THE CENTER FOR RESOURCE EFFICIENT COMMUNITIES

VALUING CENTRAL VALLEY FLOODPLAINS

A FRAMEWORK FOR FLOODPLAIN MANAGEMENT DECISIONS

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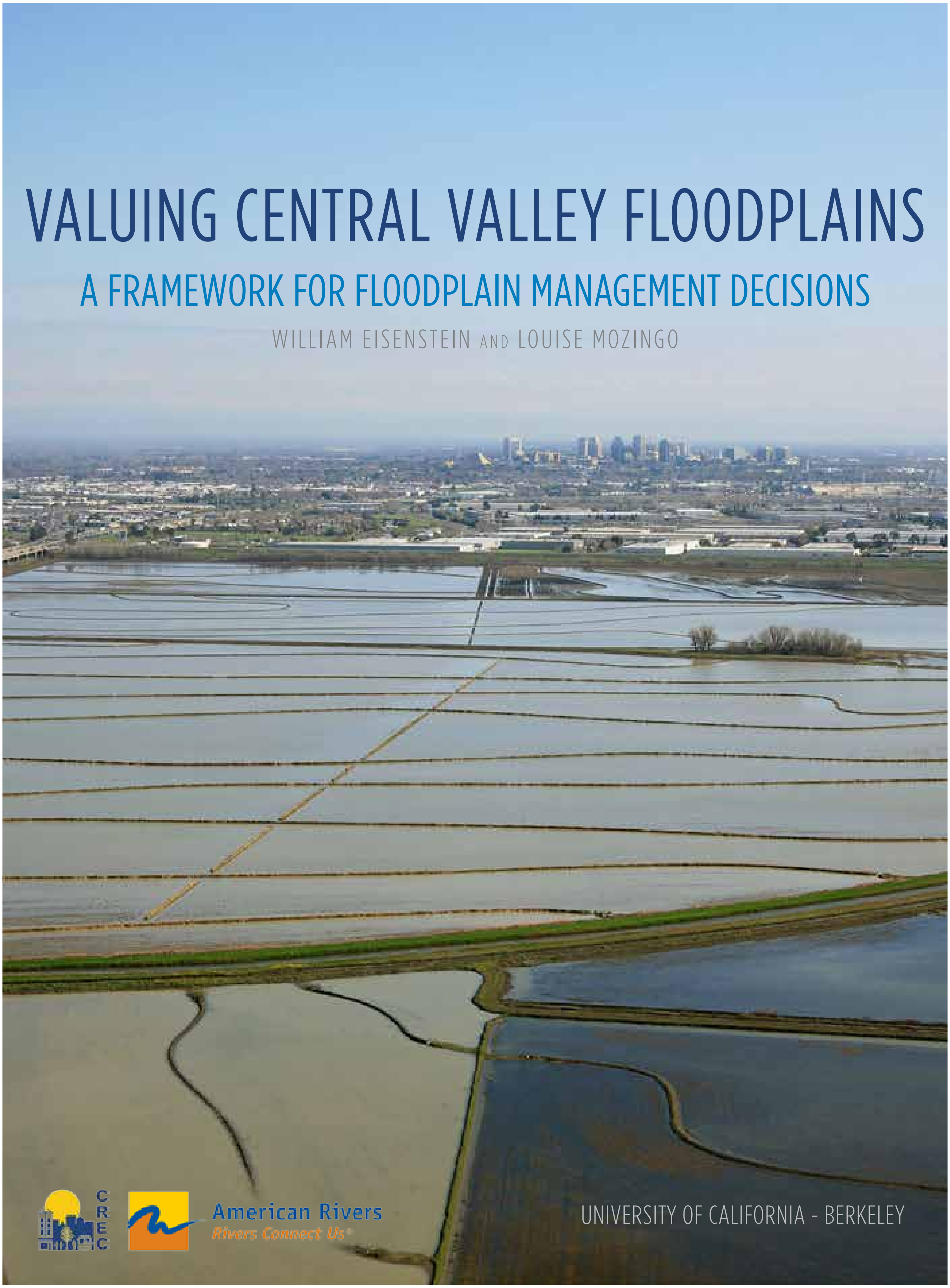

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EXECUTIVE SUMMARY

This report proposes a new general framework for assessing the economic value of hydrologically connected floodplains, especially in the Central Valley of California. Hydrologically connected floodplains are those in which rivers are permitted to overflow onto floodplain lands periodically, either under their own power or as a result of deliberate management decisions. They may or may not be conserved as, or restored to, native floodplain ecosystems, but can also host profitable agriculture and other land uses, though generally not urban development. Disconnection of floodplains by levees allows that development to occur but also eradicates certain valuable flood management and ecosystem services detailed in this report. Climate change and other trends are creating higher, more frequent and more destructive floods in many river basins, forcing flood managers into a stark choice between heightening levees and dams, or increasing the use of connected and managed floodplains that produce multiple benefit streams.

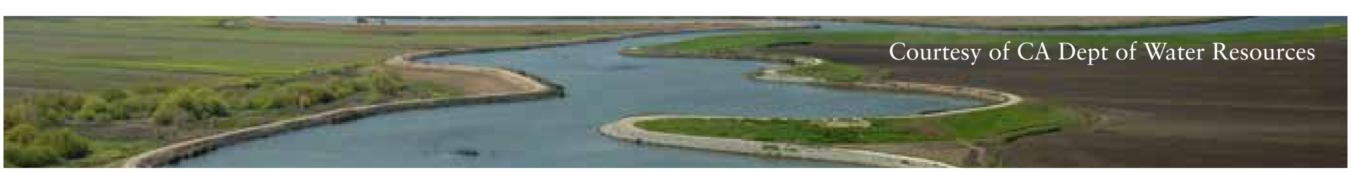
The floodplain valuation framework presented here includes four "value accounts" that can be used to comprehensively assess the full economic value of connected floodplains within the context of both basin-wide and project-level planning processes:

- Flood risk reduction value (including flood stage reductions and avoided residual risk)
- Ecosystem service value (including habitat, food web support, carbon sequestration, water management and sediment services)
- Land use value (including agriculture, recreation and aesthetic values)
- System operations value (including integrated water management, option values, climate change accommodation, and maintenance and liability management)

The current federal and state policy frameworks governing floodplain land use fail to account for most of these benefit streams, leading to floodplain management decisions that ignore important economic values that only connected floodplains can provide. By synthesizing existing literature on these values and discussing specific examples from the Central Valley, the report produces "order-of-magnitude" estimates for each major component of the four value accounts. Many of these estimates are highly context-dependent (hence the use of dollar ranges to estimate them) and must be more rigorously assessed in any particular situation. The table on the facing page summarizes these estimates.

The Center for Resource Efficient Communities (CREC) produced this report in association with a larger American Rivers research initiative to quantify the benefits to flood management, water supply and ecosystems of expanded, multi-purpose floodways in the Central Valley. This initiative was undertaken in recognition of the fact that encouragement of integrated water management planning to achieve multiple objectives is the official policy of the state of California. Despite this, widely applicable tools and protocols to systematically evaluate multiple benefits have yet to be developed.

The California Department of Water Resources (DWR) and the U.S. Army Corps of Engineers should incorporate full consideration of these value accounts into ongoing and future basin-wide planning processes, initiate new efforts to systematically assess flood risk in the valley and the role that connected floodplains could play in reducing it, continue existing efforts (by DWR) to identify opportunities for floodplain reconnection, and develop project evaluation criteria that take full account of the multiple economic benefit streams that connected floodplains provide, rather than the single-benefit methods that the Corps, in particular, relies upon currently.



Courtesy of CA Dept of Water Resources

APPROXIMATE MONETARY MAGNITUDES OF SERVICES OF CONNECTED CENTRAL VALLEY FLOODPLAINS

FLOOD PLAIN VALUE ACCOUNTS	CONCEPTUAL EXAMPLE	ANNUAL VALUE PER FLOODPLAIN ACRE	CONTEXT SENSITIVITY	NOTES
I. FLOOD RISK REDUCTION VALUE				
Reduced flood stage	Yolo Bypass widening	\$100s - \$1,000s	Depends on extent and intensity of development in affected areas	Assumes 100-year project lifetime and discount rate of 3%
Avoided residual risk	Various sites in Valley	\$0 - \$1,000s	Depends heavily on local topography	Assumes suburban development densities
II. ECOSYSTEM SERVICE VALUE				
Habitat (incl. food web support)	Central Valley salmon	\$100s - \$1,000s	Depends on commercial and recreational value of fishery	Same range as findings for habitat value of wetlands generally
Carbon sequestration	Delta	\$10s - \$100s	Depends on soil types and price of carbon	Delta has unusually good potential
Water quality maintenance	Valley-wide	<\$0 - \$100s	Depends upon intended uses of water	Effects can be negative as well as positive
Groundwater recharge	Gravelly Ford, Yolo Bypass	\$0 - \$100s	Requires suitable soils and aquifers	Value and recoverability of water varies by site
Sediment deposition	Cosumnes	\$0 - \$100s	Depends on channel morphology/hydrology	Avoided cost of channel dredging downstream
III. LAND USE VALUE				
Agriculture (net profits)	Yolo Bypass	\$100s - \$1,000s	Depends on crops and flow timing in the floodplains	Floodplain soils generally well suited to agriculture
Recreation	Delta	\$100s	Depends on proximity to population centers	Care should be taken not to double-count habitat values
Visual and place values	Lower San Joaquin	\$0 - \$100s	Depends on visual accessibility of floodplain to homes	"Place-branding" value highly indeterminate
IV. SYSTEM OPERATIONS VALUE				
Integrated water management	Yolo Bypass	\$100s	Depends on system architecture and reservoir operations	Calculating potential water supply gains is highly complex
Option value	Valley-wide	\$0 - \$10s (per \$100m in future savings)	Depends on whether floodplain connection preserves lower-cost future management options	Assumes 50-year horizon at 7% discount rate; history of Yolo Bypass suggests that future management options could vary by >\$800m.
Maintenance and liability	Valley-wide	Unknown	Depends on local soils, hydrology	Data insufficient to support generalizations

I. INTRODUCTION

When the federal government authorized the Sacramento River Flood Control Project in 1917 after decades of political wrangling, it included an innovative idea that had first been born in the mind of a Colusa newspaperman (and later California assemblyman) named Will Green 50 years earlier. Realizing that the main channel of the Sacramento River was too small to carry the peak flows that frequently roared out of the river's steep and narrow watershed, Green proposed that flood control projects in the valley make managed use of the large natural basins that flanked the river to accommodate large flows. In particular, the Yolo Basin at the lower end of the valley could be used to divert high waters away from the city of Sacramento, which had already flooded disastrously several times in California's short history as a state (Kelley 1989). Later dubbed bypasses, these conserved and managed floodplains have proven to be highly effective components of the state and federal flood management project on the Sacramento.

Almost 150 years after Green's original inspiration, bypasses and hydrologically connected floodplains have become an ever-more-critical part of flood management worldwide. Learning from the experience on the Sacramento, the U.S. Army Corps of Engineers designed and incorporated four floodways as part of the 1928 Mississippi River and Tributaries Project—the Bird's Point-New Madrid Floodway in Missouri and the Atchafalaya, Morganza and Bonnet Carre Floodways in Louisiana.[1] During the huge Mississippi River flood of 2011, the Corps made use of all three to reduce peak flows and protect urban populations in Cairo, Illinois and New Orleans, Louisiana. As with the Yolo Bypass, they have been profitably farmed and inhabited for over 75 years, even as they provide important additional flood protection to major urban areas.

Now the nation most expert in flood engineering—the Netherlands—is also making conserved floodplains a key part of its national river and flood management strategy. Titled "Room for the River," this strategy seeks to reduce growing flood risks posed primarily by the Rhine, which flows into the Netherlands from Germany. Among other measures, it will incorporate a flood bypass around the Veessen-Wapenveld metropolitan area and dredge the Rhine's floodplain to ensure necessary flood conveyance capacity. Notably, the Dutch also identify the Room for the River strategy as the best means of managing the higher peak flows expected as climate change unfolds, and as a way of generating major environmental benefits alongside public safety improvements (Government of the Netherlands 2006).

The Sutter Bypass. Courtesy of CA Dept of Water Resources.

[1] Conserved and managed floodplain areas similar to a bypass, though used less frequently

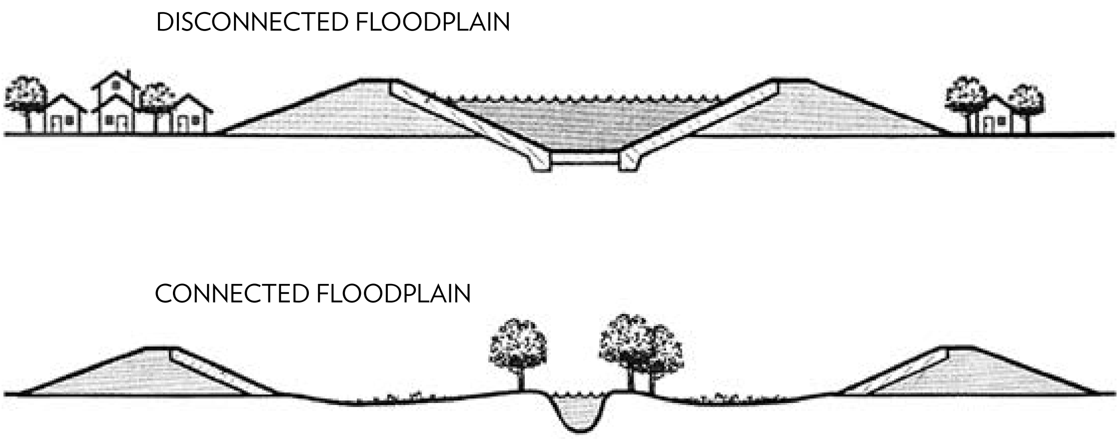


Figure 1. Levees built next to rivers disconnect floodplains. Image adapted from Water Education Foundation's *Layperson's Guide to Flood Management.*

Floodplains are also among the world's most productive ecosystems, producing larger amounts of biomass and species diversity per acre than other terrestrial ecosystem types in most regions of the world (Tockner and Stanford 2002). In the Central Valley and elsewhere, many endangered species of fish also rely on the feeding, rearing and refuge opportunities that floodplains alone can provide, and riverine ecosystems benefit enormously from the food web support provided by active floodplains, including production and export of organic carbon, plankton and invertebrates (Junk et al 1989). Floodplains are also important carbon sinks on a global level. As such, floodplain ecosystem preservation and restoration are critical to global efforts to conserve biodiversity and mitigate climate change.

VALUING FLOODPLAINS

With these recent demonstrations of the critical role of floodplains in flood management, the assessment and quantification of the economic value of floodplains is essential to understanding the benefits of floodplain conservation and reconnection. Continued urbanization of watersheds, deforestation, compaction and tiling of agricultural soils over large areas, channelization of waterways and climate change-influenced rainfall patterns are generating higher, more frequent and more destructive floods in many river basins (Opperman et al 2009). Yet these basins are generally managed using flood projects built decades ago and designed for hydrological conditions that are now irreversibly changing.

In many situations, flood managers now face a stark choice: double down on conventional approaches to flood management, such as raising levees and dams, or increase the use of managed floodplains for conveyance, detention or infiltration of floodwaters. Finding the appropriate balance among these various measures in any given river basin requires a full accounting of the multiple costs and benefits of each.

A pivotal distinction in this regard is between floodplains that are hydrologically connected to their rivers, and those that are not. *Hydrologically connected* floodplains are those in which rivers are permitted to overflow onto floodplain lands periodically, either under their own power or as a result of deliberate management decisions. These floodplains may or may not be conserved as (or restored to) a native floodplain ecosystem. Profitable agriculture also can be carried out on hydrologically connected floodplains, as it is in the Yolo Bypass.

Bypass operating during flood of 1997. Courtesy of CA Dept of Water Resources.

Hydrologically disconnected floodplains, by contrast, are those that lie behind levees that prevent the periodic overflows of the river—at least until water levels become so high that the levees fail or are overtopped, endangering human life and causing serious property destruction in the floodplain.[2] Thus, while disconnected floodplains can host higher-value land uses such as urbanization, they also typically have much higher levels of risk to people and property (see Figure 1).

Many flood management agencies have come to realize that disconnection of floodplains has important, and often irreversible, consequences both for flood risk and for the unique social and ecological values that connected floodplains can provide. Flood management is first and foremost a matter of ensuring public safety. But two projects that are designed to reduce risk to human life against floods equally may differ greatly in their economic consequences, environmental effects, and impact on the landscape. Nonetheless, floodplain managers generally lack methods for weighing the full system-wide costs and benefits of various flood management strategies. Even where floodplains are still undeveloped—and therefore potentially hydrologically connectable—they are too often viewed simply as land to be protected by flood management infrastructure (i.e. levees), rather than as a flood management asset in their own right. Beyond the ability of connected floodplains to contribute to flood risk reduction, these areas can support many other ecological and social values, and these are often left unevaluated entirely.

Comparison of the value of hydrologically connected and disconnected floodplains must look at the river system as a whole, not just one floodplain or one project at a time. Methods for assessing flood risk are well known among floodplain managers, even if they are not yet widely enough used for system-wide long-term planning. Environmental economists, meanwhile, have developed various methods for estimating the ecosystem services that floodplains provide to humanity, including the value of fish and wildlife habitat, carbon sequestration, and sediment transport, among others. The insights from ecological economics about ecosystem services should also inform the decisions that engineers and planners must make about the design of flood management systems.

[2] Throughout this report, floodplains are sometimes referred to as simply "connected" or "disconnected" for ease of reading.

Wetlands and agriculture in the Yolo Bypass. Courtesy of CA Dept of Water Resources.

BACK TO THE VALLEY

This report summarizes these insights with regard to flood risk reduction, ecosystem services, land use, and system operations. It also discusses means of applying them in the context of the Central Valley of California, where the idea of using connected floodplains as flood management first appeared. It is produced in association with a larger American Rivers research initiative to quantify the benefits to flood management, water supply and ecosystems of expanded, multi-purpose floodways in the Central Valley. American Rivers undertook this initiative in recognition of the fact that encouragement of integrated water management planning to achieve multiple objectives is the official policy of the state of California. Despite this, widely applicable tools and protocols to systematically evaluate multiple benefits have yet to be developed.

The State of California has also recently finalized its first Central Valley Flood Protection Plan (CVFPP), as required by Senate Bill 5 (SB 5) passed in 2007. The CVFPP will guide the upgrading of State Plan of Flood Control facilities throughout the Central Valley in the coming decades (see Figures 2 and 3), and the expenditure of billions of dollars of bond funds already approved by California voters. The CVFPP (DWR 2012) presents a State Systemwide Investment Approach (SSIA) that includes both structural and non-structural strategies for improving flood protection in the valley, including providing a 200-year (0.5% annual probability) level of protection for urban and urbanizing areas, as required by SB 5. Among the measures included in the SSIA are creation of new flood bypasses on the Feather River and the Lower San Joaquin River near Paradise Cut, and expansion of the existing Sacramento, Sutter and Yolo Bypasses on the Sacramento River. These bypasses will both restore hydrologically connected floodplains and reduce flood stage and associated risk for urban areas.

In each case, the CVFPP calls for further studies in the coming years to examine project feasibility (for the new bypasses) or to refine project details. Key findings on the valuation of floodplains, as well as insights into effective methods for assessing these values on a project level, will be useful to DWR and others as they pursue these studies.

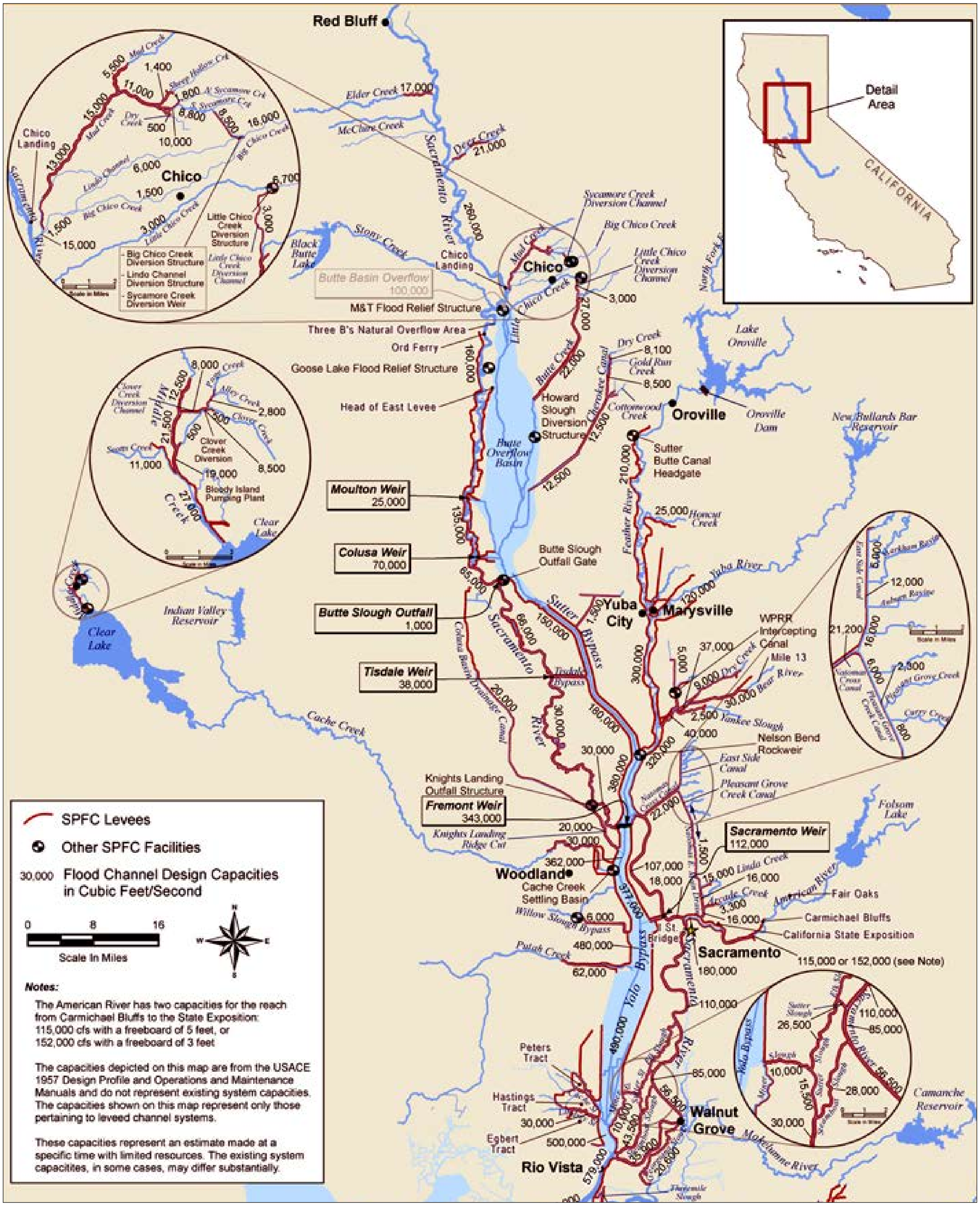


Figure 2. State Plan of Flood Control (SPFC) facilities in the Sacramento Valley. Courtesy of CA Dept of Water Resources.

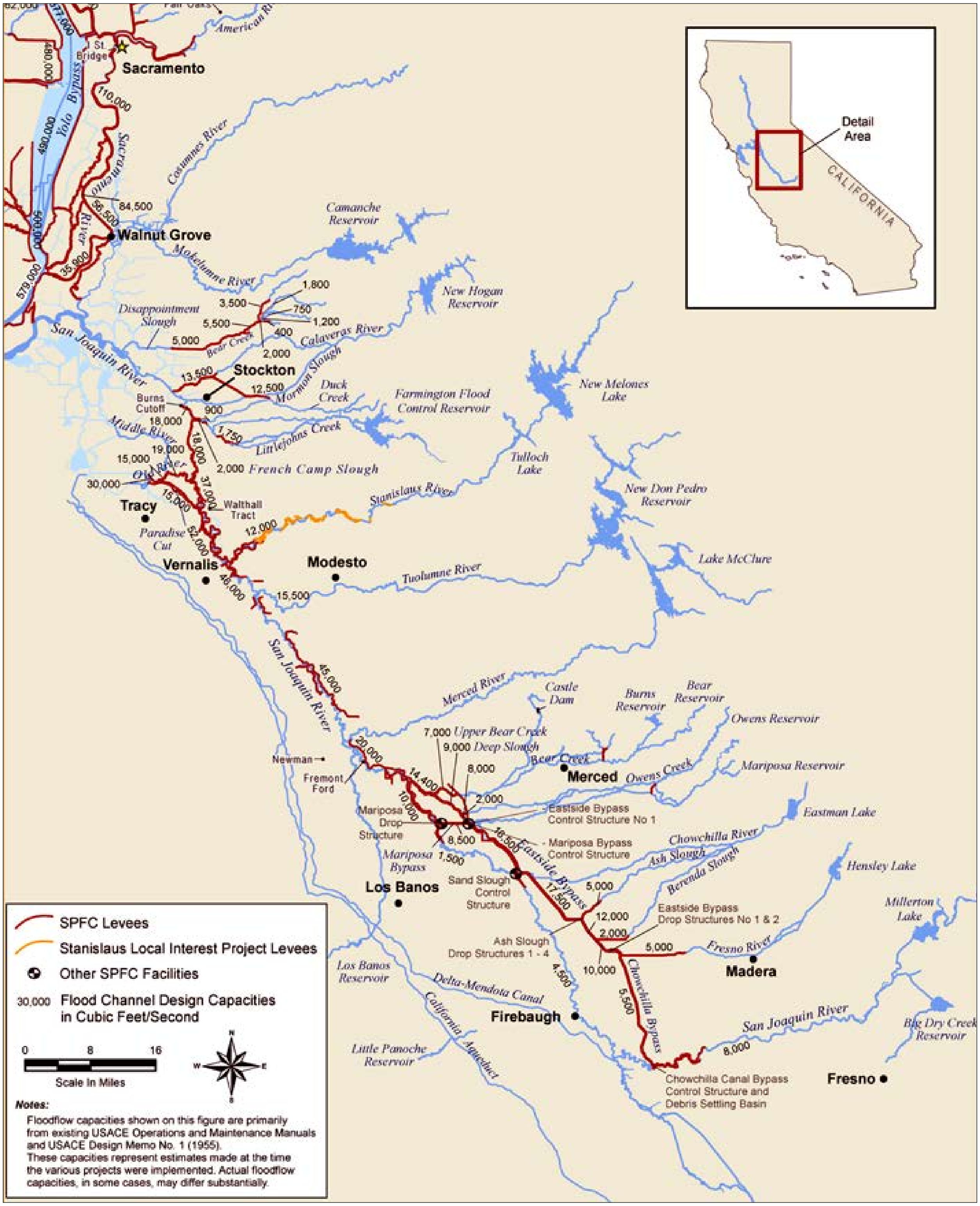


Figure 3. State Plan of Flood Control (SPFC) facilities in the San Joaquin Valley.
Courtesy of CA Dept of Water Resources.

II. A FRAMEWORK FOR FLOODPLAIN VALUATION

The concepts of flood risk and residual risk are essential to this floodplain valuation. Flood risk equals the probability of a flood multiplied by its consequences. In hydrologically connected floodplains, there is relatively high probability but often relatively low monetary consequences from flooding, yielding a relatively low overall risk level. Though these floodplains may contain productive agriculture or recreation areas, such as those in the Yolo Bypass, these land uses are generally much more resilient to periodic flood damage than intensive urbanization or industry. Indeed, periodic flooding generally enhances floodplain recreation and agriculture over the long term, though this may not be helpful to landowners at any given point in time.

In hydrologically disconnected floodplains, by contrast, there is usually low probability of flooding since levees are typically designed to protect against more frequent floods (such as those with a 1% chance of occurring in any given year). But less frequent floods will have very high consequences, since the presence of the levees usually stimulates urbanization and other high-value land uses behind the levees. Because flows higher than those for which the levees were designed will come eventually, these high-value land uses will eventually be inundated—and unlike in connected floodplains, these land uses are not adaptable or resilient to these floods. Serious economic losses, and possibly loss of life, are the unfortunate result.

The risk from flooding as a result of greater-than-design events is known as the residual risk of flooding, and it is substantial. Over the life of a 30-year mortgage on a house behind an accredited 100-year levee, there is a 26% chance that a greater-than-100-year flood will occur (Eisenstein et al 2007). Moreover, when such floods do occur, they are likely to be more damaging to the structures behind the levees, since there will be deeper inundation in areas just behind levees than there is farther from the river, given the topography of the Central Valley (see Figure 4).

The concept of residual risk is critical to the valuation of floodplains. A flood protection strategy based on floodplain connection (i.e. bypasses or spillways) and one based on disconnection (i.e. levee construction) may be designed to protect against floods of the same probability, but produce drastically different levels of residual risk. Indeed, it is entirely possible for a given community's overall flood-hazard risks to increase as a result of levee construction, if the construction of the levees results in widespread development in the areas protected by the levees. As discussed below, there is good reason to expect such development to happen. Thus, levees reduce the probability of a flood for the areas close to the river (compared to having no levee), but the development that accompanies the levees often means that the consequences of any flood larger than the 1% flood likely will be much higher.

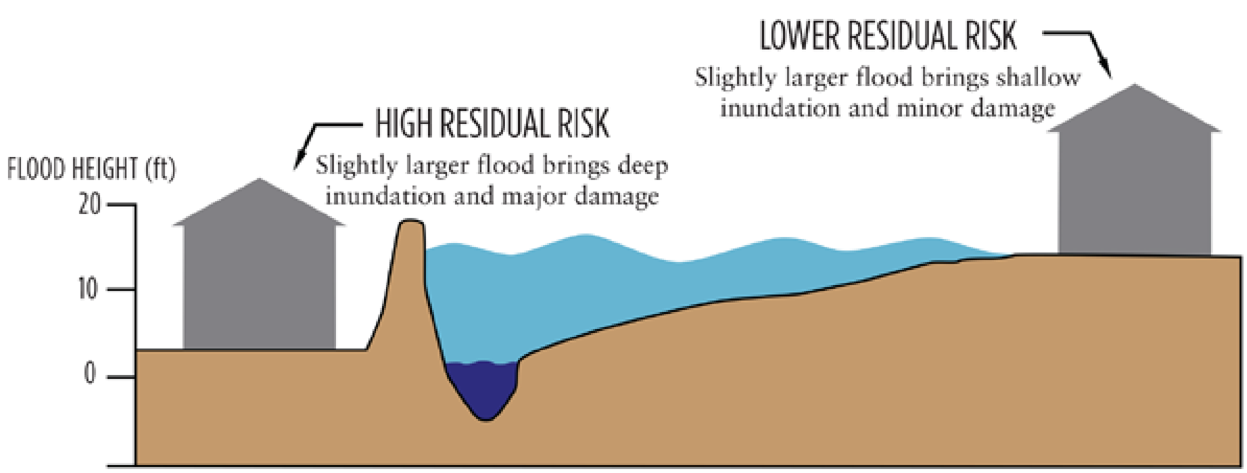


Figure 4. Residual risk typically rises as development fills in close to riverside levees. Adapted from Eisenstein et al (2007).

Overlook of Yolo Bypass. Courtesy of CA Dept of Water Resources.

In addition, flood engineers and floodplain managers are increasingly considering projects that would either conserve hydrologically connected floodplains or re-connect disconnected floodplains by setting back levees. These may be very different valuation situations. In the case of conservation, one is asking what it would cost to replace or sacrifice existing floodplain values and services, including risk reduction services. In the case of re-connection, one is asking what it would cost to obtain a new flow of floodplain values and services by re-arranging the existing landscape. The economic psychology, financing needs, and politics of these situations may be very different.

Established methods exist for assessing the financial costs and benefits of flood management plans and projects. The federal government's National Economic Development (NED) Benefit Evaluation Procedures for Urban Flood Damage (U.S. Water Resources Council 1983) establishes the official planning and decision process for federal flood management projects undertaken by the Army Corps of Engineers. The Federal Emergency Management Agency (2009) also has a benefit-cost analysis procedure to determine eligibility for FEMA grants to mitigate small-scale flood risks, such as those pertaining to a single property or a small area.

Neither of these methods incorporates any appraisal of the ecosystem service values of floodplains, nor do they allow for adequate consideration of the basin-wide and system-wide context of any given floodplain or flood management project. By focusing analysis on specific projects designed to protect specific geographical areas, these methods tend to ignore costs and benefits that accrue to the system as a whole.

What is needed is a framework to assess the value of connected floodplains at a full-system planning level over multiple time scales. Flood managers should look at the system as a whole, over its entire lifecycle, to assess the full value of hydrologically connected floodplains (or those with potential for reconnection) within their proper full-system context, then proceed to plan and implement specific flood management projects that optimize the various net benefits that these floodplains uniquely can provide.

To do that, flood managers should consider four different value accounts for any given floodplain in the context of the system as a whole:

1. FLOOD RISK REDUCTION VALUE

All flood management projects will prioritize protection of human life and property over other benefits, and in practice U.S. flood management practice has generally focused on the 100-year (1%) design flood. However, system-based risk reduction assessments may lead to very different conclusions about appropriate flood management strategies and floodplain land uses than localized project-by-project assessments. In particular, floodplain connection or re-connection often creates additional risk reduction benefits for the system as a whole above the benefits from new or heightened levee achieving the same nominal level of local protection. These additional risk reduction benefits—discussed in chapter IV of this report as reduction in flood stage and avoided residual risk—can be quite valuable in certain situations.

2. ECOSYSTEM SERVICE VALUE

While a wide variety of floodplain ecosystem services are not priced within any market, nonetheless, they create tangible value for human society. These include the provision of habitat for terrestrial and aquatic species, production and transport of food web resources such as organic carbon, carbon storage, sediment transport, regulation of water quality, and groundwater recharge. These values are generally highly contextual, but can be quite significant in some situations. In addition, some services of ecosystems—such as the continued existence of endangered species—may not be amenable to pricing in all situations but are nonetheless worth securing.

3. LAND USE VALUE

Hydrologically connected floodplains can host agriculture, recreation, and certain infrastructure land uses that produce benefit streams to the economy. Though these may not be as lucrative to the landowners as selling the land for development, public entities may actually experience larger net economic benefits when floodplain lands remain undeveloped (see section II below).

4. SYSTEM OPERATIONS VALUE

System managers should consider the value that connected floodplains can provide for integrated water management, as well as the value of preserving future management options to deal with the changing hydrology expected from climate change and ongoing alteration of watershed land cover. These benefit streams may be especially significant in systems where flood management and water supply operations are intermingled, as is the case in the Central Valley. In addition, like any other piece of built infrastructure, levees are a depreciating asset that must be maintained, particularly around urban areas, where a single weak spot can lead to a major disaster. Flood bypasses may also require periodic dredging or other forms of long-range management. Selection of flood management strategies should consider these long-term system maintenance responsibilities and the potential liabilities associated with them.

These four "value accounts" are discussed in greater detail in Section IV below.

Central Valley landscape of river channel, remnant wetlands, levees, and agricultural fields.
Above and opposite images courtesy of CA Dept of Water Resources.

III. THE POLICY CONTEXT FOR FLOODPLAIN VALUATION

The National Flood Insurance Program (NFIP), created by the Congress in 1968, dominates floodplain management policy in the United States. Congress significantly amended the NFIP in 1969, 1973, and 1994, and re-authorized it for another five years in 2012. Under the NFIP, the Federal Emergency Management Agency (FEMA) sets flood insurance premium rates based on five basic hazard zones, maps flood hazard areas, and sets minimum criteria for construction in floodplains. Local governments must then adopt floodplain land use standards that are consistent with FEMA guidelines if flood insurance (sold by private insurers) is to be available in that area (Burby 2001).

The amendments to NFIP have gradually strengthened this framework. Property owners within FEMA-delineated floodplains are now required to purchase flood insurance in order to obtain a mortgage from any federally regulated institution (such as a bank insured by the Federal Deposit Insurance Corporation, for instance). They also cannot receive federal disaster relief aid if their local government has failed to participate in NFIP (Burby 2001). Crucially, however, lands behind federally accredited 100-year flood protection levees are considered to be removed from the floodplain, and are therefore exempted from the requirements of NFIP, including the requirement to purchase flood insurance. This provision applies to the large majority of urbanized areas in regulatory floodplains in the U.S., most of which are protected by accredited levees.

The floodplain land use standards to which local governments must comply mostly involve site design and building construction standards, as opposed to direct prohibition of development in hazardous areas. In the regular phase of the NFIP program, local governments must ensure that the lowest floor of any new construction is at or above the elevation of the 100-year flood, delineate a regulatory floodway, and prohibit any development throughout the entire floodplain that would raise flood levels by one foot or more. The 1994 amendments to the NFIP created an incentive program called the Community Rating System (CRS), which allows local governments to earn points toward community-wide flood insurance rate reductions through implementation of a wide range of flood risk reduction efforts. These include measures such as floodplain open space conservation and other development restrictions in floodplains (FEMA 2007).

There are many shortcomings to this policy structure. NFIP does not accurately assess the true extent of flood hazards, since the hazard mapping process does not include areas with localized stormwater drainage problems, and does not include any mechanism to account for probable future hazards resulting from increased watershed development, sea level rise, storm surge heightening, or subsidence (Burby 2001). In addition, many have argued that the 100-year (1% per year) flood protection standard is too low, and that it should be at least a 200-year (0.5% per year) standard as now adopted by the State of California for urban areas in the Central Valley,

Housing development in floodplain. Courtesy of CA Dept of Water Resources.

and perhaps as high as a 500-year (0.2% per year) standard as recommended by the Association of State Floodplain Managers (2000). Even more important, the NFIP does not account for the possible failure or overtopping of flood protection levees. By exempting lands behind accredited 100-year levees from the requirement to purchase insurance, NFIP effectively ignores the residual risk of larger floods (i.e. those with statistical return intervals greater than 100 years) to overwhelm flood defenses and damage property.

URBAN AND SUBURBAN DEVELOPMENT IN FLOODPLAINS

The practical effect of NFIP has been to incentivize disconnection and development of floodplains, irrespective of the potential for escalation of overall flood risk. By exempting the land behind accredited 100-year levees from designation as a floodplain (and the attendant regulatory requirements), NFIP has encouraged development to occur in floodplains throughout America without sufficient attention to flood hazards or to the multiple values of connected floodplains.

Partially because of NFIP, the trend toward floodplain development has continued unabated, even after recent flood disasters. In the decade after the huge Mississippi River Flood of 1993, for example, another $2.2 billion in development covering about 18,000 acres occurred in the St. Louis region on land that was underwater in the 1993 flood (Pinter 2005). Major flooding in the Central Valley in 1997 did little to deter development in local floodplains, as at least 60,000 new homes were constructed or planned in floodplains in the Sacramento region in the ensuing years (Pinter 2005), and an 11,000-house development was approved for construction on a site near Manteca that was under at least 10 feet of water in 1997 (Eisenstein et al 2007). Only the "housing bust" beginning in 2008 slowed additional floodplain development in these and other areas.

The desire to develop floodplain land originates from the fact that land eligible for residential, commercial or industrial development near cities is much more valuable than land eligible only for agricultural use. Even in the highly productive Central Valley, irrigated farmland is typically worth thousands or (at most) tens of thousands of dollars per acre, whereas the same land with permission to develop houses is likely worth hundreds of thousands per acre. This value gradient creates a powerful incentive for landowners to sell land for development.

While landowners experience substantial net financial benefits from the sale of farmland for development, it is much less clear-cut from the perspective of public agencies. Local governments experience an increase in property tax revenues and sales tax revenue when land is developed, but they also experience an increase in expenditures on roads, police and fire protection, solid waste collection and other municipal services. When the

Houses on Levees. Courtesy of CA Dept of Water Resources.

The Central Valley flood of 1997. Courtesy of CA Dept of Water Resources.

development takes the form of low-density sprawl, as it often does in newly developed floodplains, these costs are much greater per household than when growth is more compact.

Surprisingly, over the long term, these public-sector costs of low-density development can outstrip benefits, leaving the municipality's balance sheet worse off than before. In the most robust study of the cost of sprawl in California, the American Farmland Trust (1995) found that accommodating the anticipated population growth of the Central Valley by 2040 through low-density sprawl would create a $1 billion annual shortfall for the region's municipal governments, whereas growing more compactly would create a net surplus of $200 million to municipal coffers. When the development occurs in floodplains, there is the additional substantial public cost of constructing and maintaining levees, as well as the potential need for expensive emergency response services when levees fail.[3] A large proportion of these costs are borne by local government, though they may be passed onto the developers and homebuyers through exactions, fees or taxes to fund special assessment districts (Fulton and Shigley 2005). State government increasingly experiences additional costs related to emergency response and flood liability from floodplain development as well, yet reaps a relatively small proportion of the tax revenue benefits.

The balance of these costs and benefits to public agencies is especially important because they persist in perpetuity. A floodplain landowner profits once from the sale of any given piece of land, but the ensuing development is effectively irreversible. Both tax revenues and public service expenses related to new development will be on municipal balance sheets for decades to come, so full accounting of costs is essential to decision-making.

[3] These costs are distinct from residual risk, which refers to the financial risk to property in floodplains from floods that may exceed the design standards of the flood management system. These are direct costs that government must bear if growth is to occur in floodplains in the first place.

CALIFORNIA'S FLOODPLAIN MANAGEMENT POLICY STRUCTURE

Within California, the state-federal flood management system for the Central Valley officially began in 1917, though local levee construction had been going on for decades prior to that. From the 1910s to the present day, about 1,600 miles of levees have been constructed, upgraded or maintained in hundreds of individual projects usually co-funded by local reclamation districts and the state and federal governments (WEF 2005). The capabilities of the state-federal system expanded through the construction of several multi-purpose reservoirs on the major tributaries of the Sacramento and the San Joaquin from the 1940s through the 1970s, including those behind Shasta, Oroville, Friant, and New Melones dams, among others. The state-federal system also includes the large Sutter and Yolo Bypasses in the Sacramento Valley, and the much smaller Chowchilla, Eastside, and Mariposa Bypasses on the San Joaquin. It also contains the Butte Overflow Basin on the upper Sacramento, which accommodates overflows when necessary and drains into the Sutter Bypass (see Figures 2 and 3).

The flood of 1997, along with improvements in flood risk assessment techniques, made clear that the existing state-federal system is no longer adequate to protect public safety and property in the Central Valley (DWR 2011). The 1997 flood caused more than 30 levee ruptures, inundated 300 square miles of the valley, and caused over $5 billion in direct and indirect economic costs (IRP 2007). Investigations conducted since then have revealed that:

- Approximately 50 percent of the roughly 300 miles of urban levees in the system "do not meet current engineering design criteria at the design water surface elevation"
- Approximately 60 percent of the roughly 1,230 miles of non-urban levees in the system "have a high potential for failure at the assessment water surface elevation"
- Approximately 50 percent of the 1,016 miles of channels in the system "have a potentially inadequate capacity to convey design flows" (DWR 2011)

Moreover, these assessments consider only current climatic and hydrological conditions. They do not incorporate any anticipation of the changes in rainfall, runoff, and river hydrology expected from climate change. These are expected to place even greater stress on the system by making the 1% and 0.5%-probability flood flows higher, "with long-term effects on National Flood Insurance Program map ratings, flood insurance costs, floodplain development, and the economic viability of floodplain communities" (DWR 2011).

At the same time as the system has deteriorated, the value of what it protects has grown. Population and economic activity in the areas protected by levees have increased dramatically since the system was built (partly because it was built), and are expected to continue growing substantially in the coming decades (DOF 2012). Because land use approval decisions are a local government authority, little coordination happens between development decisions in the floodplains and the needs of the state-federal system. The end result is that cumulative flood risks in the Central Valley—where risk is understood as probability multiplied by consequences—have been growing rapidly (IRP 2007). Crucially, this is likely to continue, despite improvements to the state-federal system, until much better coordination occurs between floodplain land use decisions and flood management.

Yolo Bypass during high flow. Courtesy of Dave Feliz, CA Dept of Fish and Wildlife.

The California Legislature in 2007 passed SB 5, and amended it with SB 1278 in 2012, to begin addressing this disconnection, albeit tentatively. In addition to requiring the creation of the Central Valley Flood Protection Plan (CVFPP), SB 5 as amended by SB 1278 imposed new requirements on local governments, including:

- Incorporation of the CVFPP data and analysis of flood hazards into city and county general plans within 36 months of the formal adoption of the CVFPP on July 1, 2012 and into zoning codes within 48 months;
- Identification of goals, policies, objectives, and implementation measures "that will reduce the risk of flood damage" based on the CVFPP's data and analysis;
- Prohibition against entering into development agreements, issuing discretionary permits or discretionary entitlements, or approving a subdivision map for new projects proposed within flood hazard zones identified on FEMA FIRM maps, *unless* the city or county finds, based on "substantial evidence" one of the following (CA Gov't Code §65865.5; emphasis added):
    1. "The facilities of the State Plan of Flood Control or other flood management facilities protect the property to the urban [i.e. 200-year] level of flood protection in urban and urbanizing areas or the national Federal Emergency Management Agency standard of flood protection in nonurbanized areas."
    2. "The city or county has imposed conditions on the development agreement that will protect the property to the urban level of flood protection in urban and urbanizing areas or the national Federal Emergency Management Agency standard of flood protection in nonurbanized areas."
    3. "The local flood management agency has made adequate progress on the construction of a flood protection system which will result in flood protection equal or greater than the urban level of flood protection in urban or urbanizing areas or the national Federal Emergency Management Agency standard of flood protection in nonurbanized areas for property located within a flood hazard zone, intended to be protected by the system.[4] For urban and urbanizing areas protected by project levees, the urban level of flood protection shall be achieved by 2025."
    4. "The property in an undetermined risk area has met the urban level of flood protection based on substantial evidence in the record."

[4] What constitutes "adequate progress" was specifically defined in SB 1278 (see CA Gov. Code §65007)

Should a local government fail to update its general plan or zoning code appropriately, a companion bill, AB 70, stipulates that the city or county "may be required to contribute its fair and reasonable share of the property damage caused by a flood to the extent that the city or county has increased the state's exposure to liability for property damage by unreasonably approving new development in a previously undeveloped area that is protected by a state flood control project" (CA Water Code §8307).

The provisions of SB 5 are not as strong as they first appear, however. Though AB 70 provides some incentive for local government compliance with the general plan- and zoning code-update process, SB 5 identifies no specific mechanism for the enforcement of the more important development restrictions, nor does it establish any process by which cities' and counties' findings about their own potential actions may be reviewed or appealed. Even should the state Attorney General or other entity choose to initiate legal action to enforce these provisions, it is unclear how the courts will interpret terms such as "substantial evidence."

More fundamentally, SB 5 still allows new development to occur in floodplains regardless of its consequences for the overall levels of flood risk and the systemic functioning of the flood management system, as long as the individual development project in question is protected sufficiently. Indeed the distinct possibility exists that efforts to increase the level of flood protection to meet these requirements may actually *encourage* more development in the floodplains (since individual development projects will be more robustly protected than before), and therefore elevate the overall risk to the region and the state.

Levee failure in the Central Valley flood of 1997. Courtesy of CA Dept of Water Resources.

IV. VALUING CENTRAL VALLEY FLOODPLAINS

Assessing the value of Central Valley floodplains involves examining the four "value accounts" introduced in section two:

1. Flood risk reduction value
2. Ecosystem service value
3. Land use value
4. System operations value

These are discussed in greater detail below and summarized in Table 3.

1. FLOOD RISK REDUCTION VALUE

The primary purpose of any flood management project must be the protection of human life and safety, and an important secondary purpose is the avoidance of catastrophic damage to people's livelihoods and property. This is no less true for flood bypasses than it is for levees and dams.

Both levees and floodplains clearly have significant flood risk reduction value. The question is whether there are flood risk reduction values that are unique to floodplains as a means of providing flood protection in any given location. And indeed, for any given level of flood protection, connected floodplains can generate two unique value streams that levees do not: reduced flood stages and avoided residual risk.

REDUCED FLOOD STAGES

Connected floodplains, unlike levees, reduce flood stages—the water surface elevation relative to a reference point for a flood of a given return interval—in long stretches of the river. Thus, their flood risk reduction benefits extend not only to the lands adjacent to the floodplain, but also to the opposite bank of the river and to other reaches of the river (and perhaps some tributaries) both upstream and downstream. All else equal, this will reduce flooding potential and failure probabilities of levees elsewhere, and thus avoid potentially significant damages and recovery costs associated with levee failures in those more distant locations.

A 2008 report published by the Sacramento Area Flood Control Agency (SAFCA 2008) offers an example of how significant these flood stage reductions can be. The report describes a plan to widen the Yolo Bypass by setting back its east levees and making other changes to the system to accommodate more flow through the bypass.[5] The purpose of the report was to examine a non-structural alternative for protection of the Natomas and Pocket areas of Sacramento as well as West Sacramento—all highly flood-prone, heavily urbanized areas. Hydraulic modeling of the bypass widening indeed showed that flood stages at the I Street Gage next to downtown Sacramento would be reduced by about 4 feet as a result of the project.[6] As the report points out, this is equivalent to reducing the probability of levee overtopping in these vulnerable locations from 1% to 0.5%, effectively improving flood protection from a 100-year level to a 200-year level. This finding is also consistent with the geotechnical "probability of failure" curves for the relevant levee reaches in the Army Corps Comprehensive Study of the Sacramento and San Joaquin basins (2002b).

Critically, however, the modeling of the bypass widening also showed significant stage reductions at other locations both upstream and downstream of the areas targeted for protection. In other words, a bypass widening project intended to improve flood protection in Natomas, the Pocket,

[5] The plan calls for setting back the east levee by 1 mile from Fremont Weir to roughly Interstate 5, a distance of about 6.5 miles, and then by about 1500 feet from Interstate 5 to the point where the Sacramento Bypass flows in, a distance of about 5.5 miles.

[6] This is not an isolated example. Preliminary results from modeling of floodplain expansion along the lower San Joaquin River between Vernalis and Old River have shown flood stage reductions of nearly 2 feet throughout the southern Delta and Stockton metropolitan region (American Rivers forthcoming).

Fremont Weir in operation. Courtesy of CA Dept of Water Resources.

and West Sacramento would also reduce flood stages in places like Woodland (more than 10 miles upstream) and Freeport (over 13 river miles downstream). Several other communities along the Sacramento downstream of the city (e.g. Elk Grove, Clarksburg, Walnut Grove, Locke, Isleton), as well as farms and infrastructure (including I-5 and I-80) both upstream and downstream of the city, would gain similar benefits. Levee heightening projects to achieve the same level of protection of Natomas, the Pocket and West Sacramento would not have this beneficial side effect. Indeed, they would likely marginally increase flood risks downstream by confining floodwaters into a narrower, faster, deeper-flowing channel.

Can we roughly estimate the value of such secondary benefits? Daniel et al (2009) conducted a meta-analysis of 19 different studies of the impact of flood risk on property values. They found that an increase in the probability of flood risk of 0.01 (or 1%) per year is associated with a 0.6% decrease in the sale price of residential homes. A less precise estimate by Braden and Johnston (2004) places the value of upstream flood mitigation on property values in the same range—from 0 to 2% for properties that are still within the 100-year floodplain.

The SAFCA (2008) study showed that Yolo Bypass widening reduces the probability of a levee-overtopping flood by a 0.5% increment in all locations downstream of Sacramento until the Yolo Bypass rejoins the Sacramento at Rio Vista. The Daniel et al estimate suggests that house prices would therefore be roughly 0.3% higher than they otherwise would, all else equal.[7] These property value increases would then need to be assessed and totaled across the entire acreage protected by the levees whose performance is improved by the reduced flood stages from bypass widening and divided by the total acreage of floodplain that is achieving these improvements (about 5,100 acres in the Yolo Bypass widening project).

[7] This excludes the value commercial, industrial and multi-family residential properties (which were not included in the Daniel et al study), and the value of infrastructure that may be damaged by a flood.

For example, the community of Elk Grove contains about 50,000 housing units worth an average of about $440,000 each as of 2009.[8] Given continued housing price declines in the region, the average housing unit value may be more like $300,000 today. Hence, the total residential property value in Elk Grove may be approximately $15 billion, 0.3% of which is $45 million. Assuming a 100-year project lifetime (the useful lifetime of flood-management related land acquisitions; FEMA 2009) and a multi-generational discount rate of 3% (more realistic for very long time horizons than the standard FEMA 7% rate and in keeping with practice in other countries; ASFPM 2008), the net present value of these benefits is about $2.3 million, or about $450 per floodplain acre in this example.

However, this is just for residential housing values, and only in Elk Grove. Extending this type of analysis to include the value of commercial, industrial and agricultural property, public infrastructure, and other communities experiencing these benefits would likely place the magnitude of the net present value of these benefits in the hundreds of dollars per floodplain acre per year in this particular example.[9] Again, these significant values are attributable only to the flood-stage reduction benefits outside of the areas specifically intended for protection by this project (Natomas, the Pocket and West Sacramento), and therefore are benefit streams achievable only by floodplain conservation or restoration, not by levee projects.

AVOIDED RESIDUAL RISK

As noted, there is always a chance of experiencing a larger flood than the one the flood management system was designed to handle. For the FEMA 100-year flood protection standard, for example, there is a 1% chance in any given year that a larger flood will come along and exceed the flood management system's capacity. Over the course of 30 years—the length of most house mortgages and a common time interval for local land use planning—there is a 26% chance a larger flood will take place. The probability of such an event, multiplied by the consequences of that event, forms the residual risk of flooding in a given location.

Sacramento Weir in operation. Courtesy of CA Dept of Water Resources.

[8] Data obtained at http://www.city-data.com/city/Elk-Grove-California.html as of April 25, 2012

[9] This estimate may be considerably higher or lower in another example depending upon how much urbanized land experiences enhanced protection in a given situation.

Connected and disconnected floodplains using the same design flood may differ significantly in their ability to avoid residual risk to adjacent developed areas. Although the probability of a larger-than-capacity flood is the same (say 1% per year), the consequences can be quite different. This is because, in the Central Valley at least, developed locations adjacent to connected floodplains are often at higher elevation than developed locations directly adjacent to rivers. Both developed locations will be protected by levees (a landward levee at the edge of a connected floodplain, or a riverside levee disconnecting the floodplain entirely), but the inundation of property resulting from the failure of these levees may be of different depths, and therefore inflict different levels of damage. Figure 4 illustrates this situation, simplified for ease of understanding.

The deeper the inundation, the greater is the threat to human safety and the damage to property. The U.S. Army Corps of Engineers (2002a) uses standard tables that relate inundation depth to structural property damage in order to help estimate economic risks in various floodplains. A portion of the table used for single-story residences is reproduced below as Table 1. It shows that structural damage rises rapidly as a percentage of overall property value in the lower inundation depths. For example, average damage at five feet of inundation (53.2% of overall value) is over twice as great as that resulting from one foot of inundation (23.3% of overall value), and average damage at ten feet of inundation is another twenty percentage points higher (73.2%).

How does this contribute to assessing avoided residual risk? For the sake of illustration, suppose that a proposed subdivision could be sited either behind riverside levees within a disconnected floodplain or behind levees that have been set back from the river to create a connected floodplain. The subdivision would be protected by 100-year levees in either case, but suppose that the inundation depth resulting from the 150-year flood is ten feet within the floodplain but only five feet adjacent to it. At a typical net density of about five houses per acre, and at a typical house value of about $200,000 (excluding the value of land), there would be about $1 million worth of houses per acre. Other things equal, the numbers just cited indicate that ten feet of inundation would cause about $732,000 per acre of damage, while five feet of inundation would cause about $532,000 per acre of damage, a difference of $200,000 per acre in residual risk for this particular flood event, due only to the differing elevations of the two developments.

TABLE 1.

U.S. ARMY CORPS OF ENGINEERS STRUCTURAL DEPTH-DAMAGE FUNCTION

(ONE STORY RESIDENCE WITH NO BASEMENT)

DEPTH (FEET)	STRUCTURAL DEPTH-DAMAGE (MEAN PERCENTAGE)
-2	0
-1	2.5
0	13.4
1	23.3
2	32.1
3	40.1
4	47.1
5	53.2
6	58.6
7	63.2
8	67.2
9	70.5
10	73.2

According to Table 1, each additional foot of inundation would cause tens of thousands of dollars of additional damage per acre, even at these low residential densities. In deep floodplains such as the lower San Joaquin or the Natomas Basin, inundation depths can easily reach to well more than ten feet (IRP 2007). However, much larger floods (e.g. a 500-year flood) might inundate both properties in our example so deeply that there is no meaningful difference in expected damages, so in most cases the benefits of avoided residual risks only accrue in flood scenarios that are moderately larger than the certified level of protection, but not so large that they deeply inundate everything within or adjacent to the floodplain.

In addition, avoided residual risk benefits are not universal to all floodplains, but depend heavily on local topography. In some areas, there may be very little elevation difference between the interior and the edge of the floodplain. Also, setback levees that reconnect floodplains are not always set back all the way to the floodplain edge, meaning that the lands on either side of the setback levee may be at very similar elevation. Local topography must always be assessed carefully to determine whether floodplain reconnection could avoid residual risk in any given situation.

With this caveat in mind, this conceptual illustration shows that the potential value of avoided residual risk can be quite high—hundreds of thousands of dollars per acre on a cumulative basis at suburban development densities.[10] With a slightly less than 1% chance of occurrence in any given year, this is equivalent to thousands of dollars per acre per year in potential annual avoided residual risk if a floodplain is conserved rather than developed at suburban densities.

Inundation can also occur much more quickly when riverside levees fail, reducing evacuation times and placing human lives at greater risk. Though public safety issues transcend economic valuation, FEMA (2009) uses an estimate of about $7 million per fatality in assessing flood damage costs.

These avoided residual risk value streams are not easily captured within the federal NED benefits evaluation process (U.S. Water Resources Council 1983). This method tends to build in assumptions about future development within floodplains as areas to be protected, rather than viewing the floodplain itself as a potential source of flood protection. In addition, although the method calls for reporting on “remaining flood damages” that are “expected to occur even with a flood management plan in operation” (i.e. residual risk), avoided residual risks and associated costs are not included among the benefits to be summed as part of the comparison of different flood management project alternatives (U.S. Water Resources Council 1983, 40). These methodological limitations are one reason why floodplain conservation has been under-utilized as a potential flood management strategy in the U.S.

Neighborhood flooding. Courtesy of U.S. Geological Survey


After levee failure. Courtesy of CA Dept Water Resources.

[10] This number can only be thought of as a theoretical potential, not an actual assessment to be used in any specific situation. Though an entire floodplain may not be built out at suburban densities, there are also other costs not considered in the example that tend to rise proportionally with inundation depth, such as evacuation and emergency response costs, and lost economic productivity due to extended recovery time. In addition, in a real project evaluation process, the time value of money and the project lifetime would have to be considered in order to calculate the net present value of avoided costs over the project lifetime.

2. ECOSYSTEM SERVICE VALUE

Floodplains are among the world's most productive ecosystems. The episodic deposition of nutrient-rich sediment by the parent river enriches soils to a highly fertile condition, and the capacity of these soils to grow plants and animals is correspondingly high. Riparian forests are estimated to support as much as 3.5 times more animal mass per acre than terrestrial ecosystems as a whole, and "more species of plants and animals by far occur on floodplains than in any other landscape unit in most regions of the world" (Tockner and Stanford 2002; 309). In addition, floodplains often also provide important seasonal habitat for fish and other aquatic species.

Environmental economics is a relatively new discipline that focuses on accounting for the full range of benefits that humans derive from ecosystems and devising methods of incorporating those benefit estimations into financial and policy decisions (Turner et al 2008). These benefits are typically produced by various ecosystem services, which "consist of flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital to produce human welfare" (Costanza et al 1997, 254). Among these ecosystem services are the production of basic resources such as food, water, and timber; provision of resources through processes such as pollination, soil formation, and nutrient cycling; maintenance of life-supporting (or life-enhancing) conditions through climate regulation, atmospheric gas regulation, or water quality regulation; and even provision of aesthetic or recreational benefits to humanity. With respect to lowland floodplains specifically, a variety of ecosystem services have been identified (Posthumus et al 2010).[11]

TABLE 2.

ESTIMATED VALUE OF GLOBAL "SWAMP/FLOODPLAIN" ECOSYSTEM SERVICES

FROM COSTANZA ET AL (1997)

	$ PER HECTARE	$ PER ACRE
WATER SUPPLY	7,600	3,076
DISTURBANCE REGULATION	7,240	2,930
CULTURAL	1,761	713
WASTE TREATMENT	1,659	671
RECREATION	491	199
HABITAT	439	178
GAS REGULATION	265	107
RAW MATERIALS	49	20
FOOD PRODUCTION	47	19
WATER REGULATION	30	12
TOTAL	19,581	7,924

Valuing these services comprehensively is challenging for a variety of reasons, but their economic value is nonetheless very real. Without floodplain habitats, for example, certain commercially valuable species of fish cannot survive in large numbers, and hence the economic productivity of the fishing industry is diminished. Or if additional water quality treatment costs are necessary due to alterations in a floodplain, then this can be used as the basis for an estimate of the value of the floodplain's water quality regulation services. Many techniques in environmental economics involve imputing ecosystem service values from other economic data in this manner, but other ecosystem services can be measured more directly. Greenhouse gas regulation values, for example, are now priced through regulatory cap-and-trade mechanisms within California, meaning

[11] Scientific taxonomies of ecosystem functions and services, such as the one presented by Posthumus et al (2010), can be unwieldy for project-level applications. Some of the services listed, such as agricultural production, are priced within real-world market economies; others are not. Some attributes of floodplains are listed as services just because they provide space for human economic activity, such as transportation and development,whereas others are services that are actually integral to the functioning of ecosystems. In addition, the functions into which the services are grouped are meaningful in a scientific context but do not lend themselves well to categories or accounts that can be considered and managed within a project implementation context. For these reasons, such taxonomies are not used in this report.

that the net carbon balance of a floodplain ecosystem could be expressed in dollars per ton of carbon stored or emitted.[12]

Ecosystem service values for different ecosystem types have been computed at a variety of scales. A landmark paper by Costanza et al (1997) estimated the total value of the world's ecosystem services at $33 trillion per year, about twice the size of the global economy. Among ecosystem types used in their analysis, "swamps/floodplains" produced $19,580 worth of ecosystem services per hectare (about $7,924 per acre), second only to estuaries in productivity. The services included in this study and their estimated values are shown in Table 2.

Most studies consider floodplains as a subset of wetlands, and per-acre estimates of the value of wetlands have ranged from less than $100 per acre to as much as $22,050 per acre (Heimlich et al 1998). The Costanza et al (1997) study estimated wetlands as a class (including floodplains) to be worth $14,785 per hectare (or about $5,983 per acre). However, a meta-analysis of 39 wetland valuation studies found that the average value within methodologically "strong" studies was $915 per acre (Woodward and Wui 2001). Another meta-analysis of 33 wetland valuation studies found a valuation range from $93 to $1,935 per acre for different regions of the United States (Borisova-Kidder 2006). Much of this variability in valuation may be due to the variability of wetlands themselves (ranging from isolated seasonal wetlands to large marshes, swamps and floodplains), and to the variety of services that different studies may be measuring.

These generalized estimates are of limited utility in the valuation of any particular floodplain, however. The physical landscape context of a floodplain is likely to be very important in determining its ecosystem service value. As Mitsch and Gosselink (2000) point out with respect to wetlands, the value of each remaining example of an ecosystem type tends to increase as they diminish in number—until there are so few that certain ecosystem services they provide collectively (such as wildlife habitat) may be lost. In addition, for both floodplains and wetlands generally, the overall prevalence and spatial distribution within a watershed make a great deal of difference in assessing their ecosystem service value. For example, multiple studies (Hey and Philippi 1995, Mitsch et al 1999) have found that, in a temperate zone climate, approximately three to seven percent of a watershed should be wetlands to optimize the landscape for their ecosystem service values, including flood control and water quality enhancement (Mitsch and Gosselink 2000). In watersheds with a significantly smaller or larger proportion of wetland coverage than that, each individual wetland might be making a less valuable contribution to overall ecosystem services. The same general principle may be true for floodplains.

Vic Fazio wetlands in Yolo Bypass. Courtesy of CA Dept of Water Resources.

[12] Some environmental economists use a technique called "willingness to pay" (WTP) to estimate more abstract values of ecosystem, such as the value that people place on knowing that a rare species or ecosystem is continuing to exist. WTP surveys usually involve structured scenarios that inquire how much people would pay to secure "existence values," then extrapolate them over the population. Due to their hypothetical nature, however, WTP-derived findings are mostly not included in this report.

Physically, the Central Valley essentially *is* two large floodplains. Despite radical alteration of the physical environment, the Sacramento and San Joaquin floodplains still provide important habitat to mammals, birds and fish. Before Euro-American settlement of California, both the San Joaquin and Sacramento Rivers regularly distributed floodwaters over much of the Valley floor, inundating huge areas. American inhabitants of the new state of California discovered this the hard way as floods raged down the Sacramento River in 1850, 1853, 1861, 1867, 1868, 1872, 1873, 1875, and 1881 (Kelley 1989). In the winter of 1861-1862, governor-elect Leland Stanford had to travel to his inauguration in the capital city of Sacramento in a rowboat.

Maps reconstructing the pre-Gold Rush landscape of the Central Valley reveal where floodwaters once commonly flowed. As figures 5 and 7 show, very large areas of both valley floors were comprised of wetlands and other floodplain habitat, particularly on the San Joaquin upstream of the Merced River confluence, and throughout the entire region between the Feather River and the Sacramento. These lowland floodplains were the heart of the native Central Valley ecosystem. The riparian forests, wetlands, and adjacent valley oak woodlands and native grasslands together "provided essential habitat support to enormous populations of large, wide-ranging mammals" that visited the rivers, including elk, antelope and grizzly bears, not to mention even larger populations of smaller animals that relied on localized habitat niches (Bay Institute 1998). Vast numbers of birds migrating along the Pacific Flyway relied on the wetlands throughout the Valley floor, especially in the winter. And the rivers themselves provided habitat for both anadromous and resident fish, some of which relied on the periodic seasonal inundation of the floodplains for additional breeding and rearing habitat.

The vast majority of these wetland and floodplain lands have now been disconnected from their source rivers and converted to agriculture or other land uses (see figures 6 and 8). Levee construction and conversion of floodplain lands (including wetlands) to agriculture drastically curtailed all of these habitats and the species that relied on them. Losses of wetland and riparian forest habitats are estimated at 95%, and the area of periodically inundated floodplain is thought to be approximately 85% smaller than before the Gold Rush (Bay Institute 1998). Nonetheless, these lands will always be flood-prone and retain the capacity to provide certain ecosystem services that cannot be obtained elsewhere. Indeed, these floodplain ecosystems still provide important ecosystem services to the state of California, including habitat for valuable fish species, carbon storage, nutrient transport, sediment storage, and water storage and filtration.

Wetted floodplains provide excellent temporary fish habitat. Courtesy of U.S. Geological Survey.

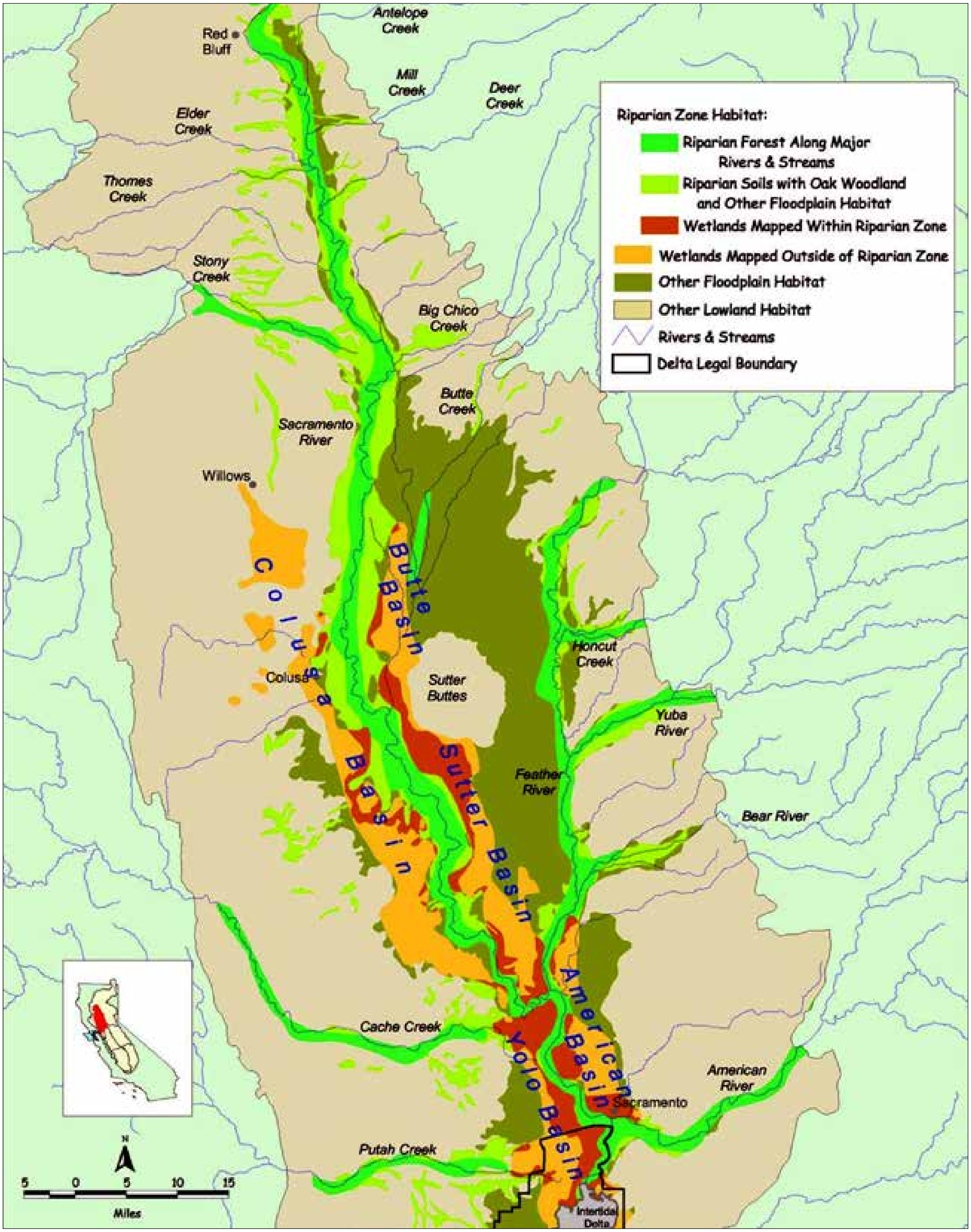


Figure 5. Historical Sacramento Valley floodplain habitats. Courtesy of The Bay Institute (1998), *Sierra to the Sea*.

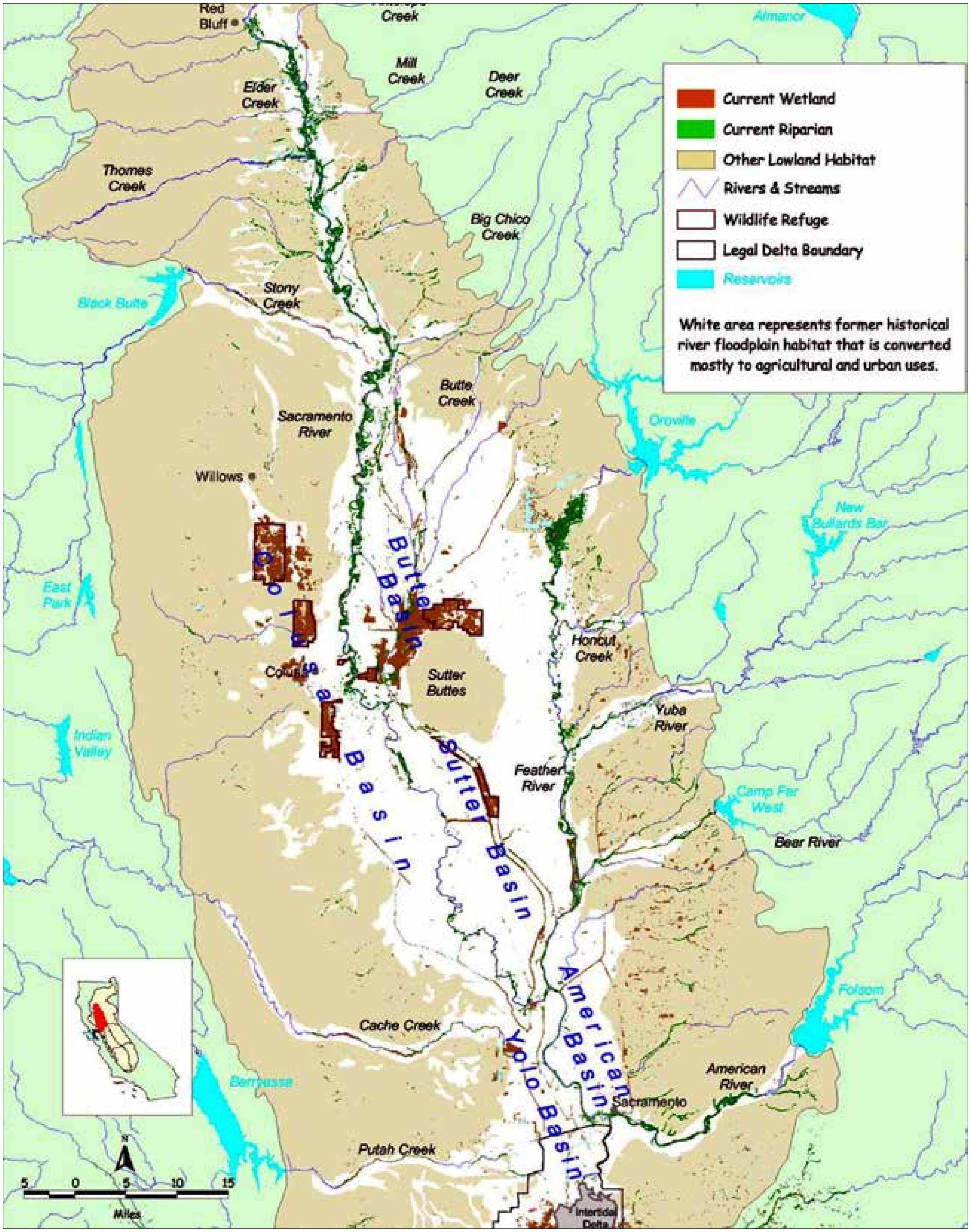


Figure 6. Current Sacramento Valley floodplain habitats. Courtesy of The Bay Institute (1998), *Sierra to the Sea*.

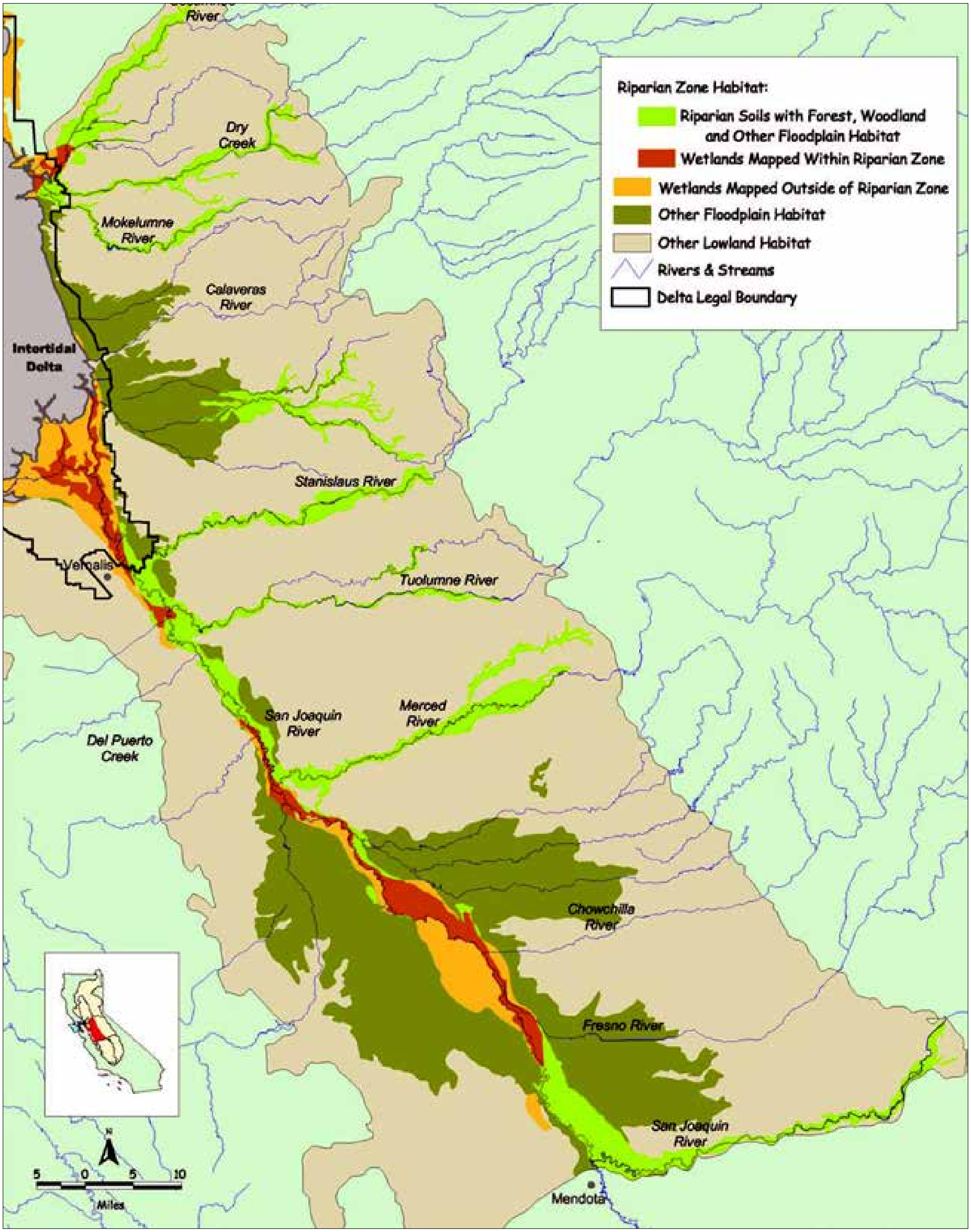


Figure 7. Historical San Joaquin Valley floodplain habitats. Courtesy of The Bay Institute (1998), *Sierra to the Sea*.

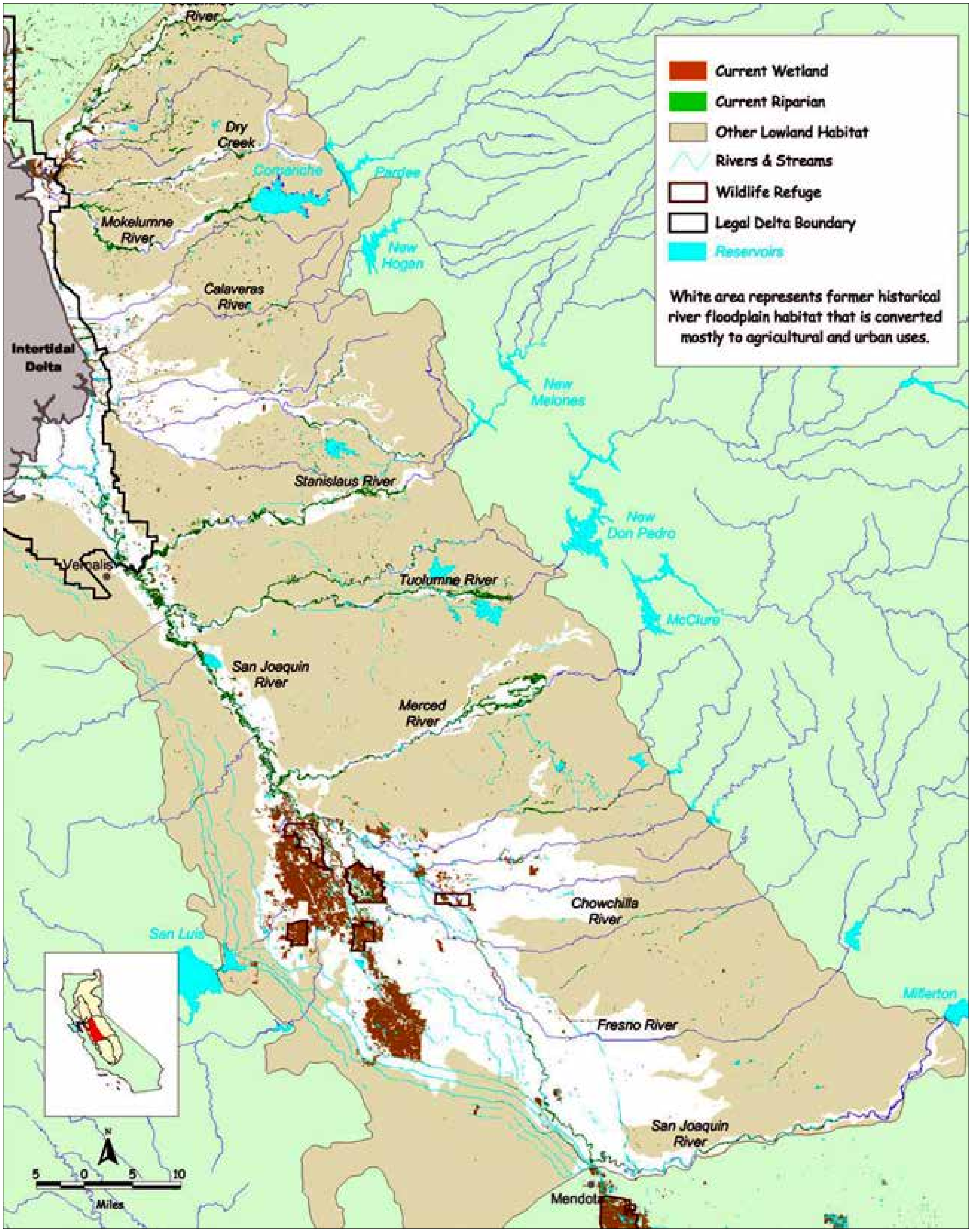


Figure 8. Current San Joaquin Valley floodplain habitats. Courtesy of The Bay Institute (1998), *Sierra to the Sea*.

Yolo Bypass bird habitat. Courtesy Dave Feliz, CA Dept of Fish and Wildlife.

HABITAT

Numerous scientific investigations have found that hydrologically connected floodplains are critical to the breeding, rearing and growth of various Central Valley fish species, including some that are commercially valuable (such as striped bass and Chinook salmon), and some that are endangered (such as Delta smelt, splittail, and some salmon runs). For example, Jeffres et al (2008) found that "ephemeral floodplains supported higher growth rates for juvenile salmon than more permanent habitats in either the floodplain or river," while Sommer et al (2004a) have found that "species diversity and richness were higher in the Yolo Bypass [than the Sacramento River channel]" for native fishes such as Delta smelt and splittail, among others. Indeed, on a global level, the fish yield of watersheds is positively associated with the water surface area of the floodplains in that watershed (Bayley 1991).

One reason why high Sacramento River outflows are associated with strong annual yields of certain fish is because high flows inundate floodplains such as the Yolo Bypass (Sommer et al 1997). These floodplains "are important nursery habitats because they provide abundant invertebrates for food, sanctuary from unfavorable temperatures and high velocity river currents, and cover from predators" (Crain et al 2004). The Yolo Bypass "has a broad suite of habitat types, including seasonal floodplain, perennial ponds, wetlands, and tidal channels, while the Sacramento River has a fairly homogenous, hydrologically stable channel with sparse riparian vegetation" (Sommer et al 2004a), accounting for some of the productivity difference between the two.

Floodplains are also known as "productivity pumps" that export dissolved organic carbon, algal biomass, and leaf litter into the main river channel (Ahearn et al 2006), to the benefit of aquatic food chains there. They may also be important sources of invertebrates preyed upon by fish (Sommer et al 2001). Indeed, major studies have found that "increased inundation of floodplain habitat probably offers the greatest potential for enhancement of high-quality organic matter to the food web of the San Francisco estuary" (Sommer et al 2004b; Jassby and Cloern 2000). Direct relationships between this nutrient transport and fish population increases in the Delta have not yet been quantified.

The value of fish habitat can only be imputed from its effects on the economy. California's salmon fishery was worth approximately $1.4 billion and supported almost 23,000 jobs in 2005 (i.e. before recent severe population declines; Southwick Associates 2009). In that year, fishermen caught roughly 400,000 Sacramento River fall run salmon, traditionally the backbone of the California salmon fishery. That catch had dropped to about 125,000 by 2010 (GGSA 2011). Although pumping activities in the Delta are said to be primarily responsible for these declines (GGSA 2011), large-scale floodplain re-connection and restoration may still be able to contribute significantly to recovery (Jeffres et al 2008).

Southwick Associates (2009) notes that recovery to historic peak annual salmon catches of roughly 25 million pounds would be worth almost $5.7 billion per year to the California economy. Even if re-connecting another floodplain the size of the Yolo Bypass (60,000 acres), without any changes to Delta pumping, brought back only 1% of this historic fishery (or about 4% of the 2005 fishery), that would still be worth approximately $950 per acre per year in commercial and recreational fishing. This order of magnitude is roughly consistent with research findings. Woodward and Wui's meta-analysis of the ecosystem service values of single-service wetlands found per-acre averages of $778 for commercial fishing and $357 for recreational fishing, for a total of $1,135 per acre. Costanza et al (1997) found the average combined habitat, food and recreation value of swamps and floodplains worldwide to be about $400 per acre per year, but there is good reason to believe that the prized salmon fisheries of a first-world economy like California would be considerably more valuable than the global average.

Moreover, this back-of-the-envelope analysis is based only on salmon. There are other important habitat values at stake, including the continued survival of endangered species such as Delta smelt and splittail (Sommer et al 2004a; Sommer et al 1997). Though the existence value of these species is arguably not quantifiable, it is also the case that legally mandatory efforts to recover these species (including Delta pumping reductions and major planning efforts) have cost hundreds of millions of dollars to date. Though valuations would certainly vary based on the specific habitat potential of any given floodplain area, it appears safe to estimate that the fish habitat values of Central Valley floodplains are, at the very least, in the hundreds of dollars per acre.

Meandering river channel. Courtesy of CA Dept of Water Resources.

CARBON SEQUESTRATION

Floodplains play a critical role in the regulation of atmospheric gases, particularly carbon dioxide that contributes to global warming. On a global level, recent research has documented that floodplain soils are important carbon sinks because "sediment deposition and erosion on riverine floodplains continually reset soil formation to early phases, in which organic carbon accumulates at high rates," though agricultural activity on these soils can entirely eliminate these sequestration benefits (Zehetner et al 2009). These sequestration rates can exceed 100 grams (0.22 lbs) of carbon per square meter per year (Zehetner et al 2009).

Locally, subsidence reversal experiments in the Delta have shown that typical soil accretion rates of 3-5 centimeters per year in test wetlands on Twitchell Island "can represent storage of more than 1 kilogram [2.2 lbs] of carbon per square meter" (Miller et al 2008), or almost 4.5 tons per acre. Carbon has recently been trading for just over 3 Euro per ton (about $4 U.S. as of mid-2013) in European carbon markets, though prices above 20 Euro per ton (about $27 U.S. as of mid-2013) have been more typical since carbon trading began in Europe. This suggests that Delta carbon sequestration services could be worth as much as $100 per acre per year under good market conditions, roughly consistent with the estimate of Costanza et al (1997) that swamp and floodplain lands globally provide about $106 per acre in "gas regulation" services.[13] Typical floodplain lands throughout the Central Valley will not have the same carbon sequestration capacity as subsided Delta soils, but this data nonetheless suggests that carbon sequestration value of floodplain lands is likely worth (at least) tens of dollars per acre. The forthcoming cap-and-trade system for managing greenhouse gases in California may provide an opportunity for Central Valley farmers to take advantage of this market, particularly in coordination with rice farming.

Central Valley floodplain wetlands are important habitat for migratory and resident birds.
Courtesy of CA Dept of Water Resources.

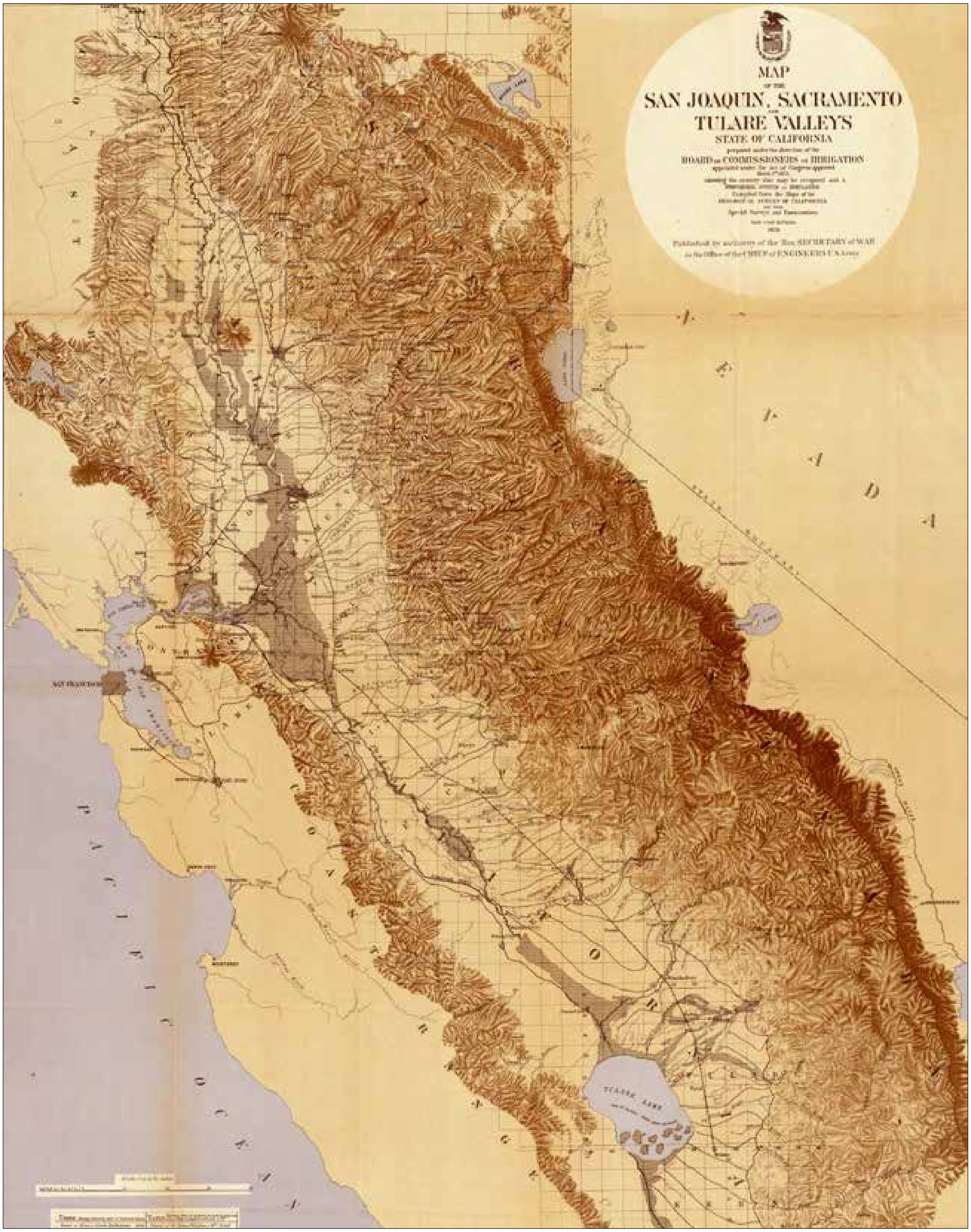
[13] This includes not only greenhouse gases, but also atmospheric regulation of gases such as ozone, sulfur oxides, and others.

OTHER ECOSYSTEM SERVICES

Floodplains provide a variety of other ecosystem services beyond habitats. Water quality considerations are highly complex, given that various human uses of water (agricultural irrigation, drinking water, industrial use) have very different, and sometimes conflicting, quality standards. Floodplains can cleanse waters through direct vegetative uptake and filtration of pollutants, nutrient leaching, chemical processes often associated with wetlands, and settlement of solids (Posthumus et al 2010). For example, floodplain wetlands can remove significant amounts of nitrogen, a service that has been estimated to be worth over $500 per acre per year in the lower Mississippi Valley (Opperman et al 2010). However, floodplain processes often increase levels of dissolved organic carbon in the water, which is harmless to agricultural purposes but interacts harmfully with chemicals used to treat water for human consumption. In the Central Valley, floodplain wetlands may also methylize mercury still in the system from 19th century gold mining activities, creating a significant hazard for fish, wildlife and humans. Any given floodplain planning process would have to study and assess these issues carefully.

Many floodplains also provide significant water management services, including the recharge of groundwater basins. In the Central Valley, several important groundwater recharge sites exist in floodplains, including the Cache-Putah Basin in the Sacramento system and the Gravelly Ford-Madera Ranch area in the San Joaquin system (Purkey et al 1998). Given that infiltration rates vary dramatically between sites, and that the value of water also varies across the state, the value of these services will vary dramatically from site to site. In locations where soils are impermeable, recharge values may be zero. In areas where infiltration rates are high, water is valuable (hundreds of dollars per acre-foot), and groundwater is efficiently recoverable, these services could be worth hundreds of dollars per acre per year.

Floodplains also accept large amounts of sediment deposition as river flows enter and slow down due to high surface roughness from vegetation (Ahearn et al 2006). In modern regulated and managed rivers, these sediments might otherwise have to be dredged out of the low-gradient reaches of rivers downstream at considerable expense to ensure navigability, though this depends upon channel geometry and other factors. Florsheim and Mount (2003) have estimated pre-Gold Rush deposition rates on the Cosumnes River floodplain at 3mm per year, and post-Gold Rush deposition rates at 25mm per year. These figures imply an accumulation rate ranging from about 16 cubic yards of sediment per acre per year under natural conditions to about 132 cubic yards per acre per year in a watershed disturbed by agriculture, mining, and altered river channels. Dredging costs in northern California vary around a median of about $10 per cubic yard (BCDC 2012), suggesting that even if only a minority fraction of the 132 cubic yards per acre per year eventually needed to be dredged from channels lower down in the system, the sediment deposition on the Cosumnes River floodplain could be worth hundreds of dollars per acre per year in avoided dredging costs. In addition, these floodplain sediment deposits often work to the long-term benefit of floodplain agriculture by introducing rich new stores of nutrients into the local soils (Posthumus et al 2010). Indeed, that is why floodplains have always been among the most desirable and heavily cultivated agricultural soils in the world.



Map of the Sacramento, San Joaquin and Tulare Valleys, State of California, 1873. Note riparian wetlands in grey. Courtesy of David Rumsey Map Collection, www.davidrumsey.com.

3. LAND USE VALUE

Floodplains can host a very wide variety of land uses. The historical use of rivers for shipping, water extraction, and wastewater disposal has meant that human populations have always been concentrated in floodplains. To this day, most major cities worldwide are located in floodplains, usually near the mouths or confluences of major rivers. This means that the outward sprawl of these same cities continues to exert pressure for floodplain development, at the expense of the values that connected floodplains can provide. But far from being "sacrifice zones," connected floodplains can host land uses, including agriculture, recreation, and open space, that increasingly valuable within urbanized regions.

AGRICULTURE AND RECREATION

Hydrologically connected floodplains still have considerable land use value for agriculture and recreation. For example, approximately half of the Yolo Bypass's 59,000 acres are in cropland in any given year, growing processing tomatoes, rice and several other crops, primarily in the late spring and summer (Sommer et al 2001). Another fifteen to twenty percent of the bypass is usually in pasture (Marchand 2012). Though a comprehensive study of this Yolo Bypass agriculture has not yet been published, a conservative estimate of its gross value based on known facts is about $30 million per year (Yolo County 2010; Marchand 2012), or on average about $500 per year for each acre in the bypass.

Agriculture also complements the Bypass's flood management functions effectively. Agricultural operations control the growth of vegetation within the Bypass, preserving its flow capacity and relieving state flood managers of the need to clear vegetation periodically. Rice fields also provide key foraging opportunities for migratory birds when flooded in the winter (Howitt et al 2012).

The Yolo Bypass contains several thousand acres of seasonal wetlands, perennial wetlands, riparian forests, and other important habitat types which collectively support hundreds of thousands of ducks and other birds (Sommer et al 2001). Birdwatching, hunting and fishing are major recreational activities associated with these land uses, and their economic impact is surprisingly large. The US Fish and Wildlife Service (2006) has found that approximately 21% of Californians participate in wildlife watching and spend almost $4.2 billion per year to do so, while about seven percent of the state's residents engage in hunting and fishing, spending almost $3.8 billion (USFWS 2006).

Within the Sacramento-San Joaquin Delta, which includes about half the Yolo Bypass and parts of other floodplains, there are about 500,000 visitor days per year for hunting alone, generating about $38 million annually in statewide expenditures (DPC 2011). Adding fishing, birdwatching, hiking, and biking likely at least doubles that total

Dairy and stock farm of S.A. Bentley, Sacramento River, Yolo County. From the Illustrated Atlas and History of Yolo County, California, 1879. Courtesy of David Rumsey Map Collection, www.davidrumsey.com.


Courtesy of Dave Feliz, CA Dept of Fish and Wildlife.

to about $76 million.[14] Even if that economic activity were distributed evenly across all of the Delta's 738,000 acres of land, it would still average over $100 per acre per year. In reality, however, these recreational uses are concentrated more within the floodplain areas of the Delta (such as the Yolo Bypass) than they are in the agricultural and dry upland areas that make up a large fraction of the Delta's land area. For floodplains, these land uses are certainly worth hundreds of dollars per acre per year, and perhaps much more in certain locations.

VISUAL AND "SENSE OF PLACE" VALUES

In addition to active recreational values, floodplains can also provide passive aesthetic values. Large areas of conserved open space and agricultural land are well known to enhance the value of neighboring properties (Nichols and Crompton 2005; Riddel 2001), because they usually provide good views and also ensure that neighboring homeowners will not have to experience any negative spillovers from future development of that land. These property value benefits have generally been estimated in the range from about 3% (Riddel 2001) to as high as 8% (Dekkers and Koomen 2008). Though this potential is not unique to floodplains, in regions like the Central Valley and other parts of the American West, historic floodplains are often more thickly forested and have more immediate visual access to water than surrounding lands, both of which are attractive features for many homebuyers.

Depending upon the specific situation, these property value enhancements could easily rise into the hundreds of dollars per acre of conserved floodplain.[15] However, it should also be noted that in predominantly rural areas where open space and naturalistic views are abundant, these property value enhancements are likely considerably smaller than they are in suburban contexts.

An emerging body of research has also explored the value of large conserved open space and outdoor recreation for regional "place branding" to attract new industries, workers and residents. Though there are few quantitative findings in this area yet, some studies have shown significant positive associations between the quality of outdoor environments and recruitment of industries and homebuyers (Deller at al 2001). Actual achievement of these benefits likely requires a high degree of regional coordination in municipal planning and sustained efforts at marketing, among other things. Whether conserved floodplains could play a role in such regional branding has yet to be conclusively demonstrated, though enhancement and restoration of urban rivers has certainly played a part in some big city revivals in recent years.

[14] More precise estimates are not available from DPC (2011) because these items are aggregated with other recreational activities—notably boating—that are very popular in the Delta but are not attributable to floodplains per se.

[15] For example, if a 6,000-acre flood bypass on the lower San Joaquin improved the property value of only 100 adjacent houses worth an average of $250,000 by 3%, that would translate to $125 of property value improvement per floodplain acre. Whether or not such a bypass would actually have these effects would depend greatly on the specific design of the bypass and adjacent developments, particularly the character of the views between the two.

4. SYSTEM OPERATIONS VALUE

The fate of floodplains can have important implications for the long-term operations, maintenance, and management flexibility of flood management systems. Moreover, in the American West, these systems are usually tightly integrated with water supply systems that are crucial to local and state economies. Management flexibility in these integrated systems could be of major importance in the coming decades, particularly as climate change alters regional and watershed-scale hydrological patterns.

INTEGRATED WATER MANAGEMENT

In multipurpose river systems such as those of the American West, hydrological reconnection of floodplains could also have important water supply benefits. State and federal regulations require many major reservoirs in California to store water for economic uses and to retain space to capture potential flood flows in the late winter and spring (a.k.a. the "flood reservation"). Though seasonal variations in precipitation and longstanding federal and state rules determine reservoir management, the reduced need for flood reservation allows more water storage for economic uses (Opperman et al 2009). Hydrologically reconnected floodplains, if located at key downstream bottlenecks, can make it possible to safely convey larger flood flows through the river system, and hence reduce the need for flood reservation and allow storage of more water. Modeling the actual water supply yield increases that may be available in any given reservoir as a result of such changes is a complex task that is only now being undertaken by researchers (American Rivers forthcoming), but the value of these increased yields could be very significant in certain situations.

Looking at this issue in a slightly different way, Opperman et al (2013) have pointed out that the Yolo Bypass conveyed approximately 3.3 billion cubic meters (2.68 million acre-feet) of water during the three-day peak of the 50- to 80-year flood of 1986—approximately the same volume as the combined flood storage capacity of the six major Sacramento River reservoirs. Given that the cost of new or enlarged surface storage ranges from about $300 to $3,000 per acre-foot (Purkey et al 1998), this suggests that the Yolo Bypass's conveyance capacity is allowing the state to avoid building $0.8 to $8 billion in additional storage infrastructure just to achieve the same levels of flood management without compromising water supply capacity. That amounts to $13,600 to $136,000 per acre of the Yolo Bypass. Amortizing over a 100-year project lifetime suggests that this value stream can be reckoned in the hundreds of dollars per floodplain acre per year.

River channels with adjacent levees. Courtesy of CA Dept of Water Resources.

OPTION VALUE AND CLIMATE CHANGE ACCOMMODATION

This added flexibility in the water supply system may become particularly valuable under anticipated climate change scenarios (Warner et al 2011). Expansion of floodplains could have significant long-term value as a strategy to accommodate climate change and to provide management flexibility to respond to unexpected changes to the system. Many watersheds such as the San Joaquin basin are likely to experience significantly larger floods in the future (Dettinger 2011), meaning that additional flood management capacity will be required just to maintain existing levels of protection. But hydrological forecasting contains substantial uncertainties, due to the uncertainties inherent in climate change, a relatively short historical record, and evolving scientific understanding of major system drivers and dynamics (Dettinger 2011). All of this places a premium on retaining multiple options for future flood management.

Given the long project lifetimes of flood management infrastructure (generally 30-100 years; FEMA 2009), investments made today must start to consider these evolving conditions and uncertainties. In particular, flood management decisions that maintain flexibility for future managers to adapt to changed conditions have special value above and beyond their present-day benefits. Management flexibility for future managers will allow them, in theory, to select the flood management strategies with the highest benefit-cost ratios, creating economic value in future years that is partially attributable to decisions made today.

Known as "option value" (Sunstein 2007), this concept is of particular relevance to flood management systems, which are generally characterized by high dependence on inflexible structural measures such as levees and dams. Because human development of floodplains behind levees is essentially irreversible once it occurs, these structural measures tend to sacrifice option value by committing future managers to levee and dam heightening as the only practical flood management strategies. By contrast, conservation and reconnection of undeveloped floodplains today allows future managers the choice of multiple management paths (including higher dams and levees) to cope with higher flood flows.

The potential magnitude of these option values can be significant in certain situations. Suppose, for example, that 50 years from now the State of California will need to make another major investment in flood management infrastructure similar to that of 2006's Propositions 84 and 1E, and that management decisions made today preserve their options to choose between flood

Levee maintenance and reinforcement. Courtesy of CA Dept of Water Resources.

Levee maintenance near new suburban development. Courtesy of CA Dept of Water Resources.

management alternatives that provide the same benefits but vary in cost by $100 million (a small variation in a multi-billion dollar bond measure). That $100 million 50 years from now is worth almost $3.4 million in today's dollars, using FEMA's very conservative 7% discount rate (and over $22 million using a 3% rate).

To the extent that such option value benefits are attributable to specific floodplain conservation and reconnection actions that expand flood conveyance capacity and hence future management flexibility, they can be calculated on a per-acre basis and added to the other floodplain values discussed above. For each $100 million in long-term savings, these would be in the tens of dollars per acre per year for plausible present-day floodplain reconnection actions such as a 6,000-acre floodplain reconnection by setting back levees along the lower San Joaquin River (Tompkins et al forthcoming), or a 5,100-acre Yolo Bypass expansion from Fremont Weir to the Sacramento Bypass confluence (SAFCA 2008). Given the documented effectiveness of the Yolo Bypass over the last 100 years in allowing the state to avoid constructing at least $0.8 billion in reservoir storage (Opperman et al 2013; Purkey et al 1998), it is not unreasonable to suggest that floodplain conservation and re-connection actions taken today could preserve future flood management options that are several hundreds of millions of dollars cheaper than competing alternatives.

MAINTENANCE AND LIABILITY

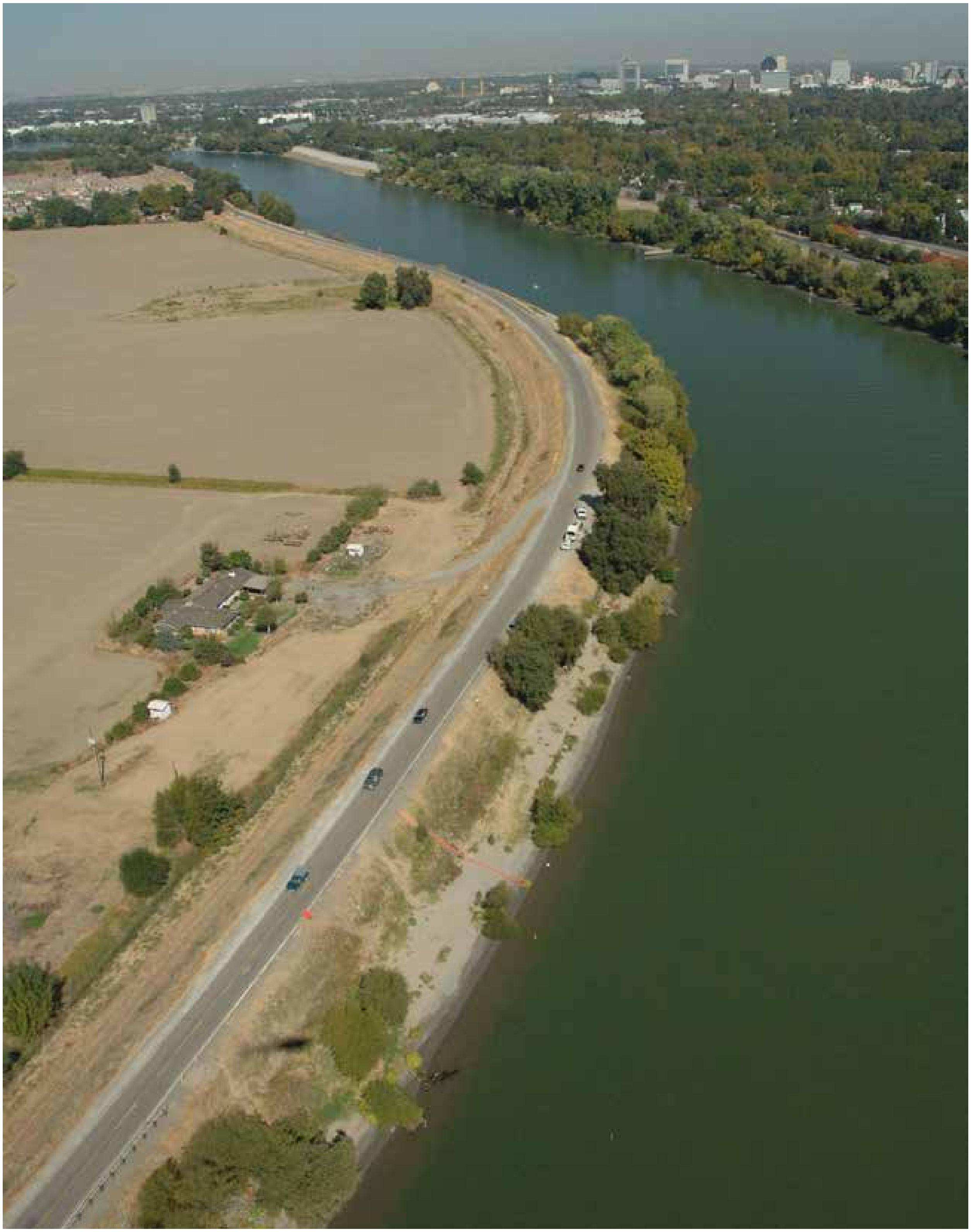
Few if any formal studies have been done of the typical maintenance costs of flood control systems. The American Society of Civil Engineers (2009) has estimated the total deferred maintenance on the roughly 100,000 miles of levees in the U.S. at over $100 billion, an average of about $1 million per mile. The Central Valley Flood Protection Plan (DWR 2011) considered an alternative devoted solely to "reconstructing [State Plan of Flood Control] facilities to meet current engineering criteria without making major changes to the footprint or operation of those facilities." This is a reasonable proxy for addressing all cumulative deferred maintenance on the system. The plan estimated the alternative to cost $19-23 billion for the remediation of 170 miles of urban and 1,400 miles of non-urban levees, an average of over $12 million per mile.

According to DWR (2011), "it is increasingly difficult for State and local agencies to maintain levees and channels" due to factors including "original system designs that do not meet existing engineering standards, inadequate funding, encroachments, inconsistent levee maintenance practices among maintaining agencies, and challenges in complying with a variety of State and federal environmental permitting and mitigation requirements." Some of these challenges also apply to maintenance of flood bypasses, which may need to be dredged periodically to maintain original flood conveyance capacity. The levees at the landward edge of bypasses and other connected floodplains also need to be maintained.

Flood management systems that integrate connected floodplains may be less expensive to maintain than others, for two reasons. First, disconnection of floodplains by riverside levees confines the rivers into higher, faster, narrower flows that exert greater day-to-day stress on levees than would be the case for levees set back from the river. In addition, because connected floodplains reduce stage for a flood of a given recurrence interval (see item 1 of section IV), less acute stress and wear on levees should result from an integrated and connected floodplain. Second, maintenance operations on the dry levees at the landward edge of connected floodplains are likely easier (and therefore less expensive per mile) than those on wet levees at the river's edge.

In a 2006 ruling in Paterno v. State of California, the California Supreme Court held that the State of California could be held liable for flood damages resulting from the failure of State Plan of Flood Control facilities, even if those facilities were not originally constructed by the State but instead incorporated into the system later. This decision instantaneously increased the State's existing potential flood liability by billions of dollars, and made avoiding potential future liability a major criterion in flood management decisions in California. Because the failure of a riverside levee can be much more hazardous to public safety and private property than the failure of a levee at the landward edge of a connected floodplain (see item 1 of section IV), such liability considerations may make levees less attractive as a flood management solution in many situations. Generating even speculative estimates of these operations, maintenance and liability costs will require better information on the general maintenance and failure histories of the levees and bypasses associated with connected floodplains.

Levee failure in the Central Valley flood of 1997. Courtesy of CA Dept of Water Resources.



Levee under repair outside Sacramento, CA.
Above and opposite images courtesy of CA Dept of Water Resources.

V. CONCLUSIONS AND RECOMMENDATIONS

The Central Valley Flood Protection Plan has proposed major flood management initiatives throughout the valley, including the study of creation or expansion of flood bypasses on both the Sacramento and the San Joaquin. For those bypass projects to be fairly and thoroughly evaluated as alternatives to structural measures, however, the full dimensions of floodplain valuation described in this report should be assessed. This more complete valuation must include not only the project-level flood protection benefits (which are adequately assessed by existing evaluation protocols), but also the systemic benefits that floodplain re-connection uniquely can provide. Evaluation protocols that focus on the system-wide costs and benefits of specific project proposals should be developed as part of this effort, ideally in a format that allows them to be used in other states and even other nations that may be considering floodplain reconnection strategies.

The approximate monetary magnitudes of the services of connected Central Valley floodplains discussed throughout this report are summarized in Table 3. Because many of these values are site-specific and can vary substantially, they are presented in order-of-magnitude ranges that allow basic comparisons between various value accounts, and are normalized to express the potential benefits stream obtainable per floodplain acre per year. Ranges that include $0 indicate values that might not be obtainable in all floodplain sites, depending upon context.

Table 3 shows that the three biggest "value lines" for connected floodplains are reduced flood stage, habitat, and agriculture, each of which can generate benefits valued in the thousands of dollars per acre per year. Avoided residual risk could achieve a similar level of importance in certain situations, while most other line items top out in the hundreds of dollars per acre per year under plausible conditions. Crucially, these values are generally additive upon one another. The Yolo Bypass, for instance, produces value in virtually all the line items summarized in Table 3, and hence any estimation of its value must sum across all of these (taking care not to double-count across related items such as habitat and recreation, or integrated water management and option value). Likewise, prospective floodplain conservation or re-connection actions such as a levee set-back on the lower San Joaquin must assess potential values across each of these line items for purposes of comparison with other potential uses of the land (e.g. housing development).

The estimates in Table 3 are based upon conservative assumptions about plausible value ranges in the Central Valley context. Notably these value ranges are generally lower than some other leading estimates of the value of floodplain ecosystem services. As shown in Table 2, Costanza et al (1997) found "swamp/floodplain" services to be worth over $7,900 per acre per year, with water supply and disturbance regulation (i.e. flood risk reduction) values each estimated at about $3,000 per acre per year, and "cultural" and recreation values summing to over $900 per acre per year. Sheaffer et al (2002) estimated the one-time replacement cost of the goods and services provided by U.S. floodplains to be over $60,000 per acre. Given these estimates, the value ranges presented in Table 3 do not seem excessive.

RECOMMENDATIONS

To understand system-wide benefits more comprehensively, more thorough investigations should be conducted into each of these "value lines" for the state-federal flood management projects in the Sacramento and San Joaquin basins. Only by viewing the system as a whole can the per-acre value of many of these services come into sharp focus, in particular with respect to integrated water management and ecosystem-level processes such as sediment transport. Moreover, the realization of some benefits depends upon the spatial scale of the habitat or process reaching a minimum threshold (Opperman 2013; Mitsch and Gosselink 2000), which implies the need for system-wide assessment.

The California Department of Water Resources (DWR) and the Army Corps also need to sponsor research into past, present, and anticipated future levels of flood risk in the Central Valley.

TABLE 3. APPROXIMATE MONETARY MAGNITUDES OF SERVICES OF CONNECTED CENTRAL VALLEY FLOODPLAINS

FLOOD PLAIN VALUE ACCOUNTS	CONCEPTUAL EXAMPLE	ANNUAL VALUE PER FLOODPLAIN ACRE	CONTEXT SENSITIVITY	NOTES
I. FLOOD RISK REDUCTION VALUE				
Reduced flood stage	Yolo Bypass widening	$100s - $1,000s	Depends on extent and intensity of development in affected areas	Assumes 100-year project lifetime and discount rate of 3%
Avoided residual risk	Various sites in Valley	$0 - $1,000s	Depends heavily on local topography	Assumes suburban development densities
II. ECOSYSTEM SERVICE VALUE				
Habitat (incl. food web support)	Central Valley salmon	$100s - $1,000s	Depends on commercial and recreational value of fishery	Same range as findings for habitat value of wetlands generally
Carbon sequestration	Delta	$10s - $100s	Depends on soil types and price of carbon	Delta has unusually good potential
Water quality maintenance	Valley-wide	<$0 - $100s	Depends upon intended uses of water	Effects can be negative as well as positive
Groundwater recharge	Gravelly Ford, Yolo Bypass	$0 - $100s	Requires suitable soils and aquifers	Value and recoverability of water varies by site
Sediment deposition	Cosumnes	$0 - $100s	Depends on channel morphology/hydrology	Avoided cost of channel dredging downstream
III. LAND USE VALUE				
Agriculture (net profits)	Yolo Bypass	$100s - $1,000s	Depends on crops and flow timing in the floodplains	Floodplain soils generally well suited to agriculture
Recreation	Delta	$100s	Depends on proximity to population centers	Care should be taken not to double-count habitat values
Visual and place values	Lower San Joaquin	$0 - $100s	Depends on visual accessibility of floodplain to homes	"Place-branding" value highly indeterminate
IV. SYSTEM OPERATIONS VALUE				
Integrated water management	Yolo Bypass	$100s	Depends on system architecture and reservoir operations	Calculating potential water supply gains is highly complex
Option value	Valley-wide	$0 - $10s (per $100m in future savings)	Depends on whether floodplain connection preserves lower-cost future management options	Assumes 50-year horizon at 7% discount rate; history of Yolo Bypass suggests that future management options could vary by >$800m.
Maintenance and liability	Valley-wide	Unknown	Depends on local soils, hydrology	Data insufficient to support generalizations

Courtesy of CA Dept of Water Resources.

As noted in section II above, SB 5 and AB 70 are unlikely to significantly restrain continued escalation in overall valley-wide flood risk, and could in fact accelerate it by creating a false sense of security behind improved levees. Without a detailed understanding of the underlying flood risk (including residual risk) and its dynamics over time, accurately assessing the most appropriate and cost-effective flood management strategies will be difficult, particularly in light of changing climatic and watershed conditions in the coming decades.

Third, DWR should continue its research to create a valley-wide base map of frequently inundated floodplains in order to systematically identify opportunity sites for floodplain reconnection. This work should strive to classify potentially inundated floodplains based on frequency, duration and timing of inundation for a variety of ecosystem functions and land uses. The bypass creation and expansion projects identified in the CVFPP are likely not the only plausible floodplain reconnection opportunities available in the valley, especially when considering the diversity of possible values and uses that any given opportunity site could provide under different flow conditions. Additional reconnection options may exist as hydrological conditions on the rivers change over time—this is a critical area for future research and documentation.

Finally, this research should result in changed basin-wide planning processes and project evaluation criteria that take full account of the multiple values that connected floodplains provide, at both the basin and individual project scales. Ultimately, the framework outlined here should be developed into a rigorous valuation methodology that allows flood managers in federal and state agencies to properly assess the value of connected floodplains (or potentially connected floodplains) as part of their flood management systems over multi-decade time scales. At the project level, Army Corps methods for prioritizing projects for federal funding should be reformed to allow multi-purpose projects such as floodplain re-connections to be evaluated based on their full range of benefits, not just their most valuable single benefit (Opperman et al 2013).

These changes should be made quickly. With floodplain lands continuing to be developed, the window of opportunity for floodplain conservation and re-connection is closing rapidly in the Central Valley, even as impending climate change and continuing ecosystem degradation increase the value of these scarce lands. Future generations will not have the same opportunity to analyze and choose wisely among different flood management approaches, making it all the more critical that we assess the full value of connected floodplains while we still can.

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