

Chapter 8. Sacramento-San Joaquin System

F. Thomas Griggs and Stefan Lorenzato

Introduction

The Great Central Valley of California occupies 22,500 square miles (58,000 square kilometers) in the interior of northern and central California. At the time of the Gold Rush in 1849, nearly 1 million acres (1,600 square miles, 4,000 square kilometers) of riparian vegetation covered the Central Valley floor along with approximately an equal area of wetlands. The riparian area flourished in the large river basins and along river channels (Katibah 1984; Thompson 1961). The Central Valley is partly defined by the Sacramento River in the north, the San Joaquin River in the south, and the Delta where the two rivers meet and turn westward toward San Francisco Bay (figs. 27a and 27b). The valley is made up of a series of basins connected by the rivers, which form a distributary floodway. Before development, heavy winter and spring runoff would flow out of the river channels and drain to the basins until waters were deep enough to continue their flow to the Delta. As flows subsided, water would sit in the basins until evaporated or it seeped into the ground. The wetland and riparian lands were nourished by these flows and extended across the low-lying areas in the valley trough and basin sinks. The land surface consisted of shallow undulating ridges and swales, creating complex soil-water-plant interactions that provided a great diversity of hydrology, vegetation, water depth and velocities, and timing. The result was a rich and dynamic system that dependably provided a mix of microhabitats and physical features (Kelley 1989; Thompson 1961).

These features that provided such a diversified ecology hindered agriculture. As cropping systems expanded to take advantage of the rich soils, riparian forests were cut down, land leveled for ease of production, and waterways rerouted. Today, the Great Central Valley of California grows over 200 crops and generates over 32 billion dollars annually in agricultural revenue (CDFA 2015), primarily due to its unique, and highly developed, hydrology and the complex patterns of alluvial soils that support diverse agricultural practices. But only about 2 percent to 4 percent of the riparian habitats remain (California Department of Fish and Wildlife's VegCamp Program 2011).

Central Valley River Basins and Forces of Change

The Great Central Valley is comprised of a set of linked basins (table 9). The basins' edges are marked by low rises in the land surface that control drainage patterns of overland flow. The rivers of the Central Valley flow through the basins in relatively small channels from the foothill watersheds to the Delta where north and south flows combine and head west into San Pablo and San Francisco Bays (figs. 27a and 27b).

Historically, flood flows in the valley were often flashy, flood peaks emerging from the upper watersheds in high volumes over short periods. The broad, flat basins of the valley floor readily absorbed the flows that escaped the channels. With these flashy flows came sediments that similarly were carried away from the channels and deposited in the basins. The resulting mosaic of soils and residual moisture provide large expanses of land

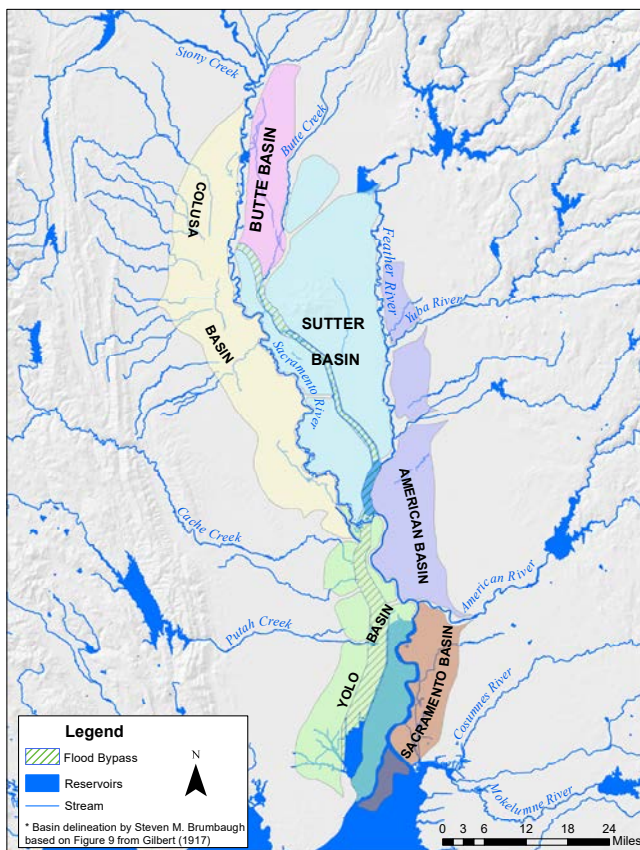


Figure 27a—Sacramento Historic Basins. All figures in this chapter are by Kevin Coulton, P.E. and CFM, Seungjin Baek, Ph.D., P.E., cbec eco engineering, as part of a USEPA Wetlands Development Grant to the California Department of Water Resources (grant CD-00T83701).

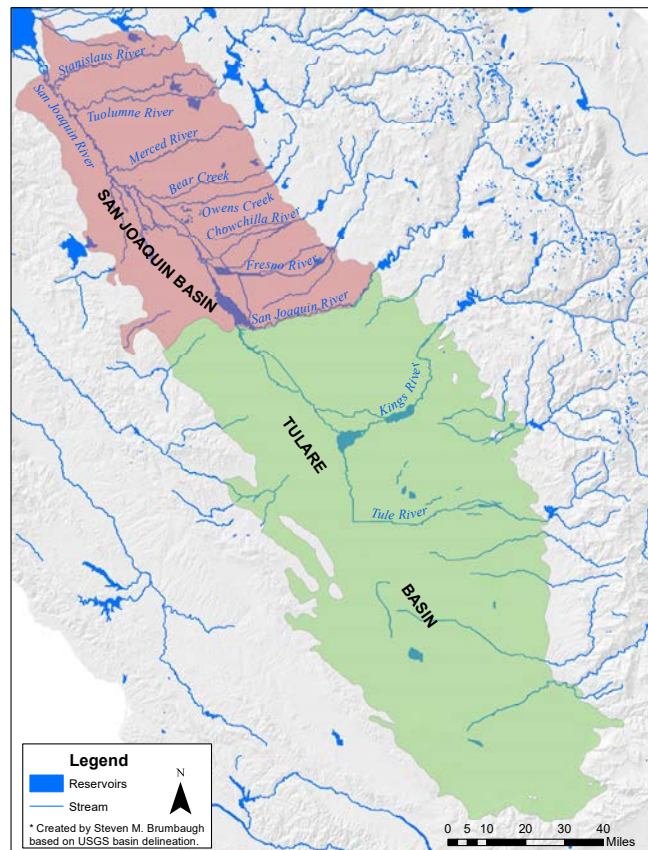


Figure 27b—San Joaquin and Tulare Basins.

Table 9—Hydrologic distributary basins of the Central Valley of California and their areas.

Basin	Approximate acres
Butte Basin	99,877
Colusa Basin	318,225
Yolo Basin	178,268
Sutter Basin	368,697
Sacramento Basin	95,545
American Basin	246,402
Lower San Joaquin	104,500
Middle San Joaquin	370,000
Upper San Joaquin	484,000
Tulare	540,000

where flood-adapted plants flourished and riparian forests established. The interaction of vegetation with the flood flows further influenced flow patterns and an even finer scale of microhabitats developed, supporting a great diversity of plants and animals (Scott and Marquiss 1984). Until the Gold Rush, people generally adapted to the patterns of flood and seasonal growth, exploiting the diversity and relying on natural cycles to produce the materials and food needed for their communities (Kelley 1989).

With the Gold Rush (1848-1855) came disturbance of land in the middle and upper watersheds and a tremendous amount—1.5 billion cubic feet (Mount 1995)—of soil, sediments, and rocks found their way into the streams and rivers from the mining operations. At the same time, agriculture was being established in the valley and farmers sought out the richest soils, which tended to be where the riparian forests stood. Farmers rapidly deforested the valley floors and carved canal systems into the land to move irrigation water diverted from the rivers, during summer low flows, into their fields.

A conflict rapidly emerged between valley farmers and miners over the sediments in the rivers and streams. Because the mining accelerated the erosion and transport of coarse sediment in the form of sand, gravel, and cobbles, when floods occurred, these sediments were deposited on fields that previously were only comprised of premier farm soils. The coarse sediments devalued the land and made farming difficult or, in some cases, not possible (James and Singer 2008).

The controversy was taken into court and in 1884 Judge Lorenzo Sawyer put a stop to the discharge of mine tailings into streams (Federal Reporter Vol 18, 1884; Mount 1995). While this stopped the input of new coarse sediment, by this time millions of tons of debris were already loaded into streams and on their way down to the valley. Farmers seeking to stop flooding of their land in order to reap more crop production also wanted to stop the deposition of sediments on their fields. Initially, the solution was for individuals to build berms and levees, but the haphazard product did not resolve the issue (Kelley 1989). Ultimately, in the early 1900s, a unified system of levees and floodways was designed to provide farmers with more predictable and manageable flood flows and to control and move sediment through the system (fig. 28).

While the farm interests were well served by the resulting flood protection systems, the riparian habitats of the Great Central Valley were rapidly succumbing to agricultural demand. The diversity and abundance of wildlife and plants that once graced the valley began to shrink and the dynamics of the ecosystem began to change (Grinnell and Miller 1944).

Another change force that emerged was the need for additional summer water for agriculture. By the mid-1900s, dams had become a common element of the landscape. With the large dam building era in full swing, major dams were placed on all the major rivers that drain into the Central Valley. The large dams created three very distinct alterations to the ecology of the Central Valley: (1) they restructured the pattern of flow, greatly limiting the medium sized peak winter and spring flows while increasing late spring and summer flows, but without significant peaks (Kondolf 1997); (2) they dramatically increased the acreage of land under irrigation; and (3) they cut off access by anadromous fish to their natal streams and the floodplains they used for rearing grounds (Sommer et al. 2003).

The plan for fish was to replace the loss of fish from lack of spawning habitat with hatchery bred fish. The result was a steady decline in populations of migrating fish. With this decline came a disruption of the nutrient cycles associated with fish returning from

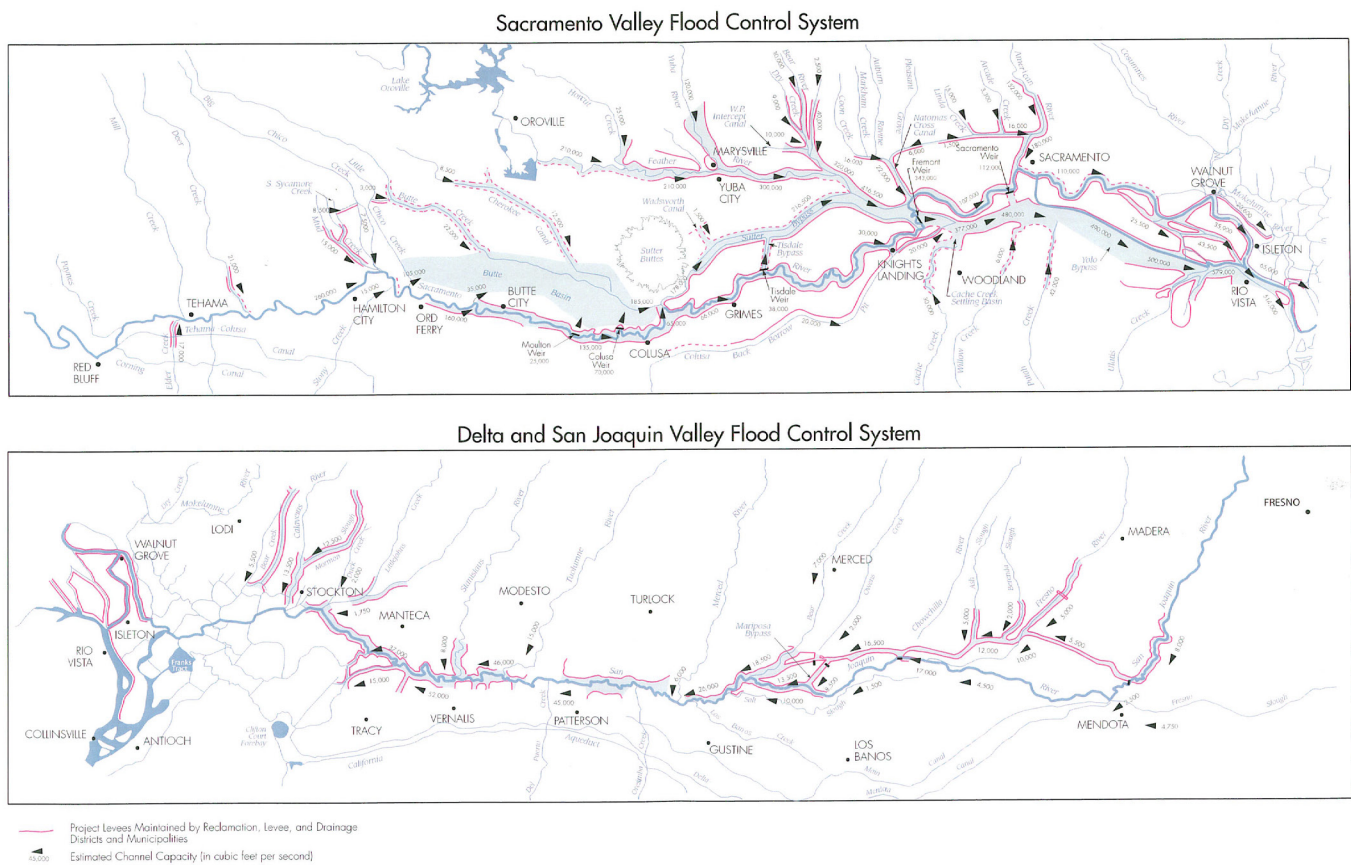


Figure 28—Sacramento and San Joaquin Valley Flood Control Systems.

the ocean and resulted in further reduction in riparian productivity (Merz and Moyle 2006). With the flow patterns disrupted, plants and animals that had evolved to be in synchronization with the natural cycles were left to find limited room to persist at the edges of the remaining floodplain resource. Of the nearly 1 million acres of riparian lands estimated to exist in the Sacramento Valley before the Gold Rush (Katibah 1984), by 2011 only 94,000 acres remained (VegCamp 2011).

What We Currently Face

The Central Valley is over 450 miles long, from its northern end at Redding to near its southern end at Fort Tejon (south of Bakersfield). The Sacramento River drains the northern portion of the Central Valley (27,500 square miles watershed), including the southern Cascade Mountains and northern Sierra Nevada (fig. 27a). Its primary tributary is the Feather River (6,000 square mile of watershed). The Sacramento empties into the Delta estuary between the City of Sacramento and San Francisco Bay. The southern portion of the Central Valley is drained by the San Joaquin River (31,800 square miles of watershed) and its larger tributaries—the Mokelumne, Cosumnes, Stanislaus, Tuolumne, and Merced rivers (fig. 27b). South of Fresno is the Tulare basin, home of historical Tulare Lake, once the largest freshwater lake west of the Mississippi River. The Tulare

basin receives flows from the Kings, Tule, and Kern Rivers from the southern Sierra Nevada and overflows into the San Joaquin Basin southwest of Fresno. The San Joaquin River flows northward and empties into the Delta estuary from the south. The Delta is the single point of outflow for the entire valley.

Flow Patterns

Dams now control river flows on all these rivers. These dams serve both water supply and flood control purposes. The dams were conceived with the goal of providing water for agriculture and for urban uses. Two large water projects dominate the water conveyance systems: the Federal Central Valley Project (which has storage capacity of 13 million acre feet [maf] that delivers about 7.4 maf annually); and the California Water Project (30 dams, 20 reservoirs, 700 miles of canals, and storage capacity of 5.4 maf) (California DWR Bulletin 132-14, 2015). Together these projects serve over 3 million acres of irrigated land and supply over 25 million people with at least a portion of their water.

In an average year, the unimpaired runoff for the Sacramento Valley is about 18.2 maf and the San Joaquin Valley about 6 maf (based on SRR and SJR unimpaired flow estimates—DWR Bulletin 132-14). For the Tulare basin, which only flows into the San Joaquin in the wettest years, the average unimpaired runoff is 3 maf. Diversions dramatically change the timing of the water flowing through the river system. And much of the water release from the dams does not reach the Delta to become outflow. The 8 River index, a measure of water released from the Sierra Nevada watersheds compared with Delta Outflow (as estimated by the Day Flow model) (see CDWR web site <https://water.ca.gov/Programs/Environmental-Services/Water-Quality-Monitoring-And-Assessment/RTDF-Summary>) shows substantial losses as water moves through the system. For example, in 1993, the 8 River index showed about 19 maf of water entering the Central Valley but only about 5 maf leaving the Valley through the Delta).

Note that these models produce coarse estimates; actual amounts are likely higher. These model comparisons also indicate how context-specific the flows are. In drier years, the gap between inflow and outflow tends to be larger than in wetter years. In consecutive wet years, the difference is even smaller (presumably due to lack of demand), and in consecutive dry years the differences again tend to be small (mainly due to lack of water supply). For riparian areas this means that in all but the wettest years there exists fierce competition for water needed to support riparian functions.

Dam building started in the 1800s and accelerated through the 1950s. By the early 1960s, dams had been built on the mainstems of the Sacramento and San Joaquin rivers and most tributaries before they entered the Central Valley from the mountains. Table 10 shows the amount of storage in several of the larger reservoirs created by these dams (Kondolf and Batalla 2005). Of particular interest, note the amount of storage on each river as a percent of average annual runoff for that stream. For example, reservoirs on the Stanislaus River are able to trap 2.94 times the average annual runoff; on the Tuolumne and Calaveras Rivers nearly twice the average annual runoff is contained in reservoirs. In contrast, note that Shasta reservoir can only capture 74 percent of the Sacramento's average annual runoff. Despite the flashiness of runoff in California, the large storage capacity in the San Joaquin reservoirs greatly diminishes the frequency of large floods and nearly eliminates the occurrence of modest floods on these rivers. Flooding is a more common occurrence on the Sacramento River.

Table 10—Central Valley rivers with impoundment ratios of average annual flow for each. (Excerpted from Kondolf and Batalla 2005.) Each watershed contains more than two major reservoirs.

River	Average annual runoff M ³ x 10 ⁹	Total reservoir storage capacity m ³ x 10 ⁹	Impoundment ratio (As percent of annual runoff)
Sacramento Valley			
Sacramento at Keswick	7.278	5.384	0.74
Feather at Oroville	5.215	6.714	1.29
San Joaquin Valley			
Mokelumne at Camanche	0.744	1.032	1.39
Calaveras at New Hogan	0.205	0.396	1.93
Stanislaus at Knights Ferry	0.202	3.518	2.93
Tuolumne at La Grange	1.772	3.444	1.94
Merced at Snelling	1.290	1.305	1.01
San Joaquin at Friant	2.095	1.140	0.54

In both the Sacramento and San Joaquin Valleys on the valley floor, a system of floodway bypasses are maintained to convey flows greater than what can be carried within the river channels. In the Sacramento Valley, the mainstem rivers are used to convey water supplies for agriculture and urban use while also functioning as a conduit for flood waters. The combined purpose has resulted in floodplains isolated from their river channels, with the timing of flows shifting away from winter and spring flood pulses to late spring and summer steady medium flows. This has simplified the hydrology of the rivers. Coupled with the transformation of riparian lands to farms, the riparian habitats have been left with truncated processes and limited area to support the historic mix of plants and animals (Hunter et al. 1999; Mount 1995). As a result, much of the riparian habitat is now also simplified and shrunken to a point that species that were once common are now absent or rare. Vaghti and Greco (2007) describe seven contemporary plant communities of the Central Valley and trends in species declines.

For example, the least Bell's vireo was the most common species in the willow thickets along the Sacramento River in the 1930s (Grinnell and Miller 1944; Howell 2010). It disappeared during the 1950s, retreating to coastal rivers in southern California. Yellow-billed cuckoo formerly ranged as far north as the Columbia River, but today the species persists in very low numbers only along the Sacramento River. Likewise, sawgrass (*Cladium mariscus* ssp. *californicum*) was an important basket-making plant for the Yokuts of the San Joaquin Valley (Latta 1938). Today, sawgrass is apparently extinct from the Valley (F.T. Griggs, personal observation). Slough thistle (*Cirsium crassicaule*) formerly grew in riparian areas in the San Joaquin Valley from Kern County northward into the Delta with collections as recently as the late 1930s (CalFlora). Today one population persists on the Kern NWR. Numerous species of native fishes have disappeared in the Delta due to introduced aggressive competitors (Sommer et al. 2003).

River Processes

Riparian ecology is driven by physical river processes of flooding (magnitude and timing) and sediment transport (geology of watershed, bank, and surface erosion;

floodplain deposition; and channel meander) (Stillwater Sciences 2007). Riparian plants and wildlife are adapted to these river processes. River processes also determine plant community succession and the evolution of its physical structure. Flooding eliminates species that are not adapted to flooding, such as many invasive plants and animals, especially rodents. Native floodplain-adapted plants can tolerate flooding for weeks or months. Flooding recharges the local groundwater table that provides moisture to all plants through the growing season. The season after a flood typically sees season-long growth by trees and shrubs that tap into the abundance of soil moisture.

Flood flows disperse seeds of many plants and deposit them in appropriate locations for germination and establishment (Stella et al. 2011). The timing of flood flows, especially the recession limb of the hydrograph, is critical for seedbed preparation, seed germination, and seedling development (Mahoney and Rood 1998). Seeds generally need the moisture available in the soil during the recession of flood waters, but seeds also require the oxygen available in those drying soils. If the seeds instead fall on dry ground, they cannot sustain their growth, desiccate, and die. Similarly, if they are subjected to repeated flooding, as often occurs in rivers managed for irrigation water, the seeds are starved for oxygen and die.

Many plants have co-evolved with the flood timing of the Central Valley to release seed when flood waters recede, such as Fremont cottonwood and several willow species. With the dam-imposed flow patterns, much of the seed bed preparation and some of the timing queues have been removed, greatly reducing the success of floodplain-adapted plants establishing in recently flooded lands. This disrupts the cycles of disturbance and succession common to floodplains and limits the quality and extent of riparian vegetation communities. Birds, fish, and other animals similarly have developed life cycles that synchronize with the flood cycles and, with the lack of cycles imposed by dam and floodway operations, are showing similar declines in their populations (Strahan 1984). Plotting these natural cycles against river hydrographs of current and former flow regimes (figs. 29a and 29b) can give a good indication of the potential of disruption to riparian systems.

Riparian vegetation on the valley floor arranges itself in relation to the magnitude and duration of flow. As riparian plant communities age and flow changes, a predictable sequence of events unfolds. This sequence involves a shift in community structure from plants adapted to high flow unstable channels to plants suited to slow water and less frequent inundation (Griggs 2009). High flow plants tend to be highly flexible and of relatively short stature that can easily lay down in the face of fast flood waters. As the plant community ages, the flexible stemmed plants shift the hydraulics in very localized spaces, which then allow other plants to take advantage of the relative calmer flows. This leads to even more stable plants, eventually leading to a mixed elevation canopy that includes ground level plants, mid-height shrubs, and various trees.

The early stage of the full mixed canopy riparian forest is marked by a high density of trees. As the tree-canopy develops, light and shade become dominant characteristics of the forest and many of the trees succumb to the dense shade, leading to fewer and fewer stems per acre (Swiecki and Bernhardt 2003). The riparian gallery forest of 80-100 years old has relatively few large trees with various shade tolerant shrubs, vines, and ground covers underneath the canopy. It is one that grades for relatively short-lived flexible plants

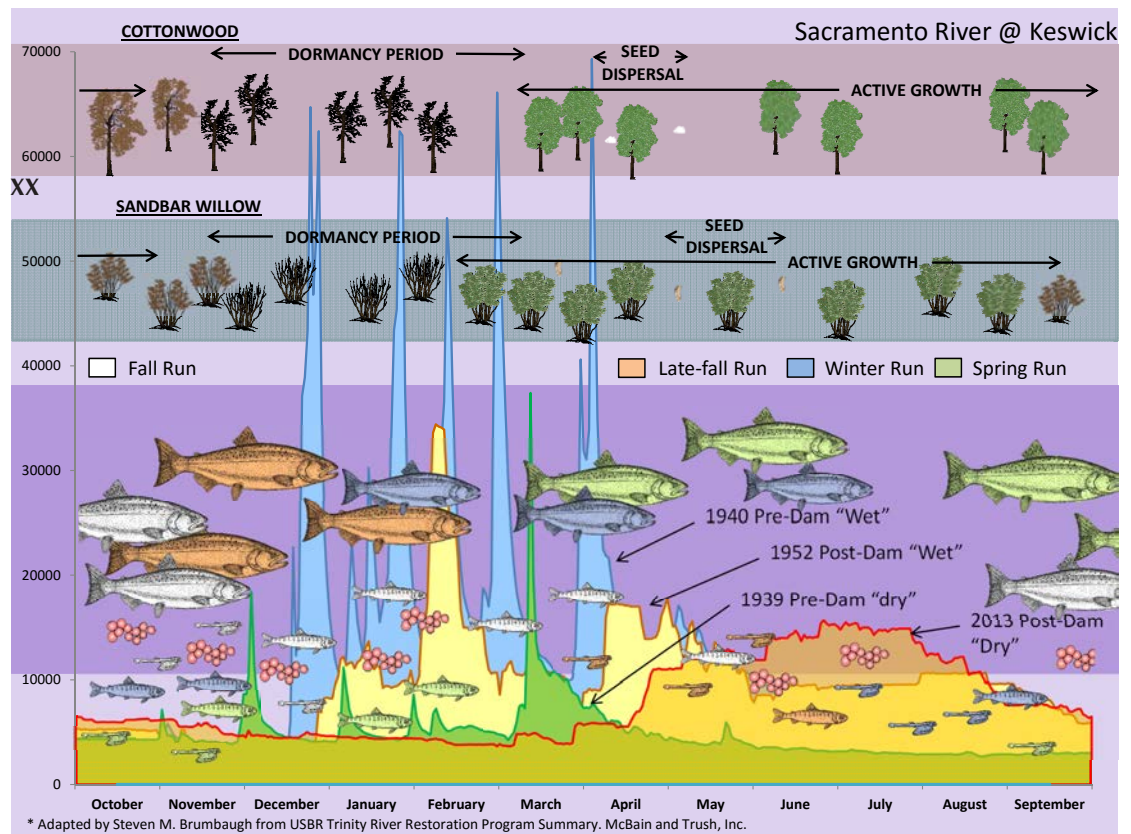


Figure 29a—Sacramento River Hydrograph.

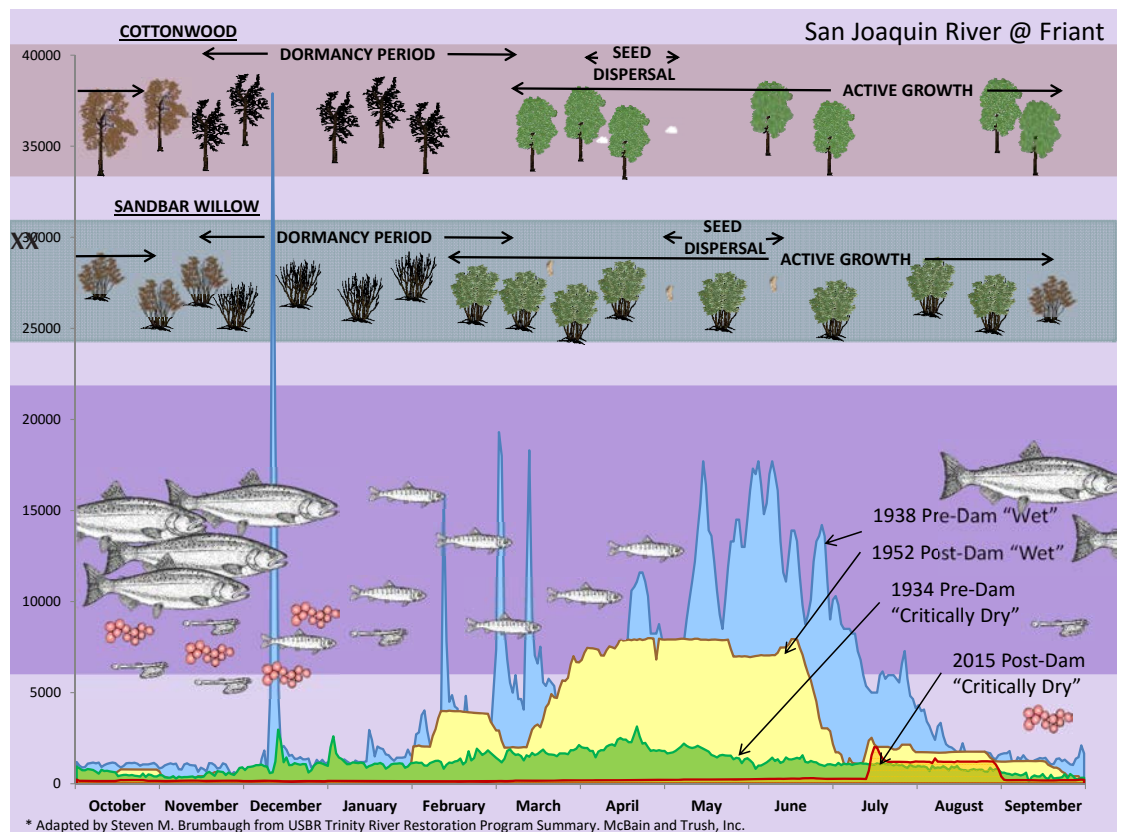


Figure 29b—San Joaquin River Hydrograph.

at the water's edge to groves of oak and walnut in areas set away from the channels. Managing for flood suppression and water supply often disrupts this plant community evolution, diminishing the occurrence of gallery forests. (Griggs 2009). One of the important research questions is: What is the successional trajectory of the riparian plant communities under the modern hydrology?

Managing for irrigation supply will tend to produce an ecologically dysfunctional flow pattern that increases flows in spring and summer when the natural pattern would be declining flows, as on the Sacramento River (fig. 30). Many dammed rivers—Stanislaus, Tuolumne—have hydrographs that are essentially flat lines. We do not have indications that native species can adapt to such extreme changes. For example, because of the management of Shasta dam, today it is difficult to find stands of seedlings or saplings anywhere on the point bars or floodplain.

Sediment Transport

Dams, levees, bypasses, farming, road building, and urban encroachment into floodplains have all contributed to changing the patterns of sediment scour, transport, and deposition. Riparian assemblages take advantage of each of the variations in scour, transport, and deposition of sediment. The shifts in sediment dynamics have led to different niches and microclimates that in turn have shifted the character and quality of riparian areas (Rood et al. 2003; Stella et al. 2011). Most dams effectively capture sediment moving in the channels above the dam and leave the water released from the dam stripped of its sediment. The suspension and transport of sediment requires energy.

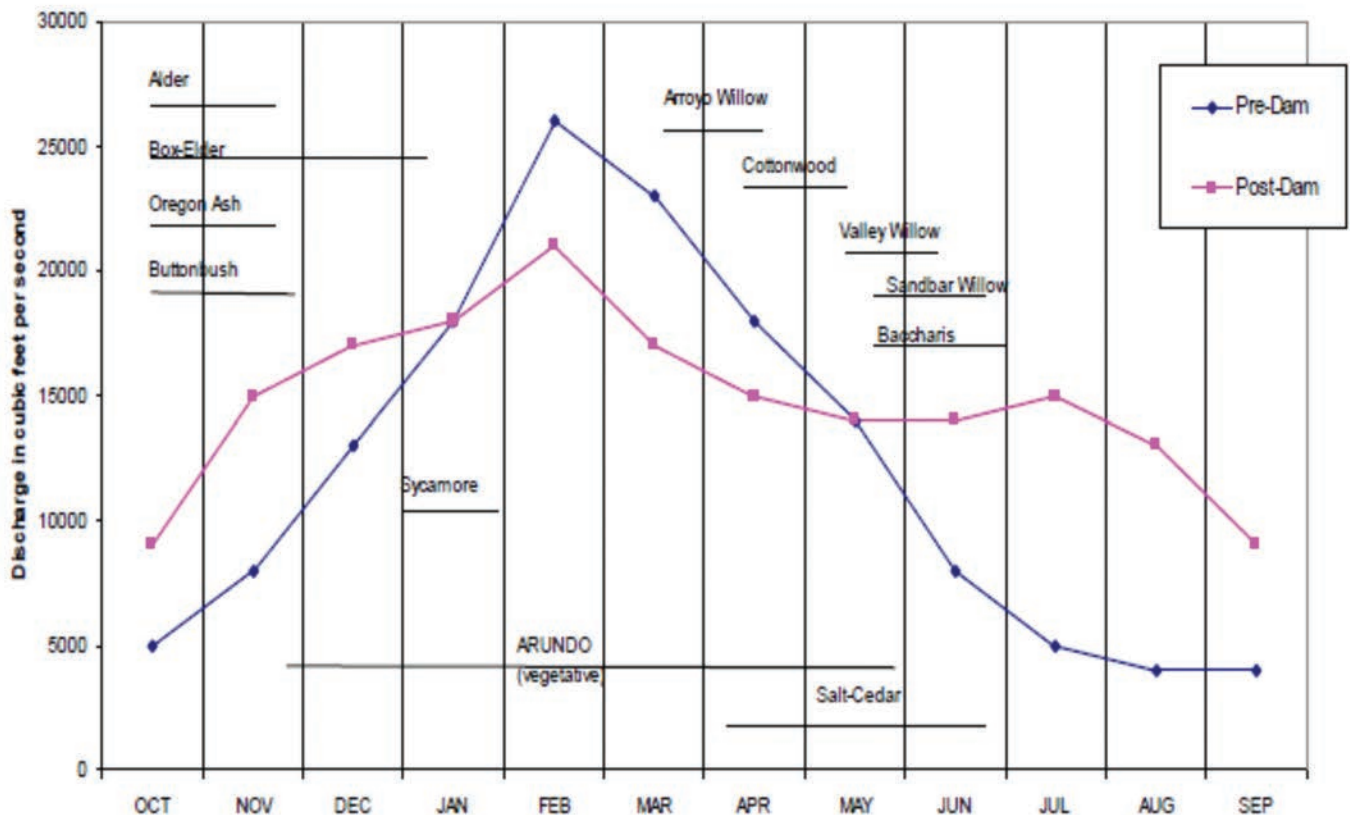


Figure 30—Dates for seed-release by water-dispersed riparian tree species and the mean monthly discharge for the Sacramento River pre-Shasta dam and post-Shasta dam.

The energy of flowing water provides the forces needed to keep sediments suspended or moving downstream. When sediment is deposited in reservoirs above dams, the water released has no sediment load to occupy its energy.

The water is then capable of working on the bed and banks and tends to erode these features until equilibrium in energy is reached where the energy of the water is balanced by the energy needed to suspend and transport sediment. The water released from the dam that contains little or no sediments has been termed “hungry water” (Kondolf 1997) because it is much more erosive than water that is full of sediments. Bank erosion and channel scour are often seen below dams. The sediment scoured away often exhibits particle size distributions different from what was being carried in the channel above the dam. Where these sediments fall out of suspension and are deposited, they can harm seedbeds for plants and nursery grounds for fish.

A feature of the shift in flow produced by dams is that the larger, more energetic flows of moderate floods are eliminated. Despite the impacts of hungry water, eliminating flood peaks stifles the process of channel meander, bank erosion, and bar formation that is a normal part of riparian areas. Rivers are dynamic systems; they continually adjust their bed and banks to the forces of flowing water (Knighton 1998). The result is a regular process of building bars and eroding them, moving banks, and rebuilding them. These processes depend on the more energetic, higher intensity flows to provide the energy needed to mobilize the bed and banks.

Deposition occurs as the storm events pass and the flows subside (Knighton 1998). Riparian vegetation has evolved to take advantage of these cycles. Species are adapted to colonizing newly formed bars, but they give way either to even greater flood flows or to encroachment from other plants better suited to the stability created by the colonizers. The result is a succession of plants with distinctly different characteristics. This plant sequence is similarly colonized by animals that align with the plant communities present. By making flows very constant, the dynamics of the system are eliminated and the ability for the plant succession to occur is greatly restricted. One example of this is when mid channel bars are covered with unnatural vegetation that would have been removed if more natural flow patterns were experienced. The loss of open bars has consequences for fish as well, limiting their spawning habitat, and often introducing algae or other organisms that pose problems for fish.

Levees and Flood Bypasses

Most of the river banks in the Central Valley mainstem rivers and tributaries are lined with levees. Together with the bypass areas, also bounded by levees, these features further restrict riparian vegetation. Many of the levees of the Central Valley have supported riparian trees in the past, but recent policy initiatives (Central Valley Flood Protection Plan 2016) have set in motion a process to remove trees from levees. Removing levee vegetation threatens to further fragment functional riparian areas and disaggregate riparian corridors. Levee construction along the river channel also separates, or disconnects, the floodplain from the river, eliminating flooding of the floodplain, sediment deposition on floodplains, groundwater recharge, and access to shallow water habitat that many organisms need for key life stages.

It has been argued that the flood bypasses provide floodplain functions (Sommer et al. 2003). But in many respects, the bypasses do not mimic floodplains. The bypasses

are used for crop production. Farmers have rearranged the land surface to improve their farm operations. By grading and orienting flow to accommodate water inlets or drainage outlets, farmers have recast the surface that floods flow across, leaving uniform surfaces, sometimes tilted in directions inconsistent with natural flow, and without topographic variation. This simplified form removes potential for microhabitats and specialized niches. With this large-scale regrading of the land surface comes a dramatic decline of the area supporting riparian vegetation. The sparseness of native plant structure further fragments and isolates floodplain features and diminishes the processes that once supported riparian ecology.

Levees impose another significant ecological limitation. They isolate the floodplain from the river channel and thereby limit access of fish, plants, and other organisms to the highly productive shallow water habitat once found in vast areas of the Central Valley. For example, salmon have recently been shown to grow much faster on inundated floodplains than in the corresponding river channels (Jeffres et al. 2008). The floodplains (and inundated agricultural fields) produce vast quantities of food for fish that cannot be produced in the deeper, colder, and swifter river waters. Levees limit the ability for fish to gain access to this critical food supply.

Riparian Floodplain Vegetation

Simplified Native Structure

Due to these modifications in flow patterns and sediment transport, today's floodplain is variously covered by stands of native woody species within a matrix of both woody and herbaceous invasive species. The remnant stands of riparian vegetation are dominated by trees and shrubs of later successional development, such as valley oaks, elderberry, and box elder. Early-successional species—Fremont cottonwood and several willows—occupy a relatively small proportion of the vegetation today (Strahan 1984). Many of the terrestrial wildlife species that are rare or eliminated from the Central Valley riparian are dependent upon the early-successional vegetation (yellow-billed cuckoo, least Bell's vireo, southwestern willow flycatcher, yellow-breasted chat).

Invasive Exotics

Invasive, nonnative plants compete with native species for space and resources. Woody invasive species include giant reed (*Arundo donax*), Saltcedar (*Tamarix* spp.), Himalaya blackberry (*Rubus procerus*), hybrid black walnut (*Juglans X hindsii*), water primrose (*Ludwigia peploides*), and perennial pepperweed (*Lepidium latifolium*), with new invaders, as *Sesbania punicea* and Chinese pistachio (*Pistacia chinensis*), arriving annually. Numerous herbaceous agricultural weeds cover the floodplain to the exclusion of any native herbs. These species are well adapted to the current farm and floodway management practices, while native plants often struggle under these management paradigms.

Agricultural and Urbanized Floodplains

The cities of Sacramento, Stockton, and Marysville-Yuba City have covered thousands of acres of floodplain with homes and businesses, with more recent construction still occurring on high quality agricultural land west of Stockton (into the Delta) and north of Sacramento (Natomas area). These portions of the floodplain are cut off from the river by tall levees. The rich, alluvial soil of the floodplains that are protected

by levees and not under residential and business development produces very large economic returns for agriculture and the surrounding community.

Summary

Severely broken river processes that change the ecology for plants and animals include the following:

- (1) Water availability: flooding—reduced magnitudes, and shifted timing, diversions, and groundwater pumping.
- (2) Sediment: trapped in reservoirs above dams, scour and erosion below dams (hungry water), particle size change and different deposition patterns, lack of floodplain deposits, channel and bank erosion.
- (3) Hydrograph: inverted or flat, constant high spring summer flows, loss of flood events/peaks.
- (4) Floodplain: land leveling and homogenization of land surface, loss of niches, loss of hydrologic connections (primarily due to levees).
- (5) Native vegetation: loss of vegetation community connectivity, simplification of species complex, significant loss of extent (95 percent gone) of flood-adapted vegetation.
- (6) Exotic/invasive species: competition with natives, exploits farming operations.
- (7) Urban encroachment.

Current Ideas and Actions for Riparian Management

In 1987 the Sacramento River National Wildlife Refuge was created by the U.S. Congress. Early-on willing sellers of flood-prone agricultural land adjacent to the river came forward to sell their marginally productive farmland for conservation purposes (Reiner and Griggs 1989). The properties were not only flood prone, but the soils were heterogeneous with areas of channel deposits (sand and gravel) mixed with the more productive silt and clay loams. This resulted in soils less than ideal for agricultural production and consequently of low economic return. Flooding and heterogeneous soil patterns were ideal for restoration of structurally diverse riparian vegetation that would function as habitat for numerous characteristic riparian wildlife species, as well as specific target species (sidebar 1) (Griggs 1993, 1994).

Sidebar 1—Focal Bird Species That Guide Riparian Restoration Design

Riparian Obligate Species

Yellow warbler
Common yellowthroat
Yellow-breasted chat
Song sparrow
Black-headed grosbeak
Blue grosbeak
Warbling vireo
Yellow-billed cuckoo
Southwestern willow flycatcher

Riparian Associate Species

Lazuli bunting
Nuttall’s woodpecker
Ash-throated flycatcher
Bewick’s wren
Spotted towhee

Horticultural Restoration

Horticultural restoration involved planting native trees and shrubs that are characteristically found growing on the alluvial soils along the channel and on the floodplain (Hujik and Griggs 1994a,b) (sidebar 2). These native trees and shrubs (and understory) would form the type of structure that target wildlife required (Griggs 2009).

Sidebar 2—List of Species Used in Central Valley Riparian Restoration Projects

Trees

Fremont cottonwood *Populus fremontii*
Valley oak *Quercus lobata*
Red willow *Salix laevigata*
Black willow *Salix gooddingii*

Large Shrubs

Arroyo willow *Salix lasiolepis*
Box elder *Acer negundo*
Oregon ash *Fraxinus latifolia*
Elderberry *Sambucus mexicanus*
Buttonbush *Cephalanthus occidentalis*

Flexible-stemmed Shrubs

Coyote brush *Baccharis pilularis*
Mulefat *Baccharis salicifolia*
Rose *Rosa intermontana*
Sandbar willow *Salix exigua*
Quailbush *Atriplex lentiformis*

Vines (Lianas)

Grape *Vitis californicus*
Pipevine *Aristolochia californica*
Clematis *Clematis ligustifolia*
Blackberry *Rubus ursinus*
Poison oak *Toxicodendron diversilobum*

Herbaceous Grasses

Creeping rye *Leymus triticoides*
Blue rye *Elymus glaucus*
Meadow barley *Hordeum brachyantherum*
Purple needlegrass *Nassella puchra*
Squirrel-tail *Elymus elymoides*

Broadleaves

Mugwort *Artemisia douglasiana*
Gumplant *Grindelia camporum*
Evening primrose *Oenothera*
Goldenrod *Euthamia occidentalis*

The vegetation that has grown in the restoration plantings has performed well (Alpert et al. 1999; Griggs and Golet 2002; Griggs and Peterson 1997; Griggs et al. 1993). Results of increasing wildlife use of the restoration plantings have been impressive (Borders et al. 2006; Golet et al. 2008, 2009; Williams 2010). Monitoring of bird populations was the most intensive and shows how different species colonized the sites over a decade. Valley elderberry longhorn beetle (listed as threatened) also moved into the planted elderberry shrubs. Special bird species—such as yellow-billed-cuckoo—nested in the new plantings, and least Bell’s vireo nested in a restoration planting for the first time in 60 years in the Central Valley (Howell et al. 2010).

As of this writing, approximately 9,000 acres have been planted by The Nature Conservancy, River Partners, Department of Water Resources, U.S. Army Corps of Engineers, California State Parks, and Resource Conservation Districts since 1989 in the Sacramento Valley, all on public lands (Refuges and Preserves). An additional 2,500 acres have been planted in the San Joaquin Valley. Funding came from Federal and State grants and contracts.

Levee Set-Backs

The levees that protect several cities and much farmland from large winter flooding were designed over 100 hundred years ago under very different flow and sediment

transport conditions than today. Hydraulic mining in the foothills of the northern Sierra Nevada in the late 1800s generated sediment that filled canyons and when in the Central Valley it filled channels causing flooding. Levee placement adjacent to the channel allowed the much deeper flows to scour and to move sediments through the system. Unfortunately, today the sediment has been flushed away and the artificially deep flows of “hungry water” from below dams are now eroding the levees at their bases.

One solution to this situation is to build new levees set back from the edge of the channel that would allow the channel to meander across the new floodplain that will be created. This would take away the intense scouring of the levees and provide acreage for riparian vegetation restoration. Benefits for flood maintenance would be the better absorption of peak flows, the reduction of maintenance costs, and the risk of levee failure (Greco and Larsen 2014; Larsen et al. 2006). The set-back area would become restored riparian vegetation to function as high quality wildlife habitat and an important means of replenishing local groundwater. See (www.multibenefitprojects.org), NGO web site.

Restoring River Processes

Ecological Flows

The ecological flows model (The Nature Conservancy et al. 2008) identifies the timing for dam releases to create flows large enough to affect sediment/scour processes and encourage recruitment of seedlings of Fremont cottonwoods and support the life histories of Chinook salmon, steelhead, green sturgeon, bank swallow, and western pond turtle.

Applying this hydrologic model to releases from a reservoir should mimic the natural hydrograph and encourage seedling establishment of cottonwood and willows. This has been carried out with success on the Truckee River through and downstream of Reno, Nevada (Rood et al. 2003). One issue that restricts this approach in the Central Valley has been dollar cost, or lost opportunity, from releasing water from dams that could have been used to grow crops.

Williams et al. (2009) have recently developed the Floodplain Activation Flow (FAF) calculation for regulated rivers to quantify the area of floodplain covered by the smallest flow (2-year recurrence) that will initiate biological activity. In this example, the 2-year recurrence flooding-interval was selected as necessary for juvenile salmon to move onto the floodplain. The flood must occur during March-May with a minimum duration of 7 days. The FAF calculation estimates area of floodplain that will be inundated at specific flows for a specific reach of a river. The manager can define quantified ranges for the criteria, allowing for better planning of the hydrological/biological objectives for any project on the floodplain.

Managed Hydrology in Farm Fields to Benefit Juvenile Rearing of Salmonids

Salmon and steelhead in their juvenile stage forage on the floodplain for invertebrates during spring floods—the same spring floods that prepare the seedbeds for the cottonwoods and willows. Due to dams and the altered flows, floodplains rarely flood today. Fish hatcheries raise juvenile salmon in concrete runways and feed them artificial food, releasing them into the river in April or truck them to the SF estuary and release them to the delight of invasive striped bass.

An alternative method for raising the juvenile salmon is to manage the hydrograph on an artificially flooded farm field (that functions as a pond) in the spring (February and March). The fish forage on native invertebrates in the pond water and rapidly increase in size and weight (Sommer et al. 2003). After 4 to 6 weeks in the pond, the fish are released into the river in March or April (Jeffres et al. 2008). This is a relatively new concept with only four seasons of demonstration projects of varying acreage. Results appear promising with significant growth (3 to 5 times weight gain) during their 4 to 6 weeks of residence on the flooded fields.

Managing Riparian Vegetation for Flood Flow Conveyance and Ecological Benefits (Flood Management)

Riparian vegetation in Central Valley today occurs between flood management levees. The California Department of Water Resources (CDWR) is legally charged with the management of the majority of levees and the floodway for the purpose of Public Safety (CDWR <https://water.ca.gov/Programs/Flood-Management>) and Greco and Larsen (2014) (fig. 28). Farmers working the lands between and outside the levees continue to try to optimize conditions for commercial production with little or no attention to river process or ecological quality. In many cases riparian vegetation is seen as a threat or nuisance. Thus, flood management and farming goals supersede the ecological goals of riparian ecology everywhere outside of the Federal refuges.

The challenge today is how to manage the landscape such that public safety, farming, and ecological riparian benefits are all realized for people and wildlife. The discussion below is an attempt to describe how ecological management of riparian vegetation can fit into the logic of flood managers that think in terms of risk and system reliability.

All of the flood-prone lands, floodways, and flood bypasses in California readily grow plants. These sites possess some of the most fertile soils on the planet, and when coupled with even a little moisture, allow vast number of species to grow. Whether those plants are useful for us and the ecosystem depends on how and what is managed. Native flood-adapted plants offer many advantages over exotic plants. (Micheli et al. 2004). They better support the historic ecology, are better adapted to the timing and processes needed to restore ecological functions, persist better under flood and drought and are therefore more predictable and reliable, and support native animals better than exotics.

Floodway Design for Flow Conveyance

Flood managers use two-dimensional hydraulic computer modeling for designing flows through the floodway. Recent work using two-dimensional computer models for flood flows shows that plants can be arranged to assist with managing flows to reduce flood risk. Until recently, flood modelers typically looked at vegetation as a problem or, at best, a necessary evil in managing floodways. Understanding of how plants can be used to help direct flood flows, reduce scour, and control erosion and deposition is now taking hold among flood modelers (Anderson et al. 2006; Stone et al. 2013). With this awareness comes the prospect of designing floodways that integrate ecological goals with risk reduction and economic goals and constraints (Fischenich 2006). Promoting native flood-adapted plants has the added advantage of assisting agriculture by reducing the seed banks of farm weeds and limiting the way weed seeds can be deposited on farm fields.

Managing Flood Risk With Riparian Vegetation

In flood management, the risk of property damage or injury of people has been

paramount. Recently the idea that risk extends to the ecosystem has been brought into flood management discussions. In the Central Valley, the large number of threatened and endangered species that occupy floodplains and riparian lands means that flood managers must now consider the implications of their flood designs not only on traditional risk factors but also on features of the landscape that support the listed species. Assessment of risk has largely been accomplished using computer models. In these models, vegetation is associated with a roughness factor and contributes to defining the maximum water surface elevation during a flood event (Aberle and Jarvela 2013; Freeman et al. 2000). Modelers have typically adjusted the roughness factor to get model outputs to align with calibration points (water surface elevations known from previous flow events). This practice has led to vegetation removal justified by a need for smoother surfaces as depicted by the models. With the widespread adoption of two- and three-dimensional flood models (Wilson et al. 2006) we now have the ability to look beyond the simple application of roughness as a calibration parameter and consider roughness as a design feature (McKay and Fischenich 2011).

Emerging work is showing that native flood adapted plants can be equal to, or less rough than, bare soils (Kavvas et al. 2009). Two-dimensional modeling is also showing that a combination of roughness values can be used to our advantage in lowering flood risk (Soong and Hoffman 2002). Older models averaged the measurements of many parameters. Two-dimensional and three-dimensional modeling allows those parameters to be treated more independently with the result that we can now design flow paths within floodways that provide for ecosystem processes to be expressed while still managing flood risk at low levels.

With these new modeling capabilities, we can now discuss ecological risks, the role and placement of specific plant species, mixed age classes, mixed canopy structure, and other ecologically important attributes in the context of reducing risk to people and property (Fischenich and Copeland 2001). Using these tools we can visualize how complex roughness can be applied to protect sensitive areas, be they levees and homes or delicate habitats. Achieving the desired mix of roughness can be accomplished by placement of plants with appropriate physical structure. This dramatically changes the perspective of vegetation in flood management. Instead of being an impediment that increases flood risk, vegetation now becomes a valuable tool used to reduce and optimize risk exposure.

Improving Flood Management Reliability With Riparian Vegetation

In considering reliability we can again borrow from the world for flood management. Reliability is the potential for a particular feature or facility to provide a repeated outcome. Flood managers want levees and floodways to be reliable at conveying flows and keeping flood waters away from valued property and people. Floodways and levees undergo constant change that in turn shifts their reliability. Much of the change arises because of the ability for plants to colonize and grow in flood systems. Maintenance of levees and floodways is a constant challenge where floodway operators remove vegetation to maintain flow capacity (reduce roughness). Denuding these features provides temporary improvements in capacity but also primes the sites for recolonization and starts the cycle over. The maintenance needs and costs are considerable and maintenance programs are regularly facing shifting budgets and damage repair.

As noted above, succession in floodplain and riparian plant communities is marked by predictable changes in the density of plants, the number of stems per area, and height of the leaf canopy above the ground (Griggs 2009). The typical change in roughness peaks after colonization when vegetation communities are transitioning to longer lived, larger species

and then declines as increasingly shade limits understory growth. Floodway maintenance schedules tend to remove vegetation at peak roughness, creating a disturbance that is somewhat unpredictable, leading to lower reliability in system performance.

Sidebar 3—Using Stand Design for Flood Risk Reduction

An alternative approach to periodic wholesale removal of high roughness vegetation is to deliberately manage to transition the plant community to mixed age class structures that include substantial percentages of older, lower roughness stands. This can be done by implementing a rotational thinning process. Two-dimensional flood modeling of Star Bend on the Feather River has illustrated the point. At this site, high roughness on the floodplain creates a threat of increasing channel scour along the left bank of the river channel where a water diversion facility is located. A rotational thinning option for the floodplain was modeled that removed a swath of plants longitudinally through the center of the floodplain at time zero. At 10-year intervals, additional thinning occurred along adjacent, parallel swaths. After four cuttings, the site had an age class distribution of 0-, 10-, 20-, 30-, and 40-year-old vegetation. Each cutting was sized to retain acceptable scour potential at the water diversion (fig. 31). At each thinning episode, a smaller swath than the previous cut was needed to maintain acceptable conveyance and roughness. At the 5th interval, it was estimated that normal tree fall and plant community dynamics would sustain the needed roughness distribution without further thinning.

While hypothetical, this exercise illustrates the potential for integrating plant stand management with risk reduction to provide a dependable, repeatable, reliable conveyance system. Rather than depend on regular infusions of funds for clearing plants, this option consistently reduced costs until a self-maintaining system emerged. At this point, the system is highly reliable, being self-regulating, and funding can be reduced to that needed for periodic assessment to ensure the stand retains its risk reduction capabilities. At the same time, the mixed age class structure increases the biodiversity and hydraulic complexity of the site, providing for a better mix of ecological process and function.

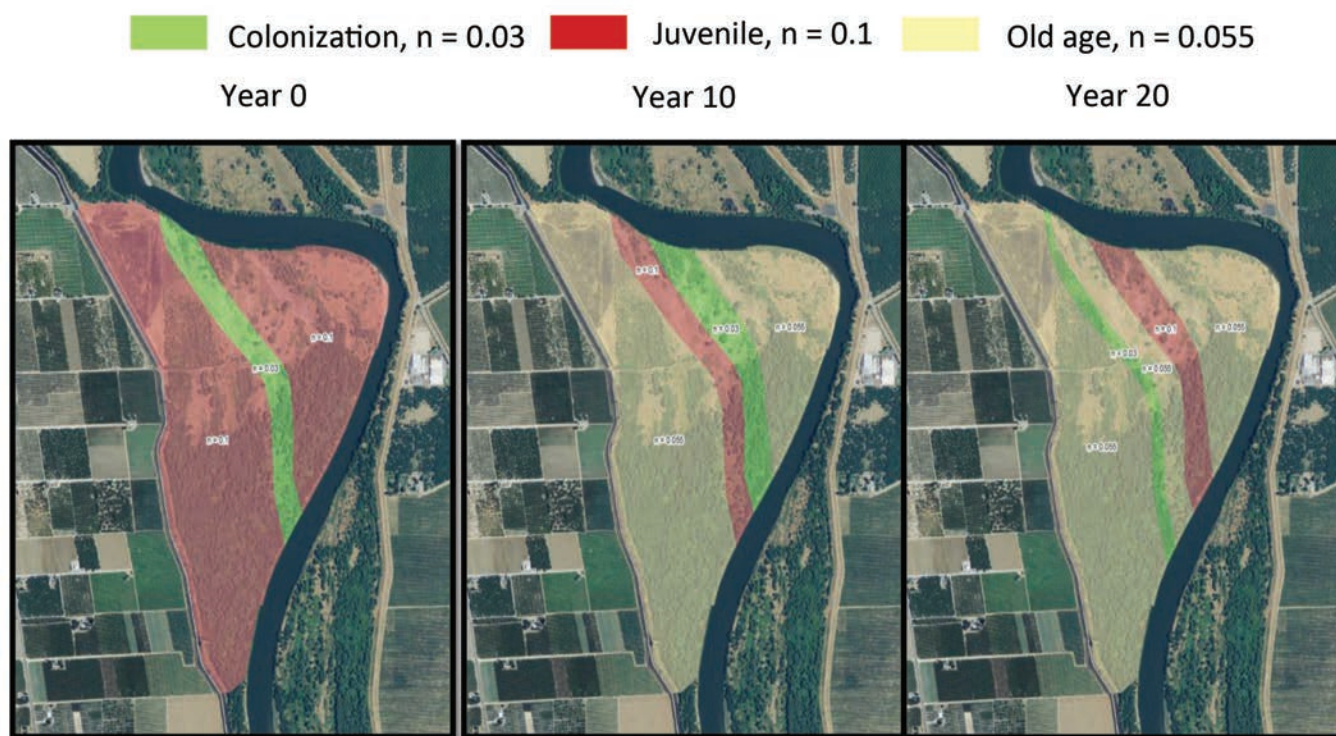


Figure 31—Rotational thinning that targets complex age class forest. Floodplain velocities change over time with vegetation growth and management resulting in higher/distributed velocities across floodplain and lower velocities (reduce erosion potential) through channel.

Monitor and Map

To achieve a greater expanse of Central Valley riparian habitat, it will be necessary to understand the quality and extent of existing habitat. Recent work has produced a fine-scale vegetation map of the riparian habitat of the Central Valley (California Department of Fish and Wildlife's VegCamp 2011). Conducted as part of the flood planning work for the Central Valley, the new vegetation maps provide data layers for GIS use, for the first time providing a valley-wide picture of where riparian vegetation flourishes. Now that a baseline has been established, changes in riparian vegetation communities can be tracked. Future monitoring will provide insights into how plants and animals are doing in the reconstituted riparian forests and whether these areas can produce the same scale of diversity and sustainability that once occurred.

Climate Change

The riparian landscape we experience going forward will not likely be the same as what we lost, or even what we have. Climate models predict a much hotter California in the future, especially in the San Joaquin Valley and Tulare Basin. Whether that heat comes with a shift in the amount of precipitation is unclear. But the models do predict more variation in precipitation and a loss of snowpack (State of California, Department of Water Resources 1993). This will likely result in more frequent flood flows of moderate scale and an increase in the frequency of occurrence of large damaging floods. The large dams and reservoirs provide a great deal of flood risk reduction for the modest events but are likely to operate much like a free-flowing river during large events, when the reservoirs are full and the dams must release everything coming at them. In these situations, we must anticipate where the flood flows will go and how the system can recover from damaging, high volume flows. One strategy is to put more flood capacity back on the floodplains, widen the bypasses, and to stabilize the most vulnerable flow paths using native floodplain adapted vegetation to maintain the floodways (Seavy et al. 2009). This is a strategy that merges flood risk management with conservation ecology in a sustainability context. Doing this would allow a revitalization of the Central Valley's riparian landscape, and the opportunity to take advantage of many contemporary and emerging tools in riparian assessment and flood modeling.

Conclusion

California's Central Valley once supported vast arrays of riparian and wetland habitats that consisted of complex topography and microhabitats. Today much of that ecosystem has been replaced with industrial agriculture and, more recently, with expanding urban landscapes. The combination of climate change and evolving social needs will continue to change the landscape structure of the Central Valley going forward. Riparian ecosystems can play an important part in providing a sustainable landscape, posing acceptable levels of risk from flood, drought, and other disruptions. To achieve this will require the combined efforts of land managers, conservationists, city and regional planners, and business interests all working to find common strategies that provide the desired mix of habitat features. New and emerging tools in flood modeling and conservation can be used to help visualize and design these future landscapes. Clear objectives will be needed to get the most value from these efforts.

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