INTRODUCTION TO ECOLOGICAL PROCESS VISIONS

This section presents visions for ecological processes. Ecological processes are physical and biological processes that act directly, indirectly, or in combination to shape and form the structure and function of an ecosystem. Physical and biological processes included are those that have a strong effect in shaping and influencing the Bay-Delta ecosystem and can be managed to improve the health of the Bay-Delta ecosystem and its resources. Table 1 identifies important ecological processes and the visions in which these processes are addressed and Table 2 presents the basis for their consideration.

Visions describe the role and importance of each process in maintaining the health of the Bay-Delta, a description of how the process currently operates in the ecosystem, stressors and changes to other processes that have altered how they operate in the ecosystem, and approaches for partially restoring processes to improve the health of the Bay-Delta and its biological resources. The Ecosystem Restoration Program Plan (ERPP) implementation objectives, targets, and actions for each ecological process are described in the "Ecosystem Restoration Program Plan, Volume II: Ecological Zone Visions". Table 3 presents the ecological zone in which implementation objectives, targets, and programmatic actions have been proposed to accomplish each process vision.

Table 1. Ecological Processes Addressed in Visions

Vision	Ecological Process
Central Valley Streamflows	Hydrograph; current velocities; estuarine mixing
Natural Sediment Supply	Sediment supply; gravel recruitment; gravel cleansing and transport
Natural Fluvial Geomorphology	Geomorphology
Stream Meander Corridors	Stream meander belts
Natural Floodplains and Flood Processes	Floodwater and sediment detention and retention
	Vegetation succession; overbank flooding; floodplain inundation
Central Valley Stream Temperatures	Water temperature
Bay-Delta Hydraulics	Hydraulic regime
Bay-Delta Aquatic Foodweb	Nutrient inputs; primary production; secondary production; nutrient cycling
Upper Watershed Health and Function	Upper watershed processes

Table 2. Basis for Selection of Ecological Process Ecosystem Elements

Ecological Process	Basis for Selection as an Ecosystem Element
Streamflows	The natural hydrograph refers to the total amount and seasonal distribution of water entering the ecosystem, including surface and groundwater, and includes episodic events such as floodflows and drought cycles. The total volume and distribution in time and location of water supports important ecological processes and functions that sustain habitats and many species of the Bay-Delta, the Sacramento and San Joaquin Rivers, and their tributaries. Human activities have had a large influence on the natural hydrograph of the Bay-Delta and the Sacramento-San Joaquin basin. There are opportunities to restore or simulate, where appropriate, a more natural hydrograph that sustains ecological functions and meets the life requirements of plants and animals.
Bay-Delta hydraulic regime	The natural hydraulic regime refers to the direction and velocity of flows in the Bay-Delta channels on a temporal, tidal, and seasonal basis for a given hydrologic condition. The direction and velocity of flows and their distribution in time and location support important ecological processes and functions in the Bay-Delta that sustain the foodweb, influence the spawning, rearing, and feeding of estuarine and anadromous fish, and support migration of adult and juvenile fish. Human activities have had a large influence on the natural hydraulic regime of the Bay-Delta. There are opportunities to restore or simulate, where and when appropriate, a more natural hydraulic regime that sustains ecological functions and meets the life requirements of fish and wildlife in or dependent on the Bay-Delta.
Natural sediment supply	The natural sediment supply comprises mineral and organic fines, sands, gravel, cobble, and woody debris that naturally enter, deposit, erode, and transport through the Sacramento-San Joaquin basin. Sediment, like water, is one of the natural building blocks of the ecosystem on which many other ecological processes, functions, habitats, and species depend. Gravel, for example, is important for maintaining spawning habitat of salmon and supports the many invertebrates on which young salmon prey. Finer sediments and fluvial processes create the conditions necessary to establish new riparian forests and wetlands. Human activities have had a large effect on natural sediment processes in the watershed. There are opportunities to restore natural sediment processes or to compensate for the loss of sediment supply from building levees, dams, and reservoirs to meet the life requirements of plants and animals.
Natural Fluvial Geomorphology	Geomorphology refers to the ecosystem's natural landscape form that serves to influence the direct effects of water, sediment, and plants on the Sacramento-San Joaquin basin. Geomorphology, like water and sediment, is a key structural component of the ecosystem. Natural barriers, channel morphometry, basin configuration, watershed and channel erosion, and other geological features determine the landscape of the ecosystem. There are opportunities to restore or manipulate geomorphology to benefit ecosystem health.

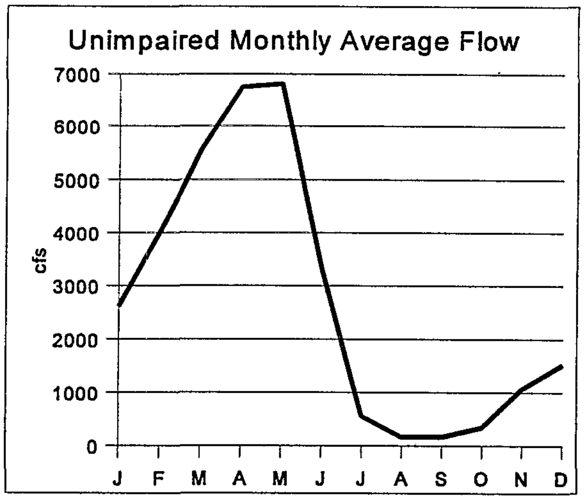
Ecological Process	Basis for Selection as an Ecosystem Element
Stream meander belts	Stream meander belts are the area in which natural bank erosion and floodplain and sediment bar accretion occur along streamcourses. Natural stream meander belts in alluvial systems function dynamically to transport and deposit sediments and provide transient habitats important to algae, aquatic invertebrates, and fish, as well as surfaces that are colonized by natural vegetation that supports wildlife.
Stream temperatures	Water temperature is determined by the natural heating and cooling process of water bodies and flows in the Sacramento-San Joaquin basin. Water temperature in the Sacramento-San Joaquin basin is controlled by water source (i.e., dam releases; runoff; and agricultural, municipal, and industrial discharges); surface and groundwater flow; geomorphology; tides; riparian shading; and, most often, air temperature. Water temperature is a key factor in habitat suitability for aquatic organisms. Unnaturally high water temperatures can become stressors to many aquatic organisms.
Floodwater and sediment detention and retention	Floodwater and sediment detention and retention is the process whereby flows and sediment are retained within floodplains of the Sacramento-San Joaquin basin. Retention and detention of water and sediment within basin floodplains are a secondary process controlled primarily by flow patterns and channel geomorphology, and secondarily by soils and plant communities. Floodwater storage and retention reduce flood effects, soil erosion, peat oxidation, and nutrient loss. The process stores water and sediment either permanently or temporarily, reducing the peak loads of both downstream systems.
Floodplain and flood processes	Overbank flooding, and floodplain inundation refer to seasonal flooding of floodplain habitats and the response of vegetation to the flood cycles. Overbank flooding is a secondary process to water and sediment flow through the Sacramento-San Joaquin basin in combination with geomorphology. Flooding of lands provides important seasonal habitat for fish and wildlife and provides sediment and nutrients to both the flooded lands and aquatic habitats that receive the returning or abating floodwaters. The flooding also shapes the plant and animal communities in the riparian, wetland, and uplands habitat subject to inundation. Opportunities to restore or enhance this process are possible by changing landscape features, geomorphology, and seasonal distribution of flow volume through the system.

Ecological Process	Basis for Selection as an Ecosystem Element
Bay-Delta Aquatic Foodweb	The Bay-Delta aquatic foodweb is driven by primary and secondary production. Primary production refers to the energy produced by algae and other plants through photosynthesis. Primary production of plants in the Sacramento-San Joaquin basin is the basic process that supports the biological system. Nearly all primary and secondary processes have some effect on primary production in the basin. Human activities have altered production in many ways and opportunities to enhance this process exist by manipulating waterflow, nutrients, and geomorphology and alleviating environmental stressors such as salts, herbicides, and other toxins in watercourses. Secondary production refers to the production of energy not directly related to photosynthesis. Secondary production in the Sacramento-San Joaquin basin occurs primarily through the breakdown of plant materials by microorganisms, such as bacteria, fungi, protozoans, and zooplankton, and through large-animal grazing. Organic forms, including the microorganisms and the byproducts of their work, are the base of the aquatic foodweb of the Bay-Delta ecosystem.
Upper watershed health and function	Watershed processes that contribute to maintaining the health of the Bay-Delta ecosystem include runoff, groundwater recharge, streamflow quantity and timing, soil erosion, and sedimentation. Water supply and water quality in the Central Valley are also dependent on healthy watershed processes in the upper portions of the tributary watersheds. Land and resource management in the upper portions of tributary watersheds have substantially modified watershed processes and affected the reliability of inflows of high-quality water to the Sacramento-San Joaquin Delta and San Francisco Bay. Management activities have also affected the available capacity of reservoirs that store water for and provide flood control to downstream residents.

Table 3. Ecological Zones in Which Ecological Process Implementation Objectives, Targets, and Programmatic Actions Are Proposed

Ecological Process Vision	Ecological Zone[1]													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Central Valley Streamflows	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Natural Sediment Supply			●	●	●	●	●	●		●	●		●	●
Natural Fluvial Geomorphology			●	●	●	●	●	●	●	●			●	●
Stream Meander Corridors			●	●	●	●	●	●		●		●		●
Natural Floodplain and Flood Processes	●					●		●		●	●	●		●
Central Valley Stream Temperatures	●					●		●	●		●	●	●	
Bay-Delta Hydraulics	●													
Bay-Delta Foodweb	●													
Watershed Processes				●	●	●	●	●	●	●	●	●	●	●

[1] 1 = Sacramento-San Joaquin Delta
2 = Suisun Marsh/North San Francisco Bay
3 = Sacramento River
4 = North Sacramento Valley
5 = Cottonwood Creek
6 = Colusa Basin
7 = Butte Basin
8 = Feather River/Sutter Basin
9 = American River Basin
10 = Yolo Basin
11 = Eastside Delta Tributaries
12 = San Joaquin River
13 = East San Joaquin Basin
14 = West San Joaquin Basin



Unimpaired Median Monthly Average Flow in the American River below Nimbus Dam, 1962-1992

INTRODUCTION

Streamflow refer to the amount of fresh water flowing in rivers and Bay-Delta channels. Streamflow comes from reservoir releases and surface and groundwater discharge into rivers, the Delta, and Bay. Streamflow varies annually and seasonally with rainfall and water supply management. The total volume and distribution in time and location of water within the Bay-Delta and its watersheds supports important ecological processes and functions that sustain habitats and many species of the Bay-Delta, the Sacramento and San Joaquin Rivers, and their tributaries. Human activities have had a large influence on the natural streamflow pattern of the Bay-Delta and its watershed.

The vision for Central Valley streamflows is to protect and enhance the ecological functions that depend on streamflow including many physical and biological processes that operate within the stream channel and associated riparian and floodplain areas to contribute to the recovery of species and overall health of the Bay-Delta. These natural processes may be limited by low streamflows or by lack of seasonal high flows. Although natural streamflows fluctuate within a wide range, many of the important ecological functions can be supported with a moderated range of flows that will allow concurrent flood control and water supply benefits to be achieved. This vision for Central Valley streamflows will achieve a responsible balance between these sometimes conflicting public trust water resource management benefits.

The vision includes three streamflow objectives:

- **Spring high flow events** - Provide sufficient high flows during spring (March-May) to sustain ecological functions that are dependent on elevated flows by allowing a portion of the natural inflow to pass through large Central Valley reservoirs in spring of all but the driest years.
- **Summer and fall flow** - Maintain sufficient summer and fall base flows to sustain aquatic habitat and ecological functions that are dependent on streamflow.
- **First fall-winter flow event** - Provide sufficient flow during the first significant precipitation event of the water year by allowing a protion of the natural inflow to pass through large Central Valley reservoirs in all but the driest years.

BACKGROUND

Streamflows in Central Valley watersheds are extremely variable. Total annual unimpaired streamflow into and through the Central Valley varies from a low of about 5,000 thousand acre-feet (TAF) to a high of about 38,000 TAF. Most of the flow comes from December through June often in the form of short-term events or freshets caused by rainfall or snowmelt.

Many natural ecological processes and functions depend on this seasonal and storm-event variability. Many of the environmental factors and functions that are controlled by streamflow dynamics are only partially understood at this time. Therefore, the vision for Central Valley streamflow includes a substantial commitment to continued monitoring and evaluation of the physical, chemical, and biological processes and ecological functions that are sustained and governed by streamflow.

Almost all major Central Valley streams are impounded by large multipurpose reservoirs (as well as smaller diversion dams) and confined by flood control levees. The operations of these reservoirs, diversions, and levee constraints are governed by many rules that affect the overall operation of water-management systems. As the effects from these facilities on the natural runoff, sediment transport, and fish migration patterns are observed, an increased understanding of the needs for instream flows is emerging. The vision for streamflow is to sustain and promote as many natural ecological processes and functions as possible within the existing Central Valley multipurpose water resources management framework. The adaptive management of streamflows will be a major ingredient in the successful ecosystem restoration of Central Valley natural resources.

ECOLOGICAL FUNCTIONS OF STREAMFLOW

Streamflow can be thought of as the life-blood of the tributary watersheds that link together to form the Sacramento and San Joaquin Rivers. Surface runoff and groundwater generate flows into the stream networks within each tributary basin. Streamflow provides the geomorphic forces (energy and materials) needed to create and maintain the stream channels and riparian corridors (floodplains). Streamflow controls the erosion, transport, and deposition of sediment within the stream channel and floodplain, and transports and cleanses the river gravels that provide substrate for invertebrates and fish spawning. Reduced streamflow can lead to sediment deposition in gravelbeds and can also lead to armoring the channel with cobble that cannot be transported by the reduced streamflow. Only natural flow patterns will maintain natural sediment erosion, deposition, transport, and cleansing patterns, and thus natural stream channel and floodplain configurations.

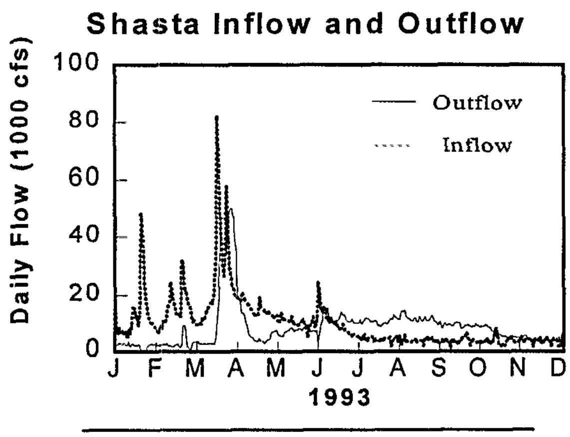
Streamflow transports nutrients as well as dissolved and particulate organic material from upstream source areas to the Delta and estuary, where these materials are important to the planktonic and benthic foodwebs. Flows provide soil moisture, transport seeds of riparian and floodplain vegetation, and are required to inundate the stream channel pools and riffles and riparian wetlands that provide habitat for fish and other wildlife. Flows transport fish eggs and larvae (e.g., striped bass, delta smelt) from spawning to nursery areas and may assist in the movement of juveniles from upstream spawning and rearing areas to the Delta (e.g., young splittail and chinook salmon).

Streamflow into and through the Delta, referred to as Delta outflow, is the combined streamflow from all tributary streams adjusted by reservoir storage and water diversions. Delta outflow has a major influence on the estuarine salinity gradient and, by tidal mixing processes, the salinity flowing into the Delta. Outflow controls the location of the "entrapment zone" (an area where fresh water overlays saline water) and the transport of planktonic organisms, particulate organic materials, and nutrients into Suisun Bay from the Delta.

HYDROLOGIC VARIATIONS

The major characteristic of California hydrologic conditions is the extreme variation in both seasonal and annual runoff. The hydrologic variation challenges our ability to control and allocate the available water supply for various beneficial uses including flood control, water supply, and instream flows. Priorities for streamflow management are dependent on the available water supply (i.e., adaptive management). The wide range of water supply conditions in the Central Valley are sometimes described as water-year classes (wet, above normal, below normal, dry, and critical). This natural year-to-year hydrologic variability is usually included in water-management-planning studies by simulating the performance of proposed facilities and operations using monthly rainfall and natural, unimpaired runoff conditions estimated from measured flows for 1922 to the present. This allows the effects of hydrologic conditions to be fully considered and evaluated.

Seasonal variability results from the episodic rainfall events that occur during the "wet" season between November and June, together with the substantial runoff from the Sierra Nevada snowpack that extends into the summer and fall. The snowmelt runoff pattern allows substantial diversion of San Joaquin and Sacramento River tributaries for irrigation from May through September. Groundwater pumping is used to augment the streamflow diversions. Central Valley reservoirs have been constructed during the last century to manage the seasonal variability by capturing winter floods and spring snowmelt (while reserving sufficient flood control storage space and maintaining minimum instream flows) to provide an increased water supply during summer and fall for water supply diversions and instream flows.



MULTIPURPOSE WATER MANAGEMENT

Recognition of the importance of streamflows to protect and promote habitat conditions for fish and wildlife populations has created an apparent conflict with existing beneficial uses of water supply and flood control. Although the present allocation of the available water supply includes substantial instream flow requirements (e.g., reservoir releases and Delta outflow) and export pumping limitations (for entrainment protection), the vision for streamflow can be expressed as sustaining and promoting as many natural ecological processes and functions as possible within the existing Central Valley multipurpose water resources management framework.

California water management can be generally described as "incremental" management because the operations of existing reservoirs, diversions, and Delta facilities are governed by many rules and controls, each of which has an incremental and interdependent effect on overall operations of water management systems. Several agencies may be involved in the operation of each major reservoir or diversion facility. Additional water management flexibility is needed within the overall operation of the California water management system to meet ecological streamflow needs.

STATUS OF CENTRAL VALLEY STREAMFLOWS

The full natural flow that would occur in a stream in the absence of upstream reservoirs and diversions is called the unimpaired flow. Data on unimpaired flows provide a record of natural streamflow patterns and can be used as a benchmark for judging the effects of water management and allocation of the available runoff for multiple water resources benefits. The ability to control natural streamflows is limited because of the extreme variability in flows, such as during major storm events and long-term droughts, relative to existing reservoir storage capacity and because of the previous allocation of water supply for existing beneficial uses (water rights and contracts). The vision for streamflow can be described as restoring natural runoff patterns within the recognized constraints of available storage and previous water use allocations (i.e., water rights) to provide the greatest potential for ecological functions and benefits from the available streamflow. Protecting spring flows and sustaining summer-fall base flows are the two major streamflow restoration activities considered in this vision.

WATER RIGHTS AND INSTREAM FLOW

Opportunities for adjusting seasonal streamflow patterns to benefit fish and wildlife while maintaining other beneficial water uses will be explored. Opportunities may include acquisition of water rights from willing sellers or development of supplemental supplies (e.g., conjunctive use or recycled water programs). Individual water rights are established subject to California law, and this vision does not propose any adjudication or involuntary reallocation of water rights.

California water rights govern the allocation of streamflow for beneficial uses. There are both riparian and appropriative water rights in California, administered or monitored by the State Water Resources Control Board (SWRCB). Riparian rights support specific beneficial uses on lands immediately adjacent to the stream. Appropriative rights to water for direct diversion or storage can be obtained for beneficial use at any location. Water rights are incremental, with a specific priority scheme that controls water use during periods of water shortage. Federal courts have assigned the jurisdiction over several California streams that are used for single-purpose hydropower projects to the Federal Energy Regulatory Commission (FERC). Additional "exchange contracts" between water-rights holders and water districts or government agencies, such as the U.S. Bureau of Reclamation (Reclamation) or California Department of Water Resources (DWR), further complicate the allocation of California water supplies. There are no California water rights granted specifically for instream flow; however, instream flows are sometimes required as conditions for water quality standards, water-rights permits, and FERC licenses. Several "agreements" between water agencies and fish agencies govern minimum flows downstream of major water projects, and some streams, such as Butte Creek, are formally managed by "watermaster" agreements.

The SWRCB has included spring flow requirements for both Delta outflow (i.e., X2 location objectives) and the San Joaquin River at Vernalis in the 1995 Water Quality Control Plan. Instream flow requirements govern the minimum flows at specific points below diversions and are often dependent on the available water supply (e.g., water-year type). Average annual instream and spring flow requirements are generally a small fraction of natural unimpaired flow and the magnitude of winter releases may be greatly reduced. Many streams have no instream flow requirements. On some streams, riparian and appropriative water rights diversions may be restricted only by an amount necessary to supply downstream users having a higher priority water right. Streamflows in some Central Valley streams are totally depleted downstream of the major diversions during the summer irrigation season.

RESTORATION NEEDS

Many stream channels in the Central Valley have been modified for flood control. Streams have been straightened and cleared (channelized) or levees have been constructed along the channelbanks to prevent flooding of agricultural or urban areas within the historical floodplain. Sand and gravel mining for construction materials have sometimes occurred directly within the active channel and floodplain. These stream channel and floodplain modifications have reduced the ecological benefits achieved by the streamflow. Restoration and protection of the stream channel and floodplain process will be required to allow maximum potential ecological functions and benefits from streamflows.

The needs and opportunities to protect, enhance, and restore natural streamflow patterns and processes will depend on the conditions of the stream channel and floodplain, as well as the existing water resource development, including impoundments and diversions within the watershed of each tributary stream.

The following are general ecological processes and functions sustained with natural streamflow patterns:

- channel-forming processes that create and sustain the pools, riffles, meanders, sand and gravel deposits, banks, side channels, and floodplain areas that are the physical framework for the stream, wetland, riparian corridor and floodplain habitats;

- water and sediment transport processes that allow the streamflows to flush spawning gravels, move nutrients and organic materials to downstream aquatic habitats where they provide the necessary components for primary and secondary foodweb production, and move larval and juvenile fish and other aquatic organisms to downstream rearing habitats;

- filling and flooding of channel and floodplain areas to provide aquatic, wetland, and riparian habitat and to sustain botanical processes (i.e., seed dispersal, soil moisture replenishment) within the floodplain, flood bypass, and riparian stream corridor; and

- water quality control sufficient to maintain acceptable water temperatures downstream of major impoundments and diversions, acceptable concentrations of toxic materials from mining discharges and agricultural drainage, and acceptable salinity gradient within the estuary.

Although the historical pattern of natural streamflows can be used as a guideline for establishing streamflow targets, the actual management of flows for each tributary or river segment will require coordination with all agencies and stakeholders. Conflicting interests and priorities will most likely be the rule rather than the exception. Streamflow targets will be developed within the existing multipurpose water resource management framework for each watershed.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for Central Valley streamflows is to restore basic hydraulic conditions to reactivate and maintain ecological processes that create and sustain habitat required for healthy fish, wildlife, and plant populations.

The health of several ecosystem elements can be used as an indirect indicator of the health of Central Valley streamflows and reflects the integral relationships between them. These indirect indicators include stream channel meander rates, natural sediment transport rates, transport of nutrients, transport of fish eggs and larvae, and frequency and duration of floodplain inundation. Direct indicators of health of streamflows are how close they emulate the natural hydrograph of the water body.

LINKAGE TO OTHER PROGRAMS

The vision for streamflow is intended to complement existing streamflow management programs. Several agencies are directly or indirectly responsible for streamflow management.

Agencies with important streamflow management responsibilities and programs include the U.S.

Army Corps of Engineers' flood control operations of reservoirs and management of flood control facilities (e.g., levees, overflow channels and bypass weirs); DWR programs to provide water supplies (State Water Project), flood protection facilities, water quality monitoring, and multipurpose management of California water resources; Reclamation's operation of the Central Valley Project (and several other independent water projects in the Central Valley) to provide for multiple beneficial water uses, including fish and wildlife protection and habitat restoration (e.g., Central Valley Project Improvement Act); FERC regulation of minimum flows below hydropower projects; SWRCB administration of water rights for storage and diversions, including decisions about required instream flows for fish, water quality, and public trust resource protection; California Department of Fish and Game responsibility to study and recommend streamflows and temperature requirements for fish protection and propagation in streams and at hatcheries; the U.S. Fish and Wildlife Service and National Marine Fisheries Service programs to recommend flows and other measures needed for mitigating impacts from federal projects and protecting endangered species, including the Anadromous Fish Restoration Program and the Water Management Program; and the U.S. Geological Survey water resources division programs to measure streamflow and water quality, providing the information necessary for adaptive management of streamflows. Their monitoring and modeling activities for Central Valley groundwater and Bay-Delta hydrodynamics are also important contributions to water resources management.

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INTRODUCTION

The natural sediment supply is composed of mineral and organic fines, sands, gravel, cobble, and woody debris that naturally enter, deposit, erode, and transport through the Bay-Delta and its watershed. Sediment, like water, is one of the natural building blocks of the ecosystem on which many other ecological processes and function, along with habitats and species depend. Gravel, for example, is important for maintaining spawning habitat for salmon and steelhead, and as a habitat for stream invertebrates. Finer sediments are important in the natural functions of riparian and wetland habitats. Major factors that influence the sediment supply in the Bay-Delta and its watershed include many human activities such as dams, levees, and other structures, dredging, and gravel and sand mining.

The vision for natural sediment supply is to provide a sustained supply of alluvial sediments that is transported by rivers and streams and distributed to floodplains, channel bars, riffles, shallow shoals, mudflats, and riverine bed deposits throughout the Sacramento-San Joaquin Valley, Delta, and Bay regions.

River-transported sediments are an essential component of the physical structure and nutrient base of the Bay-Delta ecosystem and its riverine and tidal arteries. The size, volume, and seasonal timing of sediments entering the riverine and estuarine systems should be managed to be compatible with both natural and altered flow regimes and channel and floodplain characteristics of individual rivers, streams, and tidal sloughs. Specific sediment management objectives are to redistribute sediment in the watersheds and valley components of the ecosystem so that specific habitat requirements and ecological functions are optimized by an appropriate level, rate, and size distribution.

The state of the natural sediment supply is highly variable among the streams and tidal sloughs of the Sacramento and San Joaquin Rivers and Bay-Delta ecosystems; however, most of the major rivers entering the Sacramento and San Joaquin Valleys are deprived of their primary source of sediment from the upper watersheds by large dams.

BACKGROUND

Alluvial sediment deposits created the fertile floodplains of the valley floor and extensive tule lands that have been converted to cropland, rice fields, and orchards. During the gold rush, the sediment balance of the Bay-Delta ecosystem was altered by extensive hydraulic and dredge mining of the westside Sierra Nevada mountains and streams (especially the Yuba, Feather, American, lower Sacramento, and San Joaquin Rivers and their tributary watersheds). Sediment from mining in the late 19th century greatly exceeded the amounts that rivers were able to transport. Rivers became overloaded with sediment, causing deposition and flooding in the valley towns and farms. Fine sediments pulsed quickly through the river systems, but the coarser sediments moved more gradually. By the late 20th century, most riverbeds had returned to pre-Gold Rush elevations because riverflows had cut through the old placer mining debris deposits stored along the banks. Some of the rivers and creek valleys still contain "debris dams" (e.g., Daguerre Point Dam in the Yuba River Goldfields) built a century ago in an attempt to stem the onrush of placer mining sediment that spread over the valley farmlands.

Rivers convey both water and sediment. In California rivers, most sediment is delivered and transported during winter and spring runoff events when flows are high enough to move particles as large as cobble and pass large volumes of finer sediment far downstream. Typically, bars, shoals, and braided deltas form or expand as floodwaters decline and stabilize during the dry season. Fluvial processes rearrange and sort sediment (sand, silt, and clay particles) and bedload (cobble and gravel) to create the structural support for a wide variety of important landscapes and habitats. These ecosystem forms include fish spawning gravels, substrate to which aquatic insects attach, growth medium in which riparian forests germinate and establish, and loamy floodplains that support oak woodland and grasslands. The transport of heavier cobble and gravel helps rivers dissipate stream energy, and the formation of heavy cobble bars shields the bed of the river from excessive erosion and incision.

Shallow shoals of fresh sediment form along Bay-Delta rivers and sloughs by replacing sediment lost to wave action and tidal currents, creating new substrate for tule marsh and sustaining shallow-aquatic and tidal-mudflat habitats. Fine organic particles and mineral sediment suspended in the water column also provide essential nutrients (e.g., carbon, nitrogen, phosphorus, and iron) that support algae and phytoplankton at the base of the foodweb; however, an excess of suspended particles (high turbidity) may limit growth of aquatic plants and algae by reducing sunlight penetration.

Constructed features and disturbance factors that eliminate, reduce, or alter the amount, distribution and timing of natural sediment sources include:

- reservoirs behind medium and large dams that capture the sediment supply from the watershed;
- levees that prevent deposition of fine sediments in the floodplain alongside rivers and increase sediment scour and transport within the river channel by forcing deeper, more erosive floodflows.
- sand and gravel mining in the channels and active lower floodplains of rivers and smaller tributaries that deplete the natural supply to downstream sites;
- bank armoring and channelization that alters sediment transport, reduces natural bar and riffle formation, and prevents the natural erosion of the banks and release of gravel and sediment to the river; and
- reduced ability of a river to transport bedload entering the river from tributary sources because of dam-regulated reduction of the magnitude and duration of average peak flows during winter and spring.

Levees and Bank Revetment

The sediment transport and deposition processes of the ecosystem have been significantly modified. Construction of the Sacramento River, San Joaquin River, and Delta levees and bypass systems in the early 20th century allowed the settlements of the Central Valley and California agriculture to expand. However, the levees isolated rivers from their natural floodplains and separated the Bay-Delta from the extensive freshwater and saline emergent wetlands and secondary sloughs that became the agricultural "islands" we know today. Because the original levee system of the Sacramento River was built to bypass excessive floodflows while maintaining sufficient channel depth for river navigation from San Francisco to Red Bluff, river flows have sufficiently sluiced most of the sediment past the river floodplains and Delta and out to San Francisco Bay or deposited it in deeper channels that now require dredging.

Dams and Reservoirs

Dams and reservoirs severely reduced the natural supply of gravels and sediments entering the riverine conveyor systems (Figure 2). Construction of the State and federal dam system occurred between the 1930s (e.g., Shasta Dam) and 1970s (e.g., New Melones and New Don Pedro Dams). Although they provided critical water supply and flood management functions, the reservoirs drastically altered the sediment supply below dams by capturing all the bedload and most of the finer sediment in deltas forming at the mouths of reservoirs. Smaller reservoirs, such as hydropower impoundments on the Feather River, have filled to capacity with sediment. The absence of sediment below dams and the confinement of rivers into narrow, leveed corridors triggered channel incision and bank erosion that threatened the integrity of the levee system, leading to ongoing efforts to armor riverbanks and levees with rock riprap. Implementation of these actions further reduces the natural sediment supply of rivers that would otherwise be sustained by stream channel erosion through alluvial floodplain deposits.

Confining rivers and hardening banks remove a major remaining supply of gravel and sediment from rivers below dams. Preventing or reducing bank erosion also inhibits the recruitment of instream woody cover (a component of shaded riverine aquatic cover) because the erosion required to topple trees into the channel no longer occurs. The unnatural sediment deficit and high transport efficiency of the primary Delta channels, combined with wave-wash erosion, are causing the progressive disappearance of remnant tule and willow midchannel islands and shoals, and are preventing the replenishment of deposits that support mudflat, emergent wetlands, and willow scrub habitats. The same process is undermining the submerged toe of levees along Delta islands. Immediately downstream of dams, where water temperature is often low enough to support spawning fish populations, the release or uncontrolled spills of "clean, hungry" dam water removes the spawning gravels from the channel, armoring the channelbed with more resilient cobble and boulders, and erodes the fine sediment that would normally support riparian trees and shrubs along the banks.

Farther downstream, only the Butte basin flood overflow area and the Sutter and Yolo Bypasses support a physical sedimentation process that roughly approximates a natural floodplain. However, flood conveyance capacity, intensive farming in the bypasses, and flood easement restrictions do not allow the remnant floodplains to support natural habitats, such as emergent marsh, cottonwood-willow forest, or valley oak woodland, that thrive in the fine-textured alluvial deposits. A few notable exceptions are Sutter National Wildlife Refuge, the new Yolo Basin Wildlife Management Area, and some large privately managed waterfowl habitats in the Butte basin.

INCHANNEL GRAVEL MINING

Inchannel sand and gravel mining reduces downstream physical habitat and triggers incision of the channelbed in both upstream and downstream directions. Large inchannel and low-floodplain mine pits that are excavated to a depth lower than the stream channel, such as occurs on the eastside tributaries of the San Joaquin River, often "capture" the river and create additional ecosystem disturbances by trapping bedload gravel, causing the river alignment to suddenly shift, exposing outmigrating juvenile salmon and steelhead to elevated levels of predation, and trapping outmigrating juvenile salmon and steelhead in isolated backwater ponds when the river stage recedes.

ALTERED HYDROLOGIC CONDITIONS AND REDUCED BEDLOAD TRANSPORT

Some river systems have an excess of stored channel deposits because of limited flood duration and magnitude below dams that reduce the average annual sediment transport potential of the river. The lowered bedload-transport potential prevents the distribution of gravel and coarse sediment downstream, where it is needed to create riverine habitats. Large cobble bars and deltas may form at the mouth of tributaries, causing new channel instability.

RESTORATION NEEDS

RESTORED OR AUGMENTED SEDIMENT SUPPLY

In some tributary streams, small dams that no longer serve a purpose can be modified, or possibly decommissioned and removed, to allow a larger fraction of gravel to pass downstream to where spawning occurs or has the potential to occur, and to provide spawning fish upstream access to reaches with a natural gravel and sediment supply. Studies will be conducted to determine whether smaller reservoirs could be modified or reoperated to allow some sediment from upstream sources to pass through to the dam outlet. Reservoir deposits can be excavated as a source of gravel and sediment to be used to artificially augment gravel supply below the dam for fish spawning redds and channel bar formation.

In some reaches of rivers, bank armoring could be reduced or avoided by creating unimpeded channel meander corridors using special conservation zones (e.g., erosion easements), landowner incentive programs, and strategic levee setbacks where feasible. It is especially important to avoid channel hardening downstream of major dams where the sediment supply from upstream has been reduced or eliminated, and where bank erosion and channel migration are major sources of the remaining sediment budget.

The future sediment supply from the remaining nondammed tributaries should be secured, wherever possible, as a protected ecological resource of the river and Bay-Delta ecosystem. (Cottonwood Creek is a prime example of a nondammed tributary of the Sacramento River that contributes a significant proportion of sediment, gravel, and natural flood peaks affecting the main river.) Potential new water supply and flood storage facilities will be evaluated for their possible effect on sediment or bedload discharge to streams included in the ecosystem restoration program.

Floodplains along rivers and streams, having a mixture of both natural vegetation cover and agricultural cropland, could be restored, expanded, and managed to capture sand and silt from selected rivers during high flows and to lower flood stage. Floodplains deliberately managed for ecosystem benefits will also generate a constant source of fine particulate organic matter and small food particles that reenter the Delta and main rivers from overland flows that pass over and through crop stubble, grasslands, and riparian woodlands. Managed floodplains offer additional important benefits to society by increasing floodway capacity, adding flood detention volume, and reducing river stages along levees.

Latent bank and floodplain deposits along rivers below dams could supply additional sediment through the scheduled release of simulated floodflows of sufficient duration and magnitude (e.g., 5-10 days simulating a 5- to 10-year frequency unimpaired flow) to mobilize channel-bed, bank, and bar sediments. This strategy would apply only to river systems that have an excess of stored channel deposits because of limited flood duration and magnitude below the dam that has reduced the average annual sediment transport potential of the river. This action will be coordinated with project operations and life-history requirements of aquatic species.

ENHANCED SEDIMENT CAPTURE AND STORAGE

Levee setbacks, partial historical floodplain restoration (e.g., breaching diked tidelands) and selected Delta island levee removal strategies will be evaluated and implemented where feasible. These measures, combined with increased channel roughness from marsh and riparian restoration projects, will increase the sediment-trapping efficiency of the Delta in sloughs and channels that are not essential for commercial ship and barge navigation to either the Stockton or Sacramento ports. Increasing the extent of the high-water floodplain of the Delta will reduce the potential for channel erosion, thereby reducing the rate of sediment loss from midchannel tule islands and shallow shoals. Greater floodplains along rivers would allow additional riparian vegetation to grow along the river floodways and would enhance the formation of bank and bar deposit habitats.

DESIGNATED RIVER EROSION (MEANDER) ZONES

Appropriate reaches of the Sacramento, San Joaquin, Merced, Mokelumne, Cosumnes, Feather, and Yuba Rivers and other suitable streams, such as Cottonwood and Cache Creeks, will be evaluated and, where feasible, designated for eligibility as river erosion and deposition zones, or "meander belts", where natural erosion and sedimentation processes can occur unimpeded (within reasonable limits) and sustain a diversity of sediment-driven habitats. In these meander belt conservation zones, some types of agricultural production could continue, particularly on older alluvial floodplains unlikely to be within the eroding pathway of the river within the next 20-50 years. Farmed areas within the estimated 20-year riverbank migration corridor could be targeted for special erosion and river floodplain easements and incentive programs where orchardists would be compensated for loss of fruit and nut trees caused by natural bank erosion, or for permanent acquisition as river floodplain conservation areas. Some "hard points" in river corridors are essential infrastructure that cannot easily be modified to accommodate channel migration. These include major water diversion intake structures, highway and railway bridge abutments, and high-voltage transmission towers. However, diversion hard points that must be upgraded or outfitted with new fish screens may be able to be modified or relocated to allow for partial channel migration without obstructing operation.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for natural sediment supply is to establish sufficient quantities to riverine and estuarine systems in order to restore or reactivate stream channel meander and point bar formation, provide sediments to rebuild wetlands and shallow-water habitats, and provide for nutrient transport.

Indicators of the health of natural sediment supply are measurable or calculated increases in the transport of fine and coarse sediments.

LINKAGE TO OTHER PROGRAMS

ERPP efforts to achieve the vision for natural sediment supply may involve coordination with other programs, including the Upper Sacramento River Fisheries and Riparian Habitat Council's (SB1086) group efforts and river corridor management plans; U.S. Army Corps of Engineers' proposed reevaluation of the Sacramento River Flood Control Project and ongoing Bank Protection Project, including more comprehensive floodplain management and river ecosystem restoration opportunities; San Joaquin River proposed riparian habitat restoration and floodplain management studies, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service (USFWS); USFWS's Anadromous Fish Restoration Program gravel replenishment programs and plans, and small dam removal and/or fish ladder rehabilitation projects; and planned and proposed restoration of diked tidelands in Suisun Marsh and San Pablo Bay, and islands in the south-Yolo Bypass and Delta that could be restored to tidal inundation.

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NATURAL FLUVIAL GEOMORPHOLOGY TO SUPPORT THE ECOSYSTEM

INTRODUCTION

Geomorphology is the shape of the landscape and the study of the forces or processes that cause particular shapes and landscape patterns to be repeated. Fluvial processes are waterflow-related events that shape the land (i.e., into channels, floodplains, and deltas) according to patterns that are unique to rivers. Fluvial geomorphology is primarily the pattern of erosion and redistribution of all sizes of sediment, boulders, and organic debris as influenced by the underlying geologic structure of the landforms.

The characteristic three-dimensional shape of a river described above (its "fluvial geomorphology" or landforms created by flowing water) is indicative of a river that is in dynamic balance with the interaction of its flood regime, sediment supply, vegetation patterns, climate, and valley slope. Rivers with a natural shape and hydrologic condition generally support the most diverse mixture of habitats and fish and wildlife species and are the most resilient to natural or human disturbance.

The vision for natural fluvial geomorphology is to conserve and enhance the natural structural form of streams and rivers by reestablishing adequate sediment supply and the processes of flooding and stream meander. This vision is closely associated with the visions for natural sediment supply, flood processes, and stream meander corridors.

BACKGROUND

Some parts of rivers are reformed annually or seasonally (e.g., submerged channel sand bars), whereas other riverine landscapes may require decades or centuries to form, such as the broad natural levees along the Sacramento River. Here, generations of fine sediment (and later hydraulic mining debris) accumulated in groves of riparian forests, forming extensive lowland flood basins where floodwater was trapped between the ridge of the natural levees on one side and the higher ground of the foothills on the other side of the valley. The Colusa basin is an example of a former natural lowland that is now disconnected from the river by higher constructed levees on top of the natural levees that were formed by the sediment-laden river.

On the river side of natural levees in alluvial valleys, fluvial processes typically create dynamic river meander patterns, including oxbow lakes from bend cutoffs, secondary channels that carry flow only during high stage, and nonvegetated point bars where new deposits of sand and gravel collect in low-energy zones of inside bends and bendway crossovers (riffles). In cross section, natural alluvial streams are typically terraced and asymmetrical, with steep banks on eroding outside bends, low-angle banks on inside bends, and several nearly horizontal surfaces corresponding to river floodplain elevations of various magnitude and frequency (Figure 3). If a river has incised (i.e., eroded down below the original channelbed surface) as a result of natural or human-induced factors, the abandoned upper floodplain may become a "terrace" (former floodplain) where riparian forest may then convert to valley oak woodlands or grassland-oak savannah.

Channelizing and shortening rivers; removing instream vegetation and gravel; and creating symmetrical, trapezoidal channels sandwiched between narrow, steep-sided levees run counter to the natural tendency of alluvial rivers to form characteristic compound dimensions and patterns. A channelized river may be relatively stable if the potential for major flood events has been eliminated, sediment input is minimal, vegetation does not naturally grow along the banks, and the channelbed is incapable of incising. However, this describes few streams of the Central Valley. Further, this type of river is ecologically impoverished. The absence of river floodplains and adequate meander width for bar and riffle formation within levee-confined channels prevents or depresses the formation of natural river morphology that is the structural framework for riverine and estuarine fish and wildlife habitats. Stabilizing artificial banks with rock riprap and clearing vegetation further degrades habitat and diminishes natural channel-forming processes.

Sacramento River - An important exception here is the existence of the Sacramento River basin overflow system which includes the Butte basin and Sutter and Yolo Bypasses. Although considerably smaller than their original extent, these three floodplains move and detain floodwaters in volumes and patterns similar to those of presettlement flow while reducing the risk of overtopping levees near populated areas. At flood peak, there is approximately five times more flow in the Sacramento River bypass floodplain system than in the main river channel it drains. However, the floodplain bypass system does not exist in the largest historic flood basin of the Sacramento River, the Colusa basin, which is disconnected by levees from the river. Also, the lowest areas of the Sutter basin are outside of the levees and the Sutter Bypass traverses slightly higher ground on a portion of the historical basin floodplain.

San Joaquin River - The San Joaquin River floodplain includes relatively small flood bypasses that convey a fraction of the possible flow during a major flood. For most of the length of the San Joaquin River and its major tributaries, channels are separated from their floodplains by levees built close to the channelbanks. There is no major basin overflow area except where a levee is breached during flood events.

RESTORATION NEEDS

Measures for conserving and enhancing natural fluvial geomorphology are also provided in the visions for natural river sediment supplies, flood processes, and stream meander corridors. If the floodplain, meander width, sediment supply, and natural or simulated flood peaks are in place, the river will respond by creating natural landforms that support self-sustaining vegetation communities and aquatic and terrestrial habitats (Figure 4). Even partial restoration or simulation of natural physical processes and floodplains will amplify channel characteristics and resultant habitats.

It is necessary to identify rivers and Delta sloughs where natural fluvial process and landforms are relatively intact, highlighting them as potential reserves of fluvial geomorphology process and riverine habitat.

River reaches proposed for potential restoration and enhancement of fluvial geomorphic processes include the following initial listing, although many segments will be limited by unalterable levee confinement and bridge crossings:

- Sacramento River from Redding to Colusa;
- westside tributaries of the Sacramento River (e.g., Cottonwood, Elder, Thomes, Stony, and Cache Creeks);
- Feather River below Marysville;
- San Joaquin River from Mendota to Vernalis;
- eastside tributaries of the San Joaquin River (e.g., Merced, Tuolumne, Stanislaus, and Cosumnes Rivers); and
- lower reaches of eastside tributaries of the North Sacramento Valley and Butte Basin.

Implementation Objective and Indicators

The implementation objective for natural fluvial geomorphology is to conserve and enhance these characteristics in streams and rivers to contribute to and promote natural sediment transport and deposition.

A variety of physical measurement can be used as indicators of the health of natural fluvial geormorphological processes. These measurements could include erosional and depositional patterns in selected stream reaches, frequency and extent of overflow into natural and designed floodways, and extent of channelization in selected river reaches.

Linkage to Other Programs

The Ecosystem Restoration Program Plan (ERPP) efforts to achieve the vision for natural fluvial geomorphology may involve coordination with other programs, including the Upper Sacramento River Fisheries and Riparian Habitat Council's (SB1086) group efforts and river corridor management plans; U.S. Army Corps of Engineers' proposed reevaluation of the Sacramento River Flood Control Project and ongoing Bank Protection Project, including more comprehensive floodplain management and river ecosystem restoration opportunities; proposed riparian habitat restoration and floodplain management studies for the San Joaquin River, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service; the Anadromous Fish Restoration Programs's gravel replenishment programs and plans, and small dam removal projects; current plans for all county-sponsored instream mining and reclamation ordinances and river and stream management plans; and reclamation planning assistance programs being initiated by the California Department of Conservation under the Surface Mining and Reclamation Act.

INTRODUCTION

Rivers with active meander migration of stream channels generally support a greater diversity of aquatic and terrestrial habitat types and have complex mosaics of vegetation age classes and rich botanical composition. Major factors that limit natural stream channel migration include construction of levees, bank riprap, channelization, upstream sediment loss from dams and levees, instream gravel mining, and vegetation removal for increased floodway capacity or for reclamation of the river floodplain for agricultural uses.

The vision for stream meander corridors is to conserve and reestablish them by implementing stream conservation programs, setting levees back, and reestablishing natural sediment supply to create conditions to restore riverine and floodplain habitats for fish and wildlife.

Approaches to restoring more natural stream meander corridors include conserving existing river migration zones, expanding stream meander corridors, conserving upstream and bank sediment supply, and incorporating simulated flood peaks into dam water release schedules during wet years.

BACKGROUND

The width and habitat patch size of nodes of riparian forest on meandering streams tend to be large and connected because the forest is always being replenished by new territory colonized by cottonwood and willow trees on recently formed point bars and floodplain deposits. The velocity of flow in meandering streams varies greatly, causing sediment and organic debris to be sorted into different sizes at different locations within the channel along a velocity gradient. Therefore, many species of fish, amphibians, and insects find suitable habitat in stream meander landscapes. Other habitat benefits include formation of oxbows, sloughs, and side channels (Figure 5) that create a highly productive interface between aquatic and terrestrial communities such as canopy shading and leaf and insect drop over the riverine aquatic bed.

Rivers that flow through their own valley alluvium (i.e., gravel, sand, and silt deposited earlier in time) have the potential to shift position through bank erosion and sediment deposition, forming bars that stimulate additional erosion as the river channel migrates away from the bar. The following characteristics of a river increase the probability that it will migrate during winter/spring flows:

- high average sediment or bedload source, erodible bank and bed deposits (e.g., sand and gravel);
- potential for extreme flood peaks and flashy spikes, and
- a low density of mature vegetation along the channel.

A "stream meander" is a dynamic natural process, and is also a term used to describe the shape of the river as a sinuous or bending wave form. River flora and fauna are adapted to the dynamic, unstable nature of alluvial streams. They tolerate their stems being buried by deposits of river sediment and disperse seed by wind and water to locations where new bars have formed. Meandering streams typically form the pool-riffle sequence that supports a range of fish habitats. The leading edge of the eroding side of the bend generates new sediment and gravel from the bank and topples riparian trees into the channel to create high-quality aquatic cover and provide food and substrate for aquatic insects on which fish feed. Sediment lost at the eroding bank is transported downstream and redeposited on aggrading point bars, initiating the habitat colonization and bank renewal process. When pronounced bends are formed, an unimpeded river will eventually cut off the bend by eroding a "shortcut" across the inside bend during high flows, forming backwater swales and oxbow lakes that provide important juvenile fish rearing areas and sources of foodweb production.

Meandering streams typically support a wider corridor of natural habitats because the meander band width is often greater than the width of the channel at any one cross section. Rivers with armored banks (rock riprap) or naturally stable stream channels are more likely to have urban or agricultural land use encroach into the riparian floodplain and forest, leaving room for only a narrow band of trees or shrubs along the bank and resulting in low habitat quality for fish and wildlife. Alluvial rivers with artificially hardened banks and static channels suffer a general loss of diversity and quality at the interface of aquatic and terrestrial habitats. Unfortunately, making rivers more predictable has led to a decline in river ecosystem quality because the species and habitats that evolved on rivers are dependent on the dynamic, natural disturbance cycles of meandering streams.

No Central Valley stream has been unaffected by stressors that diminish the function of stream meander migration and aquatic and riparian habitats associated with natural channel migration. However, there are significant reaches of several large rivers that still support full or partial characteristics of a dynamic stream meander pattern. The best example in California is the Sacramento River between Red Bluff and Butte City. Other important examples include the San Joaquin River (e.g., from Mossdale to Merced River); the Merced, Tuolumne, Cosumnes, Feather, and Yuba Rivers; and Cottonwood, Stony, and Cache Creeks.

Natural meander belts tend to be the most intact where there are no major levees or where levees are set back several hundred feet from the main channel bank; on rivers that have high flow stage during frequent flood peaks, thereby discouraging land conversion to urban or agricultural uses that clear the forests and promote bank riprap; and on rivers with floodplain soils that are not conducive to high-yield crops or orchards (e.g., saline hardpan soils along the lower San Joaquin River or gravelly, barren floodplains along the Yuba River).

To support a natural, dynamic stream meander system, the following important ingredients are needed, and stressors listed must be overcome or compensated for:

- An incoming supply of gravel and sediment that matches the net transport and displacement of channel sediment and bedload. Dams interfere with the natural sediment supply from upstream, while levees, instream gravel mining, and bank protection projects deplete channel and floodplain sediment supplies or render them unavailable. Most of the major tributaries of the Sacramento and San Joaquin Rivers have large dams above and elevation of 300 feet. Most of the length of these rivers in the valley floor are being mined or have been mined for gravel, and all are confined by leveed and incised channels along substantial portions upstream of the Delta.

- A series of flood peaks periodically during wet years in winter and spring of sufficient magnitude and duration to remobilize and rearrange gravel and cobble deposits, transport sand and fine sediment to form new or expanded point bars, and erode banks or low bars on outside bends. Dam releases typically tame flows or eliminate flood peaks in dry or normal years, reducing bedload transport capacity while increasing base flows during summer. Channelization and levee confinement cause high flows to become deeper to compensate for less floodplain width, resulting in artificially increased sediment transport capacity that prevents sediment capture in the offchannel floodplains and removes sediment from shallow shoal and bar deposits. The absence of frequent high-energy flows also prevents the scour of riparian vegetation, reducing the rate of natural recruitment and cottonwood regeneration.

- Dense vegetation occupying the channelbanks and adjacent low floodplains to stabilize the river planform (i.e., modulate the annual rate of bank migration), reduce current velocities to cause new sediment to aggrade on bars, build topsoil in higher floodplains, and provide shade and instream woody cover to the aquatic zone. Narrow channels created by levees set too close to the low-flow shoreline separate the river from its floodplain and leave little room for riparian vegetation, and bank protection eliminates or reduces vegetation on outside bends. Channel hardening discourages both erosion and point bar formation, resulting in a static, even-aged stand of riparian forest and a narrowing or discontinuity of the riparian canopy corridor. Artificially narrowed channels may require periodic vegetation removal to maintain minimum floodflow capacity and are more likely to require expensive bank riprap to protect the vulnerable levees straddling the river during high flows.

- Adequate floodplain width to absorb and pass out-of-bank flows (i.e., the natural flood stage), capture fine sediments, store and filter woody debris, and, most importantly, make room for the progressive meander migration of the river channel within its floodplain. Loss of river floodplain functions caused by channelization, incision, and inadequate floodplain width between levees has converted dynamic riverine ecosystems to static conveyance facilities for the transport of irrigation and drinking water and floodflow management. Urban encroachment in the floodplains and meander belts along rivers usually follows river confinement and bank hardening initiated to create or protect agricultural uses made possible by dams and levees.

In general, the loss of river meander potential and functions in the Central Valley has resulted in more sterile river ecosystems upstream of the Delta, supporting less habitat for anadromous and resident fish and providing less nutrients and food to the Delta or less seed and fine sediment to replace habitat eroded within the Delta.

RESTORATION NEEDS

EXISTING RIVER MIGRATION ZONES

Appropriate reaches of the Sacramento and San Joaquin Rivers and their major alluvial tributaries will be evaluated and suitable portions designated as important river migration and floodplain deposition zones, or "meander belts". In these zones, natural erosion and sedimentation processes occur or could potentially occur unimpeded (within reasonable limits), sustaining a diversity of sediment-driven habitats. These river reaches and potential meander zones will be eligible for river conservation programs and appropriate landowner incentives once they have been evaluated and ranked according to ecological process and function characteristics. Remaining Central Valley stream reaches where natural meander processes occur will be mapped and ranked according to the level of meander-system functions, the quality of dependent habitats, and the contribution to Delta species and important physical processes.

STREAM MEANDER CORRIDORS

Levees and floodplains along rivers of the Sacramento and San Joaquin Valleys will be evaluated to determine if some levees can be reconstructed in a setback location, creating new meander corridors or nodes of expanded floodplains and wider riparian forest. This approach also benefits flood safety and reduces flood protection maintenance costs by repositioning levees outside of the primary bank migration pathway of alluvial streams, reducing the need for expensive rock riprap and reducing the potential for levee breaches to occur. Enlarged floodplains in river reaches having inadequate floodway capacity will increase the volume of safe floodflow, while allowing additional riparian vegetation within the channel to close gaps in the forest canopy. Riparian vegetation will tend to naturally recolonize stream meanders in areas where the channel is widened by levee setbacks because point bar development and sediment capture will be enhanced by widening the floodplain. Vegetation removal practices, required in confined channels, are reduced with levee setbacks. The Sacramento River between Chico Landing and Colusa is an example of a partial levee setback that benefits both flood safety and habitat quality while reducing levee and channel maintenance costs.

In other areas, land use changes and land management costs in the floodplain outside of existing levees may no longer justify continual levee upkeep and future bank protection costs. These areas present additional potential for expanded river meander zones. Levees could be removed, breached in key locations, or allowed to gradually erode from river migration processes. Examples include the floodplain of the lower San Joaquin River near Los Banos, where former livestock pasture has been acquired for wildlife management as part of the San Luis National Wildlife Refuge, or north Delta islands, where land subsidence and frequent levee failures have diminished the value of farmed land (e.g., Prospect Island).

UPSTREAM AND BANK SEDIMENT SUPPLY

Identify and rank the sediment contribution of remaining nondammed tributaries of alluvial rivers that help support the dynamic equilibrium of meandering stream corridors and spawning gravel areas. Identify river reaches where bank and floodplain gravels and sediment deposits are, or could reasonably be made, available to meandering rivers through natural erosion processes. A variety of approaches will be needed to ensure that these remaining river sediment supply sources are conserved.

Encourage county mining ordinances to incorporate incentives and policies that promote the replacement of instream gravel mines by offchannel mines in high terrace deposits, abandoned dredger tailings, and reservoir Delta deposits. The objective is to phase out instream gravel extraction that disrupts natural meander geomorphology and depletes the annual sediment supply needed to support spawning gravels or create point bars and riffles.

DAM RELEASE SCHEDULES DURING WET YEARS

Investigate the potential for modifying reservoir storage management during wet years by concentrating releases to simulate the seasonal pattern of natural, short-duration flood peaks. The magnitude and duration of major natural flood peaks cannot be restored in rivers below large reservoirs, but even smaller spikes of high flows can contribute significantly to the physical forces that support meander formation. This was demonstrated by the experimental flows released on the Colorado River below Glen Canyon Dam, which redistributed channel sediments from tributaries to create new fish habitat and substrate for riparian vegetation. Dam releases can be combined with nonregulated tributary inflow below the reservoirs to create flow spikes of sufficient magnitude to mobilize bed and bank sediments, clean spawning gravels, and form new river corridor landforms.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for stream meander corridors is to maintain, improve, or restore natural stream meander processes to allow the natural recruitment of sediments, create habitats, and promote riparian succession.

Measurable changes through time of the average sediment or bedload movement, amount of river meander and bank erosion, presence or absence of low density mature vegetation in selected stream reaches, width of the floodplain, and frequency and magnitude of flood peaks can be used as indicators of the health of stream meander.

LINKAGE TO OTHER PROGRAMS

Ecosystem Restoration Program Plan (ERPP) efforts may involve cooperation with other programs and organizations including the Upper Sacramento River Fisheries and Riparian Habitat Advisory Council (SB1086) group efforts and river corridor management plans implemented for the Sacramento River (Resources Agency 1989); the U.S. Army Corps of Engineers' proposed reevaluation of the Sacramento River Flood Control Project and ongoing Bank Protection Project, including more comprehensive floodplain management and river ecosystem restoration opportunities; proposed riparian habitat restoration and floodplain management studies for the San Joaquin River, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service (USFWS); Anadromous Fish Restoration Program gravel replenishment programs and plans and small dam removal and/or fish ladder rehabilitation projects; The Nature Conservancy's ongoing Sacramento Valley conservation planning; expansion plans being made for the Sacramento River National Wildlife Refuge (USFWS) and California Department of Fish and Game's Sacramento River Wildlife Management Area; plans being made for the San Joaquin River Parkway; plans being put into effect for all county-sponsored instream mining and reclamation ordinances and river and stream management plans; and reclamation planning assistance programs being initiated under the Surface Mining and Reclamation Act by the California Department of Conservation.

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NATURAL FLOODPLAINS AND FLOOD PROCESSES

INTRODUCTION

Floodplain and flood processes provide important seasonal habitat for fish and wildlife, and provide sediment and nutrients to both the flooded lands and aquatic habitats of the Bay-Delta. Flooding also shapes the plant and animal communities in lands subject to flooding. Major factors that influence floodplain and flood processes to the health of the Bay-Delta include construction of levees that constrict the floodplain, dams and reservoir operations that moderate flows, and activities that maintain flow capacity in major flood bypasses.

The vision for natural floodplains and flood processes is to maintain or restore natural processes that sustain them in order to reestablish aquatic and terrestrial floodplain habitats.

Floodplains reduce flood stages by slowing flow velocities, moderate channel incision and scour by providing area for bank overflow, contribute to species diversity by creating the landforms that support different communities, contribute to the aquatic foodweb when overbank floodflows collect and transport organic matter from the floodplain back to channels and eventually the Bay-Delta estuary, provide low-velocity refuge for fish and other aquatic organisms during floods, and provide spawning habitat for fish species dependent on the Bay-Delta. Approaches to restoring more natural floodplains and flood processes include conserving existing natural floodplains and expanding confined floodplains.

BACKGROUND

A natural floodplain is an important landform component of rivers and estuaries that allows many essential ecological functions to occur. The term *floodplain* is used here in the widely accepted hydrologic and geologic application to mean the generally flat area adjoining rivers and sloughs that is inundated by peak flows that occur every 1.5-2 years and exceed the capacity of the channel to contain the flow within its normal banks ("bankfull discharge"). Peak flows in winter and spring that happen every 1.5-2 years are considered by river geomorphologists to be the "dominant discharge" that contributes the most to defining the shape and size of the channel and the distribution of sediment, bar, and bed materials. Larger flood events can cause major changes to occur, but they do not happen often enough to be the decisive factor in river geomorphology. The natural floodplain area of *bankfull discharge* is indeed part of a river under normal storm conditions.

However, a more commonly understood use of the term *floodplain* refers to the 100-year floodplain as determined and mapped by the U.S. Army Corps of Engineers (Corps) and Federal Emergency Management Agency (FEMA). This definition is used to prepare land use and flood management plans and to identify ways for people, livestock, and structures to avoid being located on the 100-year floodplain. One of the benefits of levees and flood control reservoirs is reducing the extent and hazards of the 100-year floodplain and similar high-magnitude, low-probability storm events, as experienced in the January 1997 flood. The 100-year floodplain is related to a natural river floodplain but does not apply to the following discussion of ecosystem functions as supported by flood processes. A predicted 100-year floodplain covers a much larger area than a natural floodplain of a river, slough, or stream at bankfull discharge.

At higher flow, water spills out of the channel and flows over the flat-lying land near the river. River channels are not large enough to accommodate higher discharges without overflowing. This process of out-of-bank flow is a common but little recognized attribute of all rivers. Human encroachment on the floodplains of rivers accounts for the predominance of flood-related damage. Central Valley rivers that have little or no remaining natural floodplain, because of levees placed too close to the riverbanks, typically have the lowest ecological values and present the greatest risk of flood damage to adjacent lands if a levee failure were to occur. The large-scale reclamation and separation of low-lying land from alongside rivers, streams, and estuaries have eliminated major habitat areas, such as riparian forests, tule lands, and upper tidal zones, from the system or diminished their ecological potential because of the absence of flood processes .

On many tributaries, large reservoirs and diversions that reduce the frequency and duration of bankfull discharge and restrict channel flow to the low-flow channel most of the time, including during the wet season, have also reduced the size of natural floodplains. In this case, a stream no longer comes into contact with its floodplain except during high-magnitude, low-frequency flood events that exceed the capacity of the reservoir. These types of streams may experience channel straightening and incision, and the reduction (but not elimination) of flood frequency on the lower floodplain often encourages encroachment of agricultural land uses and even recreational development on the area that once supported diverse floodplain habitats.

PHYSICAL PROCESSES

Floodplains reduce flood stages in the Delta, rivers, and streams by increasing the cross-sectional area of the channel and slowing flow velocities. At higher flows, the river merges with its floodplain during overbank flow, increasing the capacity of the river to move and temporarily store large volumes of storm flow. Slow-moving water covering large riverine floodplains and adjacent basins naturally detains the volume of floodwaters entering the Delta and leveed reaches of the lower Sacramento and San Joaquin Rivers. Temporary floodplain storage thereby reduces the peak stage of flood events in the Delta region and other sectors of the levee system, and gradually releases the stormwater after floodwaters recede. The prolonged inundation of floodplains, such as can be observed in the Yolo Bypass and Stone Lakes basin, is highly compatible with the natural flood tolerance of seasonal wetland and riparian vegetation and animal life.

Floodplains capture and store sediment, build soil, and reduce the need for dredging channels downstream and in the Delta. The overbank flow across a floodplain is wider and more shallow than in the channel. The flow often encounters more resistance from vegetation along the outer banks, which causes the river to lose energy in the floodplain areas and, in turn, causes sand and fine sediment to be deposited on the floodplain surface, creating natural levee mounds parallel to the channel banks and building soil to support forests and grasslands. Natural floodplains are thus able to capture and store enormous volumes of fine sediment spread over large areas, balancing the river's sediment budget and preventing the clogging of channels and estuaries downstream.

Floodplain overflow moderates channel incision and bank scour. The term *stream power* refers to the ability of riverflow to erode the bed and bank by the shear stress created by deep, high-velocity, turbulent water. Rivers and streams confined to a narrow channel by bedrock canyon walls or constructed levees have greater stream power, for the same gradient, than alluvial rivers with unconfined adjoining floodplains. Energy and flood volume diverted into the overbank floodplain regulate the stream power acting on the channelbed and banks and, in concert with the binding effect of shoreline vegetation, prevent channel instability and moderate the rate of change of the stream meander. Although many rivers and streams tend to experience some incision of the bed during high winter flows, the capacity of the floodplain overflow moderates stage increases and channel velocities that would otherwise cause excessive channel incision and widespread loss of riparian vegetation and riverine bed habitats during major storm events.

Floodplains contribute to species diversity. During bankfull discharge, there is a flow energy gradient from the channelbanks to the outermost extent of the natural floodplain with a corresponding gradient from larger to smaller particle deposition and greater to lesser frequency of inundation. Scour effects are also greatest nearest the channelbanks. The building up of natural levee mounds and ridges may trap floodwaters in shallow, marshy basins formed between the outermost high ground and the sediment ridge deposited alongside the channel. These physical processes combine to create highly variable vegetation community types and age classes stretched over the floodplain surface with distance from the channel. The variation in plant species and community structure provides a wide array of habitat types and interfaces, resulting in the notably high wildlife species diversity found in riverine and estuarine corridors.

Floodplains are a major source of nutrients, food, and organic matter for the aquatic zone. Floodwater passing over flat-lying lands captures organic litter, carbon and nutrient-rich soil particles, insects, and fallen trees that are transported at high flow stage to backwater basins, estuaries, and secondary channels that may then return the organic "cargo" to the river and Delta aquatic zone. These organic components provide microhabitats, prey items, and nutrients that sustain zooplankton, aquatic invertebrates, and small fish in the rivers and Delta. Organic debris and dislodged trees may be captured by the filtering effect of the floodplain during one year, forming debris piles as floodwaters recede, and then be resuspended or swept away by a subsequent inundation of the floodplain. Without a floodplain to cycle buoyant matter conveyed by rivers and streams at high flow, most of the organic matter generated would be flushed through the system without being fully utilized. By detaining floodwaters longer than in the main channels, floodplains increase the residence time of nutrients, phytoplankton, and zooplankton, which promotes greater energy utilization and higher productivity of the foodweb entering the Delta.

Floodplains provide safe haven and spawning areas for native Delta and valley fish species. Fish, especially juveniles, seek lower velocity refuge from turbid, turbulent floodflows in rivers and streams. Vegetated floodplains adjoining channels provide ideal velocity refuge and overhead and instream cover during high-flow events, where small juvenile salmon, steelhead, and resident native fish can avoid excessive predation and weather the inhospitable stormflows in the main channel. Some fish species important to the Delta, such as splittail, will disperse from the rivers and sloughs into shallow, vegetated floodplains to spawn. Splittail recruitment is highest during wet years when the floodplains of the Delta and rivers, such as the lower Yolo basin, are inundated for a long time.

STRESSORS

Levees restrict the width and extent of the river floodplain. In some areas, the width of the levees is only a slightly wider than the width of the channel at low flow, such as along the Sacramento River downstream of Colusa. Restricted floodplains typically cause deeper flow and faster channel velocity during high stage, restrict the amount and width of allowable or potential riparian vegetation, and have a low ratio of shallow-water habitats to deep, open water. Channels in these areas are typically trapezoidal in cross section, rather than a more natural compound channel cross section with low bank angles and one or more flat-lying floodplain surfaces. The physical processes necessary to sustain floodplain habitats may be absent or diminished.

Dams and reservoir operations reduce the natural spikes of a typical flood hydrograph, thereby reducing inundation of the natural floodplain. Large reservoirs on most of the tributaries of the Sacramento and San Joaquin Rivers capture the 1.5- to 2-year bankfull discharge and limit the magnitude, frequency, and duration of higher channel-forming flows that would otherwise spread into the lower floodplain areas adjoining rivers. They also capture most of the incoming fine sediment that is needed to build soil on the floodplain. The net effect is to convert rivers and streams below dams into much smaller versions of the original channel and floodplain. The managed releases may not be sufficient to interact with the remnant floodplain of the river except during higher magnitude stormflows, especially on rivers such as the American River, where there are no major nondammed tributaries downstream of Folsom and Nimbus Dams. Channel incision that often follows dam construction and associated loss of the natural sediment supply further exacerbates the shrinkage of the floodplain alongside the lowered channel.

Flood management programs and policies affecting the Sutter and Yolo Bypasses discourage vegetation in the floodplain. Although the Yolo and Sutter Bypasses provide some of the physical functions of natural flooding and floodplain benefits, the full ecological potential of the floodplain is not realized because of the artificially uniform grade and generally sterile, nonvegetated condition of most of the bypass system. As recently as 1960, there were still hundreds of acres of natural grassland and valley oak woodland in the bypass system, most of which have been removed to improve floodway conveyance and make way for more intensive cropping patterns. Along rivers and streams contained within levee systems, the width of the floodplain is restricted, and much of the remaining floodplain surface has been reclaimed for orchard and cropland that provide less inundation of vegetated areas below the water surface. In other cases, riparian vegetation is removed from the floodplain to optimize flood conveyance capacity if it is assumed that the predicted 100-year flood event will exceed the capacity of the channel.

RESTORATION NEEDS

Measures for the conservation and enhancement of natural floodplains and flood processes are also provided in the visions for river sediment supplies, natural fluvial geomorphology, and stream meander corridors. If the floodplain, meander width, sediment supply, and natural or simulated floodpeaks are in place, the river will respond by creating natural landforms that support self-sustaining vegetation communities and aquatic and terrestrial habitats. Even partial restoration or simulation of natural physical processes and floodplains will amplify channel characteristics and resultant habitats.

Conservation and management of natural existing floodplains should be promoted. Cooperative efforts with the Corps and California Department of Water Resources (DWR) should be developed to map and describe the hydrologic characteristics and conditions of all remaining natural riverine and estuarine floodplains not separated from channels by levees or irreversible stream incision. Remaining floodplains that interact with bankfull discharge should be maintained as active floodplains because of their ecological functions and habitat potential.

Flood processes and floodplain functions can be restored to many rivers, streams, and estuaries where levees are not essential for flood safety or where agricultural uses are marginal or problematic. Floodplain expansion can be implemented in one of the following ways:

- Set back levees along channels to expand the width of the river's floodplain within the levee system. This approach should be evaluated on many rivers and tributaries as part of the overall reevaluation of the valley's flood control infrastructure and floodplain management policies.

- Acquire flood easements on agricultural and natural lands allow a greater frequency and extent of floodplain inundation.

- Breach or remove levees from channels that are confined by narrow levee corridors, where feasible. In farmed areas, much of the land could continue to be farmed, if desirable, because most flooding would occur in limited areas and only during the dormant season. This approach may have wide applicability to the low-lying plains of the San Joaquin River and lower tributaries and should be studied together with levee upgrades.

- Modify bypass and channel vegetation management policies to allow greater vegetative cover on existing floodplains.

- Expand floodplains and bypasses and add additional flood relief structures to reduce maximum floodstage in the channels, allowing for more vegetation and habitat within the channels, as well as the potential to provide greater flood protection. New flood relief structures should be evaluated for the Sacramento and Feather Rivers along the Colusa basin and Sutter basin and for the San Joaquin River and lower tributaries along the extensive historic river plains.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for natural floodplains and flood processes is to modify channel and basin configurations in order to improve floodplain function along rivers and streams in the Sacramento-San Joaquin basin.

Indicators of the health of natural floodplains and flood processes are area inundated at various streamflows at selected locations in the basin.

LINKAGE TO OTHER PROGRAMS

Efforts to achieve the vision for natural floodplains and flood processes will involve coordination with other programs and organizations, including SB1086 Advisory Council efforts and river corridor management plans for the Sacramento River; Corps-proposed reevaluation of the Sacramento River Flood Control Project and ongoing bank protection project, including more comprehensive floodplain management and river ecosystem restoration opportunities; State Reclamation Board and DWR reevaluation of floodplain management, levee maintenance needs, and flood safety; proposed riparian habitat restoration and floodplain management studies for the San Joaquin River, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service; the San Joaquin River Parkway Plan; various plans for the restoration of tidelands (i.e., tidal floodplains) in the north San Pablo Bay and Suisun Bay; and multiagency plans or studies to breach levees and reopen floodplains of islands of the north Delta, including Liberty and Prospect Islands, Little Holland Tract, and portions of Sherman Island.

CENTRAL VALLEY STREAM TEMPERATURES

INTRODUCTION

Water temperature in Central Valley rivers and streams and in the Bay-Delta is determined by the natural heating and cooling process of water bodies. Water temperature is controlled by water source (i.e., dam releases, runoff, and discharges), surface and groundwater inflow, geomorphology (e.g., depth), tides, riparian shading, water clarity, and, most often, by air temperature. Water temperature is a major factor in habitat suitability for aquatic organisms. Unnaturally high water temperature can become a stressor to many aquatic organisms. Major factors that affect water temperature's role in the health of the Bay-Delta include streamflow, riparian vegetation, and discharges.

Ecological functions regulated by water temperatures include algae blooms, aquatic invertebrate reproduction and growth, fish migration, fish spawning, young fish development and growth, and general well-being of aquatic organisms. Important functions of stream temperature include regulating metabolism and behavioral cues of aquatic organisms, the amount of dissolved oxygen (DO) available in the water body, and rates of organic material decay and nutrient recycling in aquatic habitats. Major factors that limits water temperatures contribution to the health of the Delta are disruption of historical streamflow patterns on streams either from reservoir storage or water diversions, the loss of streamside riparian vegetation, and reservoir, agricultural, municipal, and industrial discharges.

The vision for Central Valley stream temperatures is to protect and improve the ecological functions that are achieved through the many physical, chemical, and biological processes that are regulated by water temperature to provide suitable fish spawning, holding, and rearing habitat conditions. Water temperatures will be reduced in summer and fall below mainstem reservoirs, in lower tributary streams, and in mainstem rivers and the Delta.

BACKGROUND

Natural biochemical processes, as well as the physiology and behavior of aquatic organisms (e.g., respiration, feeding, growth), are partially controlled by water temperatures. Many native aquatic organisms, such as chinook salmon, depend on cool water for spawning, rearing, and migrating. For example, adult salmon migrating upstream through the Delta and into the rivers are stressed when water temperatures reach into the 70-80°F range. High fall water temperatures in the Delta may delay upstream migration of fall chinook salmon from the Bay into and through the Delta. High spring water temperatures in the rivers and Delta may stress young chinook salmon migrating downstream to the ocean. High summer water temperatures in the Sacramento River near Redding may stress the eggs and fry of winter-run chinook salmon. Unusually high water temperatures in historical periods of drought were primary factors in historical declines of salmon and other fish species.

Although natural stream temperatures fluctuate seasonally and in response to meteorological conditions (e.g., air temperature and solar radiation), many important ecological functions are dependent on relatively narrow temperature ranges. For example, salmon and steelhead eggs require water temperatures below 57°F. Growth of young salmon and steelhead is generally optimal in the 50-60°F range. Delta smelt require temperatures in summer below about 75°F.

The ability to control water temperature in rivers and the Delta temperature controls is limited because water temperature is most strongly influenced by air temperature. Some ability to control heating is available through control over streamflows, the discharge of warm water into rivers and the Delta, and the extent of floodplain inundation and shading by riparian vegetation. Temperature can be controlled to some extent below major Central Valley reservoirs by the release of warm or cold water stored at different depths behind the dams. The Shasta Dam Temperature Control Device, when operational, will allow operators to release water from different depths or combinations of depths to regulate water temperature of released water. The amount of cold water that can be released from Central Valley reservoirs is limited especially in drought years.

Temperatures in Central Valley streams follow a seasonal pattern. Water temperatures are controlled primarily by meteorological conditions (indicated by air temperature fluctuations). Although Central Valley air temperatures range from 30°F to over 100°F, stream temperatures generally range from about 40°F to 80°F. Coolwater fish generally require stream temperatures lower than 65°F, which, while easily achieved in high mountain streams, are more difficult to maintain in streams at lower elevations and along the valley floor. Releases from major reservoirs and groundwater (e.g., springs) are two important seasonal sources of cool water.

Maintenance of cool water below reservoirs in valley floor rivers is especially important because salmon and steelhead are blocked from reaching their historic spawning and rearing grounds in headwaters in these rivers.

The water from many Central Valley streams is impounded by large multipurpose reservoirs (as well as by smaller diversion dams) that limit the upstream migration of anadromous fish into higher elevation tributaries historically used for holding, spawning, and rearing. The operations of these reservoirs can be used to maintain adequate stream temperatures in the segments immediately downstream of the reservoirs, but these temperature control operations must be integrated with other water management objectives.

Stream temperature is a major habitat condition that exerts a strong influence on many biochemical processes. Fish and other aquatic organisms require adequate amounts of DO in water to survive. Temperature controls the maximum concentration of DO in water. For example, the maximum DO concentration is higher at 50°F than at 70°F. The decay of oxygen-consuming organic materials increases with temperature; therefore, the net balance of DO is more difficult to maintain at higher temperatures.

Many fish behavior and physiological functions, such as spawning, are controlled by temperature. Fall-run salmon begin to spawn when stream temperatures fall to 60°F. Salmon-egg survival is a strong function of temperature, declining to near zero at temperatures greater than 62°F. Successful holding of adult winter-run and spring-run salmon until spawning occurs only below about 60°F. Temperatures below 65°F are considered necessary for successful steelhead rearing.

Within the physiological limits of each species, temperature increases the growth rate of fish. For example, at 50°F, about 100 days are needed for rearing juvenile fall-run salmon to a size suitable for outmigration (3 inches). Rearing at 45°F would require about 140 days; rearing at 55°F would shorten the growth period to about 80 days. Fish spawning in different streams will therefore have slightly different timing and duration for spawning, growth, and migration.

Hatchery temperature objectives are often targeted to provide maximum growth without increasing mortality from excessive rates of respiration and diseases that are more prevalent at higher temperatures. Coldwater virus disease (IHN) is often a substantial problem at temperatures below 50°F. Salmonid temperature objectives in hatcheries are therefore generally within the 50-60°F range, which is much lower than the full range of Central Valley water temperatures.

RESTORATION NEEDS

Natural temperature conditions in Central Valley streams vary along a continuum on a "longitudinal gradient" from the mountain headwaters to meandering lowland rivers, and on to the Delta. Therefore restoration needs for stream temperatures vary for different streams and stream segments. Restoration needs will vary by stream and stream segment depending on existing conditions. The needs and opportunities to protect and manage Central Valley stream temperatures will depend on the conditions of the stream channel and riparian corridor, as well as the existing water supply (i.e., reservoir storage) of each tributary stream. A primary restoration need will be to maintain relatively low water temperatures in summer and fall for anadromous fish populations in the upstream portion of each major tributary to the Delta, especially those tributaries with larger foothill reservoirs and impassable dams.

In relatively wet years with full reservoirs and high reservoir releases for downstream diversions, water temperatures below the major Central Valley reservoirs are maintained within the 50-60°F target range. However, as available water supply declines (i.e., in drier years), the ability to maintain sufficient carryover storage to sustain the release of cool water and to release sufficient flows to control downstream temperatures for salmon and steelhead rearing is substantially reduced. There is a need to sustain adequate temperatures below reservoirs and power diversion dams to provide coolwater anadromous fish habitat within the existing Central Valley multipurpose water resources management framework. The adaptive management of stream temperatures will be an important ingredient in the successful ecosystem restoration of our Central Valley natural resources.

Particular attention has been given to water temperatures below Keswick Dam because this area is the only remaining spawning habitat for winter-run chinook salmon. Extremely warm water in 1976 and 1977 was most likely a major cause of the decline in winter-run chinook salmon. Only very low populations of winter-run salmon have been maintained since this drought event, when Shasta Reservoir storage declined to less than 1 million acre-feet. The California Department of Fish and Game (DFG) and the Anadromous Fish Restoration Program (AFRP) suggest that Shasta Reservoir carryover storage should not drop below 1.7 million acre-feet to ensure an adequate supply of cold water for release in summer and fall. The Temperature Control Device when completed will provide additional flexibility in temperature control and conserving cooler reservoir waters through the summer and fall.

The State Water Resources Control Board (SWRCB) has added water temperature requirements below Keswick Dam (and in the Trinity River below Lewiston Dam) to the water rights for Shasta and Clair Engle Reservoirs. A multiagency Sacramento River Temperature Task Force is responsible for the adaptive management of Sacramento River water temperatures. It reports to SWRCB on the effects of its temperature management and the resulting winter-run chinook spawning and rearing success each year. These water management decisions are more difficult in years with limited water supply.

Whiskeytown Reservoir releases to Clear Creek, a tributary to the Sacramento River, are sufficiently cool to support salmon and steelhead; however, since 1965, insufficient streamflows and fish-passage problems have prevented this potential habitat from supporting many fish. Low-level outlets can be used for releases to Clear Creek. Efforts to manage temperatures in Clear Creek could be instated as they are on the Sacramento River.

Water temperature control on Lake Oroville releases to the Feather River are controlled (e.g., temperature control panels) for the Feather River Hatchery and the "low-flow" channel to maintained temperature for natural spawning and holding of spring-run salmon and steelhead. Carryover storage sufficient to maintain low fall water temperatures is limited in droughts. The California Department of Water Resources (DWR) is exploring operations of the Oroville-Thermalito complex to determine whether improved stream temperature controls can be achieved. As at Shasta, there is further need to provide additional temperature control means for these adaptive management efforts to provide optimal water temperatures within the overall water management framework. One such means would be additional storage water dedicated to temperature control in the Feather River below Lake Oroville and Thermalito Reservoir.

Yuba River water temperatures are considered well suited for salmon and steelhead below Englebright Dam (the first impassable dam), but flows and riparian vegetation have been insufficient to maintain target temperatures below the Daguerre Dam, the major water diversion dam on the lower Yuba below Englebright Dam. The Yuba County Water Agency is evaluating the temperature control potential of New Bullards Bar Reservoir (a major storage reservoir upstream of Englebright Lake on the North Fork of the Yuba River) and is working with AFRP and DFG to develop an adaptive management strategy for Yuba River flows and temperatures. Again, like at Shasta and Oroville, additional storage dedicated to water temperature and possibly the addition of temperature control devices on major storage reservoirs could improve the water temperature conditions on the lower Yuba River.

Many of the upper Sacramento River tributaries are largely nonregulated. Water temperatures on these stream and in the Sacramento River at their confluence could be improved by managing water diversions and improving riparian vegetation.

Reclamation has recently modified the Folsom Dam temperature control panels to provide some additional temperature management potential; however, the relatively low storage capacity of Folsom Reservoir limits the ability to control temperatures at the Nimbus Hatchery and in the lower American River. Additional storage dedicated for water temperature and potential improvements to temperature controls at Nimbus Dam downstream from Folsom Dam could improve water temperatures in the lower American River.

Temperatures in the San Joaquin River tributaries (Mokelumne, Stanislaus, Tuolumne, and Merced Rivers) are controlled by a combination of cold-water reservoir releases and streamflow management. Although initial efforts to monitor and control water temperatures on these rivers have begun, the upstream segment of each (below the lowest dam blocking migration), corresponding to the potential spawning and rearing habitat for fall-run salmon and steelhead, may require additional reservoir and flow management actions such as those described above for Shasta, Oroville, New Bullards Bar, and Folsom Dams. Long-term agreements to adaptively manage reservoirs on these San Joaquin River tributaries are needed to provide the best possible flow and temperature conditions for fish habitat while also protecting the other existing beneficial water uses.

Although control of water temperature is limited in the mainstem Sacramento and San Joaquin Rivers and the Delta, restoration of riparian vegetation and establishment of adjoining marsh-slough complexes should benefit water temperatures in small but significant ways. Shallow water habitats with adequate shade will not locally warm to intolerable levels for species dependent on them. Dead-end sloughs will maintain slightly lower water temperatures with adequate shading. Rivers and Delta channels will heat less early in spring and cool earlier in the fall. Although water temperature changes would be small, possibly less than an degree or two, such changes are significant when overall water temperatures are stressful or approach lethal levels for some species.

Although the historical stream temperatures can be used as a guideline for establishing stream temperature targets, the actual management of temperatures for each tributary or river segment will require coordination with all agencies and stakeholders. Therefore, stream temperature targets should be developed within the existing multipurpose water resource management framework for each watershed. The relative ecological value of streamflow and temperature should be estimated for each tributary stream so that the potential management of stream temperature (i.e., reservoir releases and drawdown restrictions) can be effectively managed. Streamflow and temperature should be accurately monitored and rapidly evaluated for both short-term and long-term management decisions. This basic streamflow information will then allow for adaptive management of streamflows and temperatures to become a major element in the restoration of ecological functions and benefits throughout the Sacramento and San Joaquin River basins.

There are several stream temperature actions that should be implemented immediately because there is general agreement that these actions will improve stream temperatures without having significant impacts on water supply or energy resources. Many of these actions have been recommended by DFG and by the AFRP but have not been implemented because of limited financial resources. They include:

- increasing coldwater releases from Whiskeytown Lake to Clear Creek to allow restoration of the habitat along this 18-mile stream segment for salmon and steelhead spawning and rearing; Whiskeytown Lake could be coordinated with the operation of Shasta Dam to minimize impacts on the water supply;

- developing a long-term agreement with Pacific Gas and Electric Company (PG&E) (to provide appropriate compensation for energy losses) to monitor temperatures and provide bypass flows in the lower North Fork and South Fork segments of Battle Creek to maintain suitable temperatures for holding, spawning, and rearing habitat for spring-run and winter-run salmon and steelhead;

- restoring stream temperature monitoring, maintained at several U.S. Geological Survey (USGS) stream gages and other strategic locations, of Central Valley streams, combined with improving fish sampling and counting devices to provide a solid basis for adaptive stream temperature management decisions; and

- increasing Feather River flows in the "low-flow" channel to a maximum of 2,500 cubic feet per second (cfs) and reducing the flows through Thermalito Forebay and Afterbay released to the Feather River. Thermalito releases can have a major effect on downstream temperatures; only water needed for irrigation diversions and peaking power generation should be diverted (energy from the Thermalito power plant would be reduced).

Because temperatures are an important habitat condition and can vary with changes in other factors, there should be a substantial commitment to continued monitoring and evaluation of the physical, chemical, and biological processes and ecological functions that are governed by stream temperature.

Many stream-temperature management actions will require a slightly longer implementation period because additional information is needed for careful planning decisions or because detailed designs for new or modified facilities are required. Nevertheless, the necessary planning studies and engineering design work can be initiated on the following longer term actions:

- Establish coordinated stream-temperature management teams for each major stream following the approach by the Sacramento River Water Temperature Task Force that is used to help the U.S. Bureau of Reclamation (Reclamation) allocate and schedule releases from Shasta and exports from Trinity River for Sacramento River temperature control. This cooperative management approach attempts to maximize the overall streamflow and temperature benefits achieved with the available water supply while maintaining other beneficial uses of water. The choice between carryover storage and increased releases for temperature control can best be made by this type of adaptive management team. The potential conflicts between different fish populations and other water uses can also be addressed using this strategy.

- Restore large blocks of riparian habitat to create nodes that are sufficiently large (>50-100 acres) to support air convection currents that will cool adjacent river water temperatures.

- Restore and protect the stream channels and riparian corridors (i.e., pools, gravelbeds, and vegetation) to minimize warming along the stream gradient and provide habitat features that allow fish to use thermal refuge areas (e.g., pools and springs).

- Develop a comprehensive series of reservoir and stream temperature models that can be used to investigate the effects of possible modifications to reservoir facilities and stream channel and riparian corridor conditions. These calibrated models can form the basis for adaptive management of Central Valley streamflows and temperatures within the overall framework of multipurpose water management objectives and constraints.

To protect and improve Central Valley stream temperatures, there is a need to achieve a responsible balance between water management for temperature controls and other beneficial uses of the available water supply.

To be implemented, these measures may require that water from willing sellers be purchased or water exchanges negotiated and alternative supplies explored. There are two general stream temperature objectives:

- Provide sufficient carryover storage and selective withdrawal facilities in major reservoirs to protect summer and fall release temperatures to allow spawning and rearing of winter-run and fall-run salmon. Because salmon eggs have increasingly high mortality rates at temperatures between 55°F and 60°F, a target temperature of 56°F during spawning and egg incubation is appropriate. For example, the Shasta Reservoir temperature device is being constructed to allow warmer water to be released in spring and early summer to reserve more of the cooler water (at greater depth) for summer and fall releases. Because some carryover storage must be maintained to protect release temperatures, specific reservoir releases for water supply may be reduced in some dry years.

- Provide sufficient summer and fall streamflows to maintain adequate holding and rearing temperatures for spring-run and winter-run salmon of less that 60°F and steelhead trout of less that 65°F in streams supporting these populations. This may require limiting hydropower diversions or providing higher reservoir releases than would otherwise be required for downstream diversions.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for Central Valley stream temperatures is to maintain, improve, and restore water temperature regimes in order to meet life history needs of aquatic organisms. Indicators of the health of Central Valley stream temperatures are stream temperature measurements during critical periods at selected locations of concern.

LINKAGE TO OTHER PROGRAMS

There are several important ongoing programs that attempt to improve the multipurpose water management of Central Valley streamflows and temperature conditions. The vision for stream temperature management is to complement and coordinate (where conflicts exist) these existing streamflow and temperature management programs. Several agencies are directly or indirectly responsible for stream temperature management. ERPP supports the policies and decisions of these individual agencies and could provide resources to implement stream-temperature management actions and mediate conflicts between water management goals of individual agencies.

Important stream-temperature management responsibilities and programs of agencies include DWR's operation of Lake Oroville to satisfy DFG hatchery and stream temperature objectives; Reclamation's operation of Central Valley Project reservoirs to achieve specific temperature criteria or objectives for salmon and steelhead habitat conditions; Federal Energy Regulatory Commission's regulation of minimum flows below hydropower projects throughout California (e.g., Butte Creek temperatures below Centerville Diversion Dam); SWRCB's administration of water rights and water quality objectives (in coordination with Regional Water Quality Control Boards) necessary for beneficial uses and for fish protection below reservoirs and dams; DFG's responsibility to study and recommend stream temperature requirements for fish protection and propagation in streams and at hatcheries; USFWS's and the National Marine Fisheries Service's programs to recommend temperatures needed for mitigation of impacts from federal projects (e.g., hatcheries) and protection of endangered species (the biological opinion for winter-run chinook salmon and the AFRP each have specific temperature recommendations and requirements); and USGS's water resources division programs to measure streamflow and temperature to provide the information necessary for adaptive management of stream temperatures.

INTRODUCTION

Hydraulic processes refers to the direction and velocity of flows in Bay-Delta channels. The direction and velocity of water and their distribution in time and location are important factors in habitat preferences of Bay-Delta organisms, erosion and sedimentation processes, migratory cues for organisms, and many other ecological processes and functions in the Bay-Delta. Major factors that affect hydraulics of Bay-Delta channels streamflow, sediment composition, and channel configuration.

The vision for hydraulic processes in the Sacramento-San Joaquin Delta is to restore channel hydraulics to conditions more like those that occurred during the mid-1960s in order to provide migratory cues for aquatic species, provide transport flows for eggs, larvae, and juvenile fish, and transport of sediments and nutrients. The Bay-Delta estuary provides important fish spawning, rearing, and migrating habitats. A healthy Bay-Delta also serves as an important link in nutrient cycling and provides for high levels of primary productivity that supplies the aquatic foodweb. Flow conditions in Delta channels affect foodweb production, transport of organisms through the Delta, and vulnerability to south Delta pumping plant diversions.

BACKGROUND

Hydraulic processes refer to the flow of water in the Delta channels. Channel hydraulics in the Delta are influenced by tides, river inflow, winds, channel diversions, and export pumping. Human influences on channel hydraulics also include physical barriers that are operated to improve central Delta water quality and barriers installed seasonally to maintain water levels for agricultural irrigation or to improve water quality conditions for upstream-migrating San Joaquin fall-run chinook salmon.

Nonimpeded tidal action into tidal wetlands affects sediment and nutrient supplies into those wetlands and complements natural marsh successional processes. Tidal action associated with flows out of tidal wetlands transports nutrients and organic carbon into aquatic habitats of the Bay-Delta.

Hydraulic patterns in the Delta are important to the survival of delta smelt, longfin smelt, striped bass, chinook salmon, and other fish dependent on using the Sacramento-San Joaquin Delta. Unfavorable hydraulic conditions, such as ebb tides moving south to Delta export facilities instead of moving west toward Suisun Bay, reduce survival of fish such as delta smelt or young chinook salmon residing the Delta.

Improved hydraulic patterns will increase residence times of Delta water; provide more natural net downstream flows; and improve rearing and spawning habitat, nutrient cycling, and foodweb integrity.

Delta hydraulics are determined by a combination of flow parameters including Delta inflow, Delta diversions, tidal flows, and facility operations (e.g., operation of the Delta Cross Channel [DCC] gates).

Unfavorable hydraulic conditions decreases survival for juvenile chinook salmon originating in the Sacramento River as they migrate through the Delta. With a high rate of north-to-south flow through the DCC and Georgiana Slough from the Sacramento River into the central Delta, young salmon may become lost or delayed within the Delta or susceptible to being drawn to the south Delta pumping plants.

Favorable hydraulic conditions are important for chinook salmon because the Delta is used as a migration corridor and as rearing habitat. Juvenile chinook salmon rearing in the Delta are exposed to adverse hydraulic conditions for approximately 1-3 months until they are ready to migrate to the ocean.

Other species, including striped bass and delta smelt, are also subject to being drawn south across the Delta to the pumping plants. Because the water has a short residence time, the food supply is generally poor for those fish drawn into or residing in the central and southern Delta.

RESTORATION NEEDS

Ecosystem restoration efforts should focus on restoring hydraulic patterns typical of those exhibited when the ecosystem was functioning in a healthy state (e.g., 1960s). Healthy channel hydraulics in the Delta during April and May are conditions generally similar to those that occurred prior to the era when large exports of water from the Delta began.

The effects of water exports and lower riverflows can be reduced by altering Delta channel configurations. The two ecological units that have the greatest need for improved hydraulics are the South Delta and Central and West Delta Ecological Units. Cross-Delta flow of water to the south Delta pumping plants reduces residence time of water in the Delta and alters flow direction and magnitude.

The greatest opportunities to restore hydraulic processes to reference levels that occurred when the estuary was healthier are linked to the water and storage alternatives. The potential for restoration is limited by a water storage and transport component that has its only export facilities located in the South Delta Ecological Unit. Under that condition, increased storage upstream or downstream of the Delta could reduce exports in portions of some months and improve hydraulics during those times. There is a greater potential for restoration of hydraulic transport patterns with a water storage and transport component that allows for exports to occur outside of the internal Delta during major portions of the year. Other more limited opportunities exist that are associated with storing water in the Delta, using physical barriers in strategic locations in the Delta, broadening specific sloughs to increase their flow-bearing capacity, and restoring large acreages of tidal wetlands and tidal channels to increase the tidal volume of the estuary.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for Bay-Delta hydraulics is to establish and maintain a hydraulic regime in the Bay-Delta in order to provide migratory cues, create and maintain habitat, and facilitate species distribution and transport.

Indicators of the health of Bay-Delta hydraulics are tidal volumes, current velocities, and residence time of waters in selected channels and sloughs of the Bay-Delta..

LINKAGE TO OTHER PROGRAMS

The objective of one current program, the Temporary Barriers Program in the south Delta, is to improve the quantity and quality of irrigation water to agricultural users in the south Delta. A secondary objective is to provide a physical barrier in spring at the head of Old River at its junction with the San Joaquin River to reroute outmigrating San Joaquin fall-run chinook salmon downstream and away from the export facilities. In fall, a partial rock barrier modifies channel hydraulics to reduce the risk of dissolved oxygen blocks near Stockton and to ensure that a greater percentage of attraction water from natal streams reaches the Central and West Delta Ecological Unit.

The DCC gates are required to be closed under the terms of the National Marine Fisheries Service's biological opinion on winter-run chinook salmon and the 1995 Water Quality Control Plan to reduce impacts on salmon migrating down the Sacramento River. The gates can be closed at the request of the California Department of Fish and Game for half of November, December, and January. The DCC gates are then closed from February 1 through May 15.

INTRODUCTION

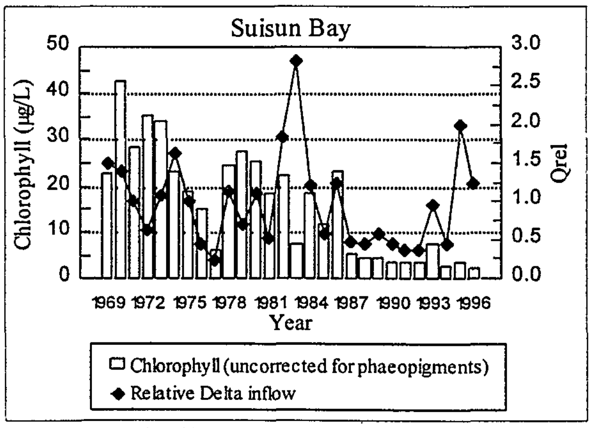
The Bay-Delta aquatic foodweb is based on energy derived from plant production (primary production) and production by bacteria, microinvertebrates, and macroinvertebrates (secondary production). Energy is transferred from these lower trophic levels up the foodweb to fish, waterfowl, and wildlife. The CALFED vision for the Bay-Delta aquatic foodweb is to restore primary and secondary production to levels comparable to those that prevailed during the 1960s and early 1970s. This will be accomplished by increasing freshwater inflow to the estuary in spring of drier years; increasing the residence time of water in the Delta during summer; restoring tidal action to diked wetlands; reducing concentrations and loadings of trace metals, herbicides, and other toxic substances in sediments and waters of the Central Valley; and reducing export losses. Increasing the amount and diversity of organic matter input from the Bay-Delta watershed by restoring aquatic, riparian, and wetland habitats within the Central Valley would also help achieve this vision. Export losses can be reduced by modifying the structure and operation of Delta conveyance and pumping facilities. Such improvements in the foodweb would contribute significantly to restoring striped bass, delta smelt, chinook salmon, and other Bay-Delta fish populations.

BACKGROUND

The foodweb of the Bay-Delta ecosystem consists of all the plants, invertebrates, and other lower trophic-level organisms that serve as prey for fish, water birds, and other higher trophic-level resources of the ecosystem. "Benthic" foodweb organisms are bottom dwelling, whereas plankton spend most of their time drifting in the water column. Total productivity of the Bay-Delta estuary is dependent primarily on the amount of plant biomass produced.

Plant contributions to the estuary foodweb consist mostly of benthic algae and phytoplankton produced in the estuary and its watershed, and vascular-plant debris input from terrestrial or wetland communities adjacent to the system. Algae are generally small (diameter <0.1 millimeters [mm]), easily transported, and highly nutritious; whereas most vascular-plant debris begins as coarse particulate organic matter that must be colonized and partially decomposed by bacteria before being usable by invertebrates and fish. Plant detritus provides a dependable, "time-released" form of food and, in combination with algae, provides for a more stable foodweb. Bacteria produced from the processing of dissolved organic matter is another important food resource for smaller invertebrates, which in turn feed larger forms.

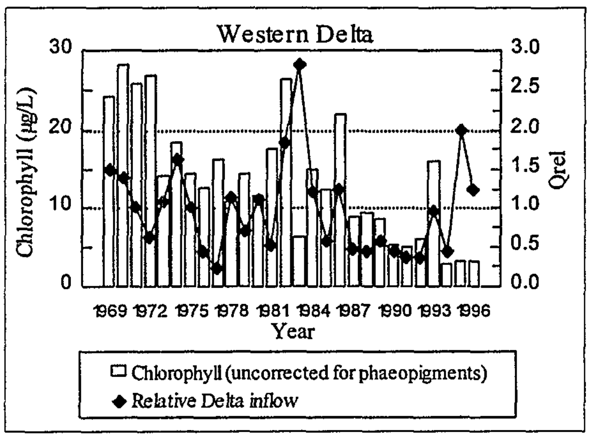
The Bay-Delta foodweb has undergone a number of changes since the 1960s. Most notably, algal abundance (as measured by chlorophyll concentrations in waters of the estuary) has declined in important fish nursery areas of Suisun Bay and the western Delta. Lowered algal abundance in Suisun Bay coincides with very low



Average May-Oct Chlorophyll Concentration in Suisun Bay and Relative Delta Inflow (Inflow Divided by 1967-1991 Mean Inflow)

Delta outflow during drier years, particularly in the drought years, such as 1977 and 1987-1992, and with very wet years, such as 1983 and 1995. Chlorophyll levels greater than 20 micrograms-per-liter (μg/l) represent productive water. Such levels have not been achieved in Suisun Bay since 1986.

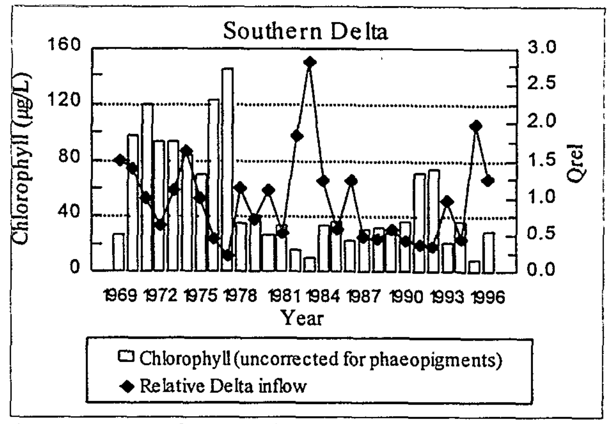
Over the past three decades, chlorophyll concentrations upstream in the western Delta have been similar to those in Suisun Bay. As in Suisun Bay, concentrations are lower in dry years and very wet years.



Average May-Oct Chlorophyll Concentration in the Western Delta and Relative Delta Inflow

A pattern of very low chlorophyll levels in Suisun Bay and the western Delta beginning in 1987 concerns many scientists. These low levels may be the result of high densities of Asian clams (*Potamocorbula amurensis*) which colonized the Bay after being accidentally introduced from the ballast waters of ships. Large numbers of the clams colonized this area of the estuary during the drought period from 1987 to 1992. The very low chlorophyll levels from 1994 through 1996 are of grave concern and may be a factor in the poor survival of young delta smelt and striped bass that depend on the high productivity of the western Delta and Suisun Bay.

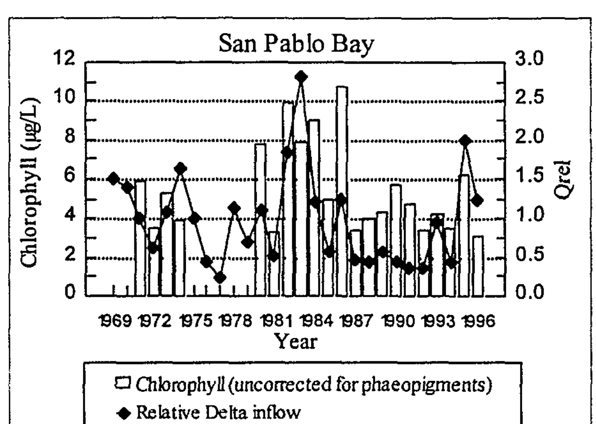
Some of the plant production appearing in the Delta and Suisun Bay is washed down from south Delta channels and the San Joaquin River.



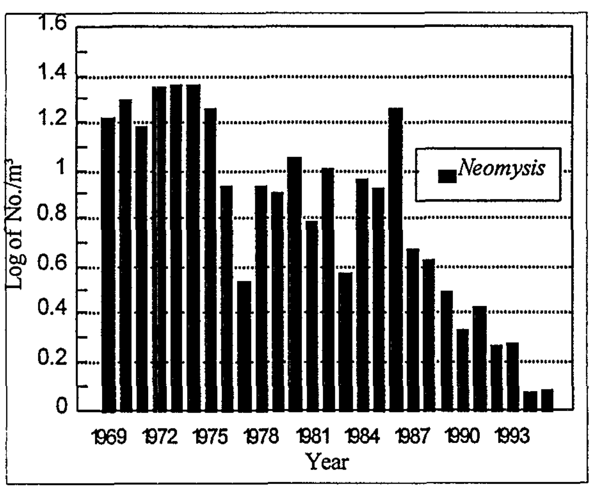
Average May-Oct Chlorophyll Concentration in the Southern Delta and Relative Delta Inflow

Chlorophyll levels in these channels reached an average of over 100 μg/l in spring and summer of some years in the early 1970s. In the past two decades, productivity in these channels, although remaining relatively high, has declined. Levels in 1993, 1995, and 1996 were low, possibly as a result of high flows (as in 1982, 1983, and 1986); however, lower levels in recent nonwet years are a concern.

In wet years, some of the algae biomass in Suisun Bay and the Delta is washed downstream into the wider expanses of San Pablo Bay and other portions of San Francisco Bay. Spring and summer chlorophyll levels in San Pablo Bay are generally low compared with those in Suisun Bay and the Delta. Peak concentrations in the past three decades occurred in wet years (1982, 1983, 1984, and 1986).



Aquatic invertebrate population trends followed those of algae over the past three decades. Species that once dominated the aquatic invertebrate community have become relatively scarce, while some others have increased in relative abundance. Many native species have become less abundant or more narrowly distributed, while dozens of new non-native species have become well established and widely dispersed. In general, the abundance of plankton has declined, while populations of many bottom-dwelling invertebrates, most notably Asia clams, have increased. This transition has been most evident in Suisun Bay and other traditionally important fish-rearing areas. Also in these areas, populations of rotifers, copepods, and other relatively small species have declined substantially since monitoring began in the 1960s. This pattern is perhaps most dramatic for the mysid shrimp, which have declined to less than one-tenth of their former abundance, particularly since 1986. The continued decline from 1993 to 1995, despite the return of higher flows, is of particular concern. These declines in zooplankton abundance have roughly coincided with the decline in algae, one of the main food sources for the zooplankton.



Concentration of Mysid Shrimp in Bay-Delta Estuary 1969-1995

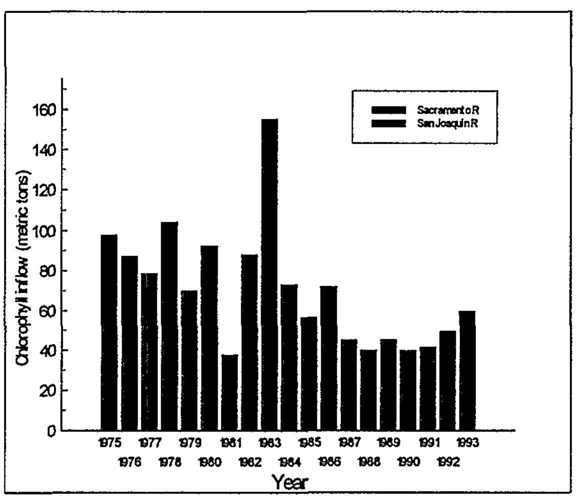
The deterioration of the zooplankton community and its algal food supply in key habitat areas of the Bay-Delta is a serious problem because striped bass, delta smelt, chinook salmon, and other species that use Suisun Bay and the Delta as a nursery area feed almost exclusively on zooplankton during early stages of their life cycles. Research indicates that survival and growth of fish larvae generally increase with increased concentration of zooplankton. Declines in the production of juveniles of these fish species appear to coincide with the declines in algae and zooplankton. Modifying the Bay-Delta ecosystem in ways that will lead to increased algae and zooplankton abundance may be critical to restoring Bay-Delta fish populations and improving the health of its ecosystem.

Areas of the Bay-Delta where hydraulic conditions allow food resources to accumulate in the water column rather than settling or washing out are important habitats for plankton. This accumulation of food resources results from passive processes and from active algal, microbial, and zooplankton reproduction. The comparatively benign hydraulic conditions and abundant food resources characterizing the western Delta and Suisun Bay permit the development of high zooplankton populations on which many estuarine resident and anadromous fish depend during their early life stages. Horizontal salinity stratification enhances this process, especially when the salinity front (sometimes referred to as X2) or the "entrapment zone" is in Suisun Bay.

Much of the plant biomass and other forms of fine particulate organic matter consumed by zooplankton in the Bay-Delta is not produced in the Bay-Delta, but is transported in from the Sacramento and San Joaquin Rivers and accumulates in the western Delta and Suisun Bay. Some comes from the lower mainstem rivers and from side channels, side sloughs, and floodplain lakes. Large amounts of organic matter and associated bacterial biomass enter the rivers, Bay, and Delta as crop residue, leaf litter, dead tule stems, and other organic debris from riparian corridors, floodplains, or other areas subject to periodic inundation by tides and flood flows. Historically, considerable organic material entered the rivers and Bay-Delta from sewage- and food-processing plants. These point source loadings have since been reduced as part of an overall effort to improve water quality.

The San Joaquin River contributes a disproportionately high percentage of the food resources supplied each season to the Delta. The river's chlorophyll levels are among the highest recorded for temperate rivers anywhere in the world because the water has a relatively long hydraulic residence time and high phosphorus and nitrogen levels. Under these circumstances, algae have an abundant supply of nutrients and enough time to process them before being swept downstream into the southern Delta. The Sacramento River, by contrast, has relatively low nutrient levels throughout most of its length and a comparatively short residence time and, therefore, low productivity.

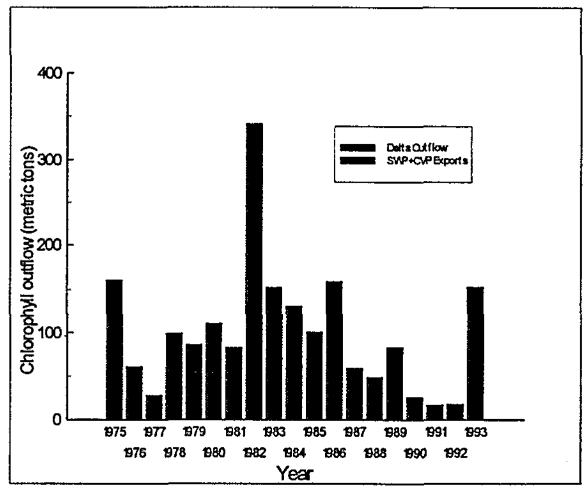
These differences between the San Joaquin and Sacramento Rivers are partly a result of natural



May-October Chlorophyll Inflow to Delta, 1975-1993

differences in regional soils and hydrologic conditions, but are also a function of how the two rivers have been engineered. The San Joaquin River is fertile and sluggish from May to October because it consists primarily of agricultural return flows. In contrast, the Sacramento River consists primarily of reservoir releases that are relatively nutrient poor. Although the San Joaquin River accounts for only 17% of Delta water inflow from May through October, it contributes 60% of the algal biomass flowing into the Delta.

From May through October, the amount of algal biomass flowing out of the Delta exceeds the amount transported in from the rivers by an average of 44%. This difference results from production of algal biomass within the Delta. Most of the biomass transported to or produced within the Delta flows out of the Delta, either through the main channel connecting the Delta with Suisun Bay or by way of the project pumps in the southern Delta. Of the total outflow of water and algal biomass from the Delta (i.e., project exports plus "net Delta outflow" to Suisun Bay), two-thirds goes to Suisun Bay and one-third is exported by the pumps.



May-October Chlorophyll Outflow from Delta, 1975-1993

The proportion of the organic material in the Delta that reaches Suisun Bay varies considerably from year to year and depends, in part, on prevailing flow conditions. At higher flows, much of the organic material brought in by the rivers will travel to Suisun Bay or farther to San Pablo Bay or central San Francisco Bay. At low flows, a greater proportion remains in the Delta or gets exported at south Delta pumping plants.

In addition to serving as a critical habitat area for food production and accumulation, Suisun Bay is an area of intense food consumption. Before the prolonged drought that began in the mid-1980s, high densities of copepods, young mysid shrimp, and other planktonic grazers usually accompanied relatively high chlorophyll levels in Suisun Bay.

Dozens of species of filter-feeding clams and other benthic grazers joined in the intense food consumption. Since the drought ended in 1993, however, chlorophyll concentrations have remained low in Suisun Bay, even though flows early in the dry season have been managed to maximize the frequency with which salt- and fresh water converge in Suisun Bay. It is likely that the reason for this lack of plankton recovery is the Asian clam. This non-native marine bivalve was first detected in Carquinez Strait in 1986. Since then, it has become very abundant throughout San Pablo and Suisun Bays and, in dry years, extends up into the western Delta. It is estimated that the clam can effectively filter the entire water column within 24 hours. Hence, some scientists believe that these clams are effectively removing algal biomass from the water column of Suisun Bay almost as fast as the Delta can supply it. The Asian clam is therefore considered an important "stressor" that will likely hamper efforts to restore the Bay-Delta foodweb; however, clam densities and upstream distribution in the estuary have declined since 1993 with the onset of higher freshwater inflows.

The decline of plankton populations and chlorophyll concentration in the Bay-Delta may be a result, at least in part, of the effects of heavy metals, herbicides, pesticides, and other toxic substances. Low concentrations of these substances in the water column may act individually or in combination to reduce productivity of plant and animal plankton.

RESTORATION NEEDS

Restoring the Bay-Delta foodweb would require enhancing productivity and reducing loss of productivity to water exports from the system, particularly in drier years. There are several options for enhancing productivity. Improving Delta inflow and outflow in spring of drier years will be an essential element of any plan. Other elements include reducing losses to exports from the system and reducing the amount of toxic substances entering the system.

Additional improvements can be gained by increasing shallow-water habitat and tidal wetlands in the Bay and Delta. Increasing the acreage of floodplain lakes, sloughs, and other backwaters in the Sacramento River drainage will increase organic matter inputs to the Delta. Actions to accomplish this include opening leveed lands to tidal or seasonal floodflows; increasing the array of sloughs in the Delta; protecting and restoring shallows, shoals, and channel islands in the Delta; and providing for a more natural floodplain and meander belt along the rivers. Restoring tidal action to leveed lands in San Pablo Bay and Suisun Marsh is another option. The Yolo and Sutter bypasses offer potential opportunities to produce more permanent slough, riparian, and wetland habitats in the Sacramento River floodplain. Setback levees or improved riparian and shallow-water habitat along leveed reaches of the rivers and Delta offer additional opportunities to increase productivity of the Bay and Delta. All of these actions will promote aquatic and riparian plant production, which should improve the foodweb for many important fish and wildlife species in the Bay and Delta.

There are several ways to increase the supply of algal biomass maintained and produced in the Delta and transported to Suisun Bay. Changes in the timing and magnitude of flows through the Delta and exports from south Delta pumping plants may increase transport of organic materials to and productivity within the Bay and Delta. Spring flow pulses in drier years from the rivers will enhance productivity in the rivers, Bay, and Delta and ensure that a greater amount of this productivity is transported to the Bay and Delta. More of the organic material transported to or produced within the Delta will be retained in the Delta or transported to the Bay if the export pumps are relocated.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for Bay-Delta aquatic foodweb is to maintain, improve, or restore the amount of basic nutrients available to estuarine and riverine systems in order to provide a sustainable level of foodweb productivity.

Indicators of the health of the Bay-Delta aquatic foodweb are indices of primary production (i.e. chlorophyll concentration) and important foodweb organisms such as mysid shrimp and other zooplankton that make up the basic elements of secondary production.

LINKAGE TO OTHER PROGRAMS

Efforts to restore the productivity of the Bay-Delta foodweb would involve the cooperation and support from established programs underway to restore habitat and fish populations in the basin. Restoring the plankton food supply for native fishes is a primary focus of the recovery plan for the Sacramento-San Joaquin Delta Native Fishes. The Central Valley Project Improvement Plan (PL 102-575) calls for doubling the anadromous fish populations (including striped bass, salmon, steelhead, sturgeon, and American shad) by 2002 by changing flows and project facilities and operations. This program involves actions that may directly or indirectly benefit the Bay-Delta foodweb. The California Department of Fish and Game is required under State legislation (The Salmon, Steelhead Trout, and Anadromous Fisheries Program Act of 1988) to restore numbers of anadromous fish in the Central Valley. Actions include restoring the food supply of anadromous fish. The Ecosystem Restoration Program Plan proposes to coordinate efforts by the State Water Resources Control Board and Regional Water Quality Control Boards to reduce the amount of toxic substances released into Central Valley waterways.

INTRODUCTION

Fire, erosion, plant succession, and surface and ground water flow are upper watershed processes that contribute to the water supply and water quality of the Bay-Delta. Major factors that effect these processes are fire suppression, wildfire, road building and maintenance, water diversions, livestock grazing, timber harvest, and forest management practices.

The vision for upper watershed health and function is to reduce the adverse effects of stressors sucha as wildfire, erosion, sedimentation, timber harvest, road construction, and water diversions in order to maintain watershed health and the ability to contribute to the health of the Bay-Delta ecosystem. Water supply and water quality in the Central Valley require healthy watershed processes in the upper portions of the tributary watersheds. Land and resource management in the upper portions of tributary watersheds have substantially modified watershed processes and affected the reliability of inflows of high-quality water to the Sacramento-San Joaquin Delta and San Francisco Bay. Management activities have also affected the available capacity of reservoirs that store water for water supply and provide flood control to downstream residents. Upper watershed stressors include wildfire, road construction and maintenance, water diversions, timber harvesting, and livestock grazing.

BACKGROUND

WILDFIRE

Prehistorically, fire was a principal mechanism by which the nutrients contained in forest material were recycled. With fire frequency reduced since the late 1800s recycling of forest nutrients has been reduced, which in turn has lessened forest and watershed health. The Native American practice of setting fires to enhance their environment has stopped and fire suppression policies and large-scale livestock grazing has been introduced (Vankat 1977, Kilgore and Taylor 1979, Swetnam et al. 1992). In response, rates of biomass decomposition have dramatically declined and fuels have accumulated throughout most upper-watershed wildlands. Because wildfires are less frequent, they now burn larger areas with higher intensity and with greater environmental damage than occurred during the presettlement period (McKelvey et al. 1996).

Wildfires can have devastating effects on watershed health that, in turn, affects the quantity, timing, and quality of inflows to the Delta and San Francisco Bay from the upper watersheds. Catastrophic wildfire can produce more intensive and extensive changes in watershed conditions than any other form of disturbance (Kattelmann 1996).

Over the past century, fire suppression and logging of large conifers have resulted in forests dominated by dense stands of tree species that are relatively small, shade tolerant, and fire sensitive, such as white firs and incense-cedars (Parsons and

DeBendeetti 1979). Consequently, there has been a large increase in the volume and continuity of live and dead wood fuels near the forest floor that provide a fuel "ladder" that connects surface fuels with the forest canopy (McKelvey et al. 1996). Risks of large, severe fires have increased accordingly. Such changes have been greatest in the lower and middle elevations of the Sierra Nevada, which is also where human development has been most rapid. With the increase in hazardous fuel conditions, human populations and property potentially endangered by fire have also increased. On a regional scale, Sierran forest ecosystems are believed to be outside the range of variability that was present in the historical ecosystem regarding fire frequency and severity, forest structure, and landscape mosaic (distribution of vegetation patches) (Skinner and Chang 1996).

Nonthinned conifer stands are widespread in the Sierra Nevada. These stands have dense understories that provide the horizontal and vertical continuity of fuels that fires need to move from the ground surface to the forest canopy. Excessive competition for water and sunlight in nonthinned stands often weakens or kills trees, resulting in increased fuel loads, potential fire severity, and the rate of spread (Weatherspoon 1996). Present fuel conditions in much of the Sierra Nevada support the potential for large, severe fires (Sapsis et al. 1996).

Timber harvesting substantially increases fire hazards unless postharvest slash treatments (e.g, piling and burning) are implemented (Stephens 1995, Weatherspoon 1996, van Wagtendonk 1996, Elliott-Fisk et al. 1996). Forest-practice regulations, which apply on all private timberland in California, require only minimal slash treatments (e.g., lopping branches and tops) and only in a highly limited area (within 50-100 feet of publicly accessible roads and 100-200 feet of structures maintained for human habitation) (14 CCR 917.2).

Catastrophic fire is detrimental to watershed function and water quality. By killing vegetation, burning the organic matter in litter and soil, and forming impervious soil layers, severe fires accelerate runoff from the watershed. More water is discharged over a shorter period of time, peak flows are greater (contributing to increased flood hazards), and summer and fall streamflows are lower than those in less disturbed watersheds. Bare soils and increased runoff cause greater detachment and transport of soil particles. With reduced infiltration, saturated soil conditions and mudslides become more prevalent. Sediment carried to streams increases markedly, particularly where riparian vegetation is burned (Kattelmann 1996). In addition to the direct effects of catastrophic fires, ground disturbance related to fire suppression and postfire activities (e.g., salvage logging) adversely affects water quality. Although total annual water yield from a watershed may increase for several years following a fire, the value of the increased yield is limited because it occurs during peak flows.

ROADS

Roads are probably the most important cause of accelerated erosion in western montane forests (Kattelmann 1996). They reduce rainfall infiltration, oversteepen adjacent cut-and-fill slopes, and, by intercepting subsurface flows, divert runoff across compact surfaces. Stream crossings are particularly important sources of sediment because of their direct disturbance to the channel. The failure of an individual culvert, for example, can cause gullies and landslides, resulting in hundreds of tons of sediment entering streams and storage reservoirs (Weaver and Hagans 1994). Landslides and surface erosion can often be traced to haphazard road design, location, and construction; carefully planned road systems disturb less ground and produce less sediment than poorly planned systems.

Road instability is often increased by inadequate maintenance. Funding for maintenance of forest roads in the State is inadequate and continues to decline. In addition to removing unneeded roads or closing them seasonally, reshaping roadcuts, pulling back side-cast material, "ripping" compact surfaces, and removing stream crossings can be effective means of rehabilitating watersheds (Kattelmann 1996).

TIMBER HARVEST

Although soil disturbance associated with felling trees and skidding logs expose forest soils to rainfall, which causes some soil compaction, timber harvesting has less of an effect on soil erosion than road construction (Kattelmann 1996). Clearcut areas are relatively susceptible to erosion until vegetative ground cover becomes reestablished. After harvest, the ability of the remaining tree roots to inhibit erosion gradually declines until new trees become well established. Using tractor skidders on highly erodible or unstable areas can lead to accelerated erosion or landslides. Timber harvesting and using heavy equipment adjacent to streams increases streamside erosion. Best management practices implemented by the U.S. Forest Service (USFS) on national forest lands and required on private forest lands by the California Forest Practice Rules limit the extent of clearcuts and the use of heavy equipment on erodible or unstable lands.

Timber harvesting affects peak flows by reducing transpiration (i.e., the amount of water used within a specific period by plants to build tissue) and by accelerating snowmelt by exposing snow-covered areas to the sun. Excessive vegetation removal can increase flooding, particularly during small and moderate storms and in small basins (Kattelmann 1996); however, increased thinning and selective harvesting has the potential to increase usable water yield by reducing transpiration.

GRAZING

Like road construction and timber harvest, past grazing practices have left a legacy of watershed degradation in California. Livestock grazing has probably affected more land in the Sierra Nevada than any other management activity (Menke et al. 1996). Although livestock density on forest lands has generally declined since the late 1800s, grazing continues to affect watershed health and function.

The hydrologic effects of grazing are primarily related to livestock behavior and management. Loss of streamside vegetation from grazing promotes soil compaction and erosion. Trampling of streambanks causes erosion and sedimentation in many montane meadow streams. Removal of riparian vegetation by livestock in headwater valleys of the North Fork Feather River, for example, has led to rapid channel widening and massive sediment loads (Kattelmann 1996). Impacts of grazing on watersheds can be substantially reduced by removing livestock before residual forage becomes deficient.

RESTORATION NEEDS

Current land uses in the upper watersheds make it infeasible to return to the prehistoric fire regime, where fires occurred every 8-26 years depending on vegetation type and climate (McKelvey et al. 1996). Not only are structures, infrastructure, and managed forests at too great a risk of fire damage to permit burning at the pre-European average rate of at least 1 million acres annually, but regulatory constraints and the social costs of fire and its effects (e.g., low air quality) prohibit burning at pre-European scales. Although fire will remain an essential element of these wildland ecosystems, it must be controlled and used in conjunction with other techniques to reduce fuel loads to levels consistent with maintaining watershed and forest health.

Prescribed fire is an effective tool for managing forest fuels (McKelvey et al. 1996). It includes prescribed ignited fires (fires intentionally set to burn a planned area at a planned intensity) and prescribed natural fires. Prescribed natural fires are those resulting from unplanned ignitions (caused by lightning or humans) but for which plans have been adopted that specify conditions and areas under which such fires will be allowed to burn. Prescribed natural-fire planning represents an important opportunity for wildfire help to meet management objectives, rather than be in conflict with them. Mechanical fuel-management techniques (e.g., thinning) can also reduce fire hazard (Elliott-Fisk et al. 1996).

From a practical perspective, perhaps the most important requirement for successful fuel management programs is a viable market for small trees and other biomass materials removed from wildlands. Products made from these materials include pulp chips, panel products (e.g., particle board), biomass energy fuel (e.g., for production of electricity), ethanol, and lumber. A major limitation on the marketability of biomass materials is their high handling costs. Recent innovations in logging equipment could substantially increase the feasibility of marketing such materials, which, in turn, would enable more extensive fuel treatments.

Unless resource commitments are made to implement fuel management on an unprecedented scale, catastrophic wildfires will have increasingly detrimental environmental and socioeconomic consequences, among the most important of which are impaired watershed functions and nonsustainable yields of high-quality water.

Except for spur roads that are needed to access local areas, the forest road systems that provide access to the montane regions of California are largely complete. Although thousands of miles of existing roads are obsolete or in disrepair, they continue to supply large volumes of sediment to streams, similar to toxic waste dumps that remain ongoing sources of water pollution (Kattelmann 1996). Substituting modern cable yarding systems for tractor log skidding could provide opportunities to replace many streamside roads with midslope or ridgetop roads to reduce sedimentation. Road realignment and installation of adequate drainage in poorly designed and drained segments could reduce erosion and sedimentation throughout the upper watersheds.

Effective implementation of best management practices for silviculture are likely to minimize the adverse effects of timber harvesting on watershed health and function. For example, compliance with streamside zone protection measures, restrictions on use of tractors on highly erodible and unstable areas, and limits on the size and density of clearcuts will minimize accelerated sedimentation associated with logging. Expanded thinning of dense forest stands could increase water yields.

Increased management of livestock herds to avoid depletion of residual vegetation, removal of riparian vegetation, and trampling of streambanks will reduce the effect of grazing on stream sedimentation.

The short-term objective to manage fuel loads in the upper watershed is to develop a comprehensive strategy, and establish treatment priorities to achieve fuel levels of pre-European-settlement conditions in selected areas. Because of the infeasibility of treating all wildlands within a reasonable time period, a strategy should be developed that identifies treatments that not only reduce hazards of treated areas, but also increase the defenses of adjacent areas against catastrophic fire. The strategy should also identify areas where such treatments should first be applied. For example, an extensive system of fuel breaks along ridgetops and roads could enhance the ability of fire suppression forces to protect surrounding areas. Similarly, a system of fuel profile zones (broad areas treated to reduce fuel loads and ladders, thus reducing fire severity and spotting potential) could be installed around forest communities to protect human life and property. The following actions would help to achieve these short-term objectives:

- Prepare fuel management plans at the county or subcounty level that identify treatments, priorities and schedules for their application, and means to ensure the availability of adequate resources to implement the treatments.

- Expand the application of prescribed natural fire, particularly on relatively remote federal forest lands.

- Increase resource allocations for fuel management without decreasing fire suppression resources to dangerous levels.

- Provide increased training in fuel management, including cross training fire suppression specialists.

- Identify means to expand markets for biomass materials removed from wildlands.

- Adopt more stringent requirements for slash disposal following timber harvesting.

- Refine analytical tools (e.g., landscape-level models of fire behavior) to facilitate identification of effective fuel management regimes and cost-effective strategies to implement them.

The short-term objective for controlling road-related erosion and sedimentation is to identify and prioritize watershed hazards that could be reduced through reconstruction or installation of drainage improvements on all major public and private timberland in the upper watersheds. The following action would help to achieve this objective:

- Conduct comprehensive road inventories on all major timberlands to identify hazardous conditions, assess the feasibility and cost-effectiveness of projects to reduce the hazards and prioritize feasible projects for implementation.

The long-term objective for fuel management in the upper watersheds is to achieve fire fuel levels comparable to prehistoric conditions in sufficient areas so that, based on the projected availability of fire suppression resources, when large, intensive fires do occur they can, with a high degree of assurance, be contained within a single fourth-order watershed (an area of 3,000-10,000 acres). The following long-term actions would help to achieve this objective:

- Implement fuel management treatments on a scale and schedule consistent with standards specified in county-level fuel management plans.

- Implement actions to expand markets for biomass materials.

The long-term objective for controlling road-related erosion and sedimentation is to replace poorly designed segments of existing forest road systems with well-designed and adequately drained roads. The following actions would help to achieve this objective:

- Decommission or obliterate obsolete roads.

- Replace streamside roads designed to facilitate tractor skidding that are sources of large volumes of sediment yield with midslope or ridgetop roads to be used in conjunction with cable yarding systems.

- Reconstruct poorly designed road segments and install adequate drainage structures in poorly drained road segments.

IMPLEMENTATION OBJECTIVE AND INDICATORS

The implementation objective for upper watershed health and function is to restore ecological processes in the upper watersheds in order to maintain and improve the quality and quantity of water flowing into the tributaries and rivers of the Sacramento-San Joaquin Delta and San Francisco Bay.

Indicators of the health of upper watersheds are the extent of forest fuel loads, timber stand conditions, extent of roads, the potential and extent of erosion, and streamflow regimes.

LINKAGE TO OTHER PROGRAMS

FUEL MANAGEMENT

Recognition of the critical need to increase wildland fuel management has increased substantially in recent years. Several land management and wildfire suppression agencies have implemented or expanded programs to increase the application of fuel treatments. ERPP's goals will be advanced by coordinating with and supporting the following programs.

California Department of Forestry and Fire Protection's Vegetation Management Program. The Vegetation Management Program (VMP) was initiated in 1981 to reduce wildfire damage and enhance resource values by reducing wildland fuel hazards. For several years, VMP focused primarily on prescribed burning of private rangelands. Following a series of catastrophic wildfires in southern California in fall of 1993, the California Department of Forestry and Fire Protection (CDF) convened the VMP Working Group to review the program's purpose and performance. As a result of that review, VMP's focus has expanded to encompass all major ecosystems in the State and a wide range of fuel management techniques. Its focus has shifted to reducing hazards at the urban interface, where most assets are at risk. In addition, the acreage targeted for annual treatment is substantially greater than the average acreage that has been treated in the past. CDF is preparing a program environmental impact report to facilitate environmental compliance for a wide variety of fuel treatment projects.

California Department of Forestry and Fire Protection's Prefire Management Initiative. As part of the California Fire Plan, CDF is implementing a prefire management initiative to conduct prefire planning at the ranger-unit (i.e., county or multicounty) level throughout the portions of the State for which CDF has fire suppression responsibility (California Board of Forestry 1996). Three ranger units (Nevada-Yuba-Placer, Tuolumne-Calaveras, and Riverside) initiated this planning process in 1996; the 19 remaining ranger units and six contract counties are expected to initiate it in 1997. The process is scheduled to be completed in 1999.

The prefire planning process will be based on developing geographic information system (GIS) maps depicting assets at risk, levels of fire suppression service, and fire weather severity. Community-level public meetings will be held to review the maps for accuracy and to solicit input regarding acceptable levels of service by area. Ranger unit staff will validate high-risk locations, which will provide the focus for developing prefire management prescriptions, and prioritize projects based on cost-effectiveness. Additional stakeholder meetings will then be held to review project priorities.

California State Water Resources Control Board's Delta Tributary Watershed Program. As part of the California Safe, Clean, Reliable Water Supply Act (Proposition 204), the State Water Resources Control Board (SWRCB) is administering the Delta Tributary Watershed Program. This is a $15 million grant program to enable rehabilitation projects in watersheds tributary to the Sacramento-San Joaquin Delta or the Trinity River. Eligible projects will reduce contamination of drinking water, increase water yield or watershed retention capability, enhance fish habitat, control sedimentation, or improve overall forest health.

U.S. Department of Agriculture Forest Service's Forest Health Initiative. A 1995 report recommended that the U.S. Forest Service shift from its traditional focus on fire suppression and control to comprehensive fire management, taking into consideration the essential role of fire in forest ecosystems (U.S. Department of Agriculture 1995). The agency subsequently announced a commitment to improve forest health throughout the national forests in the western United States, including expanded application of fuel management in densely stocked stands with excessive fuel loads (U.S. Department of the Interior and U.S. Department of Agriculture 1995). Underlying this initiative is the goal of maximizing the amount of national forest land periodically receiving fuel management treatment.

The Quincy Library Group's Community Stability Proposal. The Quincy Library Group (QLG) is a coalition of diverse stakeholders from Lassen, Plumas, and Sierra Counties who have organized to obtain consensus on forest management policies to promote forest health, ecological integrity, adequate timber supply, and local economic stability. Because most of the land in these counties is in national forests, QLG is focused primarily on strategies for managing federal forest land. Portions of the budgets of the Lassen, Plumas, and Tahoe National Forests have been allocated for projects developed by QLG. QLG is the most highly developed example of local consensus-building to influence national forest management policies and programs including those for watershed restoration and fuel hazard reduction.

ROAD-RELATED WATERSHED HAZARDS

Watershed Assessments for Programmatic Environmental Compliance Documents. Many private timberland owners are conducting watershed assessments as part of their preparation of environmental compliance documents to meet federal or State regulatory requirements. The federal Endangered Species Act, for example, enables landowners to obtain permits authorizing take of listed species incidental to otherwise lawful activities pursuant to preparation and approval of a habitat conservation plan (HCP). HCPs addressing listed or candidate fish species typically include a watershed assessment to address cumulative watershed effects, including road-related erosion and sedimentation hazards. Similarly, several private landowners are preparing either sustained yield plans (SYPs) or program timberland environmental impact reports (PTEIRs) to meet the requirements of the California Forest Practice Act regarding the maximum sustained production of high-quality forest products and minimization of significant environmental impacts. These State-level programmatic environmental compliance documents also require watershed assessments addressing cumulative watershed effects. Watershed assessments being prepared for HCPs, SYPs, and PTEIRs provide important opportunities to identify and remediate road-related watershed hazards.

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