Dam. Again, using the Golet model as a map, we see that a variety of conceptual models is required to improve our understanding of the complexity in managing the Sacramento River. Significant models need to address fluvial processes, geomorphic attributes, habitat structure, complexity, and connectivity, and fish and wildlife species and lower trophic organisms. Researchers have developed numerous conceptual models of river dynamics that have applicability to the Sacramento River.

The following are examples of additional conceptual models that have relevance to understanding and evaluating alternative flow regimes for the Sacramento River. Some of the models were developed for other geographic areas while some are Sacramento River system specific.

Sediment-Channel Maintenance Conceptual Model

The relationship of sediment transport, sediment budget, and channel maintenance is presented in Figure 4-5. In this model, the quantity of sediment below dams and the frequency of bed mobilization determine the nature of channel changes over time. For example, rivers with little available sediment and a low frequency of high flows tend to exhibit minor channel changes over time. This is in contrast to systems that have abundant sediment supplies and high frequency of bed mobilization. The latter systems are more dynamic and respond to flow events.

Flow regime requirements shown in Figure 4-5 were developed for the Sacramento River between Colusa and Red Bluff (CALFED 2000b) as part of the Flow Regime Requirements for Habitat Restoration along the Sacramento River.

In natural alluvial channels, channel form is determined by flow and sediment load, with constraints set by underlying geology and by vegetation. On many alluvial rivers, the peak flows occurring every 1-5 years on average are the flows that move the most sediment over time, and are considered the channel-forming flows (CALFED 2000b).

Because dams change the flow and sediment load downstream, they produce channel changes that are broadly predictable (Figure 4-5). For example, reservoirs trap gravel and sand, cutting off the supply to downstream reaches. If the downstream reaches still experience flows capable of transporting sediment, gravel and sand will be moved downstream without replacement, resulting in incision or downcutting of the bed and coarsening or "armoring" of the bed material. High flows released from dams, often called "sediment-starved" can eliminate formerly important spawning gravels for salmon (CALFED 2000b). This has been an important impact on the upper Sacramento River and Clear Creek.

Another potential impact, as indicated in Figure 4-5, is associated with tributaries below the dam delivering high sediment loads of sand and gravel. In this situation, the frequency of sediment transporting flows in the river is reduced; the bed may aggrade with sediment and become finer-grained. Along the Sacramento River, stream power is still high enough to transport most sediment delivered to it by tributaries, although some large bars have temporarily deposited at tributary confluences right after floods due to backwater effects of high river stage.

To address these sediment supply and transport issues, regulated rivers can be managed by releasing flows of magnitude and duration to transport tributary-derived sediments downstream, with coarse sediment introduction immediately downstream of the dam occurring at rates comparable to the transport capacity to maintain storage in the upper portion of the regulated reaches. Sediment transport measurements and modeling efforts can help develop the tools necessary to improve flow releases and sediment introduction efforts.

FIGURE 4-5. Example of a Fluvial Geomorphic Conceptual Model (CALFED 2000b).

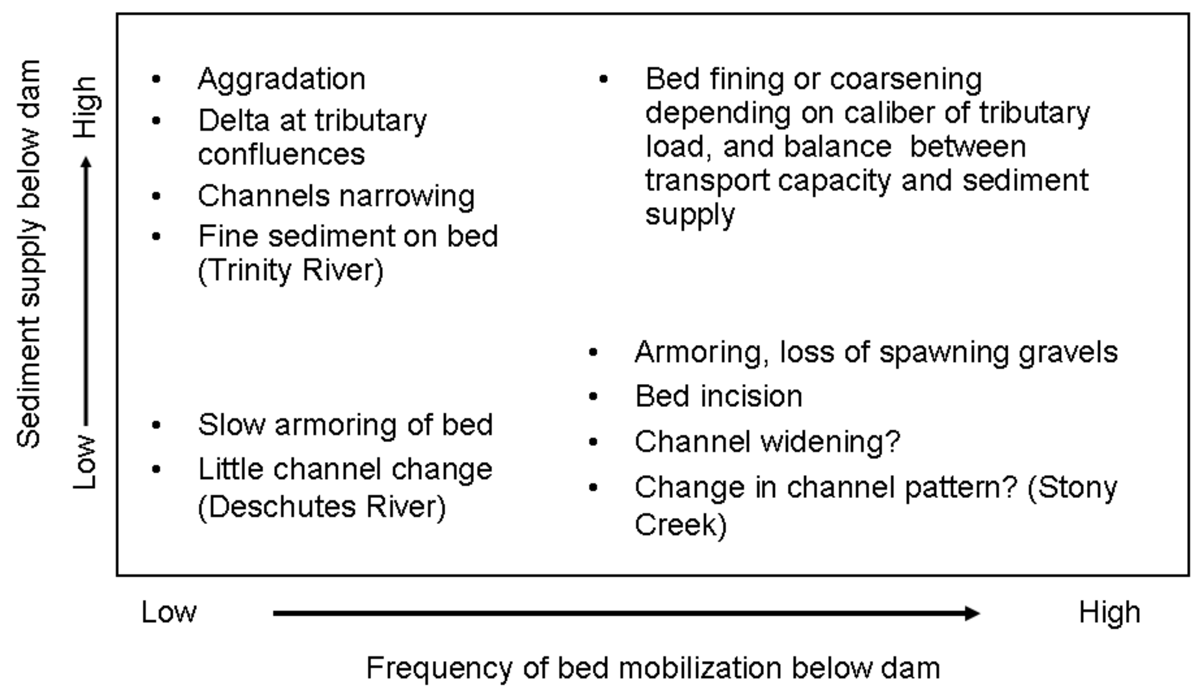


Chart showing channel changes below dams as a function of sediment supply from downstream tributaries and frequency of post-dam bed mobilization. Citations for examples listed are: Trinity River: Wilcock et al. 1996, Deschutes River: McClure 1998, Fassnacht 1997, Stony Creek: Kondolf and Swanson 1993.

Riparian System Conceptual Models

The following model (Figure 4-6) shows the relationship of channel forming processes and channel migration on the establishment of riparian systems. Figure 4-6 shows some of the floodplain building and meander dynamics that support riparian establishment. The diversity of riparian habitat depends upon the diversity of physical environments for vegetation, ranging from freshly deposited, coarse-grained point bars (colonized by early successional species) to higher floodplain surfaces underlain by fine-grained overbank sediments (supporting mature, later successional species) (CALFED 2000b). With reduced rates of channel migration below dams, the areal extent of pioneer forests may decline, offset by an increase in extent of later successional species, and resulting in an overall loss of species (and therefore habitat) diversity.

FIGURE 4-6. Example of a Riparian System Conceptual Model (CALFED 2000b).

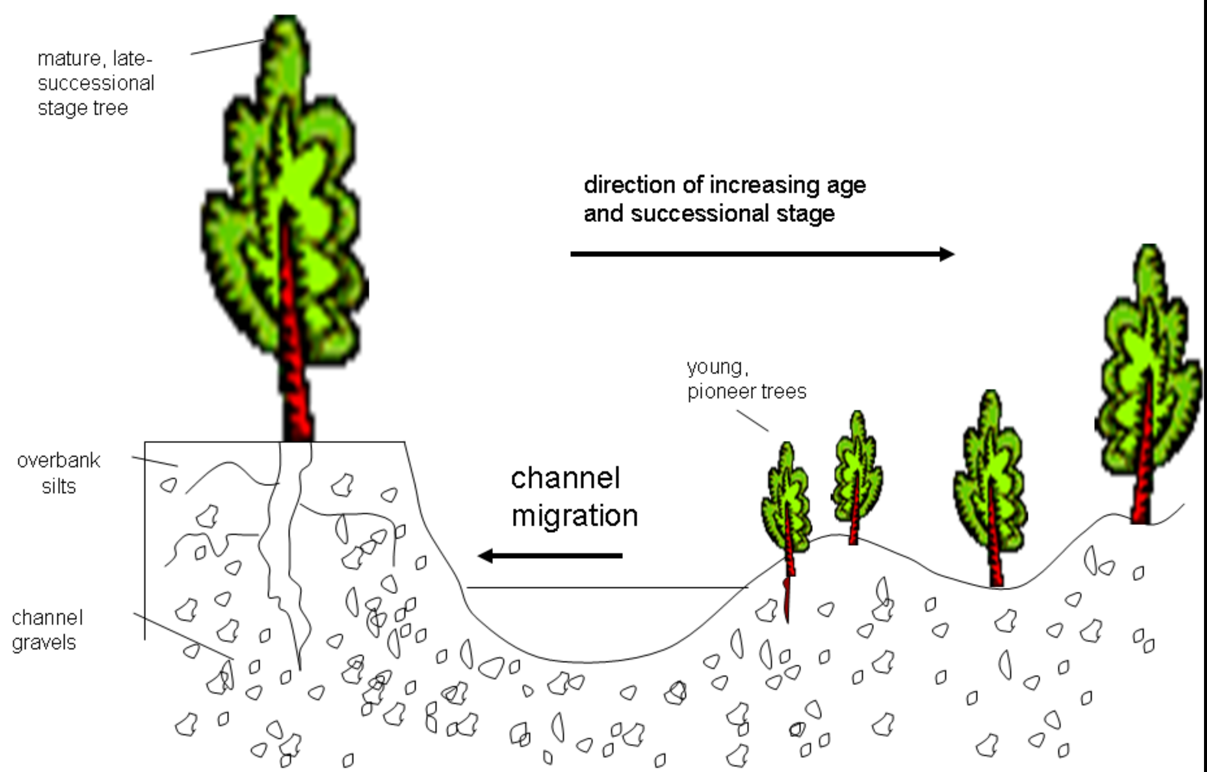


Diagram of floodplains building along a meandering river, producing a characteristic stratigraphy of basal gravels (channel deposits), overlain by sand (point-bar deposits), in turn overlain by silt and fine sands (overbank deposits). The age and successional stage of vegetation generally increase with increasing age and elevation of the geomorphic surface from the young pioneer plants on the freshly deposited point bar to the mature, equilibrium-stage vegetation on thick overbank silts on the floodplain distant from the current channel location.

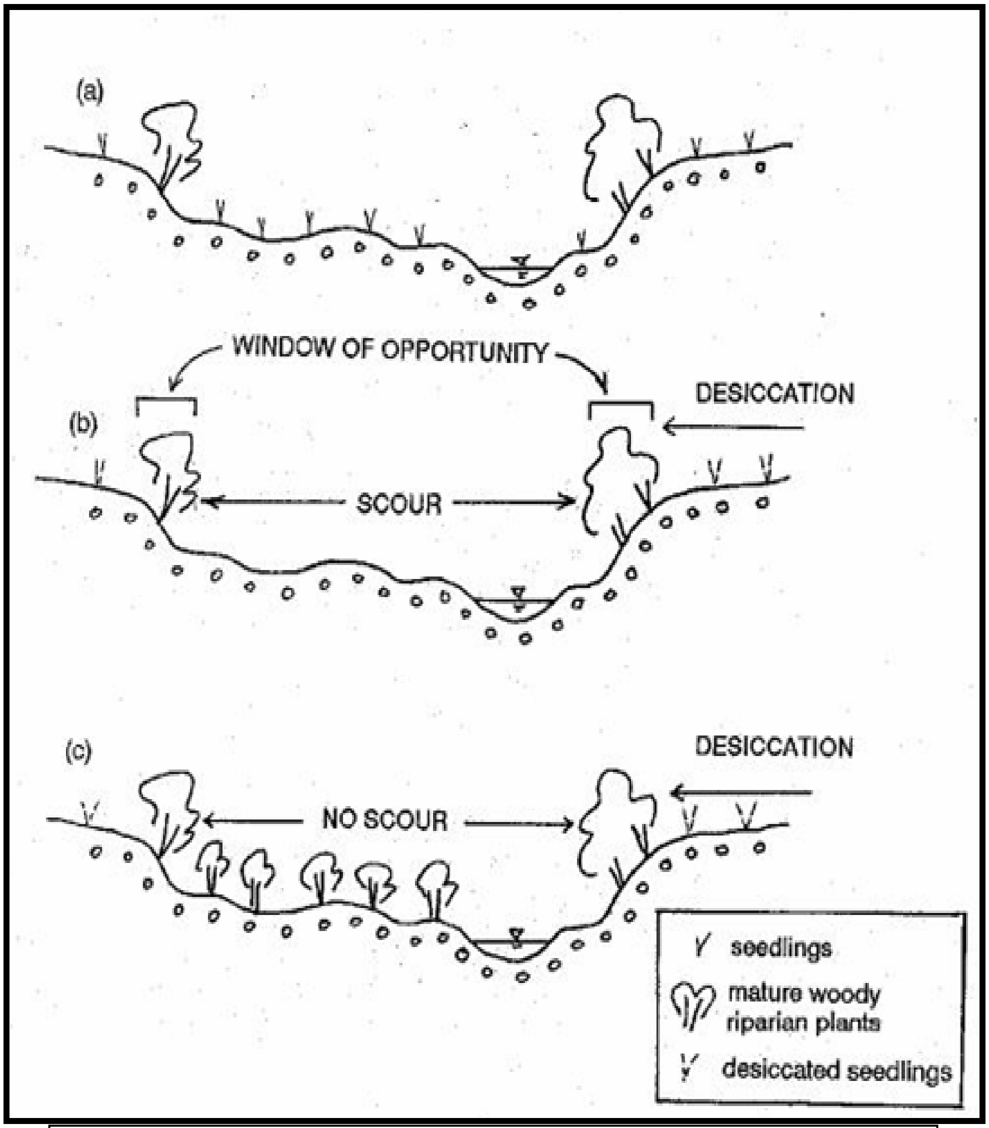
Table 4-1 provides information on the ecological needs for riparian woody species along the Sacramento River (CALFED 2000b). Species succession within the riparian forest follows a predictable sequence as river processes, interacting with vegetation, creates and alters floodplain geomorphology. Fremont cottonwood and five species of willows colonize actively growing point-bars and other exposed sediment surfaces that are at, or near, the baseflow water table. As the seedlings grow larger over the years, they trap sediments with each flood-event, causing the local vicinity to increase in elevation relative to the channel, forming a low depositional surface. As the area grows higher, flood frequency and flow velocities decrease, allowing the deposition of finer textured sediments, silts and clays, forming a higher surface above the river channel. These finer textured sediments provide the ideal seedbed for species such as box-elder, Oregon ash, and basket sedge. With increasing density of vegetation, more and finer sediments are trapped, causing a land surface relatively high above the channel and immune from all but the biggest floods. These higher surfaces supported the valley oak-elderberry forests that today grow walnut orchards (CALFED 2000b).

TABLE 4-1. Riparian Woody Species Ecological Needs and Behavior on the Sacramento River (CALFED 2000b).

Species	Location on Floodplain	Light Needs	Water Table Needs	Drought Tolerance
Fremont cottonwood	Point-bars and avulsed channels	Full sun; very slow growth in partial shade	Must have roots in moist soils. In coarse sediments, roots must reach water table.	None
Valley, Arroyo, Yellow, Sandbar willows	Point-bars, avulsed channels, low terraces	Full sun; very slow growth in partial shade	Must have roots in moist soils. In coarse sediments, roots must reach water table.	None
Oregon ash and Box-elder	Usually away from active channel	Tolerates shade	Facultative	Drought tolerant in shade
California sycamore	Along secondary channels and oxbow lakes	Full sun; tolerates some shade	Must have roots in top of water table.	Re-sprouts from crown
White alder	Oxbow lakes	Full sun	Must have roots in top of water table.	None
Buttonbush	Oxbow lakes	Tolerates shade	Must have roots in top of water table.	Re-sprouts from crown
Valley oak, Elderberry, Rose	Highest terraces	Tolerates shade	Facultative	Well-developed

In rivers with reduced flood flows below dams such as the Trinity River, vegetation may successfully establish in the active channel bed because the plants are no longer scoured regularly, a process commonly known as "vegetation encroachment" (CALFED 2000b). Reduced frequency of scour may permit seedlings of riparian trees to establish and mature in the active channel, in a zone formerly scoured annually or biannually (Figure 4-7). With elimination of frequent scour, vegetation can encroach upon the channel and induce further narrowing by trapping sediment.

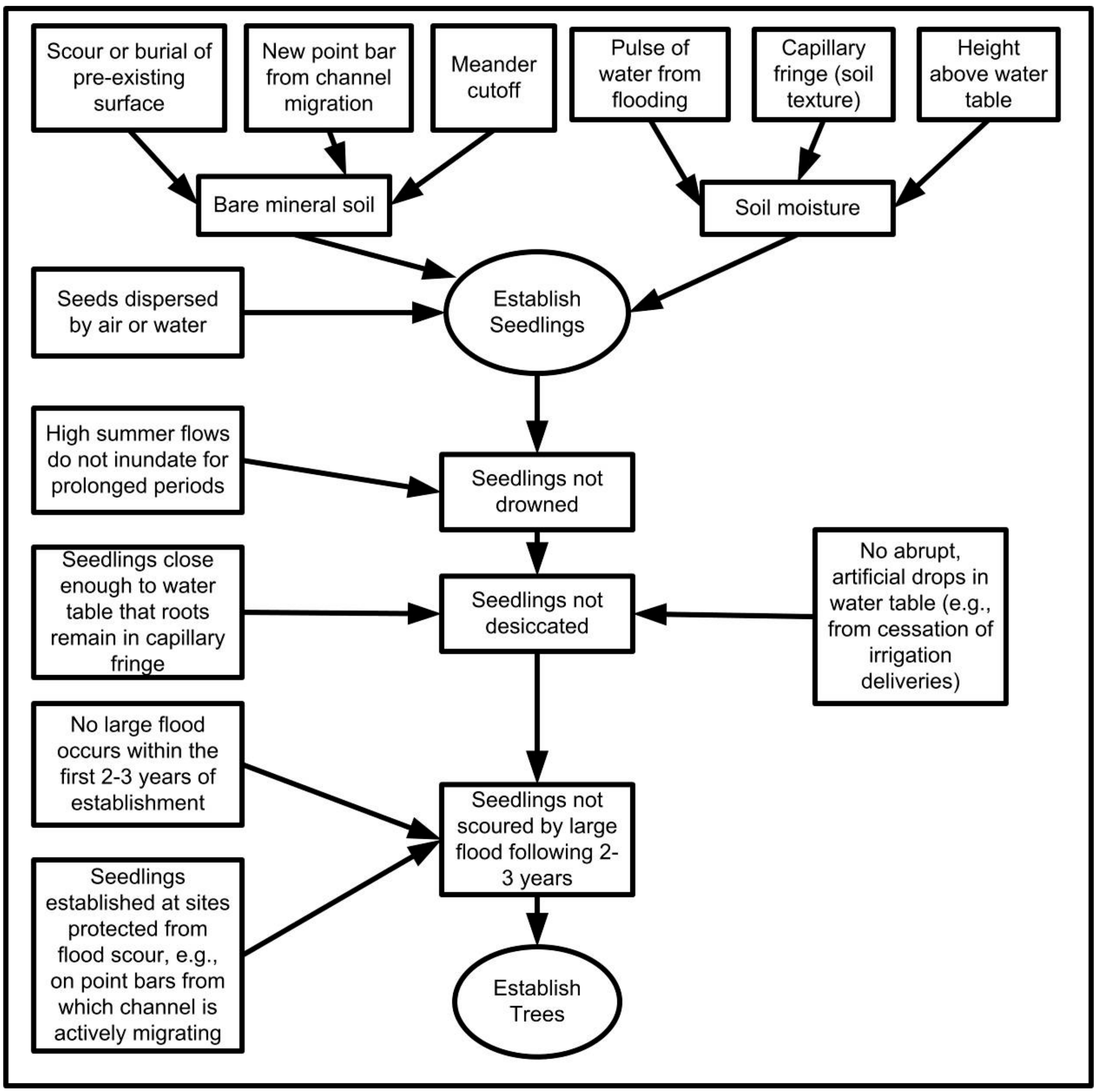
FIGURE 4-7. Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red Bluff (CALFED 2000b).



Schematic diagram illustration (a) seedling distribution following annual flood recession, (b) the "window of opportunity" for establishment of riparian vegetation between the zone of scour and zone of desiccation in an unregulated channel and (c) encroachment of vegetation into the channel after reduction of flood peaks by and upstream reservoir and elimination of scour.

Cottonwood trees do not establish every year, at least not in large cohorts. A combination of circumstances - typically associated with large floods - appears necessary for successful recruitment. On the Sacramento River, seedling establishment is further complicated by the altered hydrology. A conceptual model of requirements for cottonwood seedling establishment (Figure 4-8) follows. Two key conditions for cottonwood regeneration are the presence of bare mineral soil and soil moisture.

FIGURE 4-8. Conceptual model of requirements for cottonwood establishment on the Sacramento River (CALFED 2000b).



Qualitative Restoration Conceptual Model

The following conceptual model and discussion is from a product of the CALFED Ecosystem Restoration Science Board that addresses conceptual modeling and adaptive management. This model attempts to link measures for physical riverine processes, floodplain functions, and riparian communities. The full paper is available online at:
http://calwater.ca.gov/Programs/EcosystemRestoration/EcosystemRestorationScienceBoard.shtml

A qualitative restoration model is being used to guide restoration of salmon habitat on Clear Creek, a tributary of the Sacramento River, and on the Tuolumne and Merced rivers, both tributaries of the San Joaquin River (Figure 4-9). The model incorporates measures to reestablish natural processes that determine fluvial morphology, to reconnect the river to its floodplain, and to diversify native riparian plant communities. Many tributaries are presently confined to immobile, single-thread channels by low discharge, levees, tailings from historic gold dredging, and bank riprap, all of which greatly decrease available habitat for fish. Fish habitat is degraded further by lack of an upstream gravel supply and armoring of the river bed. The tributaries are isolated from their floodplains by levees, and floodplain elevations are too high to be inundated by present day high flows except in very wet years. Floodplains are potentially important rearing habitats for the fish species that are targets of conservation as well as other at-risk species. Restoration plans call for setting back levees, rescaling channel dimensions and gravel texture, and re-contouring the floodplain so that it will be inundated every two years on average by the present, much reduced, post-dam discharge regime (Figure 4-9). The floodplain will be planted with native forest trees and shrubs to reduce invasion of non-native plants. Gravel of a size that can be mobilized by the two-year return flow will be introduced at the upstream ends of restored reaches, and in the bed and banks of the re-formed channels.

The underlying assumption is that these measures will establish a self-sustaining ecosystem favorable to the recovery of listed native species (Chinook salmon in particular). As the river channel begins to migrate within its widened floodplain, it will redistribute gravel from upstream and from its eroding banks, creating riffles and pools that can serve as spawning and nursery habitat for salmon, and exposed point bars where native riparian species can colonize. Apart from continual gravel replenishment by humans, these reconstructed reaches are expected to be self-sustaining.

The same paper also provides a general model of action and expected outcomes for gravel reach restoration on salmon spawning tributaries (Figure 4-10).

FIGURE 4-9. Conceptual diagram of stream channel-floodplain modifications to improve floodplain interactions and support for riparian forests (top panel is before restoration and the bottom panel depicts post-restoration conditions) (Healey et al. 2004).

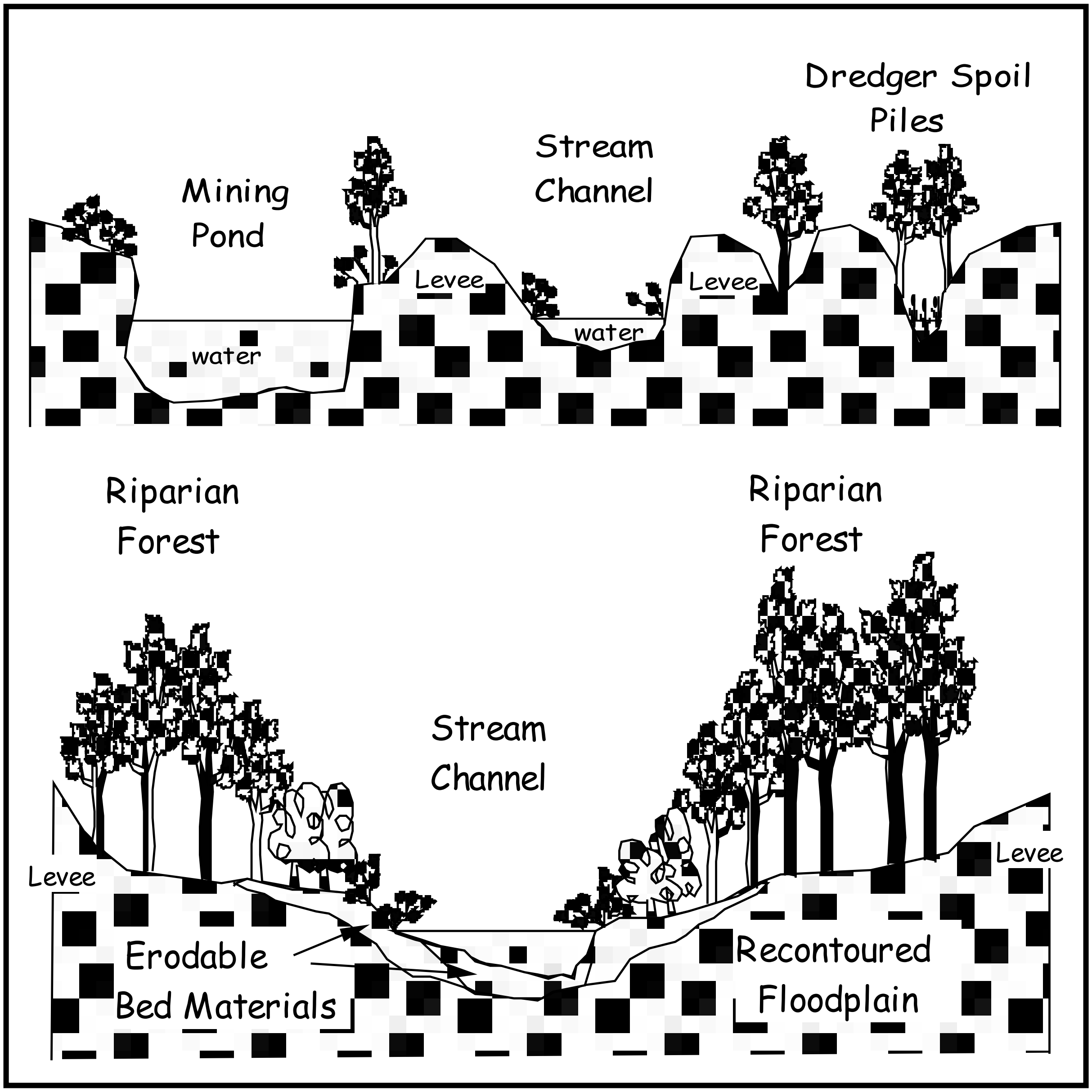
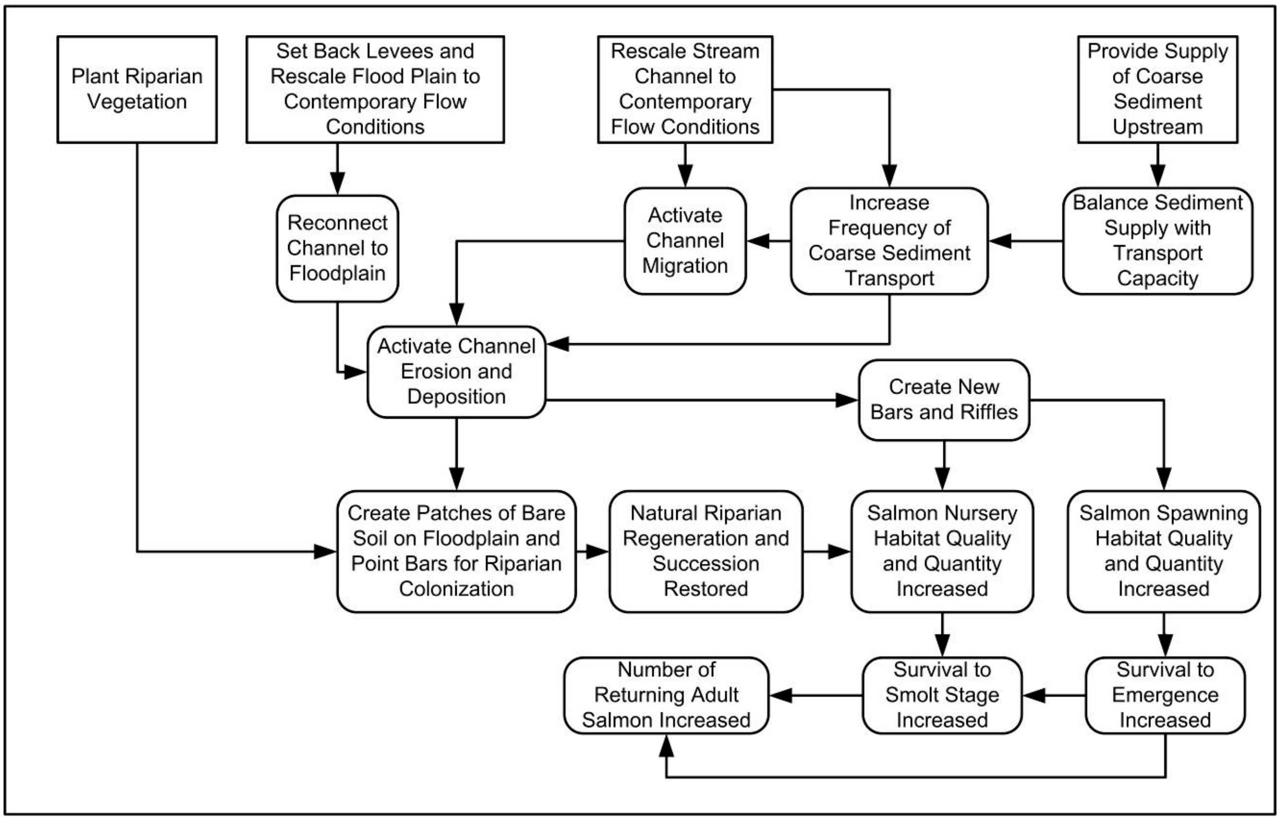


FIGURE 4-10. General model of action and expected outcomes for restoration of gravel reaches of salmon spawning tributaries. In this model, manipulating physical variables (floodplain elevation, substrate composition and supply, seasonal hydrograph) are expected to restore conditions and processes favorable to native species (Healey et al. 2004).



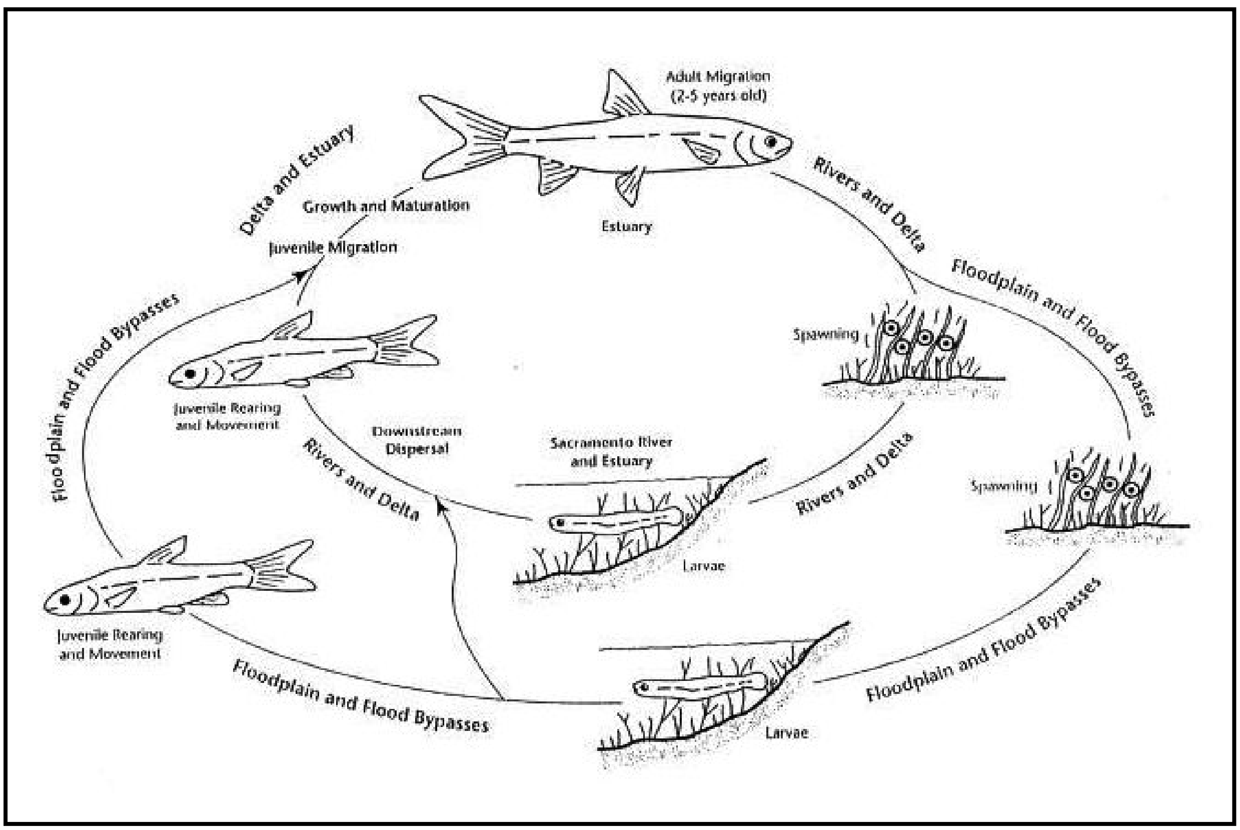
Fishery Resource Conceptual Models

This section provides conceptual and life cycle models for Sacramento splittail and Chinook salmon.

Splittail Conceptual Model

The Sacramento splittail is a large native minnow that migrate upstream during the winter and spring months to feed and reproduce (Natural Heritage Institute et al. 2002). Studies provide evidence that floodplain inundation may be a primary factor in controlling splittail abundance. The Yolo Bypass offers diverse types of floodplain habitats when submerged and provide wetland ponds, low velocity floodplain reaches, emergent vegetation, and deeper, open water with submergent vegetation. Figure 4-11 displays the splittail life cycle and use of various types of habitat situated in the lower Sacramento Valley including the rivers, delta, floodplains, bypasses, and the Delta and estuary. Actions that increase the extent or duration of floodplain inundation and bypass flooding would contribute to splittail reproductive success and actions that limited flooding would result in the opposite effect.

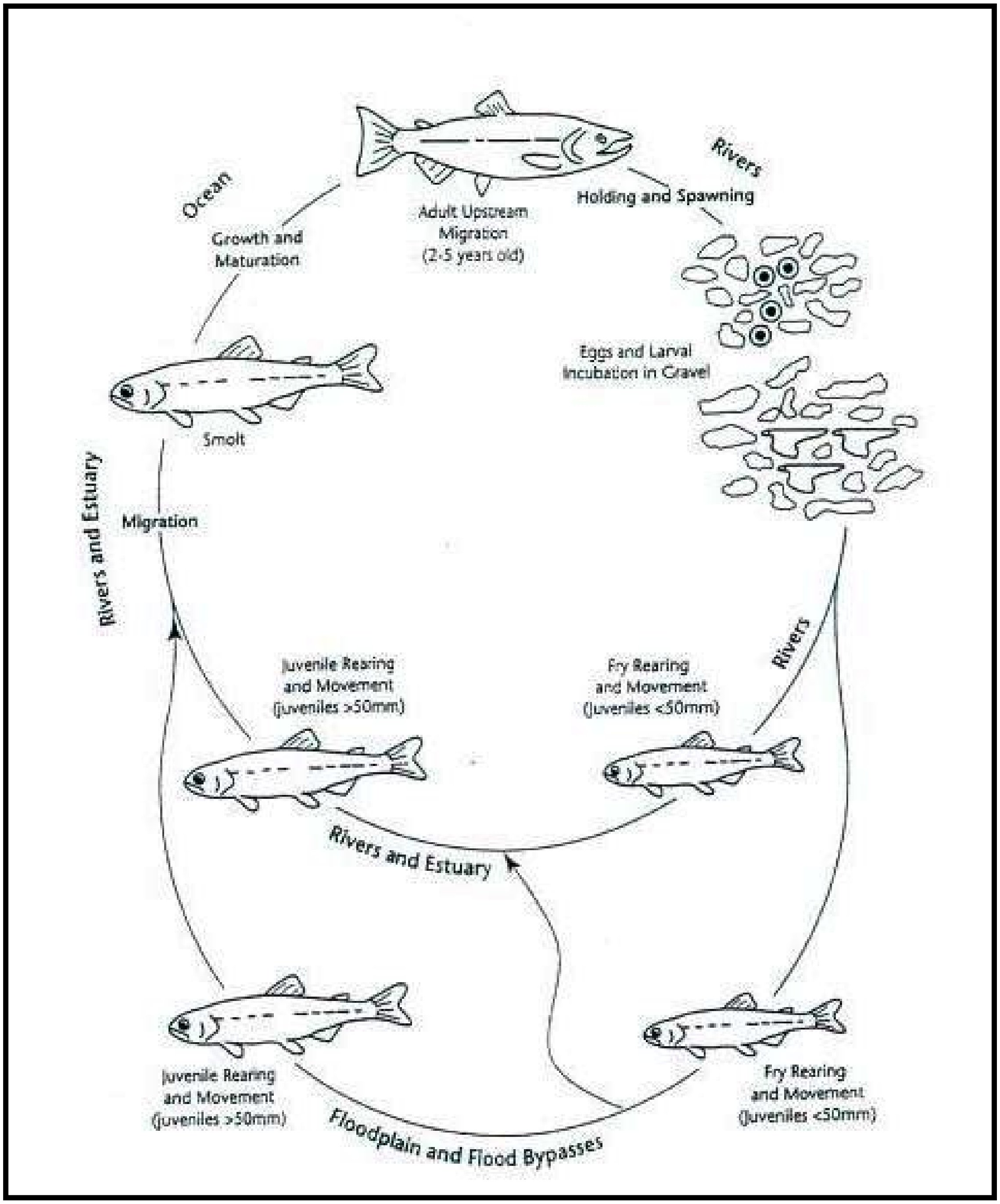
FIGURE 4-11. Life cycle diagram of Sacramento splittail (Natural Heritage Institute et al. 2002).



Chinook Salmon Conceptual Models

A model of Chinook salmon use of the Yolo Bypass (Figure 4-12) is provided. Similar to the splittail conceptual model, actions that improve floodplain and bypass access would contribute to the survival of young salmon while actions that reduce floodplain and bypass access would not improve survival.

FIGURE 4-12. Life cycle diagram of Chinook salmon in the lower Sacramento River and Yolo Bypass (Natural Heritage Institute et al. 2002).



CHAPTER 5. TOOLBOX DEVELOPMENT

The purposes of this chapter (and Chapter 4) are to identify a variety of conceptual and mathematical/simulation models that can be utilized to better understand and evaluate alternative management configurations for Sacramento River flows and the potential effects on related ecosystem processes, riparian habitats, and aquatic species. The descriptions of model capabilities are for illustration purposes only. The models discussed may or may not be the best models for a particular situation. Clearly, modeling technology will change as both modeling capabilities and data resources change. Models of the type described here will need to be implemented and linked to express effects of multiple processes (such as the influence of accelerated sedimentation on fish habitat and populations). Thus, surrounding the modeling exercise should be a number of crucial social processes, including conceptual model development, decisions about the types and resolution of predictions that need to be made, and communication of the results in a form that is useful to policy makers and stakeholders.

The tools addressed in this section include a diversity of physical process models and biotic models (Table 5-1). Not all the models described are developed or calibrated at this time. However, each has the potential to contribute to understanding the physical processes and biotic communities of the Upper Sacramento River. Some of these modeling tools may be helpful for Upper Sacramento River investigation in evaluating potential effects for pertinent feasibility and environmental documentation.

Model Descriptions

CALSIM II Temporal Downscaling

CALSIM II is a simulation model of the CVP and SWP storage and distribution systems that utilizes a linear programming solver in each monthly time-step to route water through a network given user-defined constraints and priority weights. Developers of CALSIM (the generalized water resources management model software underlying CALSIM II) also developed the Water Resources Simulation Language (WRESL), which acts as an interface between the user and the solver, time-series database, and relational database. CALSIM II simulation of the operations of the CVP and SWP systems includes physical, institutional, and regulatory constraints and an objective function composed of priority-weighted operational penalties. The CALSIM II model is limited by a monthly time-step for output, while dam operators use daily (or less) information to evaluate impacts of CVP and SWP operations on meeting permit requirements (e.g. D-1641). The primary purpose of CalSim-II model is to evaluate the performance of the CVP and SWP systems:

- at current or future levels of land development
- with and without various assumed future facilities
- with different modes of facilities operations
- under various regulatory environments

California's current regulatory environment is very complex; and that complexity is represented in the model by four regulatory layers: State Water Resources Control Board's Decision (SWRCB) 1485 (D-1485) and SWRCB Decision 1641 (D-1641); Central Valley Project Improvement Act (CVPIA), Section 3406 (b)(2); and the California Bay-Delta Authority's Environmental Water Account (EWA). While the (b)(2) layer requires that the conditions under D-1485 be known, the EWA layer requires that conditions under D-1485, D-1641, and (b)(2) be known. Because the regulatory environments are interdependent, CALSIM II simulates each regulatory condition sequentially for one entire year, before moving on to the following year. This sequential simulation of environmental conditions is commonly known as regulatory layers of CALSIM II (Ferreira 2005).

The CALSIM-II model can provide monthly discharge volumes based on current or proposed water storage and delivery operations that affect the Sacramento River flow hydrograph. The monthly stream flow data can be converted to daily flows (temporal downscaling) by a post-processing program developed by Reclamation. This post-processing methodology was developed for the Upper Sacramento River Temperature/Water Quality Model that is described below. Establishing daily discharge hydrographs from these models is an important first step in applying the suite of numerical models. This daily flow information for present or proposed conditions can be used as input data to many of the remaining numerical models.

TABLE 5-1. Models that may be Useful for Upper Sacramento River Studies

Model	Physical/ Biotic	Status	Processes Modeled
CALSIM-II Daily Time-Step Operations	P	O	Establishes a daily discharge hydrograph and operations for the Sacramento River
Sediment Impact Analysis Method (SIAM)	P	O	Water and sediment budgets of the river system at the scale of the fluvial system.
Generalized Sediment Transport for Alluvial Rivers (GSTAR-1D) Model	P	O	Unsteady flow, river hydraulics, sediment transport, erosion, and deposition.
Generalized Sediment Transport for Alluvial Rivers and Watersheds (GSTAR-W Model)	P	O	Generalized sediment transport for alluvial rivers and watersheds is a physically based, process oriented, and spatially distributed model used to assess the impacts of management and mitigation strategies.
Unsteady and Unstructured Reynolds Averaged Navier-Stokes solver (U^2RANS)	P	O	Three Dimensional (3D) River hydraulics through meander bends and shear stress computations along the river bed and banks.
MEANDER	P	U	A numerical channel migration model developed for meandering rivers to predict the future river channel alignment
The Unified Gravel-Sand Model (TUGS)	P	O	TUGS model employs a surface-based bedload equation and links grain size distributions in the bedload, surface layer, and subsurface. The model is capable of exploring the dynamics of grain size distributions, including the fractions of sand in sediment deposits and on the channel bed surface, and is potentially useful in exploring gravel-sand transitions and reservoir sedimentation processes.
Riparian Habitat Establishment Model (RHEM)	P	U	RHEM consists of a modified version of the HYDRUS-2D variably saturated water flow code. HYDRUS-2D simulates two-dimensional variably-saturated water flow, heat movement, and transport of solutes.

TABLE 5-1. Models that may be Useful for Upper Sacramento River Studies

Model	Physical/ Biotic	Status	Processes Modeled
Recruitment Box Model	B/P	O	Simulation of relationship between flow events and cottonwood establishment (Mahoney and Rood 1998)
Ecosystem Function Model	P	O	Functional relationships describe the interactions between flow, channel morphology, and ecosystems in the channel/floodplain areas
SALMOD	B/P	O	Emulates dynamics of freshwater life history of anadromous and resident salmonid populations using streamflow, water temperature, and habitat type
Winter-run Integrated Modeling Network (IMF)	B	U	The IMF can be used to predict fish benefits achieved by changes to water management, harvest regulation, hatchery augmentation, and stream habitat alteration.
Oak Ridge Chinook Salmon Model	B	O	Spatially explicit and individual-based model of fall Chinook salmon recruitment in a river below a dam that links river habitat with a model of Chinook reproduction, development, growth, and mortality (Jager and Rose 2003)
Box-Jenkins Transfer Function Model	P	O	The Box-Jenkins transfer functions modeled stream discharge and sediment concentration for a 32 year period on the Sacramento River to analyze spatial patterns in sediment transport (Singer and Dunne 2001)
U.C. Davis Meander Migration Model	P	O	Modification of the Johannesson and Parker (1989) numerical channel migration model, assumes that local bank erosion rates are proportional to local velocity factors (Larson and Greco 2002)
U.C. Davis Habitat/Species Model	B/P	O	A habitat suitability model to predict presence or absence of yellow-billed cuckoo based on a modification of the California wildlife habitat relationships land cover classification scheme (Greco et al. 2001)
Sacramento River Ecological Flows Tool (SacEFT)	B/P	U	(SacEFT) is a database centered software system for linking flow management actions to changes in the physical habitats for several focal species of concern.
Instream Flow Incremental Methodology	P	O	A decision-support system designed to help determine the benefits or consequences of different water management alternatives. IFIM is composed of a library of linked analytical procedures that describe the spatial and temporal features of habitat resulting from a given river regulation alternative(Bovee et al. 1998)
Upper Sacramento River Temperature/Water Quality Model	P	O	Simulates the temperature regime of Upper Sacramento River. The NODOS model extends from Keswick Dam to Knights Landing and included the Sacramento River, Red Bluff Diversion Dam, Black Butte Dam, Stony Creek, Tehama Colusa Canal, Glenn-Colusa Irrigation District, Glenn-Colusa Canal, Colusa Basin Drain, a proposed Maxwell pipeline, enlarged Funks Reservoir, and the proposed Sites Reservoir.
Key :P= physical process model, B=biotic model. Status : O=operational, U=under development			

SIAM Model

SIAM, Sediment Impact Analysis Method, simulates the movement of sediment through a drainage network from source to outlet to assess the connectivity of sediment sources and sinks and so estimate the effect of sediment dynamics on channel morphology. The basic premise of the model is that movement of bed material load (sediment in transport that is found in significant quantities in the bed) is limited by the capacity of the flow to transport sediment, while movement of wash load (sediment in transport that is not found in significant quantities in the bed) is supply limited. Results identify areas of short and long-term instability and provide information on the quantity and source of sediment loads in selected reaches of the fluvial system.

SIAM provides an intermediate level of analysis more quantitative than a conventional geomorphic evaluation or fluvial audit, but less specific than a numerical, mobile-boundary simulation. Using principles of sediment continuity and channel response, SIAM links basin wide processes to perform a trend analysis on a river system identifying the current state as well as the direction and magnitude of potential adjustments in both short and long term time frames. The quick setup and run times provide the opportunity to run many simulations to explore operational scenarios, perform sensitivity studies, and create risk analysis information. David Mooney developed SIAM at Colorado State University for the U.S. Army Corps of Engineers under the Regional Sediment Management program (http://www.wes.army.mil/rsm/). The model was developed to accommodate large basins, incorporate sediment sources, and prescribe rehabilitation alternatives using a system perspective. Potential uses include:

- Identifying current and future areas of instability due to sediment imbalances;
- Linking sediment impacts with the agent contributing to the problem;
- Developing and evaluating multiple rehabilitation or management options;
- Integrating sediment management and analysis with other watershed goals;
- Problems involving large networks with multiple nested tributaries.

SIAM is unique in its ability to perform a quantitative analysis on large networks of nested tributaries, track individual sediment sources to the impact on the channel structure, rapidly setup and compute simulations, and provide prescriptions to address problems. The HEC-RAS modeling software is scheduled to include SIAM in future releases as a hydraulic design module."

GSTAR-1D Model

GSTAR-1D (Generalized Sediment Transport for Alluvial Rivers) is a hydraulic and sediment transport numerical model developed to simulate flows in rivers and channels with or without movable boundaries (Yang et al. 2005). Some of the model's capabilities are:

- Computation of water surface profiles in a single channel or multi-channel looped networks.
- Steady and unsteady flows.
- Subcritical flows in a steady hydraulic simulation.
- Subcritical, supercritical, and transcritical flows in an unsteady hydraulic simulation.
- Steady and unsteady sediment transport.
- Transport of cohesive and non-cohesive sediments.
- Cohesive sediment aggregation, deposition, erosion, and consolidation.
- Sixteen different non-cohesive sediment transport equations that are applicable to a wide range of hydraulic and sediment conditions.
- Cross-stream variation in hydraulic roughness.
- Exchange of water and sediment between main channel and floodplains.

- Fractional sediment transport, bed sorting, and armoring.
- Computation of width changes using theories of minimum stream power and other minimizations.
- Point and non-point sources of flow and sediments.
- Internal boundary conditions, such as time-stage tables, rating curves, weirs, bridges, and radial gates.

Limits of Application
GSTAR-1D is a general numerical model developed to simulate and predict cohesive and non-cohesive sediment transport and related river morphological changes due to natural or human influences. GSTAR-1D is an engineering tool for solving fluvial hydraulic problems with the following limitations:

(1) GSTAR-1D is a one-dimensional model for flow simulation. It should not be applied to situations where a two-dimensional or three-dimensional model is needed for detailed simulation of local hydraulic conditions.
(2) GSTAR-1D is based on the sub-channel concept. The phenomena of secondary current, lateral diffusion, and superelevation are ignored.
(3) Many of the sediment transport modules and concepts used in GSTAR-1D are simplified approximations of real phenomena. Those approximations and their limits of validity are embedded in the model.

GSTAR-W

GSTAR-W (Generalized Sediment Transport for Alluvial Rivers and Watersheds) is a comprehensive, physically based, process oriented, and spatially distributed model. All processes are mesh cell based with arbitrarily shaped cells. Mesh cells may be small enough to ensure mesh convergent solutions or large for basin scale simulations depending on specific application needs. The hybrid zonal modeling concept makes GSTAR-W flexible, versatile, and robust. The formulation developed provides a potential to address the scale problem facing most existing models. Major application is towards event or continuous simulation of erosion and sediment yield to river systems. GSTAR-W may be used to assess the impacts of management and mitigation strategies, as well as the storm and/or flood impact to facilities, with spatial scale ranging from small to large watersheds. The model builds on years of expertise in sediment and erosion research and practice at RECLAMATION incorporating the latest technologies of other leading erosion models.

In addition to the scale issue, GSTAR-W also makes advancements in the following areas: much improved channel system modeling, new overland erosion and sediment transport modeling, and robust, efficient, and accurate numerical algorithms. These advancements enable GSTAR-W capable of simulating problems with a wider range of spatial scales.

GSTAR-W consists of two major seamlessly integrated components: 1) overland watershed model and 2) a channel/river system model. Major advantages of this model include:

Geometry Representation: GSTAR-W deals with vast arrays of spatial and time scales and heterogeneous processes. To facilitate seamless integration among different scales and processes, the hybrid zonal modeling concept is developed and used. Such a flexible representation allows the use of most existing meshing systems and unifies them under a single framework. Particularly, it allows a natural representation of channel networks, zonal modeling of different spatial scales, a tight integration among zones, and a truly mesh-convergent solution that partially addresses the scale problem.

Zonal Modeling: GSTAR-W adopts a zonal modeling approach that allows different zones to be solved with different physics and different solvers. Physical models include diffusive wave and dynamic wave equations, plus various physical sub-models with differing complexity. Solvers provide choice of explicit or implicit schemes. The conceptual zones are very flexible and may represent natural features based on topography, land use, soil types, and ground water table.

Erosion and Sediment Transport Modeling: In addition to the inclusion of several leading erosion sub-models, a new overland erosion sub-model is proposed based on the unit stream power theory. Under this general modeling approach, sheet, rill and gully erosion, as well as the sediment transport in the channel/river system, are all modeled under one unified theory.

Channel/River System Modeling: GSTAR-W incorporates the state-of-the-art channel/river system model: GSTAR-1D (Yang et al. 2005). GSTAR-1D is a recently completed product jointly funded by Reclamation and US EPA. The incorporation of GSTAR-1D makes GSTAR-W capable of simulating larger watershed scales than many existing distributed models. GSTAR-1D model allows arbitrary channel cross sections, quasi three-dimensional alluvial channel evolution with bank erosion, sediment routing by size fractions, and bed material sorting and armoring modeling. The solver is based on dynamic wave equations and offers many proven sediment transport models.

GSTAR-W is currently in a research phase.

(Source: http://www.usbr.gov/pmts/sediment/model/gstars/gstarw/index.html)

U^{2}RANS

U^{2}RANS is a three-dimensional (3D) Unsteady and Unstructured Reynolds Averaged Navier-Stokes solver. The model is highly accurate, well verified and validated, and has been successfully applied to many research and engineering projects.

Briefly, U2RANS is a comprehensive general-purpose model. Three-dimensional hydraulic flow models such as U2RANS are accurate and mature tools, which have been routinely used to address many hydraulic engineering problems such as:

- flow hydrodynamics in pools and river reaches upstream of hydropower dams;
- detailed flow characteristics around hydraulic structures;
- hydraulic impact of different project alternatives;
- fish passage facility design and evaluation;
- thermal mixing zone determination;
- design optimization, reservoir/lake stratification, selective cold water withdrawal, etc.

The main limitation is that they are usually applied to a river reach less than five miles in length due to their heavy requirement for computer power.

U^2RANS uses current state-of-the-art, unstructured CFD (computational fluid dynamics) technology, unifies multi-block structured mesh (quad or hex) and unstructured mesh (quad, triangle, tet, hex, wedge, pyramid, or hybrid) elements into a single platform, and combines 2D and 3D solvers in a common framework. A User's Manual is available, which provides a more detailed description about the general features and capabilities.

Processes modeled include:

- Accurate solution of full three-dimensional water flows with complex geometry
- 3D effects, such as secondary flows at meandering bends and point bars, and vortex/eddy generation due to hydraulic structures, are accurately captured
- Water temperature transport is simulated using the energy conservation equation

Processes Ignored

- Sediment transport is not modeled
- Fixed bed geometry is assumed

Model Input

- Detailed bathymetric data and hydraulic structure geometric data
- River discharge and water surface elevation at the downstream boundary

Model Output

- 3D spatial distribution of velocity magnitude and flow direction
- Location and strength of flow eddies and vortices
- Secondary flows due to meandering
- Bed shear stresses
- Water surface elevation distribution and backwater effect

Potential Use of Output Results

- Evaluate erosion/deposition potential at the point bar due to secondary flows
- Assess scouring potential due to hydraulic structures
- Hydraulic impact assessment of modified or new structures

(Source: http://www.usbr.gov/pmts/sediment/model/u2rans/index.html)

MEANDER

MEANDER is a numerical channel migration model developed for meandering rivers to predict the future river channel alignment. The model is based on:

- An equation to predict the rate of bank erosion and
- Use of the minimum unit stream power hypothesis (minimum VS) to determine the planform –phase-lag between the changing curvature of the river channel and the changing curvature of the flow.

The model predicts channel migration as a function of river discharge, sediment transport capacity, channel radius of curvature, channel width, hydraulic depth, and the bank material properties of the river channel including vegetation, large woody debris, cohesion, and armoring. The model can simulate the migration of tens of river miles, over a period of decades using daily or hourly variations in flow. Each model simulation can be completed in a period of minutes so that a wide range of hydrology can be individually simulated.

The model assumes that the river evolves naturally to be capable of transporting the upstream sediment load through a reach without erosion or deposition along the channel bed. The model therefore continually adjusts the channel width, depth, and slope (through the meandering alignment) so that the local sediment transport capacity matches the upstream sediment supply. The model assumes that sediment input from bank erosion is on average balanced by sediment deposition through point bar accretion. At this time, the model cannot be used to simulate channel aggradation or degradation.

The migration of river channels across their floodplains and the occasional erosion of terrace banks are natural processes. These processes become especially important to people living in or near the floodplain, or to organizations planning or maintaining infrastructure within or along the edge of the floodplain. Natural rates of channel migration can be accelerated, reduced or negated by human disturbance. For example, the clearing of native floodplain vegetation can accelerate the rate of channel migration, while the placement of riprap or other bank protection can limit or even prevent channel migration.

The channel migration model predicts the future alignment of meandering river channels. The model could be used as a planning tool to evaluate the effects of alternate patterns of water releases downstream from dams and alternative land management practices. For example, the effects of varying the annual peak river flows on the rate and extent of channel migration can be evaluated. In addition, the effects of removing bank protection along selected reaches to promote channel migration can be evaluated.

The model is currently in a research phase.

Source: http://www.usbr.gov/pmts/sediment/model/meander/index.html

The Unified Gravel-Sand (TUGS) Model: a Numerical Model to Simulate the Transport of Gravel-Sand Mixtures

Stillwater Sciences has developed The Unified Gravel-Sand (TUGS) model to simulate changes in grain size distributions of channel deposits as a function of changes in the flow regime and sediment supply (e.g., gravel augmentation, reductions in fine sediment loadings) (Cui 2006). They are currently applying the model to the Sacramento River to examine the possible geomorphic impacts from the construction and operation of Shasta Dam and their potential remediation. The model predicts grain size distributions for the surface and subsurface of a channel bed, including the percentage of fine sediment stored in the channel subsurface, and can be used to assess the effects of different restoration strategies on salmonid spawning habitat quality. The model was developed based on Wilcock and Crowe's surface-based bedload equation and hypothetical transfer functions within bedload, the surface layer and the subsurface. Examination of river management scenarios such as changes in sediment supply, water discharge, and downstream base level control all produced reasonable results. The TUGS model contributes to the CALFED ERP goal of rehabilitating ecological processes and habitats by providing a tool to assess the effects of different types of restoration actions (e.g., flow releases, gravel augmentation, levee setbacks) on sediment deposition processes and the attendant effects on salmonid spawning habitat.

Riparian Habitat Establishment Model (RHEM)

General Capability Description

The Riparian Habitat Establishment Model (RHEM) is a vadose zone model designed to simulate the growth of riparian vegetation on point bars. RHEM integrates the simultaneous effects of river stage, precipitation, evaporation, and plant transpiration on soil water content in the root zone. RHEM uses these results to determine plant survival by simulating the plant's ability to maintain sufficient transpiration to support continued root and shoot growth from germination through the initial establishment stage (typically spring through summer).

RHEM consists of a modified version of the HYDRUS-2D variably saturated water flow code. HYDRUS-2D was developed by J. Simunek, M. Sejena, and M. Th. Van Genuchten at U.S.D.A. Salinity Laboratory in Riverside, California. Detailed documentation (Simunek et al, 1999) for Version 2.0 of the software package is available from the International Groundwater Modeling Center (IGWMC).

HYDRUS has been modified to include plant growth algorithm to simulate the effects of soil water content on riparian vegetation growth. This modification considers the combined effects of river stage, groundwater, and meteorological conditions on the ability of seedlings to maintain sufficient plant transpiration for growth and survival during their initial growth period. This integrated, dynamic approach to modeling plant growth is an improvement over the current version of HYDRUS, which has only a static representation of root water uptake.

Processes Modeled

The RHEM model will be employed to simulate the integrated effects of the dynamically changing hydrologic conditions affecting the establishment phase of the riparian vegetation. This phase commences with the germination of cottonwood seeds in spring and continues through summer. The hydrologic conditions that will be simulated by HYDRUS include:

- Temporal changes in the river stage as flow varies during the snowmelt runoff and irrigation season
- Atmospheric conditions affecting soil moisture content in the vadose zone including precipitation, soil evaporation, and transpiration
- Groundwater recharge and discharge associated with regional aquifers as well as localized conditions associated with evapotranspiration from adjacent riparian forest and agricultural land, deep percolation from irrigated areas, and groundwater pumping

The RHEM model can simulate one or more 2-dimensional cross-sections in the horizontal and vertical directions that extend laterally across the stream channel and point bar into a portion of the floodplain. The upper surface of the cross-section represents the point bar surface and the channel bottom. The base of the cross-section can be placed at depth sufficient to represent the influence of regional and local hydrologic conditions controlling the elevation of water table and soil moisture in the point bar sediments.

The RHEM model can be employed to simulate the details of the growth of seedlings occurring on the point bar. In RHEM, the dynamic relationship between soil water content and root growth can be simulated directly by specifying plant growth characteristics along with potential transpiration demands imposed by atmospheric conditions. This plant growth algorithm determines the survival of the plant by simulating its ability to extract sufficient soil water to meet its transpiration demands.

The modeling approach involves running the RHEM model to determine the temporal changes in soil water content due to the integrated effects of evapotranspiration demands, river stage, and groundwater recharge/discharge. These boundary conditions can be obtained by temporally downscaling the CALSIM model operational flows and using the hydrodynamic models described in the preceding sections to simulate the river flow and stage conditions existing in the channel adjacent to a particular point bar cross-section. Potential evapotranspiration demands can be obtained by analysis of the data from the California Irrigation Management Information System (CIMIS) and the use of appropriate riparian vegetation coefficients. The effects of regional and localized groundwater recharge/discharge conditions can be obtained from existing groundwater models such as the California Central Valley Simulation Model (C2VSIM) and analysis of nearby agricultural uses of surface and groundwater. RHEM also requires information related to the growth characteristics of cottonwood seedlings. Observations of soil moisture near growing cottonwood seedlings in the field have been collected to calibrate the model. These data were collected at RM 192.5 using soil moisture sensors and observation wells that provided depth distributions of soil moisture in relation to water table depth and nearby cottonwood seedling growth. Soil physical properties have been obtained from data collected in the field at RM 192.5. Laboratory analysis of the soil samples has been carried out at a laboratory affiliated with UC Davis. The plant growth algorithm embedded in RHEM simulates the growth response of the seedlings to changes in soil water content in the root zone resulting from these combined factors and ultimately determines their survival during the initial growth period.

- The processes simulated by the modified RHEM model include:
- Changes in soil water content due river stage, regional and local groundwater conditions and evapotranspiration demands on seedlings
- Partitioning of growth between roots and shoots
- Evolution of the root distribution in response to soil moisture conditions

RHEM uses the outputs from GSTAR-1D, GSTAR-M and U^2RANS. These inputs include:

- River stage elevations during the riparian vegetation establishment period
- Cross section elevations for the river channel and point bars
- River bed, point bar and floodplain material properties

Recruitment Box Model

The fundamental hydro-geomorphic processes that facilitate cottonwood seedling recruitment in wide alluvial systems are typically characterized by correlating the flow regime and time of seedling establishment (Roberts et al. 2002). Many of the evaluations are based on work conducted by Mahoney and Rood (1998) in which they provided an ecological model to describe the relationship between seedling recruitment and alluvial characteristics. The Mahoney-Rood model (Recruitment Box Model) suggests the timing and ranges of elevation above mean low water in which the surface water recession rate of approximately one inch per day facilitates recruitment cottonwood seedlings. However, recent researchers have recommended that additional investigations are needed to further corroborate box model variables for the Sacramento River (Roberts et al. 2002).

Ecosystem Function Model

The following description is from Jones & Stokes Associates (2000).

The Ecosystem Functions Model is intended to predict aquatic and terrestrial ecosystems response to the implementation of floodway management interventions or modification of flow regime. The EFM can evaluate and compare existing conditions, with-project, and without-project conditions. The model evaluates how changes in flow regime and riverine morphology would affect key attributes of the river-floodplain ecosystem.

The model uses functional relationships between river flow, floodway morphology, and the biological communities that inhabit the channels and floodplain lowlands of the Sacramento and San Joaquin River basins. The EFM can anticipate biological consequences that may not be fully realized for many decades.

The model can simulate flood damage reduction and environmental restoration measures that modify the flow regime or physical characteristics of the floodway. Changes to the flow regime could result from reservoir reoperation, new flood storage, modifications to weirs, or other activities that affect the timing or magnitude of flood peaks. Changes to the characteristics of the floodway could include the construction or modification of levees, new bypass channels, reconnection of oxbows, or other hydrographic features, or channel modifications. The EFM predicts how these changes to the flood management system could maintain, degrade, or enhance terrestrial and aquatic biological activities. For example, the outputs of the EFM could indicate changes in the extent of suitable riparian seedling establishment areas, the extent of seasonally inundated aquatic habitats, or key environmental flow conditions that would result from a proposed measure.

The EFM is not a single model or program; rather it is a process for evaluating biologic, hydrologic, and hydraulic variables that can be applied to multiple study areas and alternative conditions.

EFM PROCESS

Step 1. Ecological Analysis - The ecological analysis identifies functional relationships between river hydrologic and hydraulic conditions and the riverine ecosystem/geomorphic system. These relationships reflect requirements of different habitat types in terms of streamflow durations, return periods, and stage recession rates. The biological effects of overbank flow are a major focus of the ecological relationships. The ecological analysis consists of two major elements: the terrestrial ecosystem and the aquatic ecosystem:

- Terrestrial ecosystem - The terrestrial element focuses on the establishment and initial survival of riparian and wetland vegetation. It evaluates criteria for suitable flows and topography to promote seedling establishment and avoid post-establishment losses due to insufficient soil moisture and/or flood scouring.

- Aquatic ecosystem - The aquatic element focuses its analysis on the seasonal inundation of floodplains and flood bypasses to evaluate potential impacts and benefits to two representative native fishes, Sacramento splittail, and Chinook salmon smolts. This element incorporates criteria for suitable overbank flows to benefit floodplain spawning, rearing, foraging/migration, and avoidance of stranding, and predicts spatial changes in the extent of suitable floodplain habitat.

Step 2 - Statistical Hydrology Analysis – This analysis translates the ecosystem relationships developed in Step 1 into discharges with specified durations, return periods, seasonal periods, and stage recession rates. The statistical analysis uses historical, existing, and/or post-project conditions from modification of reservoir operations, river levee setback, and additional transitory storages, etc. The analysis is conducted in MS Excel. The ecosystem requirements and statistical analysis developed in MS Excel are coded into a generalized FORTRAN computer software package. This step is described in greater detail later in this document.

Step 3 - Hydraulic Analysis – This analysis determines the hydraulic responses of discharges estimated in step 2. The statistically determined discharges form the input to a hydraulic model for the calculation of corresponding stages and flood inundation areas. HEC-RAS, a hydraulic model developed by the Corps of Engineers is used in conjunction with ArcView and the HEC-GeoRAS and 3D Analyst extensions. These programs were used because geometric data and hydraulic results can be iteratively exported from Arc View into HEC-RAS and back into Arc View for processing and spatial analysis.

Step 4 - Graphical Presentation – The geographic analysis step involves the use of a geographic information system (GIS), such as ArcView, to geographically overlay hydraulic results with other ecological and environmental information. Data used in the geographic analysis includes vegetative cover, soil types, land use, historic topography, ground water elevations, and the digital terrain maps. GIS provides a platform to display and compare results, allowing ecologists to evaluate how proposed flood management measures and ecosystem restoration measures will affect existing terrestrial and aquatic habitat.

Step 5 - Ecological Interpretation – The final step in the EFM is the interpretation of results presented in the graphic analysis step. Because ecological systems can be incredibly complex, it is important that EFM results are reviewed and interpreted by experts who are familiar with the ecology of the study area. Ecologists review the spatial and tabular output, along with other relevant data, and make comments and/or recommendations on the proposed flood management and ecosystem restoration measures.

SALMOD (Salmonid Population Model)

The following is a summary of the SALMOD model provided in the SALMOD Users' Manual (Bartholow et al. 2001).

SALMOD is a computer model that emulates the dynamics of freshwater life history of anadromous and resident salmonid populations. The underlying conceptual model was developed in a workshop attended by fishery experts concerned with Trinity River Chinook restoration (Williamson et al. 1993). The basic assumptions for the model are that egg and fish mortality are directly related to micro- and macrohabitat limitations and the timing and amount of streamflow. Habitat quality and capacity are characterized by the hydraulic and thermal properties of individual mesohabitats, which are described as "computation units" in the model. The model tracks a single cohort that begins as eggs and grows from one life stage to another as a function of ambient water temperature. Model processes include spawning (with redd superimposition and incubation losses), growth (including egg maturation), mortality, and movement (freshet-induced, habitat-induced, and seasonal). Model processes are implemented such that the user can modify the model to create the habitat and flow conditions thought to influence the population dynamics of the cohort. SALMOD then tabulates the various causes of mortality.

SALMOD is based on the premise that physical habitat elements such as flow dependent micro-habitat and water temperature are the primary factors controlling freshwater survival. SALMOD is best described by its structure in terms of temporal, spatial, and biological resolution. Those three components are not independent; the size of any computational unit (spatial resolution) has a direct bearing on the distance a fish of a given size (biological resolution) needs to move within one time step (temporal resolution) to encounter alternate habitat conditions.

Temporal Resolution. The model uses a weekly time step for one or more biological years. Biological years typically start with the first week of spawning. All rate parameters (e.g., growth and mortality) are weekly values unless otherwise stated. Physical state variables (e.g., streamflow and water temperature) are represented by weekly averages.

Spatial Resolution. Spatial resolution is consistent with the mesohabitat inventory approach. Classification is based primarily on channel structure and slope, modified by the general distribution of microhabitat, including cover. These mesohabitat units become the model's computational units.

Streamflow, water temperature, and mesohabitat type are the physical state variables included in this model. The stream can be divided into flow and temperature segments by distance or by computational unit. Flow and temperature data are organized by river segments and by time step for each segment. Habitat quality is defined by a flow-habitat relationship for each mesohabitat.

Biological Resolution. The biological resolution uses a typical categorization of fish life history related to physical morphology, behavior, and reproductive potential. Fish in the simulated population are tracked by cohorts within computational units. Each cohort is classified by life stage and class within life stage. Adult life stages are defined as male adult, male spawner, female adult, and female spawner. Adult life stages cannot be further divided. Juvenile life stages can be divided into eight classes ranging from egg life stages (further classified by percent development) and non-adult life stages classified by size. As a cohort ages, its life stage and size class attributes are modified to the next size class or life stage.

Model Processes. SALMOD represents the freshwater population dynamics: (1) an anadromous fish species that returns to the stream as an adult to spawn, (2) a resident population of salmonids that complete their entire life cycle in freshwater, or (3) a multiyear variant where juvenile fish remain in the stream for more than one year. The model simulates (1) spawning, (2) egg development and growth, (3) movement, induced by freshets, time of year, or living space constraints, and (4) various types of mortality. In the anadromous variant, adults die after spawning and smolts do not graduate to the adult stage; instead, they exit the study area. Thus, the population is re-initialized for each biological year. Life history patterns where the juveniles spend more than one year in freshwater are simulated with the multiyear variant; this option is much like the anadromous variant except that juvenile fish remain in the stream beyond a single biological year. In the resident variant, adults do not die after spawning and a juvenile lifestage (e.g., yearlings) may mature to adults capable of spawning.

Applications SALMOD has, to date, been applied in four study areas: (1) a fall Chinook population in a portion of the Trinity River, California, (2) rainbow and brown trout in the Poudre River, Colorado, (3) Atlantic salmon in the Narraguagus River, Maine, and (4) with four races of Chinook on the Sacramento River, California (Bartholow 2003). Potential uses of SALMOD are determination of: (1) population consequences of alternative flow and temperature regimes, (2) the relative magnitude of mortality in determining the timing and degree of habitat "bottlenecks", and (3) flow regimes that mitigate those bottlenecks.

Winter-run Integrated Modeling Framework

The IMF can be used to predict fish benefits achieved by changes to water management, harvest regulation, hatchery augmentation, and stream habitat alteration. The model user can supply economic information, and explore which suite of restoration actions, for a given level of investment, is likely to achieve the greatest increase in fish populations.

The model in its present form represents a collection of working hypotheses that need to be tested against additional data. The modeling process revealed what can be determine with the most confidence and what remains most uncertain in our understanding of winter-run Chinook population biology in the Sacramento River. Subsequently, the need for action or for more study was determined by scoring functions and parameter values in the model by three criteria: (1) quality of substantiating evidence, (2) impact on simulation outcomes, and (3) ability of managers to influence the parameter.

The winter-run Chinook IMF is based on functions and rates that are substantiated by field sampling to the full extent possible. Simulation of each brood year proceeds as follows: • Spawners produce fry based on the number of females in the spawning population, average fecundity, pre-spawning mortality, and 25% egg-to-fry survival.

- The survival of fry in the upper river to smolts arriving at the Delta is a function of fish density. This survival is calculated from a Beverton-Holt function that was derived from the historical data set of winter-run Chinook spawner abundance. Hatchery fish are released as smolts at Caldwell Park in the upper river, experience post-release mortality as a consequence of naïve behavior, and then are assigned 52% survival to the Delta.

- Survival of natural and hatchery smolts through the Delta is predicted as a function of river flow (cfs at Freeport), river temperature (°F) near Ryde, water export volume (combined Federal and State export facilities), turbidity, salinity (a function of river flow), and DCC gate position (open or closed). Parameters for this function were those estimated by Newman (2003) from an analysis of paired CWT releases of fall Chinook in the lower Sacramento River.

- Adults return to spawn at three age classes – age 2 through 4, based on differential ocean harvest and maturity rates of natural and hatchery fish from each age class according to the cohort analysis of CWT recoveries from winter-run Chinook

Oak Ridge Chinook Salmon Model

The following information is from Jager and Rose (2003).

The Oak Ridge Chinook Salmon Model (ORCM) is a spatially explicit and individual based fall Chinook salmon recruitment model. The model links a spatial representation of riverine habitat with a biotic model of Chinook salmon reproduction, development, growth, and mortality. The ORCM simulates the riverine phase of Chinook salmon ecology beginning with river entry by pre-spawning adults. The river is divided into 1.6 km segments. Simulated average daily water temperature in each segment depends on daily air temperature, dam release temperature, and flow rate. The model has numerous sub components including a habitat, an upriver migration and spawning, egg and alevin survival and development, a fry and smolt growth and development, a juvenile movement, and juvenile mortality.

Box-Jenkins Transfer Function Model

The Box-Jenkins transfer function model (BJ model) relates streamflow to outputs of sediment concentration. The relationship between discharge and sediment concentration is unidirectional and can be modeled by a combination of moving average and autoregressive function processes. Sediment concentrations are a function of discharge on any specific day and previous day (moving average) as well as a function of sediment concentrations on earlier days (autoregressive function) (Singer and Dunne 2001).

Estimation of BJ model parameters requires that sediment concentration-discharge data are collected with a frequency that captures the rising and falling patterns of stream flow and sediment discharge (Singer and Dunne 2001).

U. C. Davis River Migration Model/Habitat-Species Models

(The following descriptions were provided by Stacy Cepello, Environmental Services Section, Northern District, California Department of Water Resources, Red Bluff, California.)

Eric W. Larsen, Ph.D., Geology Department, and Steven E. Greco, Ph.D., Department of Environmental Design, University of California, Davis are developing modeling tools to predict the effects of changes in regulated flows and flood regimes on the riparian ecosystem. Because meander migration patterns determine a large part of the riverine-riparian ecosystem structure and development, Eric Larsen is adapting a numerical model for meander migration and coupling that model with a habitat evolution model that is being developed by Steve Greco.

A variety of environmental modeling tools are needed to assess the potential impacts of flow diversions from various points on the Sacramento River for the OSI Program. The modeling tools that are currently being developed will work in an integrated fashion to predict the effects of changes in regulated flows and flood regimes on the riparian ecosystem and habitats of several indicator species. Development and use of the meander migration and ecosystem dynamics models will proceed through nine stages for the Offstream Storage Investigation:

- Further development and calibration of an existing meander migration model.
- Quantification of the effect of flow changes on bank erosion within two study reaches along the Sacramento River using the mathematical meander migration model.
- Development of an interactive computer model for visualization of the meander model output.
- Development of a land cover classification model.
- Development of landscape and hydrodynamic models.
- Development of a riparian succession model.
- Coupling the meander model with the habitat evolution model.
- Development of specific habitat models.
- Extending the models to other areas of the river.

In addition to the work of these principle investigators, DWR is providing support for this effort through analysis of hydrologic data, development of detailed topography and bathymetry, providing GIS base mapping and thematic coverages, and measuring erosion rates and sediment transport.

Further Development and Calibration of the Existing Meander Migration Model.

The existing meander migration model, which combines models for the velocity flow field and bank erosion, has been successful in predicting hypothetical channel migration over an idealized reach. The model requires input values for the channel planform and five variables that represent the hydrology and hydraulic characteristics of the channel: characteristic discharge, width, depth, slope, and median particle size. The model currently uses optimization methods to calibrate the hydraulic roughness and the bank erosion rates, although these parameters can be estimated. To effectively use this meander migration model for the North-of–the-Delta Offstream Storage Investigation, software will be enhanced to allow the incorporation of riprap, levees and other hard points (such as irrigation diversions and bridges) within the model runs. In addition, further testing of the model on the Sacramento River in the proposed study areas will be done to enhance our ability to predict the roles of geologic and land use controls on bank erosion coefficients in the absence of the data necessary for optimization analysis.

Quantification of the Effect of Flow Changes on Bank Erosion within Two Study Reaches along the Sacramento River Using the Mathematical Meander Migration Model. The model, based on mechanics of flow and sediment transport in curved channels, will be used to simulate how migration rates would change for decreases in flows of 2,500, 5,000, and 10,000 cubic feet per second for two study reaches of the river. The first reach is located 10 kilometers upstream and 3 kilometers downstream of Woodson Bridge, while the second extends from River Mile 189 to River Mile 199. The output will provide graphic predictions of channel planform locations 25, 50, and 100 years from the present. Calibration of site-specific bank erosion characteristics will be done through the use of historical planform locations and direct bank erosion studies. Erosion coefficients calculated by optimization of calibration will correspond with land-use/geology types. All non-geologic channel constraints will be modeled interactively. The difference in migration between the reference migration and model runs with altered flows will be tabulated and expressed as both percentages and actual site-specific erosion rates.

Development of an Interactive Computer Model for Visualization of the Meander Model Output. Currently under development is an interactive visualization tool that models and demonstrates the response of the river to various flow scenarios projected on top of ortho-photo overlays using MATLAB. This will demonstrate model runs for users as well as for public and agency demonstrations.

Land Cover Classification Model. A fundamental concept to mapping states of landscape composition is establishing a land cover classification model. A modified version of the California Wildlife Habitat Relationship System (CWHR) will provide the land cover classification system needed to describe the initial, historical, and future states of the riparian landscape on the Sacramento River. The CWHR land cover classification system uses four primary variables as input to the functional habitat models of wildlife species within the system's database. The four primary variables of land classification for the purposes of habitat assessment are (1) land cover type, (2) woody vegetation size, (3) woody vegetation density (canopy cover), and (4) habitat elements. The class variable 'land cover type' is a description of either the dominant human land use or natural vegetation community within a delineated (mapped) polygon. If the polygon is woody natural vegetation or an agricultural orchard then the remaining three variables can be applied to describe that polygon in greater detail. Woody vegetation can be classified for size (height) and canopy cover (density). Since the vegetation community 'types' (i.e., the first variable) are rather broad categories, the dominant species, or associations of vegetation can be described using the 'habitat elements' variable. Other physical features can also be described with the 'habitat elements' variable, such as rocks, snags, etc. that are important to habitat modeling.

Landscape Evolution and Hydrodynamic Models. To adequately predict future states of a highly dynamic landscape system, several physical-modeling tools are essential in addition to the numerical meander migration model. Specifically, models of the physical base state of the landscape and aquatic surfaces are needed, i.e., topography of land and bathymetry of the channels. The US Army Corps of Engineers has recently completed a topographic map and bathymetry of the Sacramento River. These data sets are primary input for a landscape evolution model, which will couple the meander migration model with the topographic map to be used for flood inundation modeling. The use of hydrodynamic software to predict river stage and water velocity information is very important to modeling the potential biological responses to those physical variables.

Riparian Vegetation Growth Model. Once geomorphic and hydrodynamic processes are spatially quantified then a model of succession of riparian vegetation communities can be implemented. An empirically based state-and-transition modeling approach will be used to predict the future states of vegetation community types with rules derived from literature and field studies. The model will be calibrated and validated using historical spatial data.

Coupling the Meander Model with the Habitat Evolution Model. To show ecological consequences of changes in channel migration rates, the meander model output will be rendered compatible with a prototype ArcView based riparian landscape geographic model currently under development.

Habitat Models. Models of several indicator species will be chosen to quantify habitat changes through time given various river management scenarios. An example of a keystone indicator plant species is cottonwood (*Populus fremontii*) and an example of a vertebrate endangered species is the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). The habitat models will be derived from existing literature as well as from the CWHR System.

Extending the Model to Other Areas of the River. DWR will work with the principle investigators/developers to extend the integrated modeling process to the entire area of potential impact arising from altered flows. Model output for a decrease in flows of 2,500, 5,000, and 10,000 cubic feet per second will be summarized by subreach both graphically and in tabular form for changes that would occur in 25, 50, and 100 years.

Sacramento River Ecological Flows Tool (SacEFT)

Many current water planning efforts to balance demands on the mainstem Sacramento River do not explicitly account for some critical ecosystem components. Current attention focuses primarily on maintaining minimum in-stream flow and temperature requirements for the upper reaches to support listed fish species, or treating the Sacramento River as a conduit to control relationships between flow and salinity in the Delta. Incorporating additional attributes of the flow regime, and the manner in which they maintain the ecological function of the Sacramento River, should result in more effective water management and ecosystem restoration strategies.

In response to this need, The Nature Conservancy (TNC) and its partners (ESSA Technologies Ltd. and Stillwater Sciences) are investigating linkages between river flow on the Sacramento River and various ecological targets in an attempt to improve conditions for those targets. A major component of the project is the creation of a decision analysis tool for linking physical models and datasets with 6 focal species and a suite of performance measures. Specifically, the Sacramento River Ecological Flows Tool (SacEFT) is a database centered software system for linking flow management actions to changes in the physical habitats for several focal species of concern.

The vision for SacEFT is to create software that makes it easy for specialists and non-specialists to expand the ecological considerations and science foundation used to evaluate water management alternatives on the Sacramento River. To meet this vision, the system must leverage existing physical datasets and models rather than reinventing wheels, and selectively fill in ecological gaps. Use of existing models is a key aspect of the system; this includes both common water planning tools like CalSim II as well as various ecologically oriented models such as the meander migration model developed by researchers at UC Davis. In the case of focal species, SacEFT will typically "build-in" select functional relationships from external models or studies when generating habitat/biological performance measures.

The key goals for the SacEFT system are to:

- Link flow management actions to focal species outcomes on the mainstem Sacramento River.
- Improve our understanding of priority physical-biological linkages, while better clarifying critical uncertainties.
- Expand our ability to characterize ecosystem response by including a variety of species, using both quantitative and qualitative relationships.
- Capitalize on existing models and integrate many disparate information sources, using data standards and some automated import utilities to manipulate these raw input and output datasets.
- Enable exploration of ecological trade-offs in a manner that can rapidly "plug-in" to information sources used in a wide variety of Northern California water planning forums.
- Use SacEFT as an education and communications tool to guide the thinking of managers and decision makers in weighing the relative ecological merits of alternative flow actions.

Upper Sacramento River Temperature/Water Quality Model

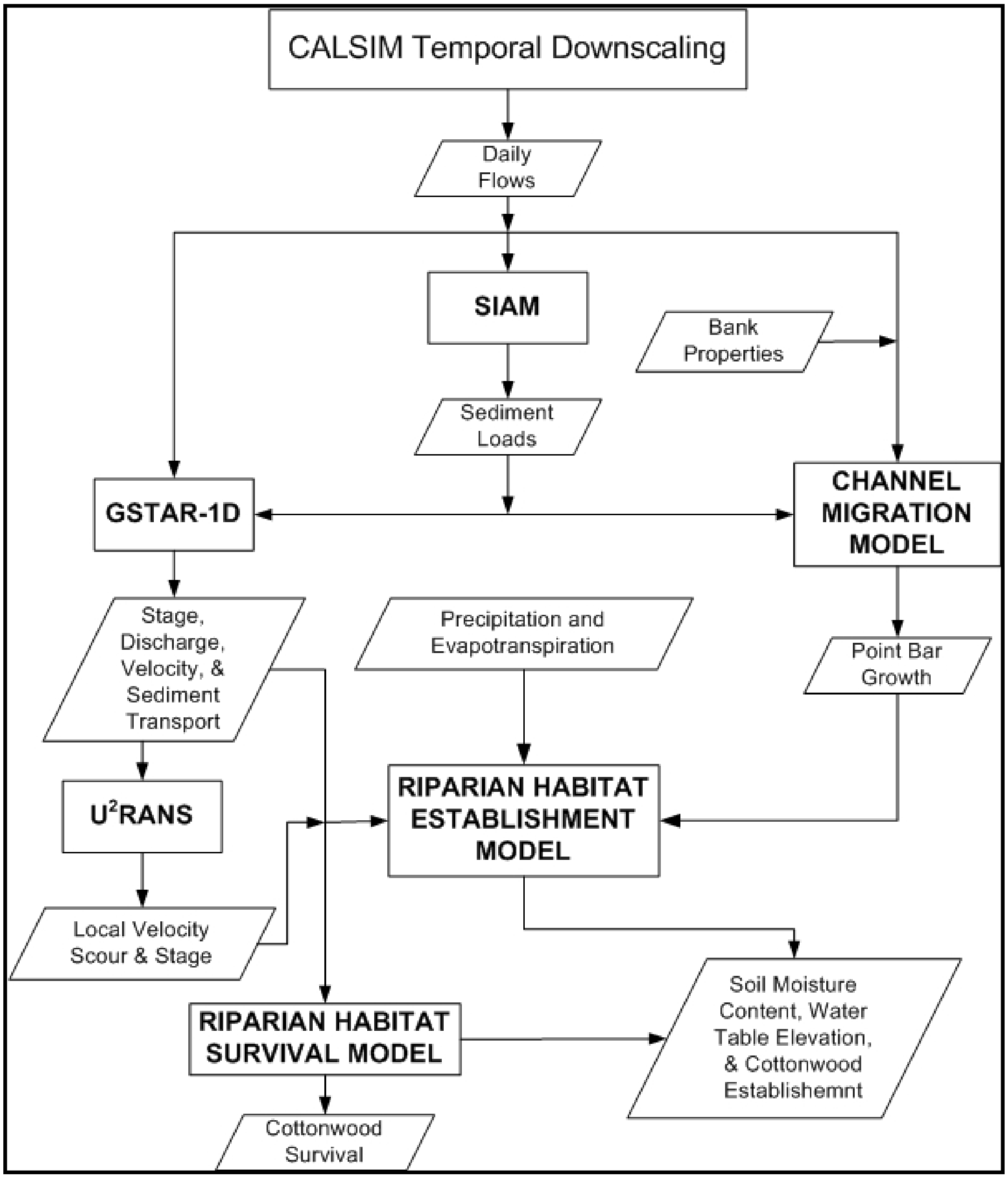
An Upper Sacramento River model was developed and calibrated by the Reclamation to simulate the temperature regime of Upper Sacramento River as affected by operations at Trinity Dam, Trinity River to Lewiston, Lewiston Dam, Clear Creek Tunnel, Whiskeytown Dam, Spring Creek Tunnel, Shasta Dam, Keswick Dam, Sacramento River from Shasta to Knights Landing, Clear Creek below Whiskeytown Dam, Red Bluff Diversion Dam, Black Butte Dam, and Stony Creek. The model was expanded to accommodate and provide evaluations of North of the Delta Offstream Storage program options including Sites Reservoir and accompanying diversions on temperature and water quality.

The NODOS model extends from Keswick Dam to Knights Landing and included the Sacramento River, Red Bluff Diversion Dam, Black Butte Dam, Stony Creek, Tehama Colusa Canal, Glenn-Colusa Irrigation District, Glenn-Colusa Canal, Colusa Basin Drain, a proposed Maxwell pipeline, enlarged Funks Reservoir, and the proposed Sites Reservoir.

Analytical Tool Integration

Reclamation has developed a conceptual model for development of analytical tools of physical river processes and riparian habitat on the Sacramento River. This framework is depicted in Figure 5-1, a diagram of an integrated set of six analytical tools and the input and output parameters that connect the tools. The model illustrates both the connectivity and interdependence of the tools as well as the physical and biological parameters necessary to evaluate the effect of management decisions on physical and biotic processes. More specifically, these tools are being developed to provide baseline information and alternative assessments to facilitate evaluation of benefits and impacts of proposed project alternatives on the ecosystem and fluvial river processes.

FIGURE 5-1. Analytical Tool Framework to Model Sacramento River Fluvial Processes.



CHAPTER 6. SUMMARIES OF RECENT INVESTIGATIONS

The Flow Regime TAG dedicated most of its meeting time to the presentation and discussion of completed and on-going studies related to the Sacramento River flow regime. The recent improvements in understanding of the relationships between flow regime and ecosystem processes were apparent in these presentations and discussions. However, as these studies were presented and discussed, TAG members frequently acknowledged that the state of the science, while improving, still needs to be significantly advanced.

The studies and reports presented at TAG meetings and summarized in this chapter have received varying degrees of technical input and peer review. However, because the scientific understanding of flow regime-related processes is still incomplete, all of these hypotheses continue to be refined as information and data become available from various studies. The TAG did not seek to provide validation or review of the science presented in each study. In addition, the information and conclusions of the studies and reports may or may not have application to the NODOS investigation.

This chapter summarizes a variety of studies that focus on the history of recent channel formation on the Sacramento River, needs for additional information related to flow and channel formation, and concepts that could potentially be used to achieve restoration goals for the Sacramento River. Most of these studies have been limited in scope due to limited availability of long-term data and observations, and nearly all of them identified the need for additional studies. The following study summaries are grouped into five categories, 1) Comprehensive Studies; 2) Flow, Sediment, and Channel Form Studies; 3) Riparian Vegetation Studies; 4) Recreation and Socioeconomic Studies; and 5) Land Management Program-related Studies. Studies that included elements from more than one of these categories are presented in the category that is most representative of the overall study.

Comprehensive Studies

Numerous investigative and modeling studies of flow regime and channel formation in the upper reaches of the Sacramento River have been conducted over the past twenty years. The issues considered in and the findings of these studies are summarized in the following sections. The studies summarized below were not collected or available during the Flow Regime TAG process prior to their inclusion in this report. Additional studies will be added to the NODOS planning process as they are identified. For example, the U.S. Bureau of Reclamation (“Reclamation”) recently initiated an evaluation of portions of the Sacramento River using a geomorphic model. Findings from this study will be incorporated in this document as soon as they are made available.

CALFED Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red Bluff

During preparation of the CALFED Programmatic EIS/EIR in 2000, the "Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red

Bluff" study (CALFED Flow Regime Study [CALFED 2000b]) was completed to consider two related questions. The initial question was "What flow regime characteristics are necessary in the reach to maintain or rehabilitate riparian and riverine habitat?" The study considered changes in the flow regime that occurred in the past 100 years, riverine conditions under the current flow regime, and constraints related to existing structures and water rights. The second question was "What are the potential effects of diverting 5,000-10,000 cfs during high flows," or, for an alternative similar to the NODOS concept, "Under what conditions - what season, what frequency, what duration, and under what flows - could we divert 5,000-10,000 cfs without adverse impacts to environmental values?." This study considered the following overall physical and ecological objectives for the Sacramento River.

- Periodic mobilization of channel bed
- Maintenance and enhancement of channel migration processes (such as bank erosion, sediment mobilization, and overbank flows) to form meanders and cutoffs and create new surfaces for establishment of vegetation
- Establishment of diverse riparian vegetation and habitat
- Facilitation of successful seed establishment by providing adequate soil moisture as the groundwater elevation declines and in areas that are not subject to excessive scour velocities every year
- Production of overbank flooding to deposit fine sediment to increase succession of willow/cottonwood vegetation into mixed forests along the banks and within the meander channel

Summary of Channel Conditions. The CALFED Flow Regime Study summarized other investigations that evaluated channel formation conditions under unimpaired flow and post-water management activities flow. The results of other investigations are summarized elsewhere in this chapter. The CALFED study also evaluated mechanisms related to riparian vegetation establishment, and reported that riparian vegetation seed release occurs at different times of year, as summarized below. Therefore, flows to support successful establishment of different species will vary each month throughout the year.

- Alder, Oregon ash, and buttonbush: late-October through November
- Box-elder: late-October through mid-January
- Sycamore: January
- *Arundo* (non-native): December through May[5]
- Arroyo Willow: mid-March through late-April
- Cottonwood: mid-April through mid-May
- Valley Willow: mid-May through mid-June
- Sandbar Willow and Baccharis: late-May through June
- Salt cedar (non-native): early-April through June

The CALFED study indicated that successful cottonwood cohorts are not established each year, and that soils must be relatively barren to support cottonwood seedlings. The new surface can be developed by scouring or deposition on point-bars. The barren surfaces minimize competition for sunlight according to the Flow Regime Requirements study that referred to studies completed

[5] *Arundo donax* does not produce viable seed in North America and reproduces by vegetative fragments transported by flood flows.

by Rood et al. (1998) and Braatne et al. (1996). The CALFED Flow Regime Study also indicated that successful cottonwood seedlings establish on silts deposited upgradient from the sands and gravels in the channel. The silt retains moisture as the water recedes and the higher elevations protect the seedlings from subsequent scouring flows. Many of the most successful cottonwood recruitment sites were reported to be in meander cutoff channels (in sloughs and oxbow lakes) along the overbanks.

The CALFED study described that under unimpaired flow conditions, cottonwood and willow seeds were released during the late-April through June snowmelt period, and late April storms also frequently contributed to soil moisture. The CALFED study also described a 1998 study (Mahoney and Rood 1998) that presented the concept of a "recruitment box model" to simulate the relationship between flow events and cottonwood establishment. The Recruitment Box Model is based on the assumption that seedlings become desiccated at higher elevations and are removed by bed and bank scour that occurs at lower elevations. The model describes the successful elevations at 2 to 7 feet above the late summer water elevation. The model also is based upon observations that the river flows declined from spring to summer elevations at a rate of about 1 inch/day, which is consistent with the root growth of willows and cottonwoods, as described above[6]. This analysis assumes that the water table associated with the recruitment box recedes at the same rate as the river. The functional relationship study also described that studies by The Nature Conservancy, as summarized below, indicated that growth rates of 1.5 inches/day [1.5 inches/day (exceeds TNC’s maximum measured growth rate of 1.3 inches/day (3.2 cm), average measured growth was 0.82 inches/day (2.2 cm)] may have occurred with Fremont cottonwoods on the Upper Sacramento River.

The CALFED Flow Regime Study indicated that successful cottonwood seedlings appear to occur at elevations not inundated by summer flows of about 14,000 cfs or removed by scouring flows in the subsequent winter. Flood management criteria that increase non-storm flows in the Upper Sacramento River could also increase the elevation at which seedlings will survive the winter. The CALFED study stated that box-elder, Oregon ash, buttonbush, white alder, and sycamore are successful at higher elevations and among riprap cobbles. These species are more successful on finer silts than willow and cottonwood, and appear to be shade-tolerant. The CALFED study indicated that the shade allows the plants to be moderately drought tolerant. Successful cohorts appear to occur on land flooded no more frequently than once every four years. The CALFED study described that Valley oak, elderberry, grape, rose, and poison oak seeds are dispersed by animals and generally are established at the highest elevations in the floodplain where scour actions are infrequent. However, establishment usually only occurs following a flood event that scours existing vegetation from the site. The CALFED study indicated that these species are shade-tolerant initially and drought tolerant when mature. In addition, the study noted that elderberry bushes can be killed by prolonged inundation.

Consideration of Channel Migration Issues. The analysis included in the CALFED study included a meander migration model based on the “JP Model” developed and described by J. Johannesson and G. Parker (Johannessen and Parker 1989). The model is described as using an approach based upon an assumption that the rate of bank erosion at a specific channel location is

[6] 1 inch/day (2.54 cm) is only consistent with TNC studies. Other documentation is pretty consistent at about 0.5 inch/day (1.3 cm). Stacy Cepello, DWR.

proportional to the difference between shear stress near the bank and average shear stress in the channel. Therefore, the bank erosion rate becomes a linear function of velocity perturbations near the bank that can change with meander bend axis.

The JP model was used to evaluate long-term erosion rates or channel migration, not changes attributable to a specific storm event. The model was used to evaluate three questions: 1) "What would be the effect on long-term rates of channel migration of diversions of 5,000 to 10,000 cfs between Butte City and Colusa during periods of high flow?" 2) "What is the effect of Shasta Dam on long-term rates of channel migration?" and 3) "What is the effect of bank stabilization measures on long-term rates of channel migration?"

A model developed by E.W. Larsen and S.E. Greco (Larsen and Greco 2002) as part of a study for DWR to evaluate channel migration near Woodson Bridge State Recreation Area (described in more detail below) was used in the evaluation. The baseline condition was simulated using flow data from the two-year flow of 88,000 cfs associated with a Woodson Bridge location and a flow of 96,000 cfs assuming a simulated channel condition that would be wider, shallower, and steeper slope than the channel at Woodson Bridge.

The analysis also considered results of other studies, including bank erosion data collected by DWR between 1986 and 1992. This information was used to relate erosion at each monitoring location to flow using a calculated value referred to as "cumulative effective stream power" that is a product of flow rate, slope, and specific weight of water. The value of the cumulative effective stream power that initiates erosion was calculated based upon a "best fit" method using observed data.

This study also described that it is difficult to define how sediment will mobilize, travel, and deposit in a complex channel system with a wide range of particle sizes and densities. While it is known that finer materials have a lower threshold flow to initiate movement than coarser particles, the study indicates that coarser particles in riffles located along bars that extend across the river channel may not mobilize until flows are almost at bankfull.

The model was used to evaluate a 5,000 to 10,000 cfs diversion from the Sacramento River between Butte City and Colusa on long-term channel migration rates. The preliminary results indicated that a 1 percent reduction in flow could reduce long-term channel migration rates by 1.25 percent. Therefore, a diversion of 5,000 cfs during high flow periods could reduce channel migration rates by 6 to 7 percent. This finding was consistent with observations and analytical results of the analysis of changes in channel migration rates following construction of Shasta Dam. The model results also indicated that with bank stabilization over a 100-year simulation period, the effects of the stabilization at a specific location generally is nullified within "one channel wavelength", or approximately two river bends.

Threshold values were difficult to calculate due to a limited data set representative of high flow conditions. The initial analysis indicated that channel migration occurs at relatively low-flows. However, the reach considered in this study (river mile 169 to 187) is located in an area where the bed load transitions between gravel and sand. The more frequent bed mobilization events may occur due to the availability of sand at this location. While the study suggested that diversion to offstream storage could have some effect on channel migration, the extent of the impact could not be quantified with the limited available data.

In addition, a numerical modeling study was conducted to compare the erodibility of forested floodplain lands with agricultural floodplain lands (Micheli et al 2004) along the Sacramento River. The study showed that bank migration rates increased roughly 50% after construction of Shasta Dam, despite significant flow regulation, as riparian floodplains were progressively converted to agriculture. The study also showed that agricultural floodplains are 80 to 150% more erodible than riparian forest floodplains. The results of this study could be used to predict future meander migrations patterns for different river management and restoration scenarios.

Consideration of Riparian Vegetation Issues. The CALFED Flow Regime Study used comparisons of historical hydrographs and seed dispersal patterns to define a hydrograph that would support cottonwood and willow establishment. The "favorable hydrograph" includes flows in late April and May that are higher than summer flows to allow vegetation establishment at a higher elevation than summer flows. Using these criteria, this analysis determined that between 1892 and 1943 there were only 11 years (of 51 years) not suitable for willow and cottonwood establishment. Unsuitable years were characterized by less than average rainfall or minimal snowpack and related snowmelt flows. Between 1944 and 1997, there were 38 unsuitable years (of 53 total years) for willow and cottonwood establishment based on actual hydrographs of impaired flows downstream of Shasta Dam.

This study also considered age of vegetation across point bars. The study was limited in scope and schedule, therefore only preliminary observational data was available using sediment composition, cottonwood growth form, trunk diameters, model predictions for discharges, aerial photos, and maps of channel locations. One of the field locations was at river mile 192.5 (right bank). The historic information indicated that in 1969, the location was in the channel and the upper end of the area started to form by 1976. Based upon observational data, the study indicates that trees may have established in 1974, 1978, 1983, and 1995.

Another field location was at river mile 197 (left bank). The historic information indicated that in 1969 and 1976, the site's location was in the channel, but by 1981 the channel had moved. The site was formed by 1988. Based upon observational data, the study indicated that the cottonwoods might have established in 1982 or 1983. The area was modified due to the installation of riprap on the opposite bank in 1975 that caused the left bank (point bar) to become too steep for cottonwood establishment and subject to scouring. There are many steep banks along the Upper Sacramento River, apparently due to the presence of bank stabilization. These conditions are probably related to the lack of young cottonwoods.

The study also noted that older trees are located farther away from the channel and that cohorts are established in bands parallel to the river as new sediment is deposited away from the original point bar location during lateral channel migration. The new sediment is generally deposited at a lower elevation than the older deposits and along a gentle slope that can accommodate establishment of vegetation.

The study discussed conditions in areas with bank stabilization. These areas did not appear to support channel migration and were characterized by poorly established vegetation on low elevation surfaces that are frequently disturbed by scouring. These areas were also characterized by older vegetation at higher elevations that were established prior to bank stabilization activities. Therefore, the study observed that mid-successional vegetation is not present at these locations.

Flow Regime Recommendations. The CALFED Flow Regime Requirements study provided recommendations related to flow requirements to maintain and restore channel migration and riparian vegetation. With respect to channel migration, results of DWR bedload trap studies indicate gravel movement may start at 24,000 cfs. However, bank erosion may not occur until flows of 55,000 to 60,000 cfs are reached (based on observations). The study also recommended that efforts should be implemented to restore an unquantified meander channel length.

To establish riparian vegetation, the study discusses that periodic overbank flows are necessary to scour surfaces for establishment of seedlings and to recharge floodplain aquifers. In addition, gradual spring recession flows that are similar to snowmelt flows are described as necessary for seedling establishment. The study indicates that flows over 55,000 cfs would maintain channel formation and assist in seed dispersal for some species. The study also indicated that ramping rates of 10 percent of the previous day's flow should be considered, however, the specific requirements would need to be developed following definition of stage-discharge relationships at multiple locations along the river. Therefore, the study recommended that flows in excess of 55,000 cfs not be reduced, except for flood management. The study also discussed the possibility of alternative flood management concepts to allow flows higher than current flood management flows.

The CALFED Flow Regime Study identified the following hypotheses that were suggested by conceptual models used in the study. The study recommended that these hypotheses be tested by observations at long-term study sites.

- Suitable areas available for seedlings are reduced as the point bar face becomes steeper
- Narrowing of the river channel following construction of Shasta Dam has changed stage-discharge relationships and reduced the suitable area for colonization on point bars
- Bank stabilization limits point bar development
- Rodent populations, including gophers, are reduced following floods and seedling success may be improved
- Finer soils occur on point bars further away from the channel and increase moisture retention and capillary action to encourage root growth as surface water elevations recede
- Fremont cottonwood and willow species have different establishment success characteristics at different elevations above the channel on the point bar
- The date of the beginning of the recession limb and the associated water elevation will determine the relative abundance of seedlings of each species on a point bar

- High summer flows followed by suddenly reduced flow in October leads to desiccation of seedlings

Data Gaps. The CALFED Study also identified data gaps including the frequency and hydrologic conditions for cohort establishment prior to construction of Shasta Dam, surface water elevation of summer flows, effects of bank stabilization, maximum surface water ramping rates for cottonwood establishment, frequency of cottonwood regeneration from seed or suckers, locations of existing and historical (i.e. pre-Shasta Dam) cottonwood cohorts, and changes in the frequency of cutoff occurrences. The study also described that a damp soil surface is required for willows and cottonwoods for germination and establishment. Historically, these conditions could have occurred through snowmelt flow patterns or by late spring rainfall. Additional studies were recommended to determine critical factors in channel formation and willow-cottonwood establishment. Data needs related to bed mobility, bedload transport, and bedload routing were also identified. These data requirements were incorporated into a figure in the CALFED Flow Regime Study and are summarized in Table 6-1. Many of these items have been addressed or partially addressed in subsequent studies as described in this chapter and noted in Table 6-1.

The results of this study were considered by CALFED in developing the preferred alternative in the Programmatic EIS/EIR and in preparing the Ecosystem Restoration Program Plan.
Other studies have been and are being completed, as described in the remaining portions of this section. Additional data are needed to better understand the relationships between flow regime and conditions for fish in backchannels and sloughs, between flow regime and macro-invertebrates in the food web, including terrestrial and avian resources, and establishment of cottonwoods in backchannels as compared to main channel.

California Department of Water Resources (DWR) Erosion, Channel Meander, Sediment Transport, and Vegetation and Wildlife Studies

The DWR has completed several studies on the Upper Sacramento River, including evaluations of historical channel meander patterns and extent, sediment transport studies, and vegetation/wildlife studies. DWR worked with researchers from the University of California, Davis, to evaluate maps, photographs, and text descriptions to develop historic mapping of the changes of the floodplain. These efforts also included mapping of the extent of riprap. This information was used to develop a meander migration model to project the extent of the meander channel based on changes in flow (Larsen and Greco 2002). The model was used to verify the DWR meander projections used in defining the "inner river zone" that is characterized by frequent flooding, channel migration, and high quality riparian habitat. This analysis was only the first phase of the modeling efforts and was limited due to the need for several assumptions. Subsequent phases could include more variables and level of detail, such as applying three-dimensional topographic information along the channel banks.

The DWR completed a series of studies evaluating the relationship of bank erosion and spawning gravel production. Spawning gravel studies related to the Upper and Middle reaches of the Sacramento River were completed during the 1980s (California Department of Water Resources

TABLE 6-1. Proposed Analyses Presented in CALFED Flow Regime Requirements Study

Objectives	Analysis Recommended	Items Initiated Since CALFED Study (described in this chapter)
Flow requirements for channel migration and flow duration versus erosion relations	Historical change migration analysis from maps and air photographs • Prepare accurate historic maps	S. Greco acquired a spatially extensive and temporally intensive historical air photo collection for areas from RM 144 to 245 Mapping by DWR and S. Greco using historic Corps of Engineers maps from 1800s along main channel, US. Geological Survey (USGS) quad sheets for early 1900s through 1910, and aerial maps since 1930s. Mapping primarily limited to main channel. Redigitized photos to delineate main channel using orthophotography. GIS-developed maps using AutoCAD with "Best Fit Rectification" from photo atlas and/or ArcGIS. Historical channel locations have been re-mapped by S. Greco (UCD) and are available as final GIS coverages (Greco et al. 2003a, 2003b, 2003c, 2003d; Greco and Plant 2003).
	Historical change migration analysis from maps and air photographs Analysis of bank erosion survey data from 1977 to "present" Analyze inundation/duration frequency at erosion sites	Annual erosion for the reach from Red Bluff to Colusa have been observed by DWR, but not thoroughly understood at this time Additional studies at Woodson Bridge by The Nature Conservancy (see below) E. Larsen (University of California, Davis) updated information related to channel cutoff and the relationship to antecedent soil moisture conditions E. Larsen, A. Fremier, and S. Greco refined the “cumulative excess stream power” statistical approach relating flow magnitude and bank erosion rates (manuscript in review)
	Historical change migration analysis from maps and air photographs Bank erosion surveys & analysis Analysis of large, woody debris effects on channel processes and fish	Analysis of large woody debris sources, quantity, and movement has been initiated by DWR

TABLE 6-1. Proposed Analyses Presented in CALFED Flow Regime Requirements Study

Objectives	Analysis Recommended	Items Initiated Since CALFED Study (described in this chapter)
Flow requirements for channel migration and flow duration versus erosion relations (continued)	Historical change migration analysis from maps and air photographs • Bank erosion surveys & analysis - Analysis of 1997 flood effects and options for alternative flood management	Corps accurately located main channel based on surveys in 1995 (prior to floods of 1996) and in 1997 (following floods of 1996) Corps developed bathymetric and topographic model based on 1997 survey and non-rectified aerial photos for reach from Woodson Bridge to Colusa. Data could be used in future to develop "channel-edge" model to simulate discharges and diversions for reach 7 miles north of Woodson Bridge to a location south of the bridge DWR completed Digital Elevation Model and supplemental bathymetric data north of Woodson Bridge
Document effects of riprap on channel migration	Mapping riprap extent, relation to channel migration, and assess potential riprap removal sites	The USACE and DWR mapped all riprap along the active channel from the Delta to Keswick. Most of riprap evaluated with respect to type, condition, and habitat value. S. Greco (University of California, Davis) prepared ArcView files using 1997 edge of channel data at riprap locations Studies by The Nature Conservancy considering potential riprap removal locations that are not located near structures
Effects of flow alteration on sediment transport & channel - floodplain morphology	Empirical analysis of suspended sediment transport • Mathematical modeling (sediment routing) • Analysis of cross-sectional & planform change	DWR collected and compiled suspended solids data during and following storm events A 2003 master's thesis by A. Fremier (under direction from S. Greco) developed a floodplain age GIS model at RM 197.

TABLE 6-1. Proposed Analyses Presented in CALFED Flow Regime Requirements Study

Objectives	Analysis Recommended	Items Initiated Since CALFED Study (described in this chapter)
Flow requirements to establish pioneer riparian vegetation and vegetation succession	Forensic geomorphic/ecological studies of successful cohorts • Survey topographic and vegetation distribution • Develop Stage-Flow relations • Flow history: water table, scour regime • Detailed historical aerial photo analysis • Reconstruct history of overbank sediment, document tree ages	S. Greco and A. Fremier (University of California, Davis) evaluated historical aerial photographs and analyzed changes in vegetation related to flow pattern change. Time since soil deposition ("age of land") and vegetation patch distribution evaluated using historical photographs and GIS modeling At River Mile 192.5, The Nature Conservancy developed stage-discharge relationships, conducted root excavations and trunk corings to evaluate cohorts, and completed transects of re-established cottonwoods. Subsequent studies are being conducted at River Mile 183 and 171 and proposed for other locations DWR has reestablished transects at these pointbars and is monitoring cottonwood seedling success. At River Mile 192.5, The Nature Conservancy excavated seedlings to better understand relationship of root growth, groundwater and surface water elevations, and water uptake. Data compared to lab analysis conducted by Dr. Wood (California State University, Chico) California State University, Chico, has prepared vegetation maps and vegetation transects since 2002 including species composition, geomorphic surface, and establishment of lateral migration of point bar as compared to channel elevation S. Greco and E. Larsen (University of California, Davis) preparing additional vegetation maps using remote sensory information and field research. A 2003 master's thesis by M. Vaghti (under direction from S. Greco) conducted a vegetation community analysis using floodplain age and depth to groundwater to develop an association-level vegetation classification between RM 144-218.

TABLE 6-1. Proposed Analyses Presented in CALFED Flow Regime Requirements Study

Objectives	Analysis Recommended	Items Initiated Since CALFED Study (described in this chapter)
Changes in channel geometry, channel migration, and sediment supply from bank stabilization	Develop reach-by-reach history of bank stabilization from field evidence, aerial photographs, and agency records Document over time and contrast between eroding and stabilized reaches: • Bank erosion rates • Channel geometry • Riparian establishment and succession	Historical information reviewed concerning scour regime.

1980, 1984), and a study of historical bank erosion on the Sacramento River was completed in 1995 (California Department of Water Resources 1994). Studies projecting future erosion rates were completed for the Red Bluff to Chico Landing and the Chico Landing to Colusa reaches in 1997 and 1995, respectively. The studies evaluated bank erosion rates in relationship to geologic controls, radii of curvature, flow velocities, sediment transport and deposition rates, soil moisture characteristics, and reaction to reduction in flow rates.

Bank erosion occurs when flowing water generates shear stresses on sediment particles that exceed the shear stress at incipient motion (i.e. the critical shear stress) and entrains the particles in the water column. The capacity of the bank to resist erosion is a function of the cohesiveness of the bank sediments. Sometimes the bank collapses and the soil particles fall to the toe of the bank where they are subject to entrainment in the water column. Erosion can also occur along gullies formed as streams flow from overbank areas into the main channel.

In this study, the banks of the Sacramento River were evaluated with respect to natural geologic controls, synclines, and anticlines that characterize channel gradients and interfaces between geologic formations. Results of field work indicated that clay and silt deposit along the oxbows, silt and sand deposit on the floodplain, and sand and gravel deposit on the point bars (inside edge of river bends). The field observations also indicated that riprap generally reacted in the same manner as geologic controls in slowing or eliminating bank erosion rates.

The DWR conducted biannual surveys at 17 sites, including 14 sites that were monitored for 14 years. Additional measurements were completed during some storms. The survey locations included Coyote Creek, two sites at Toomes Creek, Palisades, Foster Island, M&T Ranch/Phelan Island, Big Chico Creek, Golden State Island, Rancho De Farwell, Ord Ferry, three sites at Hartley Island, Larkins Island, Packer Island, Princeton, and Jimeno Rancho.

The geologic controls/bank protection locations determined the overall shape of the river channel. As the river eroded into the outside bend, or cut-bank, sediment deposited on the inside bend, or point bar, and the overall channel width narrowed through the bend. Due to the deposition of fines on the point-bar, the material in the river channel also became coarser. The results of a 1985 study indicated that 85 percent of the spawning-sized gravel in the Sacramento River was generated by bank erosion.

Erosion rates along the river change with changes in geologic formations and soil types. The clay/silt banks are generally characterized by cohesive soils with low erosion rates. Higher clay to silt ratio soils have lower erosion rates than higher silt to clay ratio soils. The clay/silt soils occur on oxbow lake deposits and within the banks as clay layers or plugs. High flow rates increase soil moisture along channel banks, lubricating the clay layers and reducing surface tension between clay particles. Wet soils also increase in weight, and slip-slides typically occur along clay lenses in the bank. The CALFED Flow Regime Study indicated that results from the DWR studies (California Department of Water Resources 1994) included an average bank erosion rate of 8 feet/year between river miles 156.5 and 232.5 during 1979 to 1993.

Banks characterized by sand were found to have extremely high erosion rates because sands have little cohesion, especially when wet. The sand banks along the Sacramento River are extremely vulnerable to collapse when river flow rates decline rapidly, and eroded sands generally deposit at the downstream end of point-bar deposits. Gravel banks are generally subject to erosion only during moderate and high flows. Eroded gravels move into the channel and can restore spawning gravels. Gravel banks on the Sacramento are frequently characterized by sand layers, and higher sand to gravel ratios increase erosion rates and the probability of bank collapse when river flow rates decline rapidly.

As banks erode and sediment is deposited along the channel, meander bends typically evolve in asymmetric patterns. The formation mechanics occur faster in the downstream portion of the bend (due to momentum increases associated with flow through the bend), unless geologic controls or bank protection are present at the downstream end of the bend. The bank erosion rate is also related to the radii of curvature of meander bends, with slower bank erosion occurring in larger radii bends. Erosion rates are also related to the angle of incidence (i.e. the angle at which flow from upstream impacts the channel bank) due to the acceleration of flow at this point on the bank soils.

The DWR study (California Department of Water Resources 1994) indicated that bank erosion rates are related to flow velocities, but not in a directly proportional way. The study indicated that the relationship is exponential in nature and referred to the "Shield’s tractive force criterion."

The DWR study concluded that bank erosion rates along the Sacramento River are related to many factors, including geologic characteristics and bank protection, and can change with time. The study also indicated that flow rates affected bank erosion rates, and therefore that changes in water management, such as construction of dams and levees, can effect bank erosion rates, meander channel formation rates, and generation of spawning gravels.

Study to determine the feasibility of removal of the private J-Levee and replacement with a setback levee near Hamilton City. The DWR also conducted a study to determine the feasibility of removal of a private J-Levee and replacement with a setback levee on the Sacramento River near Hamilton City, California. This effort included a feasibility study for ecosystem restoration and flood damage reduction in the Hamilton City area, evaluation of alternative plans, selection of a preferred alternative plan, engineering and economic analyses, and extensive stakeholder outreach.

River Partners - Flood Control, Irrigation District Facilities Protection, and Riparian Restoration: Meeting Multiple Objectives on the Sacramento River

In 2004, River Partners and an interdisciplinary team that included UC Davis, and Ayres began studies (Efseaff et al. 2006) to explore measures to protect the Princeton, Cordora, Glenn and Provident Irrigation Districts' (PCGID-PID) pumping plant and fish screen facility and develop restoration options for the Riparian Sanctuary, a unit of the Sacramento River National Wildlife Refuge. This CALFED funded project provides a case study on many of the issues that face floodplain managers: balancing multiple and often conflicting objectives (e.g. flood control, infrastructure protection, and wildlife objectives), addressing public concerns, and grasping complex river processes (and scientific uncertainty). The project employed an open, science-based process to educate stakeholders. However, this approach changed over time with the addition of regular partner meetings and the addition of technical advisors to maintain an open dialogue and minimize surprises. Science also served an important role with the diverse members of the Technical Advisory Committee providing guidance on the approach and critical reviews of documents and findings. This study also utilized sophisticated computer models to provide participants with a better understanding of river meander and flood flows. The models allowed cooperators to have a common understanding of complex river interactions, and more fully evaluate alternatives. The project successfully generated viable riparian restoration options and garnered support from divergent interest groups. One of the leading alternatives would improve bank protection, allow river meander, and restore riparian forest. This project serves as a model of how to bring divergent interest groups together to meet multiple goals and manage an interdisciplinary effort. The project demonstrates the use of collaborative methods and scientific knowledge to develop solutions to meet multiple objectives.

River Partners - Draft Pumping Plant Protection Feasibility Study for Llano Seco Unit Sacramento River Mile 178 (Draft Pumping Plant FS). The Sacramento River near RM 178, which is the current location of the PCGID-PID pumping plant, has experienced lateral and downstream meander migration in the last century. The reach in the vicinity of the pumping plant has evolved in shape through natural processes of river migration. Because the pumping plant is located on the west side of the river, the tendency for eastward migration of the channel is a concern because it potentially effects pump operations. MBK Engineers prepared a feasibility study that discusses the applicability and ecological consequences of a series of alternatives for pumping plant protection. Upon selection of a desired alternative, the project will be written into a Restoration Plan for the Riparian Sanctuary Unit of the Sacramento River National Wildlife Refuge, which is located just across the river from the pumping plant.

The Nature Conservancy - Expanding and Communicating the Ecological Considerations Used to Evaluate Water Management Alternatives on the Sacramento River

The Sacramento Ecological Flows Tool (SacEFT) (Alexander et al. 2006) is a decision support system developed by a Nature Conservancy-led team that links flow management to changes in physical habitats of chinook salmon, steelhead, green sturgeon, western pond turtle, bank swallow, and Fremont cottonwood along 158 miles of the upper Sacramento River. These models – driven by accepted planning tools like CALSIM II and HEC5Q – involve a mix of spatial / temporal scales and performance measures that vary in reliability. SacEFT employs standardized metadata to gauge reliability of component datasets and rules. The multiple "focal species" approach used in this model reduces the shortfall in ecological evaluation capability. The SacEFT effort currently faces important challenges (e.g., choosing focal ecosystem components, relating changes in physical habitats to focal species, harmonizing spatial-temporal scales across disparate models) that are being addressed by the project team through novel design approaches. A workshop emphasizing cross-domain discussions successfully defined how current planning models could be related to focal species. Outputs provide simplified "traffic light" reports anchored to ecosystem rules. Use of SacEFT requires no pre-requisite knowledge in foundational elements like CalSim II, etc., and makes it easy for non-specialists to grasp the scientific foundation used to evaluate water management alternatives. SacEFT can help water managers and stakeholders better understand trade-offs, making it easier to communicate ecological flow recommendations. By developing and refining this model, The Nature Conservancy (TNC) and its partners seek to advance stakeholder understanding of ecological linkages between patterns of flow and the native species, natural communities, and natural processes found in and around the Sacramento River. This effort seeks to: 1) synthesize existing interdisciplinary information, 2) develop a decision analysis tool to evaluate trade-offs among different ecological objectives, 3) propose strategies to achieve multiple species conservation benefits, and 4) provide information on ecological flow needs to other efforts seeking to balance ecosystem and human needs related to river flow.

University of California, Davis Research in Association with Department of Water Resources (UCD/DWR)

The Sacramento River Study is an ongoing research program being conducted by S. Greco and associated staff of the Landscape Analysis and Systems Research Lab in the Department of Environmental Design at the University of California, Davis. The purpose of this program is to estimate potential riparian ecosystem impacts from water diversion alternatives along the Sacramento River with respect to river channel meander patterns, flood flow inundation patterns, vegetation patterns, and habitat suitability for indicator species. The project has taken the following approach using a variety of models:

UCD/DWR Flow Analysis. To identify how the hydrograph has changed historically and could be modified to improve channel formation and ecosystem development, a simple flow frequency analysis was conducted to calculate the probability of exceedance and recurrence interval for three discrete time periods: 1879-1943 (pre-Shasta Dam), 1944-2000 (post-Shasta Dam), and the whole record 1879-2000 (pre- and post-Shasta Dam combined) (Lowney and Greco 2003).

UCD/DWR Geomorphic Models. Geomorphic models developed by E. Larsen were used to determine future planform (i.e. 2-D) configurations of the meandering channel and bend cutoffs, to evaluate the effects of riprap on channel migration through its limitation of ecosystem development, and to identify spatial and temporal distribution of land formation (floodplain age). The models include the meander migration model previously discussed, a meander bend cut-off model, 3-dimensional topographic and channel bathymetric surface models (digital elevation models [DEM] and triangulated irregular networks [TIN]), and GIS floodplain age models. The floodplain age models were developed by S. Greco in his doctoral thesis (Greco 1999) and refined by A. Fremier in a master's thesis (Fremier 2003). Future work could link the meander migration model to the 3-dimensional DEM or TIN model to aid in predictive vegetation and flood inundation modeling. The location of riprap between RM 144-244 was mapped and the analysis determined that bank stabilization occurred on about 50 percent of the channel from Red Bluff to Colusa.

UCD/DWR Hydro-geomorphic Models. To identify and quantify relationships between vegetation and floodplain position, a depth to summer base-flow (i.e. a potential for groundwater) GIS surface model was developed for RM 144-218. This model is based on modeled water surface elevations (from HEC-RAS) of the mean summer base-flow (post-Shasta Dam) as described in the recruitment box model. This model was used to determine relationships between groundwater depth and distribution of existing vegetation and will be used to develop a predictive vegetation model. A manuscript describing this work is currently in progress. Future work could explore relationships between floodplain inundation on deposition and scour and vegetation patterns.

UCD/DWR Vegetation Analysis and Models. To identify flows required to improve primary succession, the factors that (e.g. seed dispersal, creation of fresh geomorphic surfaces, etc.) regulate identify plant communities and factors that regulate these communities including flow regimes. The models including land vegetation cover maps (Greco et al. 2003a, 2003b), comprehensive vegetation classification system (Vaghti 2003), association or alliance predictive model for existing vegetation (currently in development for a doctoral thesis). Future work could include implementing a primary and secondary succession GIS model of vegetation establishment with the "recruitment box" (described above), patch growth model, and a successional dynamics model based on a state-and-transition modeling approach. A model of successional dynamics was developed using a chronosequence approach (trading space for time on the Sacramento River floodplain) (Fremier 2003).

UCD/DWR Indicator Species Models. To determine if habitat for indicator species can be regenerated by improving ecosystem processes, and to identify trends for habitat quality under different flow regimes, a study of RM 196-218 examined the temporal dynamics of habitat quality for the yellow-billed cuckoo (*Coccyzus americanus occidentallis*), an indicator species that lives in willow-cottonwood habitats along the Sacramento River (Greco et al. 2002). The analyses in this study included use of the Indicators of Hydrologic Alteration, recurrence interval analyses of hydrologic conditions, characteristics of inter-annual flows, characteristics of intra-annual flows during storm events, flow diversion, and amounts, and development of flow regimes to improve the ecosystem. The study indicated that optimal habitat on the Upper

Sacramento River for yellow-billed cuckoo decreased between 1938 and 1966, and then increased between 1978 and 1997. The study concludes that the increase could be attributed to habitat created by the cutoff of three meander bends between 1970 and 1976 (Greco et al. 2002). This study also identified hydrologic changes associated with construction of Shasta Dam and operation of the CVP and that bank stabilization occurred on about 50 percent of the channel from Red Bluff to Colusa, and noted that future work could model bank swallow (*Riparia riparia*) habitat in eroding banks, and Valley elderberry long-horned beetle (*Desmocerus californicus dimorphus*) habitat in mid-successional plant communities.

Flow, Sediment, and Channel Form Studies

The Nature Conservancy Comparison of Flow Patterns Using Indicators of Hydrologic Alteration (IHA) Analysis

The Indicators of Hydraulic Alteration (IHA) is a software package (developed by The Nature Conservancy (TNC) and provided through Smythe Scientific Software) that can be used to calculate flow regime characteristics and changes (Richter et al. 1996). IHA is used to integrate evaluation factors generated by hydrologists and ecologists during watershed studies. Using statistical analyses of daily stream flow data, river stage data, groundwater elevations, and/or lake/reservoir elevations, the IHA software can evaluate numerous variables using a statistical approach.

The program uses mean daily flow records from the U.S. Geological Survey or other streamflow data sources to provide output into a set of 33 easily understandable and ecologically relevant hydrologic parameters (Table 6-2). The IHA statistical analyses can be categorized as Parametric Statistics and Nonparametric Statistics. The parametric analysis assumes a normal distribution of data and uses the mean value and standard deviation for comparison. The nonparametric analysis assumes the median value for comparison within event periods and compares the results to "percentile" exceedances.

The software can be used to apply three different types of analysis: IHA Analysis, Range of Variability Analysis, and Trend Analysis. To complete the "IHA Analysis," an event that resulted in changes of the parameter is identified. For example, construction of a diversion structure on a river would change flows. In such a case, the IHA parameter is used to quantify changes in the specified variable for "pre-event" and "post-event" conditions. The Range of Variability Analysis considers the range of "pre-event" data and identifies three categories. For example, 20th percentile, greater than 20th and less than 80th percentile, and 80th percentile. The software calculates the expected frequency at which the "post-event" data should occur in each of these categories as applied to "pre-event" data. This provides a pre-event and post-event comparison of the alteration that occurred due to the event. For example, the pre-event and post-event measure of hydrologic alteration between observed flow regimes. The Trend Analysis uses graphical presentations with a linear regression analysis.

The IHA variables or parameters are selected for their usefulness in describing both hydrologic and ecological issues. For example, "annual 1-day mean maximum flow" can be used to assess the degree of hydrologic alteration of average annual peak flow that are generally associated with large storm events related to channel formation or habitat establishment events. As another example, "annual 7-day mean minimum flow" can be used to determine the degree of hydrologic alteration in low-flow conditions that may determine the availability of habitat for aquatic organisms or extent of riparian vegetation. This parameter may be used to calculate "minimum instream flow requirements."

TABLE 6-2. Hydraulic Parameters Used in Indicators of Hydraulic Alteration Calculations (Richter et al. 1996).

IHA Statistical Group	Regime Characteristics	Hydrologic Parameters
Group 1: Magnitude of monthly water conditions	Magnitude Timing	Mean October flow Mean November flow Mean December flow Mean January flow Mean February flow Mean March flow Mean April flow Mean May flow Mean June flow Mean July flow Mean August flow Mean September flow
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude Duration	Annual 1-day mean minimum flow Annual 3-day mean minimum flow Annual 7-day mean minimum flow Annual 30-day mean minimum flow Annual 90-day mean minimum flow Annual 1-day mean maximum flow Annual 3-day mean maximum flow Annual 7-day mean maximum flow Annual 30-day mean maximum flow Annual 90-day mean maximum flow Number of zero days Base flow (7-day minimum over mean annual flow)
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1-day minimum Julian date of each annual 1-day maximum
Group 4: Frequency and duration of high and low pulses	Magnitude Frequency Duration	Number of high pulses above the 75^{th} percentile each year Number of high pulses below the 25^{th} percentile each year Mean duration of high pulses within each year (days) Mean duration of low pulses within each year (days)
Group 5: Rate and frequency of water condition changes	Frequency Rate of Change	Means of all positive differences between consecutive daily values (rise rate) Means of all negative differences between consecutive daily values (fall rate) Number of reversals

The IHA Analysis for the Sacramento River included three event periods:

- Prior to construction of Shasta Dam (1892 – 1943)
- During implementation of the initial phases of the CVP (1944 - 1963)
- During subsequent phases of the CVP (1964 -1998) (This was described as "post-Trinity", however, only small amounts of Trinity River flows could be imported

through Clear Creek in 1964, the majority of imported flows enters the Sacramento River system through Keswick Reservoir which was implemented in 1967).

The results of the analyses conducted for each time period are summarized below with respect to flows in different months.

Summary of Changes in October Flows.

- Prior to completion of Shasta Dam (1892-1944), October flows were generally constant throughout the entire month with infrequent storms.

- October flows frequently were higher following construction of Shasta Dam. The non-storm October flows prior to Shasta Dam ranged from 4,000 to 6,000 cfs. Following construction of Shasta Dam, the non-storm flows ranged from 3,000 to 12,000 cfs in the first one or two weeks of October and 3,000 to 9,000 cfs in the remaining portion of October. Prior to 1964, the flows may be related to releasing flows from Shasta Lake to provide flood storage. Following 1964, the released water can be used to fill San Luis Reservoir, for rice inundation, and to increase Delta outflow during export activities.

- Between 1945 and 1984, Shasta Dam allowed irrigation water to be delivered into the first week of October, primarily to contractors south of the Delta. This flow does not increase with the addition of the San Luis Unit or the San Felipe Unit (both Delta exporters) after 1964 because the Tracy Pumping Plant is already operating at capacity to provide water to the Delta Mendota Unit.

- After 1992, Shasta Dam releases were modified to provide cold water to protect winter-run Chinook salmon.

Summary of Changes in Winter Flows (November through March).

- The non-storm flows range from 4,000 to 8,000 cfs in November throughout the period of record.

- In December, January, and early February, non-storm flows following the construction of Shasta Dam (post 1944) generally decrease at Keswick by 2,000 to 3,000 cfs and remain within the same range of variation at Bend Bridge and Butte City as compared to pre-1944 conditions. There does not appear to be any obvious change due to expansion of the CVP in 1964, 1967, and late 1980s. There does not appear to be any major change between 1992 and 1998 due to implementation of water quality control plans and biological opinions for special status species.

- From 1945 to 1972, in late February, March, and early April, non-storm flows generally decrease at Keswick by 2,000 to 3,000 cfs and remain within the same range of variation at Bend Bridge and Butte City as compared to pre-1944 conditions. From 1972 -1998, releases from Shasta Dam increase flows by 2,000 to 4,000 cfs at Keswick, Bend Bridge, and Butte City in these months when high storm flows do not occur. The released flows continue to the Delta, and the purpose of the increased releases appears to provide water for Delta export to fill the CVP portion of San Luis Reservoir using the available capacity of Tracy Pumping Plant prior to irrigation season or during pre-irrigation season in the San Luis Unit.

- Prior to construction of Shasta Dam (1892 - 1938), winter storms produced distinct and short-duration increases in flows at Bend Bridge.

- During construction of the dam, flows were slightly modified at coffer dams; however, storm flow regimes were relatively unaffected. Storm flows usually occurred at Butte City one day after the peak flows occurred at Keswick and Bend Bridge

- Following the construction of Shasta Dam (1945 - 1998), the frequency of storm events and the relative magnitude of major peak flows did not change significantly. Table 3-3 includes storms with flows in excess of 90,000 cfs. However, the duration and therefore volume of the peak flow events did change.

- Following construction of Shasta Dam (1945 - 1964), the peak flow changes at Keswick were reduced due to attenuation of storm flows in Shasta Lake. However, if storage volume was not available in Shasta Lake, the peak flows were generally released during the storm event. These changes were noted in the IHA analysis that indicated that low pulse flows decreased in both frequency and duration at Keswick and Butte City. In addition, the IHA analysis indicated that the rise rates declined at all three gauges due to storage of flows upstream of Keswick that historically had accounted for more than 30 percent of the peak flows at Bend Bridge and Butte City.

- Following 1967, Keswick flows frequently did not increase during the storm event or for several days following the storm event. The post-storm release from Shasta Dam would increase the duration of high flows at Bend Bridge and Butte City for several days up to two weeks. This eliminated the short, intense high-flow events. This change in operations may have been to improve flood management on the Sacramento River. These changes were noted in the IHA analysis indicating the reduced number of high pulse events at Keswick. However, the events were of longer duration, therefore, the fall rates at all three gauges and baseflow at Bend Bridge and Butte City increased due to the relatively longer duration of the peak flow event.

  In November, average flow at all three locations increased immediately following construction of Shasta Dam. There did not appear to be any change due to full use of San Luis Reservoir or other CVP facilities. Flows declined, but did so following implementation of flow regimes to protect fisheries and Delta water quality in 1992.

  In December, January, and February at all three locations, average flows varied within the same range prior to and following construction of Shasta Dam. The IHA analysis showed an increase in the 0 to 25th percentile. This is reflected in the observed daily flows as average flows decreased in 1945 - 1964, then increased to pre-Shasta Dam conditions in 1965 - 1972, decreased in 1973 - 1992, and then increased again to pre-Shasta Dam levels in 1993 -1998. Some of this variation is due to dry years during 1973 - 1992.

In March at all three locations, average flows declined 30 to 50 percent following construction of Shasta Dam and prior to full use of San Luis Reservoir (1945 - 1972). Following 1972, increased flows were released from Shasta Dam to fill San Luis Reservoir in years that did not include extensive March storms.

Summary of Changes in Spring Flows (April through June) and Summer Flows (July through August).

- Prior to construction and during construction of Shasta Dam (1892 - 1944), snowmelt occurred in May and early June as flows gradually declined from 20,000 to 6,000 cfs. Storms occurred infrequently.

- Following construction of Shasta Dam in 1945, the mid-April flows declined immediately to about 3,000 cfs and did not reflect snowmelt patterns, except in extremely wet years.

- Between 1945 and 1963, flows at Keswick and Bend Bridge start to increase in late April and early May from 3,000 cfs to the highest flows in mid-July at 9,000 to 11,000 cfs.

- Between 1945 and 1963, flows at Butte City increase in late April and decrease in May and remain 3,000 to 4,000 cfs lower than Keswick and Bend Bridge flows. This is probably caused by the delivery of up to 1,179,500 acre-feet to water rights settlement contractors between Bend Bridge and Butte City (the total diversion facility capacity in this reach is over 4,000 cfs).

- Between 1964 and 1972, the flow regime pattern is similar to the 1945-1963 period in many ways. However, additional flows must be released to meet CVP and water rights demands. At Keswick and Bend Bridge, the flows in late spring/early summer generally range from 10,000 to 15,000 cfs (about 2,000 to 3,000 cfs higher than the pre-1964 period). Flows at Butte City are approximately 2,000 cfs higher than prior to 1964. This is consistent with the increased diversion to Tehama Colusa and Corning canals between Bend Bridge and Butte City (about 2,100 cfs).

- In 1996 through 1998, the historical increase in mid-April and mid-May flows is delayed until June due to the Delta export limitations of the Water Quality Control Plan and to conserve cold water for winter-run Chinook salmon in the fall.

- In April, average flows decline at all three gauges by 50 to 60 percent following construction of Shasta Dam. The daily flow records indicate that April flows decline to about 3,000 cfs unless storms occur at this time.

In May, average flows at Keswick are constant from 1938 - 1964, then increase by over 30 percent. At Bend Bridge and Butte City, average flows vary within the range prior to and following implementation of Shasta Dam and other CVP systems. This lack of variation is consistent with the IHA analysis. It is caused by the change from a snowmelt flow regime that declines from 20,000 to 6,000 cfs, to a managed irrigation flow that increases from 3,000 to more than 10,000 cfs.

In June through August, average flows at Keswick and Bend Bridge increased by about 6,000 to 9,000 cfs. This increase is due to the increased releases following construction of Shasta Dam to serve water rights settlement and exchange contractors and CVP water service contractors located both north and south of the Delta. This value is relatively consistent with the associated capacity of about 9,000 cfs for the diversion pumps used to deliver this water. At Butte City, the incremental increase is about 3,000 to 7,000 cfs because about 4,000 cfs is diverted between Bend Bridge and Butte City. The IHA analysis also indicates that flows in the 75th to 100th percentile increased in these months.

Summary of Changes in Late Summer Flows (September).

- Prior to construction of Shasta Dam, Bend Bridge flows declined in late August and September to 4,000 cfs or less.

- Following construction of Shasta Dam, flows at Keswick, Bend Bridge, and Butte City declined from the high summer flows to 7,000 to 10,000 cfs in September and did not decline further until early October.

- Flows are relatively constant between Butte City and Bend Bridge in September because irrigation diversions upstream of Butte City have declined or stopped.

- Early September flows are higher in the early and mid-1990s than in the late 1980s, possibly due to drier water years in the late 1980s or the required release of cold water from Keswick to reduce impacts to winter-run Chinook salmon.

In September, the average monthly flows at all three gauges, increased by about 4,000 cfs following construction of Shasta Dam and prior to the construction of San Luis Reservoir (1945 - 1967). This could be partially due to releasing water from Shasta Lake to provide flood protection. Average monthly flows increased by about 2,000 cfs following construction of San Luis Reservoir as water was released from Shasta Lake for conveyance at Tracy Pumping Plant after irrigation season. These flows declined between the years 1973 and 1992, probably reflecting the seven years of drought in this period. These observations are consistent with the results of the IHA analysis.

The results of the IHA comparison of conditions following 1944 and 1964 with conditions prior to 1944 are summarized below.

- Mean summer flow at Bend Bridge increased 231 percent in July and 254 percent in August.
- Mean summer flows at Butte City increased 251 percent in July and 341 percent in August.
- Annual one-day maximum flows decreased 57 percent at Bend Bridge and 60 percent at Butte City
- Mean monthly spring flows decreased about 33 percent at Bend Bridge and Butte City

- Annual river stage reversals (increased flow rates followed by decreased flow rates followed by increased flow rates) increased 156 percent at Bend Bridge and 133 percent at Butte City.
- During flow rate increases, the rise rates declined at all three gauges and the "base flow increased at Bend Bridge and Butte City.
- The number and duration of low pulses decreased at Keswick and Butte City.
- The number of high pulses decreased at Keswick, however the duration increased.

The analysis also indicates that after 1964, flows were higher in October and November and lower in December through April, and June through September.

California Department of Water Resources Sediment and Water Quality Studies

DWR has also completed preliminary sediment and water quality studies as part of the NODOS preliminary engineering evaluations. The results of these studies will be published as part of the NODOS engineering evaluations. A summary of preliminary findings was presented to the NODOS Flow Regime Technical Advisory Group, and is summarized below.

The sediment study evaluated suspended sediment concentrations based on data available at river gauging stations. The study indicated that sediment concentrations were low when the majority of flow in the river was released from Shasta/Keswick or Whiskeytown dams because sediment is trapped in the reservoirs upstream of the dams. Sediment concentrations in the Sacramento River increase rapidly to high concentrations during the "rising limb" of storm-generated flows when the majority of flows are from the Cottonwood, Reeds, Red Bank, Elder, and Thomes Creek watersheds. As precipitation decreases during these storms, flows released from Shasta/Keswick and Whiskeytown dams reach the Upper Sacramento River at or downstream of Red Bluff, causing sediment concentrations to decrease rapidly. During the rising limb of these storms, sediment concentrations increase as the flow moves downstream and additional tributary flows enter the main channel. The study indicated that on average 95 percent of the sediment transported in the river is transported during five percent of the storm period. The suspended sediment generally consists of clay, silt, and sand. This type of material can damage intake pumps and lead to sediment deposition in pipelines and canals. Existing diversion facilities at Red Bluff Diversion Dam and Glenn-Colusa Irrigation District are not designed to divert water with high sediment concentrations because these facilities are primarily used in the spring through fall months during dry periods.

DWR has also been evaluating sediment quality. Preliminary findings indicate that sediment from many westside tributaries of the Sacramento River includes high concentrations of aluminum, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. Total phosphorus concentrations are also high in some of the tributaries. Ongoing studies are correlating constituent concentrations with storm hydrographs and non-storm flows.

The Nature Conservancy Study of the Evolution of Upper Sacramento River Channel Formation

The Nature Conservancy sponsored a December 2002 report entitled "The controls on and evolution of channel morphology of the Sacramento River: A case study of River Miles 201 - 185" by E. Larsen, E. Anderson, E. Avery, and K. Dole of the Geology Department of University of California, Davis (Larsen et al. 2002). This reach includes four subreaches, or zones. Zone 1 extends from about 2 miles upstream of Hamilton City (RM 201) to the confluence with Dunning Slough (RM 198). Zone 2 continues downstream to the confluence with Big Chico Creek and Bidwell River Park (RM 193). Zone 3 continues to about 1 mile downstream of the confluence with Stony Creek (RM 189) and Zone 4 extends to about 1 mile upstream from Ord Ferry Bridge (RM 185).

The study evaluated historical characteristics of the study reach and predicted future channel formation under different rip-rap management scenarios. The primary geologic units in this study period were identified as terrace deposits of the Riverbank and Modesto formations (generally sand and silt overlying poorly sorted gravels). These formations are classified as generally erosion resistant and characterized by limited lateral migration, especially on the downstream edges of channel bends, and cause limited migration in portions of the river between River Miles 194 to 185.

The study describes changes in hydrology due to construction of Shasta Dam, other flood control structures including Moulton Weir, historical conversion of watershed lands from riparian forest to orchard that started in the 1870s. In addition, this study described a related evaluation completed by others that indicated that bank migration rates and erosion had increased about 50 percent as forests were converted to agriculture. This is primarily because the vegetation, including understory vegetation, can deflect the flow along the river, cover the soil with vegetation, and have extensive root mass that can hold soil particles. The study indicates that vegetation removal could cause greater channel migration downstream as compared to horizontal sinuosity.

The study included a model using a steady flow of 80,000 cfs to represent a calculated 2-year return interval flow event to predict meander migration. The model extended beyond the reaches of this specific study. The model was calibrated for erosion using the 1952 to 1974 period (a period with minimal riprap in this reach) and the interval of 1980 to 1997 for validation. The report indicated that the meander migration model was calibrated in most reaches of the river except where the river avulsed or where high sinuosity occurred over a relatively short period of time.

The study further discusses the results with respect to "wavelengths of a meander" or twice the straight-line distance between inflection points because the shape of the river resembles a wavelength. The study reports the model results as half wavelengths, or bends, and indicates that the typical bend in this reach was measured with a half wavelength varies from about 4 to 10 channel widths. Changes in wavelengths over time appeared to be dependent upon location and years. The study also evaluated sinuosity defined as the channel length divided by the straight-line distance. The study discusses that sinuosity when considering a smaller reach may be related to hydraulic and hydrologic processes as compared to the effect on geology and land use when considering sinuosity over a longer reach. Review of historical data in the study indicates that sinuosity continued following installation of riprap by the 1970s. The study notes that over the entire reach sinuosity decreases over the period and the average half wavelength either does not change or increases during the same time period.

The rate of migration was calculated by comparing the area "reworked" (a measure of land eroded or deposited due to meander migration), average length of straight-lines in area reworked, and 3) years to allow for movement of centerlines. The comparison of historical data indicates that following the installation of riprap, the areas continued to be reworked and meander migration persisted in some locations. In Zones 1 through 3, the study indicated that the annual rate of migration from 1905 to 1997 declined following 1952. In Zone 4, annual rate of migration increases over the period.

The model was used to predict changes in river characteristics under four scenarios: 1) Maintaining existing riprap, 2) Removal of riprap in this reach where about 50 percent of the banks are armored including 98 percent of the outside bends, and 3) Removal of riprap only near Hamilton City to about 2 miles upstream of Ord Ferry Bridge. Another scenario was evaluated to simulate conditions following a major cutoff across a bend.

Overall, with Scenario 1 (maintenance of riprap), the model predicted that the half wavelength becomes longer except in Zone 1. Zone 1 is different because the upstream end of this reach (RM 201) is fixed as a hardpoint due to a bridge and associated bank protection. This simulated result is consistent with historical observations.

In Scenario 2, removal of riprap, the half wavelength slightly increases over the entire reach with a decrease in Zone 1 due to increased sinuosity in Zone 2. In Scenario 3, sinuosity decreases in all zones including the areas in which riprap is removed. The reduction in sinuosity in Scenario 3 over the entire reach through 75 years is a similar in pattern as the reduction in Scenario 1 following 75 years of study. Therefore, the study indicated that similar changes would occur in the channel with partial removal of riprap or with continued use of riprap. In all three scenarios, the area reworked and the rate of migration declines over time with the smallest reduction occurring in Scenario 2.

The Nature Conservancy Hydrologic Modeling of the Upper Sacramento River

A series of hydraulic analyses were completed on the Upper Sacramento River and summarized in three documents published in 2001 and 2002. The first study was summarized in "Hydraulic Analysis of Riparian Habitat Conservation on the Sacramento River from Princeton to Beehive Bend, Hydraulic Modeling of the Sacramento River, From RM 163 to RM 176" published in April 3, 2001 (The Nature Conservancy 2003c). This study was conducted by The Nature Conservancy to analyze hydraulic effects of riparian habitat conservation and restoration in overbank areas within the levees. The study included three hydraulic model runs to simulate the following three scenarios: 1) existing conditions in 1997, 2) potential hydraulic impacts to levees from maximum conservation and restoration activities and to sensitive areas (as represented by Manning's roughness coefficients), and 3) developing a landcover configuration to maximize riparian vegetation with minimum hydraulic impacts on levees and minimum maintenance. The model was calibrated using flow data from Butte City gauge at RM 168.5 and peak flow-stage relationships from a 1998 flow event.

For Model Run 2, it was assumed that lands within the inundation area for the 2.5 year flood recurrence interval would be restored and the remaining areas within the levees would be planted in orchards. The study indicated that the vegetation density assumed for the restoration area may be higher than what would occur naturally due to soil type, topography, and groundwater conditions. Model Run 3 was developed to design a riparian vegetation conservation and restoration configuration through an iterative approach. The study indicated that the preferred model run included a mix of riparian vegetation, orchards, and grass/sedge meadows in most of the reach and planting configuration developed by others near the Sul Norte area. The vegetation pattern was selected so as not to increase the friction factors that occurred with existing vegetation, soil types, and groundwater. The study stated that this scenario assumed restoration through natural recruitment, revegetation planting, and retention of existing vegetation with willing landowners. Primary impacts to the levees were based upon compliance with freeboard criteria for these levees, changes in water surface elevation of less than 1 foot, and water velocities that can cause changes in erosion and deposition. Model Run 2 met freeboard criteria and did not change velocities, but increased surface water elevation more than one foot. The study indicated that the results of Model Run 2 and Model Run 3 showed areas that would be sensitive to flow changes would be located near a levee constriction at RM 164.2, State Highway 162 bridge at RM 168.5, and on the east side levee upstream of RM 175. The study indicated that Model Run 3 was changed using iteration techniques to avoid any impacts to freeboard, changes in water surface elevations, or velocities.

The second study, "Hydraulic Modeling and Geomorphic Analysis of Sacramento River, RM 184 to RM 194," published in April 2002, evaluated hydraulic impacts of riparian restoration and of a potential bank revetment failure located along County Road 29 near RM 188 (The Nature Conservancy 2002b). An embankment failure occurred in January 1995 near RM 188 that led to the beginning of a cutoff near Kimmelshue Bend. The site was repaired and failed again in March 1995. The study described that this reach had a high sediment load due to overbank flows from Golden State Island/Murphy Slough, discharge from Stony Creek, and backwater conditions upstream of Ord Ferry Bridge, and that these conditions can increase meander migration. The study described that a cutoff at the neck of the bend in the overbank area causes a steeper slope in the channel bed, increased migration of bends upstream and downstream of the cutoff, and increased erosion until the channel readjusts. The modeling analyses included three scenarios: 1) existing conditions based on topographic and bathymetric data for 1995 conditions; 2) limited restoration at Kaiser Unit, Phelan Unit, and Koehnen Unit without other land use changes; and 3) meander bend cutoff conditions, neck cutoff, and a chute cutoff at Kimmelshue Bend with limited restoration. The models were operated for 195,000 cfs and 370,000 cfs conditions representing a 10-20 year and a 100 -200 year return periods, respectively. The 1995 event was similar to the 195,000 cfs simulated flow condition. Results were evaluated through the comparison of surface water elevations and water velocities. The study indicated that surface water elevations in Scenario 2 increased by less than one foot at Kaiser and Phelan units and slightly decreased near the M&T Flood Relief Structure at Murphy Slough. The study also indicated that for Scenario 3 velocities and surface water elevations in the channel increased immediately downstream of where the cutoff discharges into the river channel and decreased upstream of the cutoff. The study described the following model results: 1) effect of a cutoff near Monroeville Bend (RM 187.5 to 189.5) could reduce the effectiveness of the M&T Flood Relief Structure, and induce downstream cutoffs or migration of the Kimmelshue Bend; 2) neck cutoff near Kimmelshue Bend may cause the channel to move from the current meander bend, cause a slightly higher surface water elevation, increase sediment deposition upstream of Ord Ferry Bridge, and increase erosion of the left bank near the bridge; 3) chute cutoff at Kimmelshue Bend may cause erosion on the left downstream bank and downstream meander migration towards the 1896 historic channel which could adversely effect the Ord Ferry Bridge; and 4) chute cutoff upstream of Kimmelshue Bend may cause a major shift downstream to a location east of the Ord Ferry Bridge.

The Nature Conservancy Two-Dimensional Hydraulic Modeling of the Upper Sacramento River, RM 194 to RM 202

Including Riparian Restoration, Revised Setback Levee, and East Levee Removal, was published in October 2002 (The Nature Conservancy 2002e). The purpose of this project was to use a model to evaluate potential third-party impacts of large-scale conservation strategies. A model was used to evaluate setback levee alignment in the Hamilton City area and removal of private levees that will reduce flood damage and increase ecosystem restoration near the Pine Creek Unit. The study developed and calibrated models for the simulated 1995 flood flow event with post 1995-conditions, simulated conditions with two setback levee alignments, and simulated conditions due to removal of east levees near Kaiser, Pine Creek, and RX Ranch units and provide restoration. The existing conditions model simulation is based upon 1995 characteristics with a peak flow of 195,000 cfs, approximately a 15-year runoff event. The levee alignment is generally outside of the overbank and extends into an oxbow to protect the wastewater treatment plant near Hamilton City. A two-dimensional model (based on a digital terrain model and observed data) was used to quantify the impacts of potential land use change (as indicated by roughness coefficients) and levee locations on surface water elevations, velocities, and flow patterns. The study indicated that restoration would increase velocities less than 5 feet/second due to change in vegetation from orchard to grasslands, and therefore, would probably not change erosion potential. The study also indicated that model results show reductions in velocities if changed to riparian forests. Results described in the study showed reduced deposition upstream of RM 194 and near the Kaiser Unit where velocities become slower; and reduced surface water elevation near Pine Creek Unit and RX Ranch due to changes from orchards to grasslands, and increased surface water elevation near RM 193. Modeling of the levee realignment, as discussed in the study, showed reduced velocities from RM 193 to 198 (with increased deposition from RM 195 to 198) and increased velocities from RM 198 to 199 due to removal of a portion of the oxbow to accommodate the water. The study indicated that placement of levee in the oxbow restricts the channel cross-section area and forces additional water into Big Chico Creek. Model results, as summarized in the study, indicated that impacts of east overbank levee removal included slight increase in velocities near RM 198.5 and expansion of flow into existing overbank areas.

The Unified Gravel-Sand (TUGS) Model: a Numerical Model to Simulate the Transport of Gravel-Sand Mixtures

Stillwater Sciences has developed The Unified Gravel-Sand (TUGS) model to simulate changes in grain size distributions of channel deposits as a function of changes in the flow regime and sediment supply (e.g., gravel augmentation, reductions in fine sediment loadings) (Cui 2006). This model was previously described in Chapter 5 Toolbox Development.

CALFED Floodplains White Paper Study

Researchers at the University of California, Davis and Phil Williams and Associates, Inc. (PWA) conducted geospatial analysis of Sacramento river-floodplain interactions as part of a comprehensive project looking at large floodplain restoration in California's Central Valley (Andrews et al. 2006). As part of this analysis, they defined a specific flow, termed the 'floodplain activation flow' (FAF) that can promote ecological processes associated with prolonged, frequent flooding (e.g., fish habitat and carbon production), and parameterized this flow in terms of season, frequency, and duration. They then mapped the extent of floodplain inundated by the FAF within four sub-areas of the middle and lower Sacramento River system. The results of their initial analysis suggested that the FAF floodplain may be both rare and challenging to restore in California's highly-modified lowland rivers. By implication, they concluded that ecosystem processes that depend on this particular landscape will also be challenging to restore.

U.S. Army Corps of Engineers Projects

The U.S. Army Corps of Engineers completed a sediment budget as part of a bank protection project from Chico Landing to Red Bluff (a portion of the Sacramento River Bank Protection Project) and the Comprehensive Plan for the Sacramento-San Joaquin Rivers. The 1981 Corps of Engineers sediment study was conducted to determine if bank armoring reduced erosion and related sediment transport into navigable channels, as described in the CALFED Flow Regime study. The study concluded that the meander channel changed positions laterally without changing dimensions and that sedimentation downstream of this reach would only occur if the channel widened during the meander activity.

The U.S. Army Corps of Engineers prepared a Comprehensive Study for the Sacramento-San Joaquin River Basin following the 1996 and 1997 floods. As part of the study, an Ecosystem Functions Model (EFM) was prepared, and in 2000, a study was published by the Corps of Engineers defining the functional relationships used in the EFM (Jones & Stokes Associates 2000). The functional relationships describe the interactions between flow, channel morphology, and ecosystems in the channel/floodplain areas. The EFM consists of simulation of the aquatic and terrestrial systems and focuses on flood events with overbank flows. The terrestrial factors include extent of existing and potential riparian and wetland habitats, rates of biological change in the riparian and wetlands habitats, and wildlife habitat suitability indices based on the Habitat Suitability Index (HSI) and Habitat Evaluation Procedure (HEP) models developed by U.S. Fish and Wildlife Service. The aquatic factors are related to in-channel habitat and floodplain inundation as related to flows to maintain spawning gravels, flows to maintain channel migration and complexity, and woody riparian vegetation to provide shaded riverine aquatic habitat (SRA) and large woody debris. The SRA is defined as the area where the river meets the woody riparian habitat that shades the river, and generally includes areas with large, woody debris. The EFM uses the following variables.

- Flow rates and velocity in the channel and on floodplains
- Substrate characteristics in terrestrial and aquatic systems
- Depth to groundwater under riparian/wetland vegetation (measured as the river flow in August)
- Flood events that occur during germination and establishment periods for riparian vegetation
- Scour regimes in both river channel and riparian zones
- Rates of channel migration measured by new or disturbed substrate and meander direction change
- Frequency and intensity of scouring during floods
- Habitat connectivity between channel and overbank areas
- Spawning and rearing habitat abundance

The EFM report described results of previous studies that were incorporated into the model assumptions. With respect to the Upper Sacramento River, the model assumed that overbank flows must occur between mid-April and mid-August to support successful germination and establishment of willow and cottonwoods. Then, the flows must recede at a rate that matches the root growth rate to avoid suffocation or desiccation of the roots. The EFM assumes recession rates of 1.5 inches/day, or 0.88 feet/week. The EFM also generalized that a rate of decline greater that 1.5 inches/day would produce poor riparian tree seedling survival, a recession of 1 to 1.5 inches/day would produce fair survival, and recession rates less that 1 inch/day would provide good survival (Jones & Stokes Associates 2000).

The EFM assumes that flooding inundates the cottonwood scrub and mixed riparian forest at a 40-year frequency return period. The requirement is that an annual flow meets two criteria, first it must provide overbank flow during the correct seasonal range (mid-April and mid-August), and secondly, it must recede at an acceptable rate (1.5 inch per day or less). The EFM also assumes that germination of vegetation close to the channel will be removed through scouring activities prior to complete establishment, and that inundation of the area adjacent to the channel for 21 days or more would eliminate establishment of woody riparian vegetation. With respect to channel migration rates, the EFM assumes that migration will increase if the frequency of the 1.5-year and 5-year flood events increases. The EFM assumes that an increase in frequency of these flood events would increase the rate of habitat renewal, which is based on the assumption that flows that are sufficient to scour spawning gravel from 2 to 15 centimeters in diameter are required to remove fines and maintain healthy invertebrate ecosystem.

The functional relationships report also described previous studies published by the Division of Agricultural Sciences at University of California, Davis (Roberts et al. 1977, Thompson 1961, and Conrad et al. 1977, and Katibah 1984). These studies indicated that under unimpaired flow conditions along the Upper Sacramento River, woody riparian vegetation occurred at higher elevations along natural levees composed of silty/sandy sediment and generally influenced by the extent of the 100-year flood event. The functional relationship report also discussed of a "recruitment box model," previously described (Mahoney and Rood 1998). The model describes the successful elevations at 2 to 7 feet above the late summer water elevation. Cottonwoods are observed at higher elevations along the Sacramento River; however, the study indicates that these areas were located at lower elevations as compared to the river elevation during seedling establishment. Following establishment of the trees, sediment was trapped in the roots and created a higher topographic feature.

The functional relationship study also describes the relationship of large woody debris and a functional ecosystem. The ability of large woody debris to provide channel complexity is related to the size of the debris, orientation of the debris with the flow direction, the method and extent of burial, and whether there is a group of debris pieces. Larger debris, orientation more perpendicular to the flow direction, buried to a greater extent, and occurring with multiple pieces will be more stable than debris that is smaller, oriented parallel to the flow direction, relatively unburied, and occurring as a single piece. As described above, stable large woody debris is required to facilitate formation of riffles, to trap nutrients and sediment to support invertebrates, and to provide protective fisheries habitat for rearing and resting of juvenile fish where larger fish cannot enter the small spaces among the debris. Areas with large woody debris require vegetation along the river that usually does not occur in areas with bank protection.

U.S. Fish and Wildlife Service Riprap Impact Study

As part of the Sacramento River Bank Protection Project, bank protection was constructed to reduce sediment in the river that could effect navigation and to reduce erosion that could affect adjacent land uses including farming and roadways. The project, started in 1960, was conceived to provide riprap downstream of Red Bluff Diversion Dam. In the first 40 years, riprap was placed on 152 miles of banks. Mitigation was authorized by Congress in 1986 for the initial 81 miles of bank protection that was constructed from 1960 to 1975. The mitigation included acquisition and revegetation of 260 acres of riparian habitat. Mitigation for the 77 miles of bank protection completed between 1976 and the 1990s included establishment of environmental easements at locations with terrace-benches that extended from the levee at least 30 feet on the river side. Small rock (rock fill) was placed on the benches to allow vegetation to grow, and the landowner maintained the riparian vegetation. In 1989, mitigation measures were modified to include additional planting of riparian vegetation, construction of gravel/rock near-shore benches to provide spawning habitat for salmonids, and creation of vertical banks to provide nesting habitat for bank swallows. In 2001, the Corps of Engineers was considering placing riprap on an additional six miles of banks. In the past 10 years, the Fish and Wildlife Service has designated shaded riverine aquatic (SRA) habitat along the Sacramento River system as high value, unique, and irreplaceable.

The U.S. Fish and Wildlife Service (2000) completed a study in 2000 in response to the most recent bank riprap proposal by the Corps of Engineers. The Service's study summarized results of an earlier study by DWR (1994) that found riprapping reduced spawning gravel for salmonids between Chico Landing and Red Bluff, decreased or eliminated development of point bars and deposition of sediment to allow colonization of riparian vegetation, decreased or eliminated meander migration that supports habitat diversity and renewal, reduced the width of the low-flow channel, and increased incision of the deepest part of the channel (thalweg) next to bank protection. These losses in channel complexity were found to reduce sustainable areas for vegetation, invertebrates, fish, birds, and terrestrial animals.

The 2000 U.S. Fish and Wildlife Service study also described the results of a 1981 Department of Fish and Game study of conditions between Red Bluff and Ord Bend (upstream of Butte City). The DFG study indicated that in 1981, there did not appear to be significant differences in invertebrate species variability or abundance near banks with and without protection. However, the study did suggest that juvenile salmonids were smaller near banks with protection as compared to banks with large woody debris. These findings were consistent with subsequent studies along the Sacramento River and other rivers conducted in the 1980s and early 1990s. These studies indicated that one of the most significant factors that affected fish densities and growth in areas with bank protection was the reduction in SRA and large woody debris. The Service’s 2000 study described that the main benefit from large woody debris was the creation of eddies, ripples, pools, and backwater areas used for salmonid rearing and shelter. Large woody debris was also shown to trap sediment and organic material that supports invertebrates, and to facilitate bank erosion that supplies sediment for downstream meander channels and can modify the flow patterns to create meander cutoffs.

Recommendations of the 2000 Fish and Wildlife Service study included the following goals, objectives, and actions to be considered by the Corps of Engineers and other agencies considering bank protection along the Sacramento River between Red Bluff and Verona.

- Do not reduce functioning ecosystems due to ongoing or future bank protection projects
- Increase set-back levee programs to avoid impacts to riparian corridor
- Increase understanding of large woody debris status and historical losses
- Identify areas with greatest loss of large woody debris to develop rehabilitation plans
- Primarily for areas downstream of Colusa, further evaluate the interaction of fish and SRA
- Develop an ecosystem functions model to evaluate impacts and mitigation for bank protection
- Develop mitigation strategies for loss of large woody debris
- Develop programs for long-term rehabilitation in this reach and coordinate with other programs

Central Valley Project Improvement Act Implementation

U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation are currently developing programs to identify flow needs on the Upper Sacramento River tributaries under Section 3406(b)(3) of the CVPIA. Under this program, water can be acquired and managed in a manner to improve riverine habitat for aquatic, terrestrial, and vegetative species in coordination with other water management programs. At this time, the focus of these programs is primarily on the tributaries where spawning habitat will be improved as part of the Anadromous Fish Restoration Program with related benefits on the mainstem. One of the goals of the program is to restore more natural flow regimes. These efforts are expected to benefit both fisheries resources and riparian vegetation, and have already provided improvements on Clear, Battle, and Butte creeks.

Additional efforts are being evaluated on most of the other tributaries. Currently, evaluations are being completed to determine appropriate flow regimes for spring-run, fall-run, and winter-run Chinook salmon as well as other native species.

U.S. Geological Survey Projects

U.S.G.S. scientists evaluated lateral migration of the reach from Chico Landing to Colusa based on maps and photographs (Brice 1977). The results indicated that the sinuosity of this reach declined from 1.56 in 1896 to 1.35 in 1974 (sinuosity = channel length/valley length) (Brice 1977). The study indicated that the main reason for the decline was an increase in the number of meander cutoffs. The evaluation also indicated that the increase in cutoffs could be related to removal of riparian forests that would allow higher velocities, and therefore higher shear stresses, across the land in the meander channel, thereby causing cutoffs to occur.

University of California, Santa Barbara (UCSB) Studies

Several studies on the Upper Sacramento River were completed by researchers associated with the University of California, Santa Barbara, including the studies summarized below.

UCSB Evaluation of Sediment Concentrations. Michael Singer and Thomas Dunne assessed spatial patterns of suspended sediment transport and storage along the Sacramento River by evaluating the suspended sediment budget for the main channel accounting for all tributaries and diversions (Singer and Dunne 2001). In this research, they used time series analysis to quantify the relationship between streamflow and suspended sediment concentration for gauging stations along the main channel and tributaries. Next, they developed and evaluated a suspended sediment budget to identify reaches of net erosion or deposition. This study used the "Box-Jenkins Transfer Function Model" that describes the relationship between flow and sediment concentration. The model calculates sediment concentration for a given day as a "moving average" of flow rate on that day and previous days and based on sediment concentration on previous days using "autoregressive processes." The model divides the river between Keswick and Sacramento into six reaches: with nodes at Keswick, Bend Bridge, Hamilton City, Butte City, Colusa, Knights Landing, and Sacramento. Sediment gauges are monitored at these locations. This study used the data to calculate sediment discharge for the nodes and evaluate long-term erosion or deposition for the intermediate reaches. Sediment discharges were also calculated for Cottonwood, Cow, and Elder creeks, and the Feather River.

The Singer and Dunne study reported that there was net sediment deposition from Keswick to Hamilton City and from Butte City to Colusa, and net erosion from Hamilton City to Butte City and downstream of Colusa. The study describes sediment deposition between Butte City and Colusa due to the narrowing of the channel near Colusa that causes backwater effects, overbank flows, and sediment deposition in the overbank and adjacent basin areas. Sediment deposition also occurs at the confluence of streams upstream of Hamilton City, especially Cottonwood Creek, and along the Sacramento River floodplain downstream of Clear and Cottonwood creeks where overbank flows occur frequently. Deposition also was predicted by the model in this reach along sand bars and within the channel gravels due to reduction of peak flows following construction of Shasta Dam. The model predicts net sediment erosion between Hamilton City and Butte City due to steep channel grades that leads to erosion of banks.

UCSB Modeling Flow and Sediment Transport and Storage. In 2003, M. Singer published a dissertation titled "Modeling spatial and Temporal Patterns in Flow and Sediment Transport and Storage in Large, Lowland Rivers" as part of the requirements to receive a doctorate degree from University of Santa Barbara (Singer 2003). The purpose of the dissertation was to develop models to analyze decadal patterns in sediment transport and storage and to model the influence of restoration concepts. A portion of the research was published in the 2001 study described above. This study used the "Box-Jenkins Transfer Function Model" as described above.

This study developed a suspended sediment budget for Water Years 1948 to 1979 based on data collected in 1977 and 1979 for 6 gauging stations on the Sacramento River and 4 gauges on tributaries. Data was collected for another gauging station on the Sacramento River for 17 years. The Box-Jenkins Model was used to –flow and sediment discharge relationships for the 1948 to 1979 period to support development of a set of consistent sediment budgets. The study primarily focuses on the impacts of Shasta Dam construction and indicates that implementation of CVP Trinity River facilities and gravel mining did not modify flood flows or suspension of sediment. The study calculated sediment losses at Glenn-Colusa Irrigation District diversion based on records of dredging settling ponds near the intake. The study determined that the impact of the remaining diversions were negligible.

Singer's dissertation describes that the model indicates sediment deposition between Keswick and Hamilton City and between Butte City and Colusa. The primary sediment source upstream of Hamilton City is Cottonwood Creek. Between Butte City and Colusa, the channel becomes narrower, resulting in overbank flows and suspended sediment deposition that includes both vertical and lateral accretion.

The model also indicated net erosion between Hamilton City and Butte City and between Colusa and Sacramento. Between Hamilton City and Butte City, the study described that the channel has become more straight and steeper due to two major bend cutoffs in 1946 and the presence of engineered levees.

Downstream of Colusa, main channel flows during flood events are reduced due to diversions into Butte and Sutter basins upstream of Colusa. Downstream of Knights Landing, flows and sediment enter the main channel from the Feather River and Sutter Bypass. A limited amount of channelized meandering occur between Colusa and Sacramento.

The model results indicated that a flood pulse to wet the soils and flow reduction rates to allow for root growth during establishment of cottonwoods occurred infrequently following construction of Shasta Dam. The model also indicated that dams in the upper reaches of the river may not reduce flood risks in the lower river due to release patterns and/or storms that occur in the lower portion of the watershed. The model results also showed that channel incision increases flood risk due to the exposure of permeable banks at the base of natural or constructed levees.

The bedload model indicates that bed-material transport is not in a balanced condition with sediment storage, and that floods transport most of the bedload material in the Sacramento River. The use of the model for rehabilitation scenarios indicated that if gravel augmentation was conducted at Bend Bridge, gravel and sand erosion would decrease upstream and increase downstream for these types of materials. Augmented gravel was a mixture of the following grain size classes: 96 mm (10%), 48 mm (30%), 24 mm (20%), 12 mm (10%), 6 mm (5%), 3 mm (5%), 1.5 mm (5%), and 0.75 mm (5%) (Singer 2003). Singer (2003) also suggested that augmentation of gravels of an appropriate mixture could beneficially alter sediment transport and sediment storage. Important augmentation issues included: (1) median grain size of the mixture affects transport rates (e.g., adding higher median grain sizes than present in the existing substrate results in lower transport rates), (2) the addition of well-sorted sediments decreases the sorting coefficient and lowers transport rates for each grain size, and (3) the injection site for sediments affects average cross sectional transport rates (e.g., most sediment transport occurs in the thalweg).

The studies described above are concisely presented in four peer-reviewed journal articles, summarized below:

- ***An empirical-stochastic, event-based program for simulating inflow from a tributary network: Framework and application to the Sacramento River basin, California*** (Singer and Dunne 2004). Developed a stochastic streamflow model based from a network of gauged tributaries. Used model to represent spatial and temporal patterns of flood events in the main stem. Used model on the Sacramento River to simulate flow at ungauged main stem locations, assess potential efficacy of restoring riparian vegetation, and to detect bed level change.

- ***Modeling decadal bed-material flux based on stochastic hydrology (Singer and Dunne 2004).*** Drove sediment budget calculations with stochastic hydrology model to estimate decadal bed material flux and net storage. Computed estimates of annual total and annual peak bed material discharges into and through the main stem over a 30-year period and identified reaches of net accumulation and scour. Study identified large imbalances in sand and gravel storage throughout the Sacramento River which were attributed to a combination of local hydraulics and bed material grain size distributions.

- ***Modeling the influence of river rehabilitation scenarios on bed material flux in a large river over decadal time scales*** (Singer and Dunner in press). Evaluated gravel augmentation, levee set-backs, and flow alteration on the Sacramento River using stochastic hydrology model and calibrated sediment transport formula. Showed that gravel augmentation (to improve salmonid spawning habitat) induced gravel accumulation locally and downstream, levee setbacks (to restore the river corridor) lowered sediment flux, and flow alteration (to mimic natural flow regimes) systematically decreased total annual average bed material flux.

- ***The influence of major dams on hydrology throughout the drainage network of the Sacramento River basin, California*** (Singer in press). Analyzed streamflow data from ten Sacramento River tributaries for periods before and after dam construction. Results showed limited flood control benefit of foothill dams in the lower Sacramento River valley, and potential hydrologic signature of climate change.

Field Measurements of River Bank Erodibility Along the Sacramento River. Constantine et al. (2006a) measured the erodibility of five different types of bank material along the Sacramento River: non-cohesive sand, non-cohesive gravel, indurated silt, cohesive clay with silt or sand, and cemented alluvium. The only type of material not tested was dense cohesive clay like that found in an oxbow lake deposit. Testing of a particular bank material type was carried out where that material composed the lower part of a river bank. In the case of indurated silt, blocks fallen from the upper bank but resting on the lower bank were tested. The results show that for non-cohesive banks, sandy banks are about 9 times more erodible than are banks with gravel at their bases. The most resistant non-cohesive banks, however, are those with an indurated upper silt layer. When indurated silt blocks fall onto the lower bank, they offer substantial protection from erosion, reducing erodibility by 5 times in the case of gravel banks. According to the jet-test results, non-cohesive banks are up to 5 times more erodible than cohesive banks composed of clay with silt or sand. The most resistant banks are those composed of cemented sand and gravel where erodibility is too low to be measured by the jet-test apparatus. The results from these field tests are useful for understanding geologic controls on and improving prediction of Sacramento River meander migration.

A Bed-Material Sediment Budget for the Sacramento River from Hamilton City to Colusa and Its Relation to Rates of Meander Migration. Constantine et al. (2006b) constructed a detailed bed-material sediment budget for an 85-km segment of the Sacramento River using the numerical model FLUVIAL-12 to facilitate computation of flow and sediment transport in a curved channel and to examine patterns of sediment storage on the scale of a bend or multiple bends. They used an 8-yr hydrograph to drive the simulation and compared the results with long-term migration rates measured from aerial photographs to determine the spatial correlation between net bed-material storage and rates of channel shifting. The model predictions showed an overall decline in average annual bed-material sediment flux with distance downstream, indicating net deposition over the 85 km reach, a prediction that is consistent with measured decreases in slope and grain size and with previous, lower-resolution sediment budgets constructed over the same distance. At a finer scale, the model predicted the presence of distinct zones of net bed-material deposition and erosion. Within zones of deposition, predicted cross-sectional changes include bar deposition, the occurrence of which is corroborated by recent aerial photos. They also found that measured long-term migration rates are higher in zones of deposition than in zones of erosion, and suggested that this spatial correlation indicates that availability of sediment for deposition on bars is an important control on migration rates in the Sacramento River. The experimental model runs also indicated that where upstream sources of sediment exist, deposition of the material on a bar downstream can accelerate erosion of the outer bank there.

Patterns of Sedimentation Observed in Off-Channel Water Bodies of the Sacramento River. A team of researchers from UC Santa Barbara, UC Berkeley, and CNRS in France (Constantine et al. 2006c) described patterns of sedimentation observed in off-channel water bodies of the Sacramento River and attempted to identify controls on the rates of their terrestrialization. They found that the angle of connection between the upstream arm of each water body and the main channel controls rates of infilling; water bodies whose arms intersect at lower angles experience higher rates of infilling than those whose arms intersect at higher angles. They also found that gravel makes up a greater proportion of fill in the rapidly in-filling water bodies, implying that the duration in which the water bodies transmit bed material is an important control on in-filling rates. The removal of off-channel water bodies from the floodplain through terrestrialization may have significant implications for the function of the Sacramento River ecosystem. This study is part of an effort to identify the controls on the rates of terrestrialization of the off-channel water bodies of the Sacramento River, and may allow for projections to be made of the duration in which off-channel water bodies exist in the floodplain.

Glenn-Colusa Irrigation District Studies

In 1988, Glenn-Colusa Irrigation District evaluated conditions along the river between Woodson Bridge and Hamilton City (WET 1988). This study also indicated that the sinuosity of this reach increased from 1.57 in 1896 to 1.62 in 1923. The findings of the study stated that increased sinuosity reduces the channel slope, and that this would cause increased deposition in the upstream area of the meander bend that would lead to the cutoff - instead of removal of mixed forests, as summarized in the CALFED Flow Regime Study. The CALFED Flow Regime Study indicated that this study assumed that there was adequate sediment in the water column to deposit in the channel as slopes become flatter, which may not be the case throughout the reach. The CALFED Flow Regime Study also indicated that this mechanism does not exclude the effects of vegetation removal.

Riparian Vegetation Studies

California Department of Water Resources Cottonwood Seedling Survival Studies

The Environmental Services Section of the Northern District of DWR is conducting a long-term study of Fremont cottonwood (*Populus fremontii*) to better understand specific growth habits and determine flow regime requirements. The study locations were characterized by active point bar and cutback complexes in the riparian zone. In 2002, the study was conducted at one site (River Mile 192.5). Two additional sites were added in 2003 and 2004 (River Mile 183 and 172). All three sites were located between Hamilton City and Butte City. Most of the monitoring program was conducted during the growing season to facilitate observations of germination and seedling establishment elevations, measurements of root growth and elevations, and analysis of hydrograph patterns and river stage. The initial study concept was developed based on information provided by The Nature Conservancy (Roberts et al. 2002). This study is described in later portions of this section and predicted that successful cottonwood establishment occurs at about 5.5 to 9 feet higher than summer mean low water (MLW) of 9,000 cfs.

Studies in 2002. In 2002, DWR observed that cottonwood seed release started in mid-April and extended into late June. Flow in mid-April of 2002 was about 4,500 cfs and increased throughout the seed release period. The study indicated that seedlings germinated along the water edge, at relatively low elevations on the point bar. By July 2002, flows had increased to more than 11,000 cfs, and the study indicated that seedlings germinated at higher elevations throughout the season and experienced repeated inundations. Seedlings were documented at elevations four to seven feet lower than the predicted establishment zone, and the average height of seedlings reported for the 2002 season ranged from 0.79 to 1.2 inches. The study suggested that the limited growth may be due to the high water levels in the root zone. In addition, the study documented maximum seedling densities of 90 to 100 seedlings/10.76 square feet for the season and zero percent survival in September. The study also indicated that observed seedlings which established on non-transect locations and survived beyond September lacked the bulk density to survive the first major storm event in December 2002 when a peak flow of approximately 80,000 cfs inundated the seedlings with 10 feet of water.

Studies in 2003. In 2003, the study considered a revised "recruitment box." As previously described, the "recruitment box" studies predict the zone for successful seedling establishment. The 2003 predicted recruitment zone was revised to 3-6 feet above a summer mean low water of 8,500 cfs on the Sacramento River.

This study reported that the peak flow during seed release in 2003 occurred on May 4 and was about 48,123 cfs at Hamilton City. The hydrograph flow pattern was atypical of a natural snowmelt pattern, which contributed to seedling mortality. The flows receded to 16,532 cfs by May 13 and then increased again between May 13 and May 17 when seedling monitoring began. Between May 30 and June 2, flows receded at about 3.2 inches/day and resulted in seedling mortality. From June 14 to June 26, flows decreased by 5,000 cfs, or 1.6 inches/day. This flow reduction was fatal to seedlings, and seedlings were later inundated when flows increased between July 4 and July 14. Between August 7 and August 11, the flow receded at a rate of 3.2 inches/day to 6,000 cfs and was fatal to an observed cluster of seedlings.

This study observed seedlings that germinated following May 17 when flow rates decreased. These seedlings mostly occurred between 0 and 3 feet above mean low water. This area is not located within the "recruitment box". The study reported that seedling densities increased throughout May, peaked in June, and decreased to zero percent by mid-August. The seedlings that germinated in May did not survive. A new band of seedlings was documented on June 5 when densities peaked, and this band was affected by the reduction in flow to 5,000 cfs, when many of the seedlings died as the point bar soils (sands or silt mixed with gravel and large cobbles) remained too high above the water level. This study also noted that seedlings that remained into early July were inundated by high flows and subjected to rapid reduction in flows in August. Finally, a cluster of over 100 seedlings was observed and only two remained on October 8, as described in the study.

The Nature Conservancy Modeling of Plant Communities

The Nature Conservancy published "Modeling Plant Community Types as a Function of Physical Site Characteristics" to begin to identify the relationship between how local site characteristics affect vegetation composition at restoration areas (The Nature Conservancy 2002a). The study included surveys between 1990 and 1994 at 106 sites in four restoration areas. The surveys included soil characteristics, depth to gravel refusal, depth to groundwater refusal, and depth to sand refusal in the first 15 feet of soil. In 2001, the sites were revisited about 4 to 7 years following restoration and the vegetation was classified as forest, savanna, and grasslands. The study indicated forest cover increased with moderately deep soils and high groundwater, and savanna and grasslands increased on deeper soils or sand. The study results also indicated that forest cover occurred in and near abandoned channels and transitions to savanna or grasslands towards center of point bars. Savanna also occurs on floodplain areas without meander channels and grasslands occur on floodplains with gravels, according to the study. The study used this information and results from other studies to develop a predictive model to correlate soil characteristics and flood frequencies to vegetation patterns.

The Nature Conservancy Pilot Investigation of Cottonwood Recruitment

In May 2002, "A Pilot Investigation of Cottonwood Recruitment on the Sacramento River" was prepared to calibrate the box model, discussed above, for the Sacramento River and to conduct a preliminary investigation into issues related to cottonwood recruitment (Roberts et al. 2002). The study evaluated the impacts near RM 192.5 for the 1983, 1986, 1995, and 1997 floods that represented 50-70 year, 5-10 year, and 10-20 year return-interval events. The site is located at a point bar with sandy gravel overlain by sandy silt at an active meander channel that moves about 67 feet/year. The location evaluated in the study has two distinct age cohorts of cottonwoods, and included excavations of the root crowns of 28 cottonwoods to identify the elevation of establishment for trees that represent a range of ages, with the older cohorts located farther away from the active river channel. Cores were taken from 40 trees from the excavated root crowns to determine ages. In addition, a streamflow gauge was established to develop a stage-discharge relationship using discharge data at Hamilton City, about 5 river miles upstream of the site.

As part of this study, rates of recession were calculated for spring runoff events and cottonwood seedlings were excavated to determine growth rates for roots. The study indicated that cottonwoods were established at 5.5 to 9 feet above mean low water. The study applied the box model to the Upper Sacramento River and discussed the predicted establishment elevation as 9 feet above mean low water. Flow comparisons indicated that flows from 36,000 to 53,000 cfs inundate 118 to 123 feet above mean sea level, which is within the range of elevations for cottonwood establishment. The study noted that flood monitoring stage and flood warning stages occur at Hamilton City at 142 and 148 feet above mean sea level, respectively.

Comparison of data collected during the study indicated that most of the cottonwoods at the study location established in 1965 and 1974. Hydrologic records were used to identify years with flood events and spring runoff conditions that were consistent with suitable conditions on other rivers for cottonwood cohort establishment. The study indicated that events occurred in 1964, 1967, 1969, and 1971. Peak flows during these events were 144,000 cfs (1964), 92,000 cfs (1967), 110,000 cfs (1969), and 94,900 cfs (1971) which represented 15, 3, 4, and 3 year return events, respectively. April 15 was assumed as the initiation of seed release for cottonwoods, and surface water elevation at the site on April 15 for the appropriate flood event years were 121.5, 118, 116, and 122 feet above mean sea level. Hydrologic records were evaluated to correlate years with flood events and high spring runoff with observed age of cohorts. Peak flow events in 1974 and 1978 reflected return events of 20 and 5 years, respectively, and would have had surface water elevations of 121 and 119 feet above mean sea level, respectively.

This study also included a comparison of historical photographs and determined that the the older cohort was located in the channel alignment on the 1960 and 1964 photos, and on a developing point bar in 1969. The younger cohort was starting before 1976. The study discussed the possibility that the cohorts started following the 1964 and 1974 flood events and that the locations of the point bars at that time would be consistent with the projected establishment elevation.

The study also described a cohort that was established in the early 1980s but was limited in extent as compared to other cohorts. The study did not have adequate data to determine the limiting factors, but speculated that impacts due to installation of riprap and a levee on the opposite bank in 1983 may have had some effect.

Seedling root growth rates were observed and compared to surface water recession rates in 1965, 1971, 1974, and 1978 as years with spring runoff conditions. The observed growth rates were 0.87 inches/day on an average basis with a maximum rate of 01.26 inches/day. The study indicated that if soil moisture is maintained in the capillary fringe by other means than river elevations, the recession rate of the river may not be critical.

This study also considered that steep gravel bars along the main channel, such as those that commonly occur adjacent to a bank opposite riprap, have limited flat area available for seedling establishment. Results of the evaluation of historic flow patterns during seed release periods indicated that spring surface water elevations are too low to provide adequate moisture at the elevation appropriate for seedling establishment, and that seedlings established at lower levels are lost to scour events in following years.

The study also discussed the reduced frequency of high flow events and spring runoff events associated with operations of Shasta Dam. Observations during the study indicated that sand bar willows were more successful than cottonwood on point bars between Red Bluff and Colusa. This success is because sandbar willows are more successful at lower surface water elevations than cottonwoods. The study also considered changes in Shasta Dam releases that could provide appropriate flows for cottonwood establishment at the study location.

The study also considered effects of bank protection and hydrology during seed release periods in the spring. More specifically, the study discussed that although high flow conditions associated with preparing surfaces prior to seed dispersal were appropriate in 1986, 1995, and 1997, limited cohorts were established. The study described that following installation of bank protection on the opposite bank in 1983-84, the erosion shifted across the point bar and that the channel shifted. In addition, water surface elevations during the seed dispersal period in both 1986 and 1997 were too low to wet the potential seed beds.

The Nature Conservancy Pilot Investigation at Beehive Bend

The "Beehive Bend Subreach Addendum to: A Pilot Investigation of Cottonwood Recruitment on the Sacramento River" used methods previously developed at RM 192 to evaluate conditions at RM 183 and 172 (The Nature Conservancy 2000). The site at RM 183 is located upstream of USACE project levees and bordered with bank protection on the west side of the river. RM 172 is characterized by levees on both sides of the river and bank protection bordering the site on both sides of the river. Both locations are characterized by erosion, and the study indicated that at RM 172, the river migrated approximately 112 feet between 1986 and 1993. There are three to four distinct cohorts at each site.

During the study, 34 and 32 cottonwood tree root crowns were excavated at RM 172 and 183, respectively. Stage discharge relationships were developed using flow gauges at Ord Ferry Bridge and Butte City and stage recorders at the sites. The study determined that the average elevation for establishment was 7.2 and 9.1 feet above mean low water at RM 183 and 172, respectively as compared to 7.1 feet for RM 192 (described above). The study results indicated that several cohorts were established prior to 1983 when bank protection was initiated in this area, and limited cohorts may have been established from 1983 - 1986 and from 1995 – 1997, and occurred within 3 to 6 feet above mean low water elevation. The study considered that recruitment at lower elevations could occur due to channel degradation associated with channel narrowing, accelerated erosion, and depletion of islands and point bars. The study also discusses that consequences of channel degradation could also reduce moisture to all riparian vegetation and increase susceptibility to non-native invasive species.

Evaluation of the spatial extent of the riparian forest at these locations indicated that recruitment areas were not as limited as determined for RM 192 for willow and cottonwood, but willow is the dominant species. The study considers that willows may become the dominant colonizer species due to rapid recession rates and lower surface water elevations during seedling establishment periods.

The study discusses the comparison of steep point bars and reduction in successful recruitment. The discussion indicates that this may not be the only limiting factor, but it will contribute to lack of success.

Comparison of hydrologic conditions at the sites indicated that flows of 23,000 cfs to 37,000 cfs would be required to provide appropriate surface water elevations at RM 172, 183, and 192. These flows would have been realized in flood events of calendar years of 1952, 1957, 1958, 1963, 1965, 1967, 1974, 1978, 1982, 1993, and 1995. The study indicated that these years generally correlated to establishment of cohorts. The study discusses that the frequency of flood events has decreased following construction of Shasta Dam, but flows from tributaries also provide high flows.

The study considers three scenarios to modify the flow regime to improve cohort success. The study indicates that a critical factor is the timing of water releases, not the volume of flow events, especially during the spring time recession limb to mimic spring runoff.

Quantifying Vegetation Loss on the Sacramento River: a Case Study Comparing Future and Past Impacts

A team of UC Davis researchers (Fremier et al. 2006) used a model of river channel meander migration coupled with ecological data to evaluate the potential effects of a newly proposed water diversion structure on the Sacramento River. This study also included an analysis of previous water diversions to estimate total impact. The study simulated 130 years of meander migration on the Sacramento River, CA under seven flow scenarios: pre-dam, post-dam, current base operations and four scenarios with the proposed off-stream storage diversion unit in place. Models of riparian plant species were overlaid on the simulated floodplains to quantify the aerial extent of impact for each species. Modeled off-stream storage scenarios produced 6-9% less migration than a base scenario. Migration potential has decreased 38% due to changed flows (not considering bank revetment) when measured from pre-dam conditions, and 22% if measured from post-dam conditions. If bank revetment is accounted for, migration potential has decreased 79% from pre-dam conditions. Vegetation modeling suggests that mid-seral communities will be the most impacted within a 130-year time frame. The methods applied in this study allow for quantitative measures to assess the impacts of flow on the remaining habitat along the Sacramento River, and therefore on potential ecological impacts of reduced meander migration rates caused by flow regulation.

Riparian Valley Oak (*Quercus lobata*) Forest Restoration on the Middle Sacramento River

Griggs and Golet (2002) compared survival and structural development of oaks planted as acorns at six riparian restoration sites initiated by The Nature Conservancy from 1990 to 1994 on the floodplain of the middle Sacramento River, California. At nearly all restoration sites Valley oak (*Quercus lobata*) comprised a major component of the planting design. Valley oaks are a keystone tree species of lowland floodplain habitats in California's Central Valley, contributing greatly to the structural and biological diversity of riparian forests in the region. The focus of this study was on how the plants responded to natural site conditions following the cessation of maintenance activities (including irrigation and weed control). Initial comparisons demonstrated considerable variability among sites in survival and structural development (i.e., stem diameter, canopy cover, and dominance). Although some of this variability was ascribed to known physical and biological differences in site conditions (e.g., soil type, herbivore pressure, etc.), the authors noted that additional study and more detailed assessments of site conditions would be required to further understanding of factors that affect valley oaks on the Sacramento River floodplain.

Characterizing Hydrochory Along the Sacramento River, California

Researchers from CSU Chico and UC Santa Cruz (Little et al. 2006) documented the species composition and abundance of viable seeds deposited during sediment deposition in flood events along the Middle Sacramento River to test the hypothesis that species composition and abundance differs between winter and spring flood events. Seed dispersal by flooding (hydrochory) is important for the regeneration of riparian plant communities, but little quantitative data on hydrochory exists for the Sacramento River. In fall 2005 sediment traps were placed on floodplains within five restoration and five remnant forest sites in the one-year flood-frequency interval. After large winter flood events, the mats were retrieved from the field and transferred for germination trials. The mats were replaced and collected again after spring floods. Each mat with its deposited sediment was transferred into a flat on top of a thin layer of potting soil. Both trials occurred in outside conditions and were irrigated as necessary. Germinating seeds were identified to species weekly where possible, and characterized by life form, native status, and wetland status. Results showed that a greater percentage of germinating individuals and species were exotic species. Germinating grasses were heavily dominated by exotic species including *Lolium multiflorum, Poa annua, Polypogon monseliensis,* and

Piptatherum miliaceum. However, native sedges and a native *Juncus* germinated with moderate frequency. *Acer negundo* was the only native tree species that germinated. Early results from the spring germination trials were similar to the winter trials with respect to species composition. Sampling will be continued throughout the summer, at which time more detailed results will be obtained. This research gives insight into the importance of flooding and the timing of flood events for the regeneration of remnant and restored riparian plant communities along the Middle Sacramento River.

Recreation and Socioeconomic Studies

The Nature Conservancy Recreational Opportunities Study

The Nature Conservancy completed the "Sacramento River Public Recreation Access Study" (The Nature Conservancy 2003a) This study summarized previous studies conducted to assess existing public recreation uses, access, needs and opportunities on lands along a 100-mile actively-meandering and at times flooded stretch of the Sacramento River between Red Bluff and Colusa. The report makes recommendations on enhancements to existing facilities and programs, and development of other publicly owned properties along the river. The report concludes that recreation planning along the Sacramento River needs to strike a balance between recreation use, other human uses, and programs for the protection and restoration of the dynamic Sacramento River ecosystem. The report only addresses recreation, and does not discuss the flow regime of the river.

The Nature Conservancy Economic Indicators Study

Members of the Sacramento River Conservation Area Forum have recognized that potential social and economic impacts associated with habitat restoration along the Sacramento River corridor are of concern to implementing entities and the public. In 2000, The Nature Conservancy received a CALFED grant to assess the regional socioeconomic effects of riparian habitat restoration along the Sacramento River from Red Bluff to Colusa. The results were presented in "A Socioeconomic Assessment of Proposed Habitat Restoration for the Sacramento River Conservation Area" published in February 2003 (The Nature Conservancy 2002d). The study focused on: 1) changes in regional economic activity and fiscal conditions, and 2) changes in resource costs and benefits. The assessment of economic and fiscal effects included agricultural production, recreation activity, jobs and personal income, and local tax revenue. The assessment of social costs and benefits included farmer's profits, costs for bank and flood protection, recreation benefits, and ecosystem protection benefits.

In general, the study indicated that the regional agricultural economy would be most affected by riparian habitat restoration along the Sacramento River through 2030. The study also found that the greatest opportunity to offset the effects to the agricultural economy is in recreation-related income associated with improved fishing in the region.

While the report does, in general, support the efforts of improving flow regime restoration, specific assessments or conclusions related to water use or the flow regime of the Sacramento River were not included in the study or report.

Land Management Programs

"SB 1086" Sacramento River Conservation Area Forum Handbook (1999)

Sacramento River Area. The Sacramento River Area described in the Handbook consists of about 40,000 acres, of which 12,000 acres was owned by the Federal government in 1999, and 500 acres was owned by the state. Also in 1999, the U.S. Bureau of Land Management was attempting to acquire 19,000 acres of land in Tehama County north of Red Bluff. The Bureau of Land Management also owns and operates Foster Island at River Mile 211 and Todd Island at River Mile 237. The Bureau of Land Management works cooperatively with the Department of Fish and Game, Wildlife Conservation Board, American Land Conservancy, Trust for Public Land, Sierra Pacific Industries, Santa Clara Unified School District, California State University, Chico, Shasta College, California State Lands Commission, Tehama County, Department of Boating and Waterways, and Bend School District. The cooperative efforts include funding for acquisitions and management, development of educational trails and other materials, and public access facilities.

The Handbook describes existing conditions (of riparian forests and the four major river reaches between Keswick and Verona), summarizes conservation programs and institutional considerations, and provides recommended actions. The Handbook includes the following institutional and restoration recommendations: 1) Non-profit management organization for the Upper Sacramento River area; 2) Memorandum of Agreement between all participants; 3) Site specific plans for restoration areas, land acquisition methods, landowner protection, floodplain management; 4) Consistent regulatory and permitting policies; 5) Mutual assistance for public access and recreation enforcement and monitoring programs; 6) Education and outreach programs for an information clearinghouse, workshops, forums, newsletter, and exotic plant management control; and 7) Monitoring and research programs including GIS and topographic mapping databases, development of a model to prioritize habitat protection in a way that would optimize biological diversity and maintain ecological integrity, evaluate the relationship between succession and hydrologic/geomorphic processes, and vegetation monitoring.

In May 2000, a non-profit public benefit corporation called the Sacramento River Conservation Area was established. The Board of Directors of the corporation includes state and local agencies, federal agencies, and landowners. The name of the non-profit corporation was later changed to the Sacramento River Conservation Area Forum, External guidance for the program has been provided by a Technical Advisory Committee that includes agency and academic scientists and other stakeholders. Most of the focus of the corporation is on the inner river zone between Red Bluff and Colusa. A Memorandum of Agreement was signed by 19 federal, state, and local agencies to work cooperatively.

An updated handbook was completed in 2002 (The Resources Agency 2002) and in 2003 (Sacramento River Conservation Area Forum 2003). The Handbook included an updated description of the riparian forest and the four major reaches between Keswick and Verona, summaries of recent conservation programs, institutional issues, and updated recommended actions.

Institutional Issues. The updated Handbook described policies, requirements, and funding opportunities of counties, cities, irrigation districts, reclamation districts, state agencies, federal agencies, and private organizations. The private stakeholders include California Central Valley Flood Control Association, Sacramento River Discovery Center near Red Bluff, Sacramento River Preservation Trust (established following bank stabilization projects between Red Bluff and Chico Landing), and Sacramento Valley Landowners Association.

Recommended Actions. The updated Handbook recommendations were similar to those developed in the 1999 Handbook and included the following institutional and restoration recommendations: 1) Site specific plans for restoration areas, land acquisition methods, landowner protection, floodplain management; 2) Consistent regulatory and permitting policies; 3) Mutual assistance for public access and recreation enforcement and monitoring programs; 4) Education and outreach programs for an information clearinghouse, workshops, forums, newsletter, and exotic plant control; and 5) Monitoring and research programs including a GIS and topographic mapping databases, development of a model to prioritize habitat protection that would optimize biological diversity and maintain ecological integrity, evaluate the relationship between vegetation succession and hydrologic/geomorphic processes, and vegetation monitoring.

The Handbook described that site-specific plans should consider ecological processes at each location, sensitive species, issues for adjacent lands such as trespassing and fire potential. The Handbook also encouraged evaluation of negative effects on local taxes due to the removal of commercial land uses. Following this review, the non-profit organization would solicit funds to acquire and restore the land, obtain permits and approvals, and lead the restoration efforts. This program would apply to acquisitions, conservation easements, and set-aside agreements. Set-aside agreements would provide incentives to private landowners to voluntarily reduce agricultural and bank stabilization activities within the riparian corridor for a short-term renewable term for a payment per acre without transferring ownership of the land or surface easements. The Handbook also addressed bank protection, acquisitions, land trades, and transfer of development rights.

The Handbook identified the need to develop regulatory consistency and streamlining for mitigation measures and banking, and consolidation of permit application processes. The Handbook also described landowner protections especially for adjacent lands that are not participating in the program. The protections would include levee and bank protection, trespassing issues, and funding programs.

These recommendations have been implemented by the corporation to continue restoration efforts in the inner river zone and coordinate with efforts of other agencies, such as recent restoration activities by the Corps of Engineers at Hamilton City.

Study Findings

Riparian Forest Description. The riparian forests of the Sacramento River are characterized by deciduous broadleaf trees. The primary successional forest includes willows and cottonwoods that are adapted to colonize overbank areas of fresh sands and gravels as spring water elevations recede with rapid foliage and root growth. Sycamore seeds are released in January as surface water elevations rise to allow deposition of seeds on high terraces during high water events. This study notes that riparian forest plants include specific adaptations that provide for establishment on areas that are seasonally inundated with periodic deposition of sediment. The periodic erosion and subsequent deposition provides new point bars for willow and cottonwood recruitment. As willows and cottonwoods become established, they trap sediment among their roots, thereby allowing species that require silty and moist soils (e.g. box elder) to establish among the willows and cottonwoods. The Handbook also describes the importance of certain types of vegetation to certain types of wildlife. For example, willow scrub supports nesting blue grosbeaks and cottonwood supports foraging for yellow-billed cuckoos.

The Handbook describes issues related to discontinuous habitat along the Sacramento River. A continuous riparian corridor with a wide variety of plant species in various stages of growth (i.e. a mosaic) is important to provide foraging corridors with cover from predators, nesting sites with adequate area to allow younger birds and animals to grow, and a variety of food sources that occur throughout all seasons. Fragmentation of the riparian forest can reduce the use of the forest by some species. For example, the Handbook describes that Western yellow-billed cuckoo requires dense, deciduous forests with low understory species adjacent to slow-moving water. Suitable forest patch sizes for nesting are usually greater than 300 feet in width and several thousand feet in length because the thick cover in patches of this size reduces potential for predation, provides adequate area for nesting pairs, and provides suitable habitat for food, including caterpillars. Other species have similar needs for relatively large areas of riparian habitat. Therefore, the Handbook recommends working towards maintenance, acquisition, or creation of larger forest patches as compared to many smaller patches with equal area. However, in some situations several small patches in close proximity may be better than a large, highly isolated forest patch. The Handbook also indicates that a fragment with a larger ratio of interior area to perimeter length has more habitat value than a long, narrow fragment with more perimeter length to interior area.

The SB1086 Advisory Council recommended establishment of an ”Inner River Zone” where natural fluvial geomorphic and associated ecosystem processes would be allowed to occur. The concept was based upon voluntary participation by landowners and agencies. The Handbook also describes a “Riparian Forest Succession” zone and a 100-year meander belt. The 100-year meander belt was described as a combination of all historical channel locations between 1896 and 1991. Because the average lifespan of a cottonwood tree is about 100 years, the 100-year meander belt encompasses all successional stages of riparian forest. The Handbook recognizes that some restrictions on the extent of the meander belt may be necessary to protect sensitive public and private facilities. The 100-year meander belt boundaries were compared with two erosion condition projections by DWR (one assuming maintenance of current bank stabilization and one assuming removal of all current bank stabilization) to define guidelines for the Inner River Zone that willing participants can use to develop site-specific plan in this zone.

Description of Major River Reaches from Keswick to Verona. The Handbook describes the geological and vegetation characteristics of each reach, land use issues, and recommendations to evaluate projects within each reach with respect to methods to: 1) protect physical processes where not influenced by human activities; 2) allow riparian forests to reach maturity through conservation programs; 3) restore physical and successional processes, especially by allowing flooding and by developing more natural flow regimes to coincide with seed establishment periods; and 4) conduct reforestation activities, with priority for re-establishment of large forest areas. These methods are considered with respect to the following restoration guidelines.

- Use of ecosystem and sustainable approach for recovery of special status species
- Use of most effective and least environmentally damaging bank stabilization to allow minimum meander where appropriate
- Maintenance of flood control and bank protection programs
- Participation of landowners only on a voluntary basis
- Provide full consideration of agency and landowner concerns
- Provide for an information exchange and educational program

Recent Conservation Programs. The Handbook describes several programs developed to restore areas along the Upper Sacramento River, including the CALFED Program (described in following portions of this section), Sacramento River Project, Sacramento River National Wildlife Refuge, Sacramento River Wildlife Area, Sacramento River Area, State Parks lands along the Upper Sacramento River, Sacramento River Bank Protection Project Mitigation, and Reclamation Board projects.

Sacramento River Projects

The Nature Conservancy (TNC) is conducting several related studies in support of its Sacramento River Project (see detailed descriptions in categories above). The project is focused along the mainstem of the Sacramento River from Red Bluff to Colusa as a riparian protection, restoration, and sustainable agricultural project. The project includes public and private partners to protect and restore lands within the floodplain. One aspect of this project is to demonstrate examples of integrated land use along the Sacramento River. Land has been acquired since the 1980s to create large areas of riparian forest using biologically and economically feasible methods. Monitoring programs have been used to understand the mechanisms of riparian forest establishment and to assess restoration efforts.

In 1994, The Nature Conservancy implemented a sustainable farming program to integrate agriculture and wildlands in an environmental and economical manner. The program was completed with California State University, Chico, University of California Cooperative Extension, and farmers on several farms managed by The Nature Conservancy. The program included field trials of biological pest controls. In 1996, the Biological Prune System Program was developed to provide education and technical support for sustainable agricultural practices and funded by California Department of Pesticide Regulation.

Kopta Slough was the first restoration project in the Sacramento River Project. This 700-acre site near Corning was initiated in the 1980s and is owned by the State Controller's Trust. Research conducted at this site includes restoration methods for land remaining in agricultural production and other restoration methods. In 1999, 140 acres had been planted with riparian forests.

The Nature Conservancy, together with the Corps of Engineers, U.S. Bureau of Reclamation, and U.S. Fish and Wildlife Service, restored 260 acres as mitigation for a bank stabilization project. In 1999, 203 acres had been planted, including the River Unit, Sam Slough Unit, Princeton Ferry Unit, Loman Unit, and Shaw Unit. The conceptual idea was for the areas to be planted in the first year of restoration, and then irrigation and weed control provided for two years. The areas were to be self-sustaining after three years with an annual monitoring program.

In 1991, a 2,900 acre conservation easement was purchased in Butte County from the owner of the 18,000 acre Llano Seco Ranch. The easement included a riparian forest, oxbow lakes, and cropland. The project provided opportunities to restore riparian and grassland areas in a manner that is compatible with agricultural activities.

The Nature Conservancy works with U.S. Fish and Wildlife Service to acquire and manage land under a Cooperative Land Management Agreement for the Sacramento River National Wildlife Refuge. Some of the land is leased to farmers that are involved in agricultural and restoration activities. In partnership with the Point Reyes Bird Observatory, monitoring is conducted for birds in riparian forests adjacent to agricultural land and in restoration areas. The Nature Conservancy also works with California State University, Chico to develop restoration techniques including propagating more than 29,000 native plants for restoration activities by 1999, University of California Cooperative Extension, and pest management companies.

Sacramento River National Wildlife Refuge

This refuge (described below in more detail) is one of the most recent additions to the Sacramento National Wildlife Refuge complex and is envisioned to include 18,000 acres along the Sacramento River between Red Bluff and Colusa. The refuge was established in 1989 and included 6,544 acres owned by U.S. Fish and Wildlife Service and 1,281 acres of riparian conservation easements in 1999. Many of the refuge restoration activities include cooperative efforts such as with the Parrot Ranch. The Wildlife Conservation Board completed the combined acquisition under fee title and conservation easements of 14,000 acres.

Sacramento River Wildlife Area

The California Department of Fish and Game manages habitat at the Sacramento Wildlife Area located between river mile 145 and river mile 215 (from the Mouth of Jewett Creek near the northern border of Tehama County to the Sacramento River State Recreation Area north of Colusa). The wildlife area includes 3,615 acres where the river is allowed to maintain channels, oxbow lakes, backwaters, banks, and related habitats. These refuge lands are protected with land use constraints and limited public access. The California State University, Chico University Farm manages prune and almond orchards and field crops on the Pine Creek Unit of the wildlife area (at river mile 195 to 197).

Other areas managed in a similar manner by Department of Fish and Game include Island Fishing Access, Cottonwood Wildlife Area, Battle Creek Public Access, Bonnyview Road Fishing Access, Bend Bridge Public Access, Anderson Fishing Access, and an additional 950 acres (including Turtle Bay East Fish Access, Redding Red Bluff River Park and Fishing Access, Beaver Lake, and Collins Eddy). There are also 350 acres of conservation easements along the Sacramento River.

State Parks

The California Department of Parks and Recreation owns and manages about 700 acres in William B. Ide Adobe State Historical Park, Woodson Bridge State Recreation Area, Irvine Finch River Access, Bidwell-Sacramento River State Park, and Colusa-Sacramento River State Recreation Area.

State Lands Commission

The State Lands Commission is responsible for management of several larger areas along the Upper Sacramento River near Battle Creek, Lawrence Island, and Mary Lake.

Sacramento River Bank Protection Project Mitigation

The conservation easements between Red Bluff and Collinsville (at the confluence of the Sacramento River and the Delta) are located on the waterside of the levees and were approximately 300 acres in 1999. In addition, the Reclamation Board acquired about 780 acres on Phelan Island and Murphy Slough as mitigation and maintenance of the Sacramento River Bank Protection Project. The Handbook summarized a 1987 review of management of conservation easements and indicated that the easements were only partially successful due to "overuse" of fire and cultivation. The Handbook indicated that a 1991 review of mitigation measures found that most lands acquired were not restored at that time and that bank swallow and fishery mitigation structures did not fully provide habitat values as described in previous planning studies.

Reclamation Board Projects

The Reclamation Board purchased 440 acres through 1990. These areas are managed cooperatively with Sacramento River National Wildlife Refuge and Sacramento Wildlife Area.

Sacramento River National Wildlife Refuge

The U.S. Fish and Wildlife Service recently implemented a program to reestablish or enhance native riparian vegetation on lands within the Sacramento River National Wildlife Refuge (SRNWR) owned (in fee title) by the Service. Approximately 2,372 acres of land on 11 existing units or subunits within the SRNWR will be planted or allowed to revegetate with native vegetation as a result of the proposed action. These efforts focused on restoring or enhancing natural vegetation communities that have been converted to agricultural and other uses in the past. To accomplish restoration, native species will then be planted in a mosaic of riparian communities and actively maintained for several years. The restoration sites are along the Sacramento River from River Mile (RM) 240 downstream to RM 164 on the Ryan, Ohm, Haleakala, Pine Creek, Kaiser, Phelan Island, Koehnen, Hartley Island, and Stone units of the refuge.

Sacramento River Wildlife Area

The Sacramento River Wildlife Area is composed of approximately 3,770 acres of important riparian habitat located along a seventy-mile reach of the Sacramento River in Colusa, Glenn, and Butte Counties. The Wildlife Area includes thirteen physically separate units that extend from RM 145 just north of the City of Colusa, upstream to RM 215, or three miles south of Woodson Bridge.

The Department of Fish and Game prepared a Comprehensive Management Plan that describes the commitment to manage the important resources of this Wildlife Area in accordance with State and Federal laws, incorporating the best available scientific information and professional judgment. Department of Fish and Game also committed to coordinate and cooperate with Wildlife Area neighbors, other local interests, the Sacramento River Conservation Area Forum and other conservation entities that are active along the Sacramento River. This Plan proposes practical, science-based conservation of the natural ecosystem with provision for compatible public recreation uses. It is based on an ecosystem approach to habitat management consistent with the principles of the Sacramento River Conservation Area Handbook and the objectives of the California Bay-Delta Program. It is also intended to contribute to the recovery of Special Status Species and the maintenance of other native species and game species utilizing natural processes to create a sustainable system over the long term.

The plan notes a number of conclusions consistent with those associated with the Sacramento River Conservation Area Forum. For example, the regulation of flows for water supply and flood control that is provided by Shasta Dam has seriously impacted the ability of the river to meander and to create and renew riparian habitat. The flood flows are reduced in the winter and spring such that the frequency and duration of inundation are reduced. The rate of flow is greatly increased in the summer season and varied in response to water demand, especially those south of the Delta. The loss of riverine processes, primarily related to flow regulation and bank protection, has seriously impacted the ability of the river to meander and to create and renew riparian habitat.

The plan notes that these changes to the natural conditions make conservation and restoration of riparian habitat necessary to support special status species, other native species, and game species of fish and wildlife. More specifically, the initial colonization and long-term survival of these species is directly related to the river's flow regime. If the flow level drops too fast, the roots of young plants cannot maintain connection with groundwater and subsequently die. Recently, 505 acres of riparian habitat within the Wildlife Area have been replanted with native species. This restoration occurred as part of eight separate projects, with the first occurring in 1992 and the most recent in 2002. In each area, managers determined that the natural processes alone would not restore the area to riparian habitat of sufficient value in the near term. Irrigation was generally provided for a three year establishment period. Beyond these general references to historical flow regime processes and Wildlife Area water uses, the plan does not specifically evaluate or recommend either the flow regime of the river or irrigation water requirements.

CHAPTER 7. FLOW REGIME MODIFICATION SCENARIOS INVOLVING SITES RESERVOIR

The NODOS investigation of scenarios will include identification of appropriate conceptual models and use of analytical tools. As mentioned previously, early conceptual formulations conceived that the flow regime of the Sacramento River and some associated ecosystem processes could be improved using NODOS facilities. The NODOS PMT had specifically requested that the Flow Regime TAG provide guidance on the opportunities available to improve the flow regime. A number of discussions at Flow Regime TAG meetings centered on these potential opportunities. Eventually, in order to explore these opportunities in greater detail, two sub-groups were formed. A fisheries sub-group and a channel formation sub-group focused on developing a more comprehensive listing of ecosystem restoration opportunities that could be accommodated with NODOS implementation. Ultimately, five flow regime modification scenarios were considered and are described in this section.

The discussion of the scenarios here does not indicate comprehensive justification or priority of restoration scenarios for inclusion in NODOS alternatives. The scenarios do, however, provide a starting point for prioritizing and justifying flow regime modification scenarios that may be included in NODOS alternative formulations. DWR and Reclamation recognize and appreciate input from members of the flow regime TAG in development of these scenarios. The agencies will continue to seek advisory input from the TAG, other agencies, and stakeholders as justification and prioritization of restoration scenarios are developed.

Historic Flow Regime Modifications Identified

Some of the largest changes in the Upper Sacramento River flow regime have occurred due to the following modified flow conditions.

- Reductions in the magnitude and duration of peak flows during late-winter and early-spring storms that disturb the soil and contribute to formation of point bars in-channel and overbank habitat areas suitable for seed germination.
- Reduction or elimination of “snowmelt runoff” patterns (including recession rates) in spring that provided soil moisture for successful seed root growth, especially in the overbank areas.
- Abrupt reductions in mid-October flows following or during the fall-run Chinook salmon spawning period and increased summer flows.
- Sporadic and unsustained flows into the bypasses during peak flow events, including the Yolo Bypass.
- Diversions from the Sacramento River that entrain or entrap juvenile fish.

North-Of-The-Delta Offstream Storage Facility Assumptions to Be Used In Flow Regime Modifications

Presently, DWR and Reclamation are considering several reservoir locations as well as Sacramento River and tributary diversion locations in NODOS planning studies. Those studies are ongoing and not complete at this time. For this evaluation, however, DWR and Reclamation assumed that Sites Reservoir is the North-of-the-Delta Offstream Storage facility. This evaluation also assumes use of Tehama-Colusa Canal, Glenn-Colusa Irrigation District Main Canal, and a new pipeline to convey water from the Sacramento River to the offstream reservoir. The assumptions for these facilities are briefly summarized below.

Reservoir Assumptions

The NODOS reservoir is assumed to be located at Sites, about eight miles west of Maxwell, with a capacity of 1.8 million acre-feet. Water would be conveyed from the Sacramento River to Funks Reservoir, which acts as a forebay and afterbay for Sites Reservoir. Funks Reservoir is located west and north of Maxwell (Figure 3-1), on the Tehama-Colusa Canal, and is currently used as a regulating reservoir.

Diversion and Conveyance Assumptions

In addition to studying several reservoir locations, DWR and Reclamation are studying a number of conveyance options that will be combined to develop conveyance “alternatives”. For Sites Reservoir, sources include the Sacramento River, using the three conveyances described above, and tributaries of the river. For this discussion, conveyance will assume use of TC and GCID canals and a new pipeline.

Use of Tehama-Colusa Canal is assumed to include a new intake structure similar to that recently considered by the Tehama Colusa Canal Authority and Reclamation as part of the Fish Passage Improvement Project at the RBDD. The scenarios considered in this evaluation would not require the use of Red Bluff Diversion Dam and consequently diversion would occur throughout the year. This would eliminate fish passage problems at RBDD and also provide a high degree of reliability of existing deliveries in the spring and fall. The existing Tehama-Colusa Canal would be used with only minor modifications and would provide a total capacity of 2,100 cfs to Funks Reservoir. (Note: DWR and Reclamation are also considering other alternatives that would expand the canal capacity in several increments up to 5,000 cfs.) Water diverted from the Sacramento River at Red Bluff would be conveyed to Funks Reservoir and then Sites Reservoir. The diversion and conveyance to Sites would be operated in a manner that would not conflict with existing Tehama-Colusa Canal deliveries. Water released from Sites Reservoir would be conveyed to Funks Reservoir to serve a large portion of the Tehama-Colusa Canal Authority service area by gravity.

Diversions are assumed to continue at the Glenn-Colusa Irrigation District intake near Hamilton City at up to 3,000 cfs. Existing capacity of the GCID Canal near Funks Reservoir is about 1,800 cfs. The scenarios considered in this evaluation assume that the existing diversion structure would be used with minor modifications to accommodate winter diversions. The existing Glenn-Colusa Irrigation District Canal would be used in the scenarios, assuming some lining of the canal and construction of a regulating reservoir and a pipeline connection to Funks

Reservoir. The regulating reservoir would be used to pump water from the Glenn-Colusa Irrigation District Canal into Funks Reservoir. (Note: DWR and Reclamation are also considering several alternatives that could expand the canal capacity in several increments up to 5,000 cfs.) The pipeline and regulating reservoir would intercept the existing GCID Canal near Delevan Road. The pipeline is designed to also convey water from Sites Reservoir through Funks Reservoir and back into the Glenn-Colusa Irrigation District Canal to serve a large portion of the service area by gravity.

A new 3,000 cfs river diversion opposite Moulton Weir and near the Maxwell Irrigation District diversion is also included in the scenarios considered in this evaluation. The new diversion would include a new intake and fish screen, pump station, and pipeline to Funks Reservoir. The pipeline would be parallel to and near Delevan Road. The final reach of the pipeline would also convey water from the Glenn-Colusa Irrigation District Canal. The pipeline is designed to also convey water from Sites Reservoir through Funks Reservoir and back to the Sacramento River for potential uses downstream. Additional studies considering water quality, impacts to aquatic habitat, and flow regime patterns would need to be completed to determine the actual feasibility of the return of water to the river. At this time, this evaluation is only considering the physical feasibility of such a facility. (Note: DWR and Reclamation are considering several different capacities for the intake facility and pipeline that range from 1,500 to 5,000 cfs.) One 12-foot inside diameter pipeline is required for every 1,000 cfs in capacity. The large pipes have thick walls and a total outside diameter of about 15 feet. Assuming appropriate spacing between pipes in the corridor, a 3,000 cfs facility would require approximately 60 feet of width. Pipelines are being considered for the new conveyance to avoid adverse impacts to wildlife that can become trapped in or whose migration routes can be disrupted by canals. Pipelines also will allow continuing cultivation of the land following construction, as compared to removal of the cultivated lands if canals are constructed. Finally, use of a pipeline will avoid exacerbation of potential flood effects associated with a canal crossing the Colusa Basin.

Operational Assumptions

There are several concepts being considered for the use of NODOS to improve Sacramento River flow regime. One of the concepts would increase the duration of full channel flows in the river to improve conditions between Keswick and Colusa for channel formation, vegetation establishment, and fisheries. Some of the supplemental water released from Shasta Lake could be diverted into Sites Reservoir using one or several of the diversion and conveyance facilities described previously. This re-captured water would be subsequently released to serve Tehama-Colusa Canal and Glenn-Colusa Irrigation District canal users, thus “repaying” the supplemental water released from Shasta. This operation also would reduce the amount of water diverted during the irrigation season.

Another concept would include diversion of water that is excess to water required in the system to meet water right users needs or regulatory flows. Water stored in Sites Reservoir could then be used for a number of identified needs including flow regime modifications, other restoration scenarios, or other water use needs.

Diversion of water at any of the three river diversion locations may be limited by the presence of suspended sediment. As described earlier, preliminary observations indicate that suspended sediment concentrations increase during the "rising limb" of the peak flow event and decrease abruptly as high runoff from the westside tributaries decreases following the rain event. It may not be feasible to operate pumps and conveyance facilities to accommodate the high suspended sediment concentrations, and therefore, it may be necessary to limit diversion periods to avoid peak flow/peak sediment events. Specific limitations on diversion related to sediment have not yet been established.

Present U.S. Fish and Wildlife Service requirements for operation of the Glenn-Colusa Irrigation District intake require a minimum instream flow of 4,000 cfs downstream of the oxbow diversion location. This requirement was developed for the presently permitted irrigation season. Due to a lack of other information at this time, this requirement is assumed to be included for all of the following scenarios that utilize the Glenn-Colusa Irrigation District intake.

All NODOS operations would be designed to have no effect on the Central Valley Project's ability to meet water supply, flood control, and existing environmental requirements.

Flood Constraint Assumptions

Flood constraints regarding the operation of the Sacramento Valley Flood Control System are maintained and included as operational assumptions. Specific operational rules exist for both facilities and streamflows at various locations. The primary downstream control point for flow associated with real-time Shasta Dam operations is Bend Bridge. As large flows move downstream to the Delta, the operators of Shasta Dam and other flood-related facilities must increasingly accommodate tributary inflows. Examples of flood operation constraints include maintenance of dedicated flood control capacity in Shasta Reservoir and maximum flood flow targets at specific river gage locations such as Bend Bridge.

Flow Regime Modification Scenarios

The following five flow regime modification scenarios have been developed to improve habitat conditions along the Upper Sacramento River. These scenarios have been derived from the Historic Flow Regime Modifications Identified list at the beginning of this section. The following discussions include brief descriptions of considerations to determine feasibility and, if potentially feasible, assumptions that could be used in subsequent analyses. While these scenarios have not yet been associated with specific restoration goals and objectives, some preliminary progress has been made in understanding the type of response and ecosystem benefits that these scenarios may support. In addition, the evaluation of these scenarios has not been completed and may require extensive analysis and consideration of many factors. However, the following discussion is provided to facilitate consideration of these concepts that could integrate methods to improve flow regime conditions, meet the CVP legal commitments, and provide flexibility to users of Sacramento River water. Furthermore, the scenarios have been developed to facilitate operations modeling using CALSIM II. Ultimately, if these concepts are considered further as NODOS formulations are refined, specific operation rules will need to be clearly stated in terms of facility criteria that could be implemented by project operators. Additional evaluation and modeling may be required to analyze the effectiveness of these scenarios in providing ecosystem restoration benefits. The CALSIM modeling will help indicate the ability of NODOS to provide the specific flow regime conditions.

The five following scenarios to improve environmental conditions are considered in this section.

1. Scenario 1 - Increase flows during peak storm events in late-winter and early-spring - Red Bluff to Colusa to improve cottonwood seed dispersal, support stream meander processes and the development of point bars.
2. Scenario 2 - Modify spring flows into a snowmelt pattern in years with peak storm events in late-winter/early-spring - Red Bluff to Colusa to improve seed dispersal, recruit large woody debris, improve cottonwood germination and survival, and provide increased support for riparian vegetation and dependent species.
3. Scenario 3 - Stabilize fall flows to avoid abrupt reductions - Keswick to Red Bluff: from September through November to protect salmon spawners and their redds from dewatering, improve rearing habitats for winter-run Chinook and steelhead, and increase the natural production of all runs of Chinook.
4. Scenario 4 - Increase flows (especially duration) diverted into Yolo Bypass in March and April during years with high flows in those months to reduce fish stranding and loss, improve rearing conditions for juvenile Chinook, improve spawning and rearing for Sacramento splittail, and improve upstream fish passage for white sturgeon.
5. Scenario 5 - Reduce spring diversions at Red Bluff (to provide water into the Tehama-Colusa Canal) and at Hamilton City (to provide water into the Glenn-Colusa Irrigation District Canal) to protect all runs of Chinook salmon from entrainment and protect juvenile steelhead, lamprey, and sturgeon.

Scenario 1 - Increase Flows During Late-Winter and Early Spring Peak Storm Events

Peak flow events with extremely high flows are required periodically to cause disruption of the soils in the overbank areas along the main channel. Within the in-channel areas, these high flows redistribute and recruit sediment, supporting stream meander and point bar development, which sustain high quality salmonid, other fish, and wildlife habitat. More specifically, disruption of the soil lens allows re-stratification of soil particles and development of a soil surface that will more easily allow germination of seeds, primarily cottonwood, when the seeds are released in the late-spring.

To emulate more closely the flow regime of a pre-Shasta Dam condition, supplemental flows (in addition to those that would currently be released under the existing operating criteria) would need to be released at Keswick during specific peak storm events. This flow regime analysis did not establish specific criteria for when supplemental releases would occur or the magnitude and duration of supplemental flows. A portion of the supplemental flows could be re-diverted using NODOS diversion and conveyance facilities associated with the Sacramento River.

To achieve the benefits of the increased flows, supplemental flows would need to be re-diverted downstream of Red Bluff, where the meander channel starts, and probably more towards Colusa. As described above, the maximum flow that could be re-captured would be limited by the capacity of the GCID and new pipeline conveyance facilities. For the purposes of this analysis, if it is assumed that 10,000 cfs could be diverted and recovered using an expanded Glenn-Colusa Irrigation District canal and new pipeline opposite Moulton Weir, this capacity would still often not be sufficient to increase the moderate size peak flow events into events that would rework the overbank soils and then fully recover the supplemental flows.

The primary controlling flood management operational limit is 100,000 cfs at Bend Bridge. There is also an operational limit of 79,000 cfs at Keswick and a notification and coordination requirement associated with required road closures in Redding for flows greater than 36,000 cfs. The notification and coordination requirement would not preclude supplemental releases resulting in flow greater than 36,000 cfs under the current flood management rules, but that flow can be considered a starting point where flood effects would begin. Since supplemental flows would be released from Shasta Lake to achieve the Scenario 1 objective, these flood management operational constraints will limit the size and frequency of the supplemental releases.

Potential Environmental Benefits: Environmental benefits that might accrue by supplementing flows during late winter and early spring peak flow events include:

- Improved cottonwood seed dispersal
- Stream meander processes
- Point bar development

These benefits would support aquatic and riparian habitats for all runs of Chinook salmon, other anadromous fish, and riparian-dependent species.

Potential Evaluation Tools: Conceptual models of riparian regeneration, stream meander, and species life histories would contribute to discussions and improved understanding of the manner in which this scenario could provide environmental benefits. In addition, numerical models such as CALSIM II, SIAM, and channel migration models would further improve the overall understanding of the potential benefits or environmental weaknesses in this scenario.

Flow Regime Scenario 1 Conclusion: Additional evaluation is necessary to determine the magnitude, duration, and frequency of supplemental releases that would be required to support and sustain the conditions and benefits described above.

Scenario 2 - Modify Spring Flows into Snowmelt Patterns in Years with Late-Winter /Early-Spring Peak Storm Events

Historically, receding Sacramento River flows during the snowmelt from late March through July coincided with seed dispersal for many native plants, including willows and cottonwood. As described in Chapter 6, recent studies have correlated recession rates for Sacramento River flows of 1.1 to 1.3 inches/day to root growth rates for seedlings and the successful establishment of willow-cottonwood cohorts. Historical “snowmelt pattern” flows in the Sacramento River at Bend Bridge occurred prior to construction of Shasta Dam between 1892 and 1938. The “snowmelt pattern” as used in this evaluation refers to a relatively asymptotic flow reduction recession pattern during spring. This flow regime characteristic is contrasted against abrupt declines in flow rates.

This evaluation considered snowmelt pattern flows apparent at Bend Bridge in 1893, 1897, 1904, 1905, 1907, 1910, 1914, 1916, and 1938, as described in Chapter 3. There is limited evidence from studies that cohorts successfully established during these snowmelt years. This scenario concept is based on the hypothesis that successful establishment of willow-cottonwood recruits is closely associated with the timing of seed dispersal and the historic snowmelt flow pattern. This analysis does not attempt to correlate cohort success with either spring rain events or successor soil substrate conditions providing relatively elevated groundwater levels that may also significantly contribute to cottonwood establishment.

The Bend Bridge site is located in an area that has relatively stable geology, and this analysis assumed that the present cross-section is similar to the cross-section prior to 1938. Stage-discharge values included in the U.S. Bureau of Reclamation 2003 Operations Criteria and Plan (OCAP) study were used to determine flow elevations, as summarized in Table 7-1. The hydrographs for each of these years were evaluated to determine the recession rate or rates following the last major storm event or when snowmelt flows became apparent in the hydrograph. In some years, the recession rate changed once or twice during this period.

TABLE 7-1. Average Recession Rates During Snowmelt In Sacramento River At Bend Bridge.

Year	Dates of Recession	Flow Decline During Recession (cfs)	Range of Elevation Decline During Recession (inches)	Average Recession Rate (inches/day)
1893	May 27 to June 27	19,800 to 11,400	105 to 54	1.65
1897	April 22 to May 9	22,800 to 14,600	115 to 75	2.67
	May 9 to June 20	14,600 to 8,000	75 to 31	1.05
1904	May 6 to June 18	28,300 to 10,900	138 to 51	2.02
1907	April 30 to June 9	18,000 to 10,700	95 to 46	1.2
1910	March 26 to April 8	28,000 to 17,000	137 to 90	3.9
	April 8 to May 24	17,000 to 8,000	90 to 31	1.28
1914	April 14 to April 25	28,000 to 23,600	137 to 120	1.55
	April 30 to June 3	18,200 to 12,200	96 to 60	1.03
	June 3 to June 21	12,200 to 8,300	60 to 33	1.5
1916	March 26 to April 9	23,600 to 18,200	120 to 96	1.7
	April 9 to May 28	18,200 to 9,540	96 to 41	1.1
1938	April 8 to June 28	29,600 to 7,240	142 to 25	1.65
1965	April 8 to June 17	15,600 to 9,370	82 to 40	0.6
1974	May 12 to July 8	17,800 to 13,500	94 to 68	0.5

All of the years considered in the snowmelt analysis also included large storm events that resulted in flows of more than 40,000 cfs in March or early April and at least two storm events between late March and mid-June. The 40,000 cfs flow threshold was based upon observations reported in studies conducted by the Nature Conservancy as previously summarized. Years that meet these criteria in the CALSIM II simulation period (1922 - 1994) include 1938, 1941, 1948, 1957, 1958, 1963, 1964, 1965, 1974, 1978, 1979, 1982, 1983, and 1993. The analysis of snowmelt flow patterns also considered the average monthly changes in flows, as summarized in Table 7-2.

In years where March was the peak flow, April flows are often about 43 percent less than March flows. With the exception of 1902 (21%) and 1907 (51%), May flows are 31 to 43 percent less than April flows. Similarly, with the exception of 1907 (21%), June flows range from 28 to 52 percent less than May flows. Average monthly flows in March or April (when the peak occurs) are greater than 25,000 cfs in all but one candidate snowmelt runoff candidate year. Average monthly flows in June are less than 15,000 cfs in all candidate years.

TABLE 7-2. Comparison Of Average Monthly Flows For Years With Snowmelt Patterns In The Sacramento River At Bend Bridge.

	Average Monthly Flows (cfs)				Change in Average Monthly Flows (cfs)		
Year	**March**	**April**	**May**	**June**	**March to April**	**April to May**	**May to June**
1893	37,032	38,670	24,416	14,887	4%	-37%	-39%
1897	21,650	22,650	13,723	8,051	5%	-39%	-41%
1902	25,819	21,760	17,098	9,159	-16%	-21%	-46%
1904	73,058	38,277	24,055	11,611	-48%	-37%	-52%
1905	31,106	17,663	12,140	8,038	-43%	-31%	-34%
1907	55,300	31,480	15,277	12,033	-43%	-51%	-21%
1910	28,932	16,010	9,308	6,314	-45%	-42%	-35%
1914	24,710	27,553	15,729	10,257	12%	-43%	-35%
1916	28,861	16,473	10,997	7,955	-42%	-34%	-28%
1938	51,484	29,133	20,139	9,915	-43%	-31%	-51%

The results of this analysis were directly compared to the average monthly flows developed through the CALSIM II Baseline simulation. It is not possible to compare on a "year-to-year" basis due to the assumptions used in the CALSIM II simulation. A more appropriate comparison was to compare the changes in average monthly flows in the years with similar characteristics to the snowmelt patterns that occurred prior to construction of Shasta Dam. Actual daily flows were evaluated to identify years with flows equal to or greater than 40,000 cfs at Bend Bridge in late March or early April and another lesser storm in late April or May. This occurs in 1938, 1941, 1948, 1957, 1963, 1964, 1965, 1974, 1978, 1979, 1982, 1983, and 1993. Flows and average changes in these years during the snowmelt period are presented in Table 7-3. Red Bluff was selected as the location for the flow comparison because it is located near Bend Bridge (serves as the basis for this analysis) and it is located at the upstream portion of the reach of the meander channel. Flow patterns of the CALSIM II results for Sacramento River flows at Red Bluff are similar to flow patterns below Glenn-Colusa Irrigation District intake at Hamilton City and at Moulton Weir. The flow patterns are not similar to flows below Keswick because flows at Red Bluff are influenced by inflow from the Upper Sacramento River tributaries.

In the CALSIM II Baseline simulation for 1948, 1964, 1965, 1979, and 1993, the average monthly flows do not exceed 15,000 cfs in March through June. Low average monthly flows generally are not consistent with the changes in snowmelt patterns prior to construction of Shasta Dam or indicative of major storm effects. Therefore, these years were not considered further in this analysis.

TABLE 7-3. Comparison Of Average Monthly Flows From CALSIM II Baseline Simulation For Years With Comparable Snowmelt Patterns In Sacramento River At Red Bluff.

	Average Monthly Flows (cfs)				Change in Average Monthly Flows (cfs)		
Year	March	April	May	June	March to April	April to May	May to June
1938	53,521	17,134	10,551	9,106	-68%	-38%	-14%
1941	27,443	26,762	16,638	9,394	-2%	-38%	-44%
1948	8,340	14,656	12,083	10,664	76%	-18%	-12%
1957	17,251	10,687	10,093	9,593	-38%	-6%	-5%
1958	32,337	23,541	11,366	10,715	-27%	-52%	-6%
1963	13,419	37,278	10,299	9,064	178%	-72%	-12%
1964	4,740	10,685	8,273	9,670	125%	-23%	-17%
1965	8,843	14,982	10,008	9,643	69%	-33%	-4%
1974	47,930	15,458	9,299	9,812	-68%	-40%	6%
1978	26,748	13,875	10,371	10,294	-48%	-25%	-1%
1979	7,761	7,507	9,141	11,656	-3%	22%	28%
1982	21,643	33,989	9,400	9,619	57%	-72%	-1%
1983	21,641	33,989	9,400	9,619	-75%	-4%	-4%
1993	11,365	11,258	10,784	11,937	-1%	-7%	11%

It is noted that the CALFED Programmatic EIS/EIR Ecosystem Restoration Program suggests spring flows that range from 15,000 – 20,000 cfs for a number of restoration purposes, including create and maintain riparian habitat. The historic snowmelt flows shown in Table 7-2 all have one or more monthly average flows that exceed 20,000 cfs. However, for the purpose of this scenario, the threshold of 15,000 cfs was used to provide a basis for scenario evaluation.

The analysis subsequently focused on modification of flow patterns in 1938, 1941, 1957, 1958, 1963, 1974, 1978, 1982, and 1983. These nine flow modification years in the 72-year CALSIM sequence would provide a recurrence of one in eight years. Flows in March and June were not modified. However, flows in April and May were increased to provide monthly recession rates similar in nature to the snowmelt recession hydrograph pattern observed prior to construction of Shasta Dam. The increase in flows was assumed to be released from Shasta Lake and could be diverted into Sites Reservoir at either the Glenn-Colusa Irrigation District intake or the new pipeline opposite Moulton Weir. If capacity is not available for diversion, it is assumed that this flow would become part of Delta outflow. The modified flows and rates of change for this scenario are presented in Table 7-4. These flows could be used in future CALSIM II analysis to be used for gaming of flow regime modifications.

TABLE 7-4. Proposed Average Monthly Flows For CALSIM II Simulation For Years With Modified Environmental Flow Patterns To Support Cottonwood Establishment Flows In Sacramento River At Red Bluff.

Year	Baseline or Scenario	Average Monthly Flows (cfs) (changes are in bold typeface)				Change in Average Monthly Flows (cfs) (changes are bold typeface)		
		March	April	May	June	March to April	April to May	May to June
1938	Baseline	53,521	17,134	10,551	9,106	-68%	-38%	-14%
	Scenario	53,521	**20,000**	**15,000**	9106	**-63**	**-25%**	**-39%**
1941	Baseline	27,443	26,762	16,638	9,394	-2%	-38%	-44%
	Scenario	27,443	26,762	16,638	9,394	-2%	-38%	-44%
1957	Baseline	17,251	10,687	10,093	9,593	-38%	-6%	-5%
	Scenario	17,251	**15,000**	**11,000**	9,593	**-13%**	**-27%**	**-13%**
1958	Baseline	32,337	23,541	11,366	10,715	-27%	-52%	-6%
	Scenario	32,337	23,541	**15,000**	10,715	-27%	**-36%**	**-29%**
1963	Baseline	13,419	37,278	10,299	9,064	178%	-72%	-12%
	Scenario	13,419	37,278	**16,200**	9,064	178%	**-57%**	**-44%**
1974	Baseline	47,930	15,458	9,299	9,812	-68%	-40%	6%
	Scenario	47,930	**20,000**	**15,000**	9,812	**-58%**	**-25%**	**-35%**
1978	Baseline	26,748	13,875	10,371	10,294	-48%	-25%	-1%
	Scenario	26,748	**19,000**	**13,500**	10,294	**-29%**	**-29%**	**-24%**
1982	Baseline	21,643	33,989	9,400	9,619	57%	-72%	-1%
	Scenario	21,643	33,989	**18,000**	9,619	57%	**-47%**	**-47%**
1983	Baseline	73,566	18,233	17,466	16,303	-75%	-4%	11%
	Scenario	73,566	**30,000**	**20,000**	16,303	**-59%**	**-33%**	**-18%**

The supplemental releases required from Shasta Lake are presented in Table 7-5. In the nine candidate years, thirteen months were identified for supplemental releases to support cottonwood establishment. If possible, the majority of the flow should be diverted at the new pipeline opposite Moulton Weir and the remaining amount could be diverted at Glenn-Colusa Irrigation District intake.

TABLE 7-5. Average Supplemental Releases From Shasta Lake to Improve Cottonwood Establishment.

Year	Releases in cfs		Releases in acre-feet/month	
	April	May	April	May
1938	2,900	4,500	172,565	276,694
1941	No change required	No change required	No change required	No change required
1957	4,300	900	255,868	55,339
1958	No change required	3,600	No change required	221,355
1963	No change required	5,900	No change required	362,777
1974	4,600	5,700	273,719	350,479
1978	5,100	3,100	303,471	190,612
1982	No change required	8,600	No change required	528,793
1983	11,800	2,500	702,149	153,719

Some of the flows would exceed the combined capacities of the Glenn-Colusa Irrigation District and the new pipeline near Maxwell. For example, a supplemental release in April 1983 of 11,800 cfs could not be fully recovered in NODOS even with the largest diversion facilities under consideration associated with the new pipeline and GCID. Two 5,000 cfs diversions could recover up to 10,000 cfs. In addition, the supplemental releases shown are monthly averages so that actual operations would likely require some days with more than 11,800 cfs and some days would require less than the supplemental release target shown. Under the assumed NODOS formulation previously described, up to 4,800 cfs (3,000 cfs using the new pipeline and 1,800 cfs using GCID) of supplemental release could be recovered.

A number of potential operations solutions exist to support feasibility of this scenario. Gaming scenarios could explore the potential to reduce the release amounts to the diversion capacity or assume that additional flows could be paid back by exchange of water released from Sites Reservoir that would normally be delivered from Shasta. If Shasta Lake spills subsequent to the supplemental release, the exchange pay back would likely not be necessary. And the portion of the supplemental release that was recovered would provide additional supply for other system uses as compared to the no-project existing operation.

The hypotheses related to spring snowmelt recession and successful cottonwood cohort establishment need to be further refined.

Potential Environmental Benefits: Environmental benefits that might accrue by modifying spring flows into snowmelt patterns in years with late-winter and early-spring peak storm events include:

- Improved seed dispersal
- Recruitment of large woody debris
- Improved cottonwood germination and survival
- Increased support for riparian plants, riparian trees, and riparian-dependent species

Potential Evaluation Tools: Conceptual models of hydrology/flow recession and life history of riparian species (cottonwood in particular) would contribute to discussions and improved understanding of the manner in which this scenario could provide environmental benefits. In addition, numerical models such as the daily CALSIM II model and riparian/cottonwood germination models would further improve the overall understanding of the potential benefits or environmental weaknesses of this scenario.

Flow Regime Scenario 2 Conclusion: Supplemental flow releases, shown in Table 7-5, could be diverted into Sites Reservoir through the new pipeline if capacity is available, and remaining flows could be diverted through Glenn-Colusa Irrigation District intake. A significant portion of these supplemental flows could not be recovered directly by Sites Reservoir. However, the need and feasibility to repay these supplemental releases needs to be further investigated. This scenario may conflict with Scenario 5 because flows recaptured at GCID intake will increase rather than decrease diversion during critical periods for fish in the Sacramento River. The theoretical basis for this scenario should continue to be studied and refined so that the role of all factors affecting cohort success can be more accurately understood.

Scenario 3 - Stabilize Fall Flows to Avoid Abrupt Reductions

Flows between Keswick and Red Bluff in the months from September through November are primarily influenced by releases from Shasta Lake during dry weather periods. Flows in September and early October in this reach generally range from 7,000 to 11,000 cfs. These flows are primarily released to maintain cold water temperatures for winter-run Chinook salmon in this reach. The water is often subsequently diverted for Sacramento Valley rice decomposition activities, other downstream uses, or for storage in San Luis Reservoir. Some water flows all the way through and supports meeting Delta outflow requirements. In October, the flow rate typically remains high until mid-October when flows decrease to about 3,000 to 5,000 cfs. This change coincides with a decrease in in-basin diversions, lesser tidal energy occurring in the fall months that results in lower outflow requirements needed to meet Delta standards, and a normal drop-off in CVP exports from the Delta. These relatively lower flows are then maintained until wet weather events begin to occur.

The reduction of flows from 7,000 to 11,000 cfs to 3,000 to 5,000 cfs in mid-October through November occurs simultaneously with migration and spawning for fall-run Chinook salmon in the entire reach between Keswick and Red Bluff. Fall-run Chinook salmon typically spawn in relatively shallow flowing water. Subsequently, if the water recedes in mid-October, incubating eggs can be dewatered and the eggs lost through desiccation. In this reach, the most appropriate flows for successful spawning are approximately 6,000 cfs. The CALFED Programmatic EIS/EIR ERP recommended a stabilized flow range of 6,000 – 8,000 cfs. The 2003 IFIM study by USFWS says that about 4,000 cfs maximizes fall and late fall-run Chinook spawning habitat. Desired flow levels are higher for winter run, but they spawn in summer when flows are high anyway. For steelhead, the maximized condition occurs at 3,250 cfs in the upper 2 reaches and 12,000 cfs in the lower reach (Battle Creek to Cow Creek). The main objective is to avoid dewatering a significant portion of the redds. This objective can be supported by a stable flow regime during spawning periods. There is likely sufficient spawning habitat for the various fish species that spawn in this reach at any stabilized level at or above 4,000 cfs.

This analysis evaluated results from the CALSIM II New Baseline Study. The simulated September flows were less than 6,000 cfs in 9 of the 72 years in the simulation period (1924, 1931, 1933, 1934, 1935, 1977, 1990, 1991, and 1994). The simulated average October flows were less than 6,000 cfs in 49 of the 72 years in the simulation period. In November, the average simulated flows were less than 6,000 cfs in 66 of the 72 years. According to the Baseline Study, flows less than 6,000 cfs occur in every year of the 72-year simulation period.

The total conveyance capacity associated with the existing canals is 3,900 cfs. The largest supplemental fall stabilization release according to CALSIM is 3,000 cfs. According to this preliminary evaluation, these supplemental releases could be accommodated in every year and fully recovered in NODOS using existing capacity. During the following irrigation season, this water can be delivered in the TCCA and GCID service areas so that Shasta storage is maintained at the end of that irrigation season. The effect of lowering Shasta storage between the fall supplemental release and the irrigation delivery payback will need to be assessed.

During September, the flows exceed 6,000 cfs in most years of the simulation period. These flows are primarily released to meet temperature criteria in this reach; therefore, it is not possible to reduce the flows to 6,000 cfs. Years with September flows less than 6,000 cfs generally occur during dry periods when water is not available for temperature control in this reach and therefore, conditions may not be appropriate to support salmon spawning. If CVP operations would be in violation of the temperature control criteria or (b)(2) discretionary actions, these supplemental releases would not occur. Therefore, if Shasta Lake storage is less than 1.9 million acre-feet or if this supplemental release causes storage to be reduced to less than 1.9 million acre-feet, the supplemental release would not occur. These requirements would also be maintained through October and November. There were several years (1954, 1959, 1964, 1976, and 1984) in which temperature requirements of anadromous fish were such that flows could not be reduced below 6,000 cfs. Table 7-6 summarizes the years during which flows could be released from Shasta Lake and diverted into Sites Reservoir to increase flows to 6,000 cfs during the September to November period. The supplemental flows released from Shasta Lake are presented in Table 7-6 as average flow and shown in "cfs" and "acre-feet/month." This scenario will be evaluated using CALSIM II to determine how reliably this objective can be met.

During October, it is still not feasible to reduce flows below 6,000 cfs because the flows are primarily being released to meet temperature criteria. October scenario operations will also be subject to the temperature and (b)(2) requirements. The flows recommended for release in October are also included in Table 7-6.

In November, the flows that exceed 6,000 cfs occur due to storm events; therefore, it is not feasible to reduce the flows to less than 6,000 cfs. November scenario operations will also be subject to the temperature and (b)(2) requirements described previously. The flows recommended for release in November are also included in Table 7-6.

Potential Environmental Benefits: Environmental benefits that might accrue by stabilizing fall flows to avoid abrupt reductions include:

- Protection of spring-run and fall-run Chinook salmon spawners and their redds from dewatering
- Improved rearing habitat and water temperatures for winter-run Chinook salmon and steelhead
- Increased natural production of Chinook salmon

Potential Evaluation Tools: Conceptual models of hydrology and Chinook salmon life history (fall-run Chinook in particular) would contribute to discussions and improved understanding of the manner in which this scenario could contribute to or improve the natural production of Chinook salmon in the upper Sacramento River. In addition, numerical models such as CALSIM II and salmon life history models (such as SALMOD) would further improve the overall understanding of the potential benefits or weaknesses of this scenario.

Flow Regime Scenario 3 Conclusion: NODOS could provide minimum instream flow from Keswick to Red Bluff of 6,000 cfs in September through November. CALSIM and other modeling tools will need to assess both the scenario feasibility and potential effects.

Recent changes in actual operations to provide water for rice straw decomposition will cause a currently unmodeled change in the flows with and without NODOS operations. These recent flow pattern changes need to be evaluated in the future to determine potential changes in the need for flow stabilization.

Scenario 4 - Increase Flow Duration into Yolo Bypass

Currently, high flows are diverted into Yolo Bypass when Sacramento River flows at the Fremont Weir diversion structure exceed 60,000 cfs. As flow rates in the Sacramento River decrease and flows are not diverted into the Yolo Bypass, fish in the bypass channels may become stranded and splittail eggs laid along the bypass channel may become desiccated. Currently, there are several studies considering modifications to the diversion structures from the Sacramento River into the Yolo Bypass to improve habitat conditions. These studies are currently in early phases; however, at least one concept would utilize increased flows from the Sacramento River into Yolo Bypass based upon the following trigger events.

- If average February flows are less than 18,000 cfs in the Sacramento River at Wilkins Slough, and

- If average March or April flows are between 12,000 to 15,000 cfs at Wilkins Slough

Then 3,000 cfs would be released from Sites Reservoir through the new pipeline opposite Moulton Weir to the river for the diversion of about 750 cfs into the Yolo Bypass. This flow regime scenario operation was provided as a preliminary concept by DWR staff working on continuing Yolo Bypass studies.

TABLE 7-6. Supplemental Releases From Shasta Lake to Stabilize Fall Flows.

	September (a)		October (a)		November (a)	
YEAR	Flow in cfs	Flow in AF/mo	Flow in cfs	Flow in AF/mo	Flow in cfs	Flow in AF/mo
1922					1519	90,387
1923			1125	69,174	2392	142,334
1924	1078	64,145	996	61,242	1207	71,821
1925			2720	167,246	3000	178,512
1926			1375	84,545	2266	134,836
1927			2125	130,661	2750	163,636
1928					1561	92,886
1929			604	37,139	2493	148,344
1930			1132	69,604	1582	94,136
1931	848	50,460	1375	84,545	2713	161,435
1932	871	51,828	2185	134,350	3000	178,512
1933	557	33,144	2125	130,661	2750	163,636
1934	735	43,736	1949	119,839	2955	175,835
1935	58	3,451	2250	138,347	3000	178,512
1936			2125	130,661	2750	163,636
1937			781	48,022	1193	70,988
1938			1125	69,174	2750	163,636
1939					81	4,820
1940			1822	112,030	1548	92,112
1941			1125	69,174	279	16,602
1942					1774	105,560
1943					874	52,007
1944			1125	69,174	1698	101,038
1945			1375	84,545	2750	163,636
1946					2100	124,959
1947			535	32,896	2448	145,666
1948			1375	84,545	2750	163,636
1949			1125	69,174	1352	80,450
1950			783	48,145	551	32,787
1951			1125	69,174	2750	163,636
1952					2100	124,959
1953					1980	117,818
1954	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1955					2079	123,709
1956			1375	84,545	1802	107,226
1957					177	10,532
1958			1125	69,174	272	16,185
1959	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1960			823	50,604	1377	81,937
1961			423	26,009	2375	141,322
1962	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1963			1125	69,174	1282	76,284

TABLE 7-6. Supplemental Releases From Shasta Lake to Stabilize Fall Flows.

	September (a)		October (a)		November (a)	
YEAR	Flow in cfs	Flow in AF/mo	Flow in cfs	Flow in AF/mo	Flow in cfs	Flow in AF/mo
1964	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1965			1194	73,416	2750	163,636
1966			1125	69,174	2286	136,026
1967					2019	120,139
1968					747	44,450
1969			1125	69,174	2750	163,636
1970					896	53,316
1971			693	42,611	2550	151,736
1972					1088	64,740
1973			1125	69,174	2750	163,636
1974			295	18,139		
1975					324	19,279
1976	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1977	457	27,193	1179	72,494	2626	156,258
1978					2405	143,107
1979					1996	118,770
1980			1125	69,174	2750	163,636
1981			1125	69,174	968	57,600
1982			1375	84,545	2750	163,636
1983			1125	69,174	1174	69,858
1984	Flows in excess of 6,000 released to meet temperature requirements for anadromous fish					
1985			75	4,612	2149	127,874
1986			1234	75,876	2750	163,636
1987			1125	69,174	1272	75,689
1988			842	51,773	2076	123,531
1989			365	22,443	3000	178,512
1990	340	20,231	1375	84,545	2750	163,636
1991	1343	79,914	707	43,472	1589	94,552
1992			1790	110,063	1593	94,790
1993			1226	75,384	1951	116,093
1994	615	36,595			1584	94,255

(a) The Environmental Flow Recommendation would be to provide a minimum instream flow of 6,000 cfs below Keswick in September through November. These values are the incremental value that would need to be released as compared to the Baseline Run of CALSIM II

The intent of the increased flows is to increase the duration of inundation in the Yolo Bypass to improve aquatic habitat for splittail and juvenile salmon. Current concepts assume that a new "notch" weir could allow diversion of approximately 25 percent of a supplemental upstream release. Other concepts for increasing flow duration in Yolo Bypass may be considered. For example, one alternative concept would be to release water from Sites Reservoir to the Colusa Basin Drain for diversion into the Yolo Bypass through a modified Knights Landing Ridge Cut.

Other alternatives might include releasing water in Cache Creek or Putah Creek via an extension of the Tehama-Colusa Canal.

Under CALSIM II Baseline conditions, the triggers for this event described above would only occur in six years of the seventy two year planning period: 1928, 1930, 1935, 1979, 1981, and 1982. Providing supplemental flows based upon these triggers would provide a recurrence of one year in twelve. None of these years coincide with the years considered for improved flows for cottonwood establishment described above.

Potential Environmental Benefits: Environmental benefits that might accrue by increasing flows into the Yolo Bypass include:

- Reduced fish stranding and loss
- Improved rearing conditions for juvenile Chinook salmon
- Improved spawning and rearing conditions for Sacramento splittail
- Improved upstream fish passage for species such as white sturgeon

Potential Evaluation Tools: Conceptual models of hydrology and bypass operations coupled with life history models for Chinook salmon and Sacramento splittail would contribute to discussions and improved understanding of the manner in which this scenario could contribute to or improve the survival of juvenile Chinook salmon and splittail.

Flow Regime Scenario 4 Conclusion: Release 3,000 cfs from Sites Reservoir to the Sacramento River with 25 percent diversion into Yolo Bypass at Wilkins Slough during the month of March in 1930, 1935, 1979, 1981, and 1992; and during the month of April in 1928.

Scenario 5 - Reduce Spring diversions at Red Bluff (to provide water into the Tehama Colusa Canal) and at Hamilton City (to provide water into the Glenn-Colusa Irrigation District Canal).

During March, April, and May, several important fish species are present in the Sacramento River near the intakes at Red Bluff and Hamilton City, including spring-run Chinook salmon, winter-run Chinook salmon, late fall-run Chinook salmon, fall-run Chinook salmon, Pacific lamprey, river lamprey, and sturgeon. Fall-run Chinook salmon would be the most abundant run at that time.

Currently, diversions occur at Red Bluff Diversion Dam between March and October. Diversions in March and October are generally less than 5,000 acre-feet/month and do not occur in every year. In April through September, diversions range from 14,000 to 43,000 acre-feet/month. This scenario assumes construction of a new fish screen and pumps for the purpose of water supply diversions into the Tehama-Colusa and Corning canals. With these facilities, operation of the Red Bluff Diversion Dam would no longer be necessary for water supplies associated with the canals. This scenario would reduce the adverse impacts to fisheries resources associated with the diversion dam at Red Bluff. Reduction in diversions in spring and summer months with Sites Reservoir would further reduce adverse impacts associated with entrainment and entrapment at the fish screen, especially in April and May. During this period, water would be released from Sites Reservoir to the Tehama-Colusa Canal service area. The simulated April and May diversions for the Tehama Colusa and Corning canals are up to 53,000 acre-feet/month, an average flow of 860 cfs. The portion of the Red Bluff diversions associated with Corning Canal and northern Tehama-Colusa Canal deliveries could not be eliminated using Sites Reservoir without construction of several pumping plants and additional conveyance facilities, and therefore, are not included in this analysis.

Diversions occur in all months at the Glenn-Colusa Irrigation District intake at Hamilton City. The delivery pattern within the district is based primarily on irrigation uses. Some water is delivered in the late fall and winter for wetlands, duck clubs, and wildlife areas. Use of Sites Reservoir could reduce diversions in spring/summer months to decrease adverse impacts associated with entrainment and entrapment at the fish screen, especially in April and May. During this period, water would be released from Sites Reservoir to serve a large portion of the Glenn-Colusa Irrigation District service area. The entire Glenn-Colusa Irrigation District service area could not be served from Sites Reservoir without construction of several pumping plants and additional conveyance facilities, and therefore, are not included in this analysis. According to the CALSIM II Baseline Model Simulation, average diversions are 5,000 acre-feet/month (81 cfs) in March, 94,000 acre-feet/month (1,529 cfs) in April, and 144,000 acre-feet (2,342 cfs) in May.

Potential Environmental Benefits: Environmental benefits that might accrue by reducing spring diversions at Red Bluff and at Hamilton City include:

- Protection of juveniles of all runs of Chinook salmon from entrainment
- Protection of juvenile steelhead
- Protection of Pacific lamprey and river lamprey
- Protection of juvenile sturgeon

Potential Evaluation Tools: Conceptual models of hydrology and fish life histories (Chinook salmon, steelhead, lamprey, and sturgeon) would contribute to discussions and improved understanding of the manner in which this scenario could improve the natural production of all species of anadromous fish in the upper Sacramento River. In addition, numerical models such as CALSIM II and salmon life history models (such as SALMOD) would further improve the overall understanding of the potential benefits or weaknesses of this scenario.

Flow Regime Scenario 5 Recommendation: Minimize diversions at modified Tehama-Colusa Canal intake and Glenn-Colusa Irrigation District intake in March, April, and May to protect fisheries resources. This scenario would require diversion of excess flows or re-patterned flow releases from Shasta Lake to serve these areas into Site Reservoir. Deliveries to these local service areas would be made from Sites Reservoir rather than from Shasta Lake. This scenario may conflict with Scenario 2 in some years.

ISSUES TO BE CONSIDERED IN NODOS INVESTIGATION

During the Flow Regime TAG meetings and preparation of this report, many issues were identified for inclusion in the NODOS investigation. An additional set of issues associated with flow regime and suggested for study is identified in Appendix C, Potential Future Studies.

Issues for NODOS Evaluation

The Flow Regime TAG identified many issues that need to be considered in the preparation of the NODOS environmental and technical documents. The TAG issues are summarized in Table 7-7 and will be considered by the NODOS engineering and environmental team.

Four major issue areas were identified: (1) geomorphology and hydrology, (2) vegetative resources, (3) fishery resources, and (4) terrestrial resources. Many of the issues framed questions related to the level-of-detail. For example, one question was "Will the hydrologic model consider evaporation from lake surfaces?" While it is not the purpose of this report to answer or respond to each of the following questions or statements, it is important to record the issues so that they can be addressed at the appropriate time and in the appropriate NODOS document.

TABLE 7-7. Issues For Consideration in NODOS Evaluation as Identified by the Flow Regime Technical Advisory Group.

Geomorphology and Hydrology
Spatial and temporal uncertainties in hydrology, stream channel and floodplain parameters need to be addressed in hydrologic model simulations.
Channel avulsion and meander cutoffs should be addressed using a meander model.
The NODOS investigation needs to define the timing and magnitude of flows in the river at the potential diversion points for the range of diversion volumes.
The effect of diverting various amounts of flow at different stages in the flood hydrograph needs to be evaluated using an accurate model.
Mitigation measures should consider changes in frequency, timing, volume, and duration of diversions to mitigate adverse impacts associated with potential diversions. The mitigation measures should include removal of bank protection or levees.
NODOS should evaluate impacts of potential diversions on natural ranges of variability of hydrology.
The hydrologic model should consider evaporation from lake surfaces.
Impacts to Yolo and Sutter bypasses and the Colusa Basin Drain should be evaluated.
Limitations of the hydrologic model and its results should be presented.
The NODOS investigation needs to integrate with other efforts evaluating flow regimes in the Central Valley including: • Sacramento and San Joaquin Basin Comprehensive Studies and Ecosystem Function Model • San Joaquin River Restoration Studies
The impacts of potential diversions on bed load transport and sediment budget needs to be addressed
Vegetative Resources
Impacts of potential diversion from the Sacramento River on existing and future publicly funded (such as CALFED Ecosystem Restoration Program) riparian restoration activities needs to be evaluated.
The potential impact of a diversion from the Sacramento River on cottonwood "recruitment flows" needs to be evaluated.
The potential impact of diversion from the Sacramento River on spatial heterogeneity in vadose zone properties and potential effects on the establishment and survival of riparian vegetation needs to be modeled.
The effect of groundwater pumping on water table elevations in the riparian zone needs to be modeled.

TABLE 7-7. Issues For Consideration in NODOS Evaluation as Identified by the Flow Regime Technical Advisory Group.

The effects of stream-aquifer disconnection and unsaturated soil conditions within the riparian zone on the establishment and survival of vegetation needs to be evaluated or modeled in the No Project/No Action Alternative and flow regime alternatives.
• An appropriate number of vegetation community types on the Sacramento River need to be determined for the environmental evaluation. • A comprehensive classification system of plant communities should be used in the evaluation. • An appropriate number of alliance-level communities should be determined. • Identify the common and rare communities • An appropriate number of association-level communities should be identified including the common and rear communities. • The analysis should consider the spatial distribution of communities according to groundwater depth or land age.
Fisheries Resources
The maximum diversions by month that could occur without affecting Pacific lamprey, Chinook salmon, green sturgeon, and splittail and critical months in which diversions should not occur should be determined.
How will a potential diversion from the Sacramento River contribute to costs of programs associated with addressing the loss of species and potential regulation under the Endangered Species Act?
Will a meander model and habitat model be used to address fish habitat and passage issues?
Water quality issues related to changes in fish habitat and survival should be addressed using the appropriate tools.
The NODOS investigation needs to evaluate changes in Shasta Lake storage and the ability to provide adequate summer flows and meet temperature criteria for winter
The primary fish species to be addressed in the NODOS investigation should be identified.
The analysis should consider the best time to divert to minimize effects on fish, identify the time of year and at which flows would water be diverted.
The fish species and life stages that rear downstream of the diversion point when diversions would occur should be identified.
Determine effects of changes in geomorphology on fish habitat in the effected reaches
Determine how different methods of diversion from the river effect fish differently. Identify the various types of screens that are available.
The investigation also should identify minimum flows to meet bypass criteria and hydraulic criteria at the fish screens.
The NODOS investigation should consider use of wintertime gate operations at Red Bluff Diversion Dam to replace the summer gate operation and determine effects of that operation on adult upstream migration and survival of juveniles.
The NODOS investigation should identify threshold criteria for water quality constituents (including nutrients), temperature, and velocities for discharge into the river opposite Moulton Weir to protect fisheries and terrestrial habitat near the discharge.
Fisheries Resources (continued)
Identify if there are water quality constituent sources downstream of Red Bluff that are present in concentrations that approach threshold criteria which require existing flows for dilution to less than significant levels. Determine if potential diversions will reduce the dilution flows. Determine if these conditions vary throughout the year or with hydrologic year type.
The NODOS investigation should identify minimum threshold stages/velocities that would attract invertebrates in the water column, provide an available food source for aquatic organisms, and determine the impacts of potential diversions on these flows.

TABLE 7-7. Issues For Consideration in NODOS Evaluation as Identified by the Flow Regime Technical Advisory Group.

Terrestrial Resources
Determine how a potential diversion from the Sacramento River might impact conditions for the yellow-billed cuckoo, valley elderberry longhorn beetle, and bank swallow.
The NODOS investigation should identify which animal and vegetation species will be used as indicators of riparian ecosystem conditions. The species should be representative of trophic levels and food web dynamics. The important habitat suitability variables should be identified. Key habitat elements for each species should be identified. • Appropriate habitat patches need to be defined and the rate of change within the patches need to be considered with relationship to habitat suitability.
The data sets (spatial and temporal) that will be used for defining the baseline conditions for wildlife species on the Sacramento River should be identified. Data sets from different studies, especially those completed at different times need to be evaluated to determine if the data are comparable.
Habitat suitability models should be used and the accuracy of the models with respect to analytical errors and errors of omission determined.
Habitat for indicator species needs to be regenerated and sustained in the long-term.
The trends for habitat quality for the indicator species under various hydrological and geomorphic regimes needs to be determined over 50-100 year time spans.
The manner in which animal species respond to changes in the vegetation mosaic need to be evaluated.
The vegetation communities and habitat elements are beneficial to the indicator species and should be targeted for restoration and/or conservation.
General Issues
The NODOS investigation should include a cost-benefit analysis.
The NODOS investigation should include a comparison between NODOS and raising Shasta Dam.
The methods that will be used to incorporate review and comments from the NODOS Flow Regime TAG into the NODOS investigation and documents needs to be determined.
The manner in which comments will be presented in the final documents needs to be determined.
The NODOS investigation should include analysis of proposed operational changes on flood protection.

CHAPTER 8. POTENTIAL FUTURE STUDIES

During the Flow Regime TAG meetings and preparation of this report, there were many additional issues that were identified as needing further evaluation and study. This section summarizes the next steps of the NODOS analysis to determine potential benefits and negative impacts of using the NODOS facilities. This section also summarizes issues that have been identified to be completed in future Upper Sacramento River watershed studies that would not be related to NODOS efforts.

Evaluation of the Use of NODOS to Improve Upper Sacramento River Conditions

The following scenarios, as described in Chapter 8, should be considered using a variety of analytical tools, including CALSIM II modeling, gaming spreadsheets, and daily flow spreadsheets. If other models are available, those tools could also be used.

- Modify spring flows into a snowmelt pattern in years with peak storm events in late-winter and early-spring - Red Bluff to Colusa
- Stabilize fall flows to avoid abrupt reductions - Keswick to Red Bluff: from September through November
- Increase flows diverted into Yolo Bypass in March and April during years with high flows in those months
- Reduce spring and summer diversions at Red Bluff Diversion Dam and Glenn-Colusa Irrigation District Intake to protect juvenile anadromous fish from entrainment
- Augment winter and spring peak flows for over bank flooding of the floodplain and flows sufficiently large to promote geofluvial processes

Initially, assumptions will be made for evaluation using the monthly CALSIM II model. The assumptions, as presented in Chapter 8, assumed flow and diversion patterns throughout a month.

Following the CALSIM II model runs, information could be integrated into gaming spreadsheet models or daily flow spreadsheet models could be developed to further refine the benefits and determine the feasibility of improving the flow regime for habitat and fisheries without adversely impacting current water users.

Evaluation of Potential Impacts of NODOS Diversions on the Upper Sacramento River

Impacts associated with NODOS diversions from the Upper Sacramento River have not been evaluated at this time because specific diversion patterns have not been determined. These issues should be considered during those evaluations. This discussion is presented with respect to three diversion locations: 1) Red Bluff, assuming diversion with new pumps through a new fish screen; 2) Glenn-Colusa Irrigation District intake near Hamilton City; and 3) new diversion and fish screen near existing Maxwell Irrigation District intake, opposite Moulton Weir.

All of these intakes would be located on the west side of the channel and would need to be evaluated with respect to diversions that may occur all-year. The reach between Red Bluff and Colusa is characterized by a meander channel that is undergoing sporadic restoration both along the Sacramento River and along tributaries. Therefore, the fish screens used for NODOS diversions will need to consider methods to provide year-round protection of fall-run, winter-run, and spring-run Chinook salmon, sturgeon, and many resident fish. The NODOS alternatives are being developed in coordination with U.S. Fish and Wildlife Service, NOAA Fisheries, and Department of Fish and Game to determine the technical requirements to divert flows up to 5,000 cfs at each location. This information then will be used to determine the physical feasibility of constructing and operating fish screens to divert water at several flows up to 5,000 cfs at each location.

Impacts associated with flow diversions depend upon whether flows are released from Shasta Dam specifically to be diverted by NODOS, or if NODOS diverts "excess" flows from the Upper Sacramento River.

Flows Released from Shasta Dam Specifically for Diversion by NODOS

If NODOS is being operated in a manner that allows flows to be released from Shasta Dam from the fall through early spring months to be specifically rediverted by NODOS for the sole purpose of improving water supply reliability, the base flow conditions will not be reduced during the diversion procedure.

If the flows are diverted at Red Bluff, there would be no changes in the meander channel flows between Red Bluff and Colusa as compared to current operations; however, flows would increase between Keswick and Red Bluff. The increased flows could improve conditions for fish that spawn above Red Bluff. This concept also would reduce flows during the irrigation season between Keswick and Red Bluff because a portion of the water demands for the Tehama-Colusa Canal service area would be provided by NODOS.

If the fall through spring flows are diverted at Glenn-Colusa Irrigation District intake, flows would increase between Keswick and Hamilton City during the diversion procedure. The increased flows could improve conditions for fish that spawn above Hamilton City. These flows would probably not improve terrestrial habitat conditions unless the flow patterns were specifically developed to meet one of the scenarios described in Appendix D. This concept also would reduce flows during the irrigation season between Keswick and Hamilton City because a portion of the water demands for the Glenn-Colusa Irrigation District service area would be provided by NODOS.

If the flows are diverted opposite Moulton Weir, flows would increase from Keswick through most of the meander channel during the rediversion procedure. The increased flows could improve conditions for fish that spawn in the meander channel and area and upstream of Red Bluff. These flows would probably not improve terrestrial habitat conditions unless the flow patterns were specifically developed to meet one of the scenarios described in Chapter 8. This concept also would reduce flows during the irrigation season between Keswick and Hamilton

City because a portion of the water demands for the Tehama-Colusa Canal and Glenn-Colusa Irrigation District service areas would be provided by NODOS.

As discussed above, diversion structures would need to be designed to protect many species of fish through multiple life stages throughout most of the year.

Excess Flows Diverted by NODOS

Diversion of excess flows into NODOS could occur from fall through spring. The determination of "excess" flows would be based upon the ability of the CVP and SWP to meet water rights, water contracts, and environmental requirements that are served by Shasta Dam releases. Diversion of these flows would reduce flows in the Sacramento River downstream of the diversion. As previously discussed, the NODOS alternatives will be developed in coordination with U.S. Fish and Wildlife Service, NOAA Fisheries, and Department of Fish and Game, including development of minimum instream flows downstream of the diversions.

Diversion of excess flows opposite Moulton Weir (associated with potential new conveyance) would not affect flows in most of the meander channel reach (Red Bluff to Colusa). Diversion of excess flows at Red Bluff (associated with T-C Canal) would reduce flows for the entire meander channel reach. Diversion of flows near Hamilton City (associated with GCID canal) would reduce flows in the lower portion of the meander channel reach.

Diversions of the flows during peak flow events would probably not occur during the rising limb of the storm. Sediment is high during the rising limb and could cause operational problems. Therefore, those flows that cause erosion, changes in the channel, and overbank flows would probably be modified to a lesser extent due to these operational problems.

Peak flow events that affect channel formation and cause overbank flows are generally characterized by flows in excess of 40,000 cfs. Diversion following high flow events would probably not change channel formation events based upon information described in the previous sections of this report, however, detailed analysis would be required following the identification of specific diversion patterns and correlation to historic flow events. Diversion of excess flows during periods when flows without NODOS operations resemble snowmelt patterns may need to be limited at Red Bluff or Hamilton City. Specific diversion concepts will need to be identified during development of NODOS alternatives. The alternatives, including diversion concepts, will be identified and reviewed by the NODOS Project Management Team.

Potential Other Studies for the Upper Sacramento River

Numerous studies have been conducted on the Upper Sacramento River, as described earlier. The CALFED Flow Regime Requirements Study included a discussion of issues that required more information to allow a better understanding of channel formation and aquatic/terrestrial habitat along the Upper Sacramento River. Many of these studies were initiated in the past five years; however; other studies still need to be considered. During the completion of these studies, additional information needs have been identified.

The information collected and analyzed to date has improved the understanding of historical changes in the river system. This understanding is helpful in determining methods to modify existing river conditions in a manner that is affordable and acceptable to all users of the Upper Sacramento River. In addition, accurate and appropriate models also must be developed.

As indicated by changes that have occurred at some locations where restoration has been initiated, it may be feasible to realize measurable local improvements without overall system changes in water management and supply flow patterns. Therefore, monitoring will be important as these programs move forward to determine the location and the extent of benefits with all changes in flow regime and land use. Monitoring also will indicate if changes do not result in measurable improvements, and provide an opportunity to understand better the relationship between the physical and biological mechanisms on the river. However, monitoring efforts would occur following the completion of the NODOS planning process and other studies.

Issues identified in the CALFED Flow Regime Requirements Study that have not been fully addressed, issues identified by the Flow Regime TAG, and issues identified in published recent papers and reports that have not been identified as being addressed in this study, which included representatives of many agencies, research programs, and interest groups, are summarized in Table 3-1. Issues identified in published studies and other discussions with interested parties are summarized in Table 8-1 in a format similar to that used in the CALFED Flow Regime Requirements Study. These issues are generally not related to the NODOS investigation, and therefore, would probably not be considered as part of NODOS.

TABLE 8-1. FUTURE STUDY PRIORITIES IDENTIFIED BY THE FLOW REGIME TECHNICAL ADVISORY GROUP

Geomorphology and Hydrology
Does bank erosion occur after a threshold stage, velocity, or period of high flows?
Does bank erosion occur after the flow stages/velocities ramp down? Is the potential for bank erosion related to the downward ramping rate or to the length of time for the ramp?
Is there a threshold stage/velocity to move sediment from bank erosion locations?
Are there assumed or preferred soil densities and particle sizes that should be moved for point bar restoration? Are there assumed ranges of soil densities and particle sizes that would be adverse to channel reconfiguration?
Are point bars primarily formed on the downward ramp of a peak flow event? Are they formed on a gradual flow release from Shasta Reservoir?
Are there threshold stages/velocities where soils are not deposited on point bars and move downstream below Colusa? Should this type of soil event be discouraged by modifying flow patterns?
Are there minimum/maximum threshold stages/velocities that would deposit soils in areas not favorable to point bars between Red Bluff and Colusa?
Are there advantages to maximizing the presence of flows with high sediment loads from the "westside streams" at the beginning of flow events to provide a different type of sediment characteristic than from bank erosion?
What affects the rate of channel migration and bend cut-off at various locations along the river of: • What *were* pre-Shasta Dam rates of channel migration and bend cut-off in relation to flow volume (magnitude and duration)? • What *are* current rates of channel migration and bend cut-off (post-Shasta Dam) in relation to flow volume (magnitude and duration)? • What is the influence of bank stabilization (riprap) on channel migration? • Where and when was bank stabilization installed? • How does riprap affect bend cut-off processes? • How does riprap affect ecosystem development? • How do natural and other geologic constraints affect channel migration?
Can the change in slope of point bars be modeled as a topographic surface?
How has the spatial distribution of land age changed over time (i.e., floodplain age)?
In the current floodplain, what are the boundaries of flood events at recurrence intervals of 1.1, 2, 5, 10, 25, and 50-years?
How do hydro-geomorphic conditions affect topographic patterns? • To what degree does floodplain inundation influence sediment deposition? • To what degree does floodplain inundation influence gravel bar scour?
How do hydro-geomorphic conditions affect vegetation patterns? • To what degree does floodplain inundation influence vegetation scour?
Does the mean summer low-flow (base flow) adequately represent groundwater patterns? • How accurate is a spatial model using this approach?
Are existing flows approaching critical volumes or velocities that if modified could increase or decrease sediment transport regime? Does this occur in all months and all parts of the hydrologic cycle?
What are the maximum flow stages under recent flood control facilities that need to be met to avoid flooding in downstream areas that require flood protection?

TABLE 8-1. FUTURE STUDY PRIORITIES IDENTIFIED BY THE FLOW REGIME TECHNICAL ADVISORY GROUP

Geomorphology and Hydrology - continued
What are the attributes to be protected with respect to channel avulsion and meander to avoid or minimize negative impacts on the river?
How can flow patterns be modified to facilitate ecosystem development, including hydrograph "naturalization?"
How has the recurrence interval of different hydrologic patterns changed following construction of Shasta Dam - what methodology would be used to determine the changes?
What would be the flow criteria to modify winter flow to improve ecosystem objectives?
Does the release of flows in early spring for pre-irrigation season water and subsequent increase in flows in late spring effect recruitment of primary successional vegetation communities?
Do the locations of existing or future diversions effect ecosystem dynamics?
Are there changes in diversion patterns that could improve ecosystem dynamics?
What are the patterns of groundwater depth in the floodplain adjacent to the main stem channel using a base flow model?
What is the relationship between surface water and groundwater recession rates? Are these recession rates uniform spatially and temporally?
Vegetative Resources
Has there been observations and data collection to understand preferred flow stages for seed settlement for: Alder in October/November Oregon Ash in October/November Sycamore in January Valley Willow in May/June *Baccharis* in May/June Box-Elder in October through January Buttonbush in October/November Arroyo Willow in March/April Sandbar Willow in May/June
Are there flows to discourage nuisance species seed settlement on point bars?
Are there flows that help to rework or allow multiple seed dispersal periods to achieve a complex vegetative mosaic?
Based on preliminary observations, are there maximum flow stages and/or temperatures that should be maintained to promote healthy root establishment for each type of plant listed above? Do these flows need to occur multiple times per year? Do these flows need to occur for a series of years, and then could be variable? Does this vary at different locations along the river?
How does root establishment for each type of plant listed above respond to multiple wet years? What are the responses if wet-dry year periods are interspersed? What if there is a series of dry years?
What are the effects of spatial and temporal variability of meteorological conditions on riparian vegetation establishment and survival?

TABLE 8-1. FUTURE STUDY PRIORITIES IDENTIFIED BY THE FLOW REGIME TECHNICAL ADVISORY GROUP

<u>Vegetative Resources - continued</u>
How many discernible vegetation community types are on the Sacramento River? (or, what constitutes a comprehensive classification system of plant communities? • How many alliance-level communities are discerned? Which are common? Which are rare? • How many association-level communities are discerned? Which are common? Which are rare? • How strongly are communities spatially distributed according to groundwater depth? • How strongly are communities spatially distributed according to land age? • Is there a longitudinal trend (north-south) in the pattern and species composition of vegetation communities on the Sacramento River?
What flow and geomorphic conditions favor primary succession (early serial states)? • Can the "recruitment box" theory be implemented as a GIS model? • Does the pre-water delivery season hydrograph depression and subsequent ramp up in late spring affect recruitment of primary successional vegetation communities? • What are the optimal ramping rates for recruiting *Populus fremontii* and *Salix* spp. on islands and point bars? • What is the influence of major geomorphic events such as bend cut-offs on vegetation recruitment and structure (i.e. oxbow lakes and forests)?
What are the rates of secondary succession in later serial stages? • How does plant species composition change with increasing land age? • Does secondary succession have multiple transition pathways?
What regulates plant community growth and development? • How does the magnitude of flood peak affect vegetation structure? • How does duration and spatial extent of flood plain inundation affect vegetation structure? • What is the patch growth rate of communities dominated by *Populus* and several *Salix* species? What is the relationship between patch structure and land age?
How will the effects of spatial and temporal variability of meteorological conditions on riparian vegetation establishment and survival be addressed?
What are the linkages between flow regime changes and riparian vegetation species other than cottonwoods?
Are there flow patterns that may promote nuisance species rather than desirable species?
What are the relationships between soil characteristics such as particle size distribution, soil horizonation, permeability, and moisture holding capacity and the occurrence of successful cohort recruitments?
Fisheries Resources
There are several studies that have considered presence of different life stages for different races and runs of salmonids in the Sacramento River. Are there specific flow stages that have been considered for the life stages present during each month? Are there studies that consider these issues for tributaries?
What are the minimum flow volumes and durations that may be needed to be diverted into the Yolo Bypass to promote fisheries resources at the downstream confluence of the bypass? Does this vary by the occurrence of multiple wet years or multiple dry years?

TABLE 8-1. FUTURE STUDY PRIORITIES IDENTIFIED BY THE FLOW REGIME TECHNICAL ADVISORY GROUP

Fishery Resources - continued What is the potential to meet minimum fish flows in the Delta under current operations, and what types of flows would be desirable from October until May to improve these conditions for delta smelt, Pacific Lamprey, Chinook salmon, green sturgeon, and splittail?
What are water quality criteria, including temperature, that are desirable for all life stages in the Upper Sacramento River for delta smelt, Pacific Lamprey, Chinook salmon, green sturgeon, and splittail?
What are linkages between flow regime changes and alterations to floodplain nutrient cycling? and to macro invertebrate communities?
How do changes in geomorphology affect fish habitat (spawning and rearing)?
How has the quality of fish habitat in the lower Sacramento River changed since flow regulation began and as a result of flow regulation?
Terrestrial Resources
What animal species are good indicators of riparian ecosystem conditions? • What data sets (spatial and temporal) exist for wildlife species on the Sacramento River? • Are the species data sets time series? Are they comparable? • Are special-status species preferable as indicators? • Can indicator species represent trophic levels and/or food web dynamics?
What are the important habitat suitability variables for the indicator species?
How accurate are the habitat suitability models in terms of omission and commission error? • What are the key habitat elements for the indicator species? • How are patches defined for each species? • What are the rates of change of these patches in relation to habitat suitability?
Can habitat for indicator vegetation species be regenerated and sustained for the long-term?
What would be trends for habitat quality of indicator species under different flow regimes over a 50 to 100 year period?
Can habitat for indicator species be regenerated and sustained in the long-term? • What would be the trends for habitat quality for the indicator species under various hydrological and geomorphic regimes over 50-100 year time spans? • How do animal species respond to changes in the vegetation mosaic? • Which vegetation communities and habitat elements are beneficial to the indicator species and should be targeted for restoration and/or conservation?
How do animal species respond to changes in the vegetation mosaic?
Which vegetation communities and habitat elements are beneficial to the indicator species and should be targeted for restoration and/or conservation?

TABLE 8-2. FLOW REGIME AND HABITAT ISSUES FOR THE SACRAMENTO RIVER THAT MAY REQUIRE FURTHER ANALYSIS

Objectives	Issues to be Considered in Future Sacramento River Studies
Flow effects on channel migration	Complete bank erosion surveys and update annually through several hydrologic cycles Further analysis of annual erosion for the reach from Red Bluff to Colusa including correlating observations with measured data. Analyze inundation/duration frequency at erosion sites spaced throughout reach from Red Bluff to Colusa Analyze effects of large woody, debris on channel process and fish habitat at several locations in reach from Red Bluff to Colusa Complete "channel-edge" model to simulate discharges and diversions for several reaches. Previous studies recommended initial modeling of area upstream of Thomes Creek and downstream of Woodson Bridge
Riprap effects on channel migration	Use of recent mapping and classification of riprap to evaluate potential riprap removal locations that are not located near structures
Flows effects on riparian vegetation establishment and succession	Develop stage-discharge relationships at numerous locations between Red Bluff to Colusa. At these locations, complete root excavations, trunk corings, vegetative transects, seedling growth rate, and water uptake studies. These locations also need specific topographic mapping, vegetative mapping including differentiation between species and age, evaluation of historic channel erosion and migration patterns, and correlation to historical flow events. Use this information with recently collected data to reconstruct historical overbank sediment types and elevations with cohort age. Determine the relationships between lateral migration of point bar as compared to channel elevation Complete vegetation maps from Red Bluff to Colusa using remote sensory information and field research. Monitor groundwater and soil moisture near channel, in overbank areas, and adjacent upland elevations to determine relationship between groundwater and soil moisture. The monitoring should be completed throughout the year for several hydrologic years. Develop channel formation, soil moisture, and flow patterns requirements for several vegetative species. Requirements should then be compared to estimated conditions prior to construction of Shasta Dam, conditions between 1945 and 1970, and current conditions following recent changes in CVP operations. This analysis also should consider changes along the river between Red Bluff and Colusa that reflect both spatial and temporal characteristics of vegetation with changes in flow rates and channel conditions, such as bank protection and erosion patterns.

TABLE 8-2. FLOW REGIME AND HABITAT ISSUES FOR THE SACRAMENTO RIVER THAT MAY REQUIRE FURTHER ANALYSIS

Objectives	Issues to be Considered in Future Sacramento River Studies
Identification of sediment transport & channel - floodplain morphology methodology	Complete a sediment model that includes sediment sources on the tributaries, sediment sources from erosion within the channel and overbank areas, and sediment transport. The model should project cross-sectional and planform changes. The model needs to address several types of sediment to reflect a range of particle sizes and densities. The model inputs need to consider variations in geology both vertically and horizontally along channel, overbank areas, and adjacent upland areas. The model needs to consider existing structures and bank protection that effects scour patterns and flow regime. Information to calibrate model should be collected including documented changes in bank erosion rates, channel geometry, and riparian vegetation.
Identification of relationship of food web support for aquatic and terrestrial wildlife and conditions of channel, overbank, and adjacent upland areas	Consolidate existing information and complete surveys of completed life-histories of aquatic and terrestrial wildlife present in the channel, overbank, and adjacent upland areas for several locations between Red Bluff and Colusa. May consider including locations along tributaries near confluence with Sacramento River. Ecosystem relationships would be identified between the species and with the river system conditions throughout the year and through a variety of hydrologic conditions. Further analysis of habitat condition requirements for all life stages for fall-run, spring-run, and winter-run Chinook salmon, sturgeon, and other important fish species in the Upper Sacramento River with potential changes in channel formation and vegetation establishment. Evaluation should include opportunities for spawning and rearing areas and food web support. The analysis may need to consider associated habitat created near tributary confluences with backwater effects from changes in flow patterns in Sacramento River. This evaluation should consider the effects of individual scenarios to allow adaptive management and implementation of individual scenarios.

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APPENDIX A. SUMMARY OF SACRAMENTO RIVER FLOW REGIME TECHNICAL ADVISORY GROUP

The 2000 Flow Regime White Paper was an important part of the initial investigation of West Sacramento Valley reservoirs during the CALFED EIS/EIR efforts. Similarly, a Flow Regime TAG and evaluation was initiated for the current NODOS efforts. The purpose of the NODOS Flow Regime TAG is to consider methods to improve flow patterns in the Sacramento River and identify methods to reduce/avoid impacts in the Sacramento River associated with potential NODOS operations. In addition, the TAG was convened to improve the general understanding of the river's flow regime and related ecosystem processes.

Early in the Progress Report phase of the investigation, stakeholder participants identified the flow regime of the Sacramento River as one of the primary areas of concern related to potential implementation impacts. At the same time, early conceptual formulations of a NODOS project conceived that the flow regime and associated ecosystem processes of the river could be improved with an offstream storage facility. Subsequent to initiation of the current investigation, the NODOS PMT requested establishment of a Flow Regime TAG and associated evaluation to consider methods to improve flow patterns in the Sacramento River and identify methods to reduce/avoid impacts in the Sacramento River associated with NODOS operations.

The mission of the Flow Regime TAG includes the following items.

- Identify Sacramento River flow regime characteristics necessary to support ecosystem processes (including meander channel, fish migration, and downstream habitat quality) and achieve relevant CALFED Ecosystem Restoration Program goals and objectives.

- Identify potential synergies and conflicts between desirable Sacramento River flow regime characteristics and potential NODOS operations in order to: 1) identify NODOS features and operations to assist in achieving relevant Ecosystem Restoration Program and other CALFED objectives; 2) identify alternatives to NODOS that may also achieve these objectives; and 3) accurately evaluate impacts of NODOS alternatives.

- Determine the Sacramento River's potential to achieve relevant Ecosystem Restoration Program objectives to maintain or enhance ecosystem processes (including meander channel formation and fish migration) under existing operational conditions and under assumptions for CALFED implementation of Ecosystem Restoration Program goals.

- Determine the potential effects to the ecosystem processes on the Sacramento River and downstream habitats (including floodplains, bypasses, and the Delta) of diverting water from the Sacramento River during defined higher flow periods for NODOS.

- Identify potential mitigation and strategies to offset potential impacts associated with NODOS and identify potential alternatives to avoid impacts but meet the associated CALFED goals.

- Determine potential benefits to the ecosystem processes and downstream habitat that may be derived from NODOS.

- Determine specific conditions (season, frequency, duration, temperature, water quality, and flows), if any, when diversions from the Sacramento River can be made with minimal adverse impacts to the ecosystem processes, including meander channel formation, fish migration, and downstream habitat.

- Coordinate flow regime studies and findings with associated programs including SB 1086 Program, CVPIA programs, Corps of Engineers Comprehensive Study, and Ecosystem Restoration Program.

- Provide information, analysis, and tools that will assist the SB 1086 Program to meet goals to preserve remaining riparian habitat and to reestablish a continuous riparian ecosystem along the river.

- Coordinate with the CALFED Science Program to allow scientific peer review of the tools, evaluations, and conclusions developed by the NODOS Project Management Team and its member entities relative to the Flow Regime Evaluation.

The Flow Regime TAG consists of the following participants with affiliation:

Laura Allen -- U.S. Bureau of Reclamation
John Baker -- National Oceanic Administration Atmospheric - Fisheries
Randy Benthin -- California Department of Fish and Game
Gary Bobker -- The Bay Institute
Matt Brown -- U.S. Fish and Wildlife Service
Gwen Buchholz -- CH2M HILL
Koll Buer -- California Department of Water Resources
Burt Bundy -- Sacramento River Conservation Area Forum
Dan Castleberry -- California Bay-Delta Authority - Ecosystem Restoration Program
Stacy Cepello -- California Department of Water Resources
Dick Daniel -- CH2M HILL
Steve Evans -- Friends of the River
Rebecca Fris -- California Bay-Delta Authority - Ecosystem Restoration Program
David Fullerton -- Metropolitan Water District
Steve Greco -- University of California Davis
Mike Hagman -- Tehama-Colusa Canal Authority
John Hannon -- U.S. Bureau of Reclamation
Brian Heiland -- California Department of Water Resources
Fred Jurick -- California Department of Fish and Game
Laura King-Moon -- State Water Contractors
Alicia Kirchner -- U.S. Army Corps of Engineers
Gail Kuenster -- California Department of Water Resources
Eric Larsen -- University of California Davis
Sam Lawson -- The Nature Conservancy

Gary Lemon -- U.S. Army Corps of Engineers
Aric Lester -- California Department of Water Resources
Cindy Lowney-- formerly with University of California Davis
Rick Massa -- Orland Water User's Association
John Merz -- Sacramento River Preservation Trust
Tracy Middleton -- California Department of Water Resources
Terry Mills -- California Department of Water Resources
Marlyce Myers –The Nature Conservancy
Tom Patton -- U.S. Bureau of Reclamation
Shawn Pike -- California Department of Water Resources
David Purkey -- Natural Heritage Institute
Don Rasmussen -- California Department of Water Resources
Harry Rectenwald -- California Department of Fish and Game
Jerome Ripperda -- California Department of Water Resources
Mike Roberts -- The Nature Conservancy
Steve Roberts -- California Department of Water Resources
Sean Sou -- California Department of Water Resources
Tina Swanson -- The Bay Institute
Mike Tansey -- U.S. Bureau of Reclamation
Steve Turek -- California Department of Fish and Game
Peter Vorster -- The Bay Institute
Paul Ward -- California Department of Fish and Game
Jim Wieking -- California Department of Water Resources
John Wise -- Natural Heritage Institute
Peter Yolles -- The Nature Conservancy
Dave Zezulak -- California Department of Fish and Game