Subsidence, Sea Level and Seismicity: Hell and High Water in the Delta

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Probably the greatest insult you can give to a scientist making a presentation is "This is old news." I'm going to give you some old news but put a twist on it. I'll start with three hypotheses: (1) The Delta is a dynamic landscape undergoing significant change; (2) Future change will be considerable due to continued subsidence and sea level rise; and (3) There is a high probability of abrupt change in the next 50 years.

We all know that for 6,000 years the Delta was a tidal freshwater marsh system in which sediment input from the watershed and organic production were able to keep up with the slow rate of sea level rise. We also know that severe subsidence took place from 1900 to 1950, principally associated with microbial oxidation in the soils. The general view is that subsidence in the Delta is no longer a problem—it's old news. Today I want to evaluate whether it is old news or whether it is in fact future news.

To investigate this my colleague Joshua Johnson and I created two indices. The Accommodation Space Index shows what's likely to happen in response to subsidence. Accommodation space is simply the space made available for the accumulation of sediment.

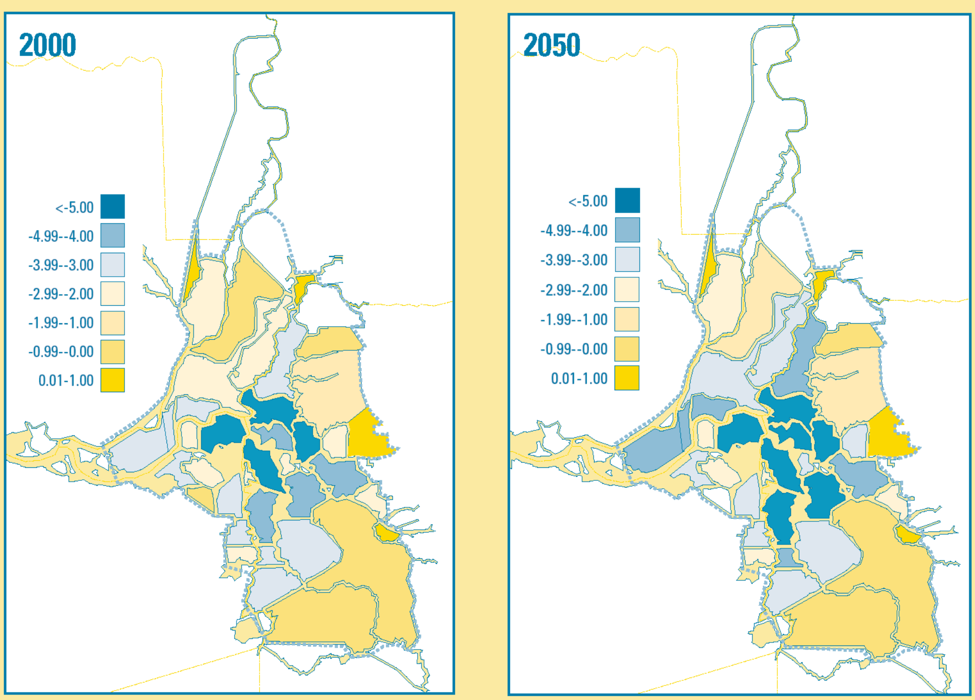
"…gradual change is a certainty and abrupt change is highly likely."

Today, through a combination of subsidence and the building of levees, we have created a new kind of accommodation space, "anthropogenic accommodation space," which is below sea level but not filled with sediment or water. This is a disequilibrium condition; something that would not normally occur in a coastal estuarine system. The Accommodation Space Index is proportional to this anthropogenic accommodation space.

The second index, the Levee Force Index, attempts to sum up the regional hydrostatic forces as a proxy for all the processes that are trying to undo that accommodation space and restore the connection between the water and the subsided land. It is essentially the hydrostatic force per unit levee length times total levee length. Now we know that if you double the height of a dam you quadruple the hydrostatic forces. The same process operates here—the force on the levees is a function of depth squared.

Using DWR data, we were able to estimate average annual accommodation space change for the period 1900 to 2000. We found that while subsidence has declined since the 1950s, when better management practices were implemented, it hasn't stopped. The average decline in the rate of subsidence is roughly 30%; the ultraconservative figure is 50%. Factoring in a conservative estimate of a 50%

Mean Island Elevation



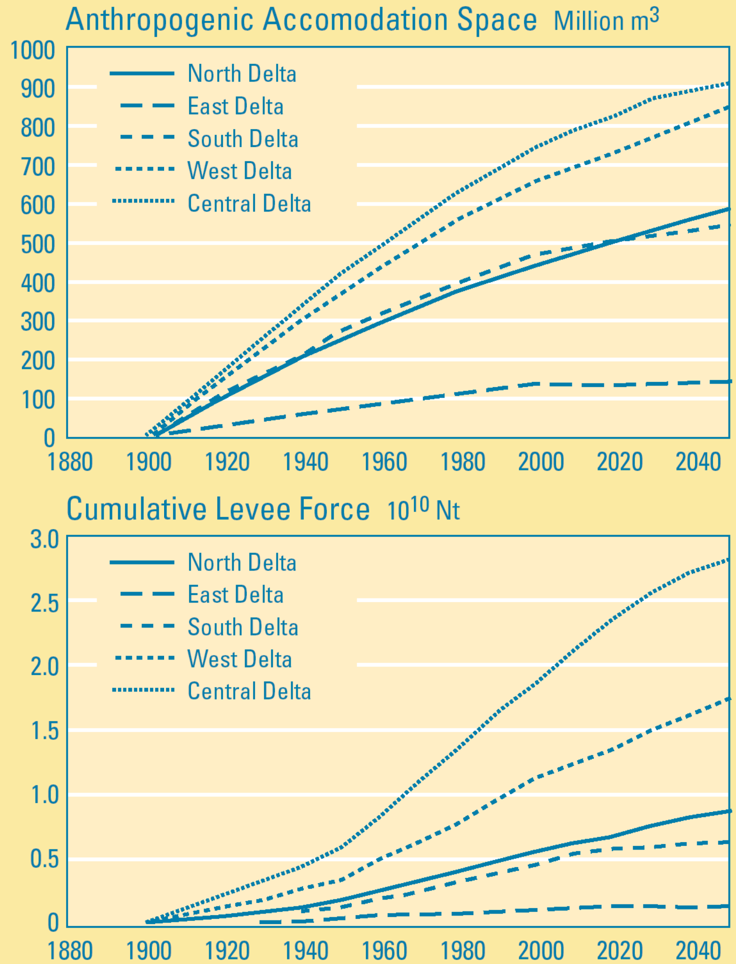
Simulations suggest the elevation of Delta islands will continue to decrease. Subsidence and associated anthropogenic accommodation space generation is the dominant landscape-forming process in the Delta during the past 100 years and will remain so for the indefinite future (figure courtesy J. Mount).

increase in the rate of sea level rise by 2050, we constructed a simplistic model that simulates stepwise subsidence of Delta islands down to the base of the peat layer. The model shows that for some time we will have continued subsidence that will create a substantial volume of accommodation space, chiefly in the west Delta and the central Delta.

Already, today, we have around 2.6 billion cubic meters of empty accommodation space in the Delta. To fill that space with the sediment that's currently coming into the Delta would take 1,500 years. But the system is not static. On an average annual basis, the Delta loses 27,000 cubic meters every day. And don't forget the Levee Force Index. Just because accommodation space creation is slowing doesn't mean that the pressures on the levees are slowing commensurately. On the contrary, sea level rise ensures that those forces continue to grow—and grow substantially, because the force is a function of depth squared.

Based on just this first-order simulation, the potential for and consequence of island flooding increase steadily through time despite our best efforts—and so far we've only talked about gradual landscape change. What about abrupt landscape change, like a catastrophic flood or earthquake? A 100-year quake would likely cause failures in five to 20 levee segments. The potential for rapid reorganization of the Delta—that is, the creation of a "new" Delta—increases steadily as you increase accommodation space and the forces on the levees.

Calculated and simulated Anthropogenic Accommodation Space and Cumulative Hydrostatic Force



Continued subsidence will magnify the instability of the Delta levee network in the future (figure courtesy J. Mount).

"Policymakers tell me that I'm just a fearmonger."

Policymakers tell me that I'm just a fearmonger. They say that these things are far out in the future. But consider that the probability of a 100-year earthquake over a period of 50 years is 0.40, and the probability of a 100-year flood is the same. The probability of either an earthquake OR a flood is 0.64. So there is a two in three probability that we'll have a substantial event in the Delta over the next 50 years.

It's my contention that gradual change is a certainty and abrupt change is highly likely. However, our management and our planning do not take either into account. We have no technologically and economically feasible method to restore elevations. We have only one contractor in the Delta for fixing levees—how could we respond to a catastrophic multi-island failure? CALFED program planning remains predicated on a fixed landscape; it assumes maintaining the hydraulic integrity of the Delta in its current configuration. I think we need some reform.

Lessons from the Jones Tract Levee Breach

Chris Enright and Curt Schmutte (DWR), Session Chairs

Background

On June 3, 2004, the Jones Tract Levee failed. The breach occurred rapidly and without warning in a levee section that was considered well-maintained. Approximately 140,000 acre-feet of water, roughly equivalent to two weeks of moderate CVP/SWP exports, poured through the break over two days, inundating the island to an average depth of 12 feet. Delta outflow standards and water quality were affected by the break, causing the projects to alter normal operations to maintain flow objectives.

The Jones Tract failure was not an isolated anomaly, although the recent breach did serve to focus attention on the fragility of Delta levees. Delta levees have been built incrementally since the 1850s by landowners and reclamation districts, and just since 1971 there have been 43 levee breaks on 36 islands in the Delta.

Maintaining and improving Delta and Suisun Marsh levees is a central commitment of the CALFED ROD, touching on all of the other CALFED programs. In his plenary session talk, Jeff Mount of UC Davis (page 21) examined Delta levees and island subsidence on a landscape scale. His work suggests a high probability of catastrophic, systemic failure exists in the next century.

In this session, presentations were made both about how to prevent future failures, and about the consequence of future failures. Calls for urgent increases in levee failure response capability, and for 'zero-failure' policies, were balanced by concerns about the overall costs and risks associated with current policy of levee maintenance and repair.

How to reconcile critical assessments of the future of Delta levees with calls for action by those who depend on their stability will be a critical question in upcoming years. The CALFED Science Program sponsored a special session at the 2004 Science Conference to discuss issues related to Jones Tract and Delta levees in general. Policy viewpoints were presented alongside new science. Both are summarized here to help ensure that policy and management of Delta levees will be guided by science.

Impacts on Projects and Water Supply

- CVP
  - Deferred deliveries to later in season
  - Export impact of approximately 30 thousand acre feet (taf)
  - Released ~30 taf for additional Delta outflow in June, but benefit of pumping out water from the flooding island may negate this impact
- SWP
  - Deferred deliveries to later in season
  - Deferred pumping to later in season
  - Released ~10 taf for additional Delta outflow in June - the pump-out benefit may negate this impact

Jones Tract Timeline

- June 3 – Jones Tract Levee break
- June 30 – Breach closed
- July 12 – Island pump out begins at ~ 450 cfs
- July 26 – Island pump out increases to ~ 750 cfs
- October – Pumping rate of < 600 cfs and dropping
- Estimated island pump out complete mid-December

(Leahigh)

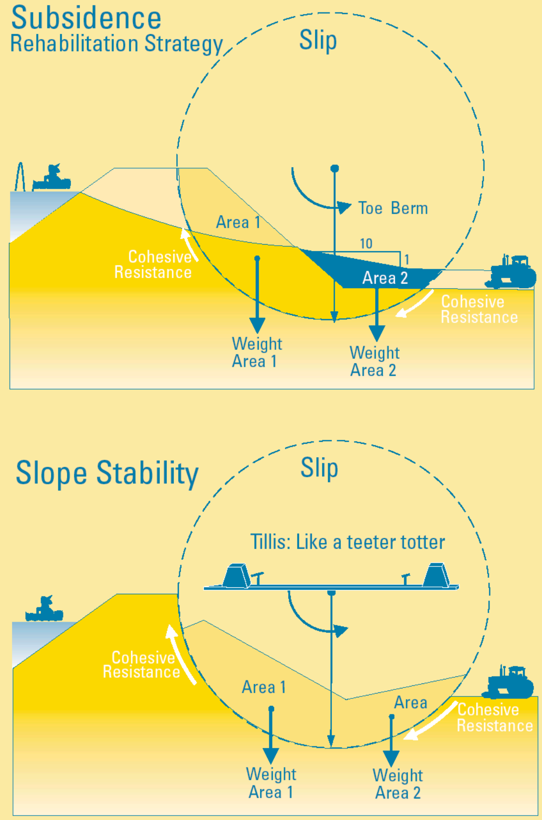
SCIENTIFIC INFORMATION

- Salinity at two Delta monitoring sites rose dramatically after the breach, particularly during the first spring tide after the breach. The Projects initially responded to the Jones tract breach by reducing exports and increasing upstream reservoir releases levels to counteract salinity intrusion. Salinity levels never elevated as much as was anticipated (Leahigh).
- Model simulation of the levee breach and repair under the CALFED Levee Risk Assessment Project successfully predicted salinity at four Delta monitoring stations during initial flooding, repair, and recovery. Salinity west and south of Franks Tract increased. Simulations of leaving the breach open showed a slight initial reduction in central Delta salinity. Further modeling showed the overall water quality impact of the Jones Tract breach was negligible. Even if the breach had not been repaired and exports were not curtailed, the system would have stabilized itself, although more slowly (DeGeorge).

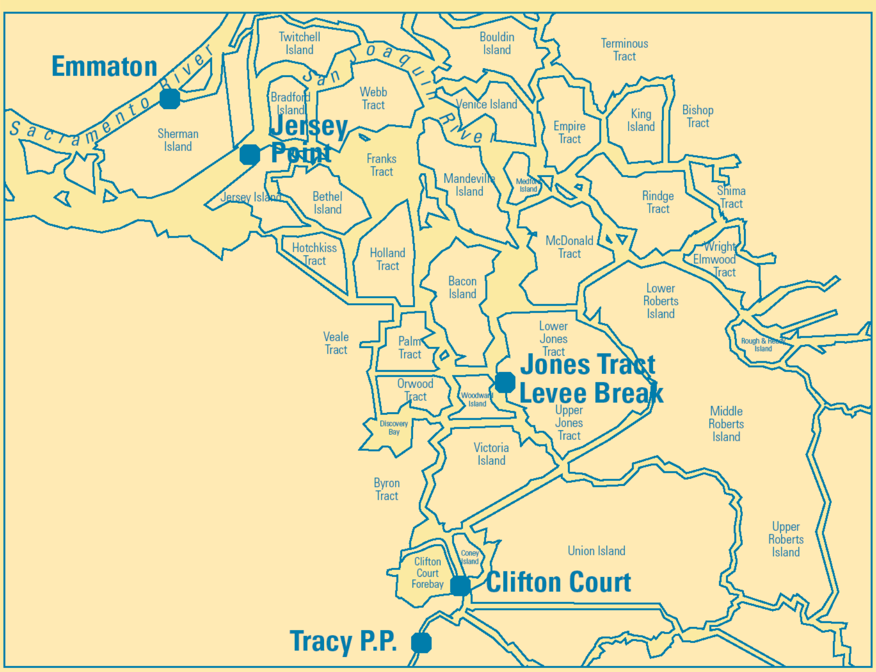
- continued

SCIENTIFIC INFORMATION CONTINUED

- Overall, there are competing explanations for why the Delta remained fresh after the Jones tract breach—project operations, tidal salinity responses, and favorable starting conditions. Testing and vetting each of these working hypotheses to determine which and to what extent each one explains observed salinity will require additional analyses.
- Analysis of water export salvage data before and after the breach suggests salmon were probably not affected by the event since they had finished migrating through the Delta by this time. 20 mm fish survey data indicate that neither delta smelt nor striped bass were entrained into Jones Tract (Coulston).
- Delta smelt distribution centroid moved 5-6 miles inland towards the San Joaquin River after the breach. This is consistent with a model of particle behavior of smelt, as modeled salinity effects (DeGeorge) suggest the Jones Tract breach moved water upstream by this amount. This increased their exposure to entrainment at the export facilities (Coulston).
- There was an increase in the number of delta smelt and striped bass salvaged at the state and federal diversion facilities after the levee breach, but it is not clear whether this was due to the breach. These diversion losses, however, are not considered a significant contribution to the low 2004 juvenile abundance indices for both fish (Coulston).
- Using vegetation to reduce levee erosion can create stable landforms, increase soil strength and bank stability, and create habitat. However, plants can potentially hinder inspection, attract unwanted wildlife including burrowing animals, and hinder floodway conveyance, and vegetation may need annual maintenance (Hart).
- Many levee repair efforts pile fill on top of existing levees. In tests at such repair sites at Webb Tract and Bouldin Island, levees showed significant lateral deformation (8-14") with light fill through settlement of underlying peat soil. Lateral deformation can also continue long after filling. Such movement can create stress, cracks, and seepage, compromising levee stability. It can also contribute to settling of the levee crest, reducing flood protection (Tillis).



Subsidence and levee slope stability. Delta levees can fail when the saturated peat soils on which they are built lack the cohesive resistance to halt the levee sliding down under its own weight, "like a teeter totter." One method for shoring up levees is to add a "toe berm" as this figure indicates (figure courtesy C. Enright).



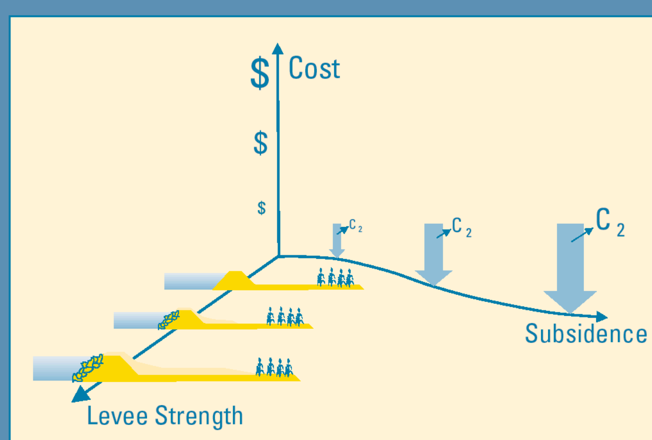
MANAGEMENT IMPLICATIONS

- Committed finances to assess levee construction and make repairs, equipment availability for quick emergency response, and a maintenance plan that can effectively operate without affecting critical fish populations in the Delta could all improve levee management (Zuckerman).
- By working with media in an open forum, providing them with details of the event and "embedding" them in the emergency operation, DWR was able to quickly disseminate information to the public. This avoided potential miscommunication by the press, and promoted an important link to public understanding and awareness of the event (Burkhart).
- Standardized Emergency Management System (SEMS) guidelines allowed DWR to conduct an effective multi-agency and multi-jurisdiction emergency response to the Jones Tract breach by emphasizing team orientation, allocating individual responsibility over succinct domains, and encouraging expertise and specialization. On occasion, when SEMS guidelines were not followed, flood fight efforts quickly became destabilized and inefficient. Fighting the flood from a Delta basin perspective, without having to fulfill bureaucratic processes, helped expedite emergency response efforts (Burkhart).
- Though the Jones Tract break entrained a large amount of water, the CVP and the SWP experienced minimal impacts. However, managers can not necessarily count on this in future breaches, as the Delta was 'fresh' at the time, making salinity levels easier to maintain (Leahigh).
- Data sources used for predictive modeling are generally good, but emergency response modeling requires more accurate Delta bathymetry (DeGeorge).
- Using more vegetation in erosion control could improve efforts to build a sustainable and safe levee system. Current rock revetments along much of the levee system, which offer sparse habitat value, could benefit from emulating more natural conditions (Hart).
- Soil beneath levees deforms under pressure from fill. This suggests the need to rethink current maintenance methods, as building up the crest of levees by filling creates lateral deformation, settlement, and weakening (Tillis).
- Subsidence, which naturally occurs on peat soil, creates the need for ever larger and more expensive levees to maintain the same level of protection. Thus, subsidence increases levee cost, and apportioning this cost could take subsidence into account. However, how to perform a true economic analysis to assess proportion in costs is a delicate and complex matter, as the levee system is a privately owned infrastructure that protects a public resource (Enright).
- The Jones Tract Levee breach brought to public attention many important issues regarding Delta resource planning.

  The following points from the session were summarized by Jeff Mount:

  - Some levees are essential to the integrity of the water projects.
  - Reclamation districts who own levees are not prepared for levee failure.
  - Private levee management can become a statewide water resource issue.
  - We were lucky – a different failure could have created far more serious problems.
  - Prevention is far more cost effective than recovery.
  - Sufficient risk analysis has not been performed on the levee system.
- With the current rates of accretion, developing technologically and economically feasible methods to reverse subsidence may be impossible. However, there is currently no focused research to settle this debate, nor is there any work to cover the elemental questions of how fast subsidence is occurring, where is it occurring, and how is it distributed. We have the technology to answer these basic questions (Mount).

Subsidence Increases Levee Costs



Subsidence increases the requirements for levee strength, and thus levee cost (figure courtesy C. Enright).

Floodplains and Riparian Systems

Jeff Opperman (UC Davis)
Session Chair

Background

Evidence indicates that riparian and floodplain habitat has direct and indirect importance for species of concern, but very little floodplain habitat remains in the Bay-Delta region. On the Sacramento River, most of the floodplain habitat has been degraded through water diversion, flood control, rip rap or invasive species. In addition, only about 2% of historical riparian forest area remains, often in small isolated patches, and changes in the hydrologic regime have significantly altered the system.

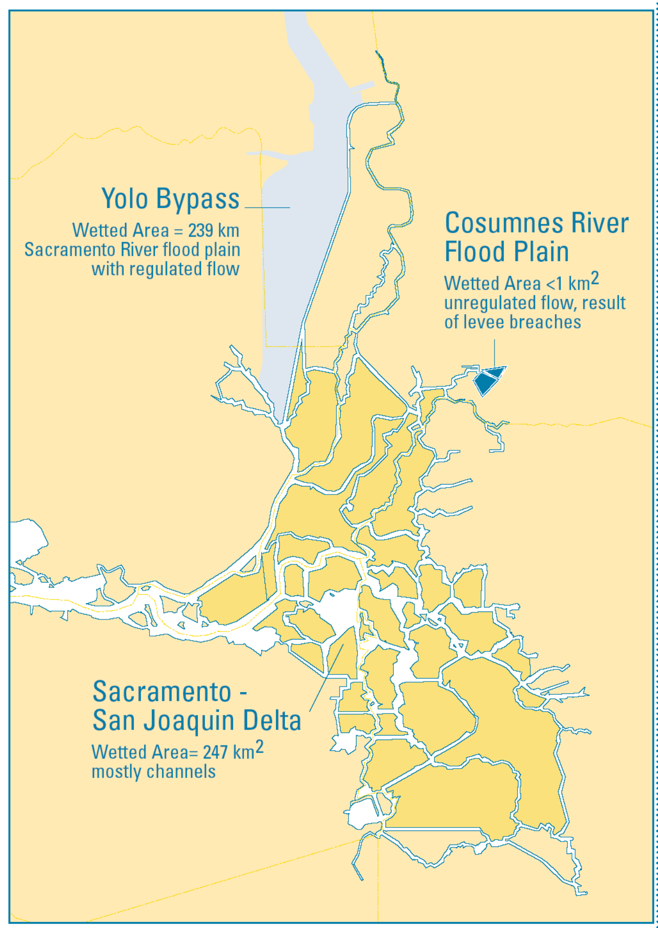
Floodplains are areas adjacent to rivers that are periodically inundated by high flows that deposit the material which forms the floodplains.

Riparian zones are generally defined as the zone of vegetation closest to the river.

Linking ecological data on floodplains to the data and perspective of flood managers can be difficult because typically available data often pertains to rare, 100-year flood events. These flows create and maintain floodplain topography, but are less directly relevant for ecological processes such as phytoplankton and fish habitat. One representative "straw man" definition of an ecologically functioning floodplain could be 28 days of inundation between March 15 and May 15, at a frequency of two years in three. Based on this definition, 3 to 11 percent (50,000 to 160,000 acres) of historical functional flood plain remains in the Central Valley (Andrews). In seven years, CALFED has restored 16,000 acres of floodplains, and has plans for more.

An overarching theme of restoration research is that restoring ecological health to riparian ecosystems requires an understanding of how the river's floodplain, vegetation, and channel have changed due to natural processes and human alteration. This understanding is a critical part of successful adaptive management. To this end, research in this session spanned topics from biogeochemistry to re-vegetation and monitoring.

Because of the complexity of aquatic restoration projects, not all actions yield desired results, so they need to be monitored and refined. An adaptive approach is critical for restoration, and science presented here demonstrates how monitoring riparian restoration projects can inform future management actions.



Map of existing floodplains in the Delta region (figure courtesy A. Mueller-Solger).

MANAGEMENT IMPLICATIONS

- Functional floodplains depend on inundation regime. Re-establishment of ecologically functional floodplains requires more than simply breaching levees. Managers will need to re-establish key attributes such as inundation regime and disturbance if they are to provide intended ecological results (Andrews).
- Flood magnitude matters for floodplain restoration projects. Large floods reset biogeochemical processes, and small pulses enhance existing conditions. In addition, designing floodplains that drain slowly is important for water quality and nutrient cycling (Gallo).
- Organic matter availability (and therefore zooplankton and fish production) is higher in floodplains with natural flood regimes than in the Delta or managed floodplains. Floodplain restoration will have a greater ecological benefit with natural flow regimes, varied vegetation and varied hydrologic residence time patterns (Mueller-Solger).
- Inundated floodplains are productive. Phytoplankton from inundated floodplains such as the Yolo Bypass may enhance food supplies for fish not only within the floodplain, but also through export to downstream regions (Lehman).
- Timing of peak productivity in the Yolo Bypass likely benefits native fishes. This productivity could be enhanced by early flooding to take advantage of the high net growth in the early spring. Total carbon could be enhanced by long residence time between flood phases to allow accumulation of algal biomass (Lehman).
- Restored habitats tend to be used more heavily by native species in the spring. While non-native species tend to predominate in the summer and fall, this does not diminish their utility to native species in other seasons (Dietl).
- Restored shallow water habitats such as those on the Napa River can be made more suitable for native fish by breaching additional levees, increasing circulation, decreasing water temperatures, and providing better access for fish to the restored habitat (Dietl).
- Successful planning and implementation of riparian or floodplain restoration actions may require the application of adaptive management. One process for riparian/floodplain restoration has three major phases; articulating desired responses, testing through modeling and observation, and refinement of actions (Bowles).
- Riparian restoration is possible in dredge-tailing areas. In particular, the porosity of the tailings can be overcome through active and passive restoration techniques (Souza).
- Pre-dam measurements from relatively undisturbed areas on the Lower Mokelumne suggest some potential metrics for restoration goals. Managers could strive to reduce riparian buffer fragmentation to 5% or less. The first 20-30 meters of the buffer could be composed of at least 75% riparian forest and 20% riparian shrub. Secondary channels and seasonal lakes could also be restored (Edwards).
- Riparian metrics applied to records of historical riparian condition can quantify pre-development conditions. Values for these metrics can then help quantify restoration objectives and monitor restoration progress (Edwards).
- It is necessary to monitor assemblages of avian species in Central Valley riparian habitat to determine response to management – indicator species have not been found that can represent the diversity of bird species and the complexities of riparian vegetation. However, the success of restored riparian trees and shrubs is itself a good predictive indicator of avian success (Nur). Presence/absence and abundance data are both necessary for a clear picture of species health (Wood).
- Results suggest restoration efforts at Clear Creek could have greater benefits for songbirds if they increased understory foliage volume by including herbaceous plant species into planting mixes, increased the amount of wetland habitat within the active floodplain, and increased the amount and density of the shrub layer at restoration plots (Burnett, Wood).
- Long-term monitoring is critical to assess the results of restoration actions. Initial results often reveal changes in early successional species, and understanding the factors that lead to stable populations requires monitoring on the scale of decades (Burnett).
- Riparian birds benefit from restoration projects that are staggered in time and thus at different stages of development, corresponding to the naturally dynamic landscape of riparian floodplain. Mid- and early successional habitat is important to some species that also use forested areas for breeding

SCIENTIFIC INFORMATION

Food web

- Continuous monitoring on the Cosumnes River revealed that during flood events inorganic sediments deposited, organic material flushed out, and volatile solids increased along with hydraulic residence time. Dissolved organic carbon rapidly increased during floodplain draining, while chlorophyll-a decreased during flow events (Gallo).
- Nutrient uptake and cycling are dependent on floodplain connectivity and hydrologic residence time. The microbial loop plays a larger role in floodplain biogeochemistry than previously thought (Gallo).
- Zooplankton production in Delta waters and the Yolo Bypass tends to be driven by algal carbon availability, while Cosumnes River floodplain zooplankton production tends to be driven by detrital carbon availability (Mueller-Solger).
- Data suggest overall nutritional quality of organic matter is greater in Cosumnes River floodplains than in Delta channels or the Yolo Bypass, perhaps leading to greater trophic efficiencies and consumer production. Sites with high residence time were not only more nutritionally productive, but also had less grazing pressure on food supplies than sites with low residence times. (Mueller-Solger).
- On the Yolo Bypass in 2003, net productivity was highest in the early spring when native fish spawn there, and decreased later in the spring as respiration increased. Both the quality (cell diameter) and production of carbon was higher in the Bypass than in the adjacent Sacramento River. Yolo Bypass was an important source of high quality carbon for the food web downstream (Lehman).
- The freshwater Siberian Prawn (*Exopaleomon modestus*) rapidly invaded the Yolo Bypass starting in 2001 – it now often has a greater biomass than fish in monitoring samples. However, neither the zooplankton or phytoplankton community appeared to undergo substantial changes attributable to the prawn invasion (Sommer).

Restoration

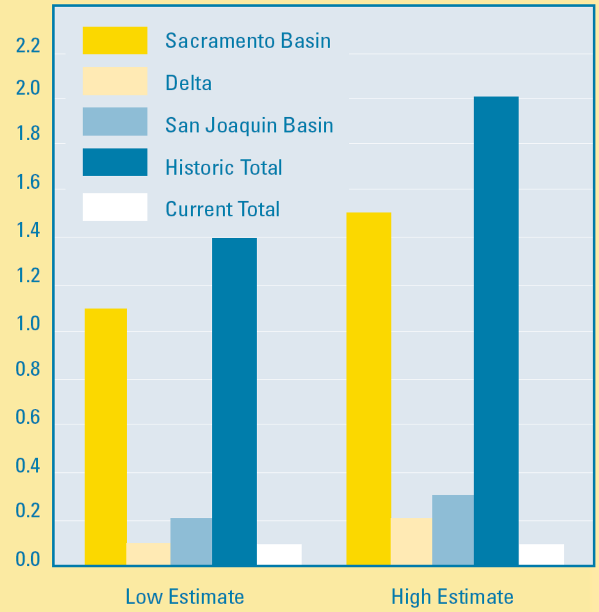
- Adult and juvenile splittail made extensive use of recreated Napa River marsh plain terraces, consistent with observations in the Sacramento and San Joaquin river drainages. Seasonal separation in the use of restored habitats by native (spring) and non-native (summer-fall) fish species was observed (Dietl).

Comparison of Biota in the Yolo Bypass to the Sacramento River

Organism	Trend
Chlorophyll a	Higher
Cladocera	Similar
Copepods	Similar
Diptera	Higher
Other Aquatic Inverts	Higher
Terrestrial Inverts	Higher
Salmon Growth	Faster
Salmon Survival	Higher
Splittail Production	Higher

Ecological variables are more favorable on the floodplain habitat than in the main stem river (after Sommer).

What used to exist?
Estimated Historic Floodplain Area
Million Acres



High and low regional estimates of historic floodplain area in the Central Valley system, compared to current total floodplain area. Current total area estimate includes the Yolo Bypass, the Cosumnes River, and wetted area in the Delta. Historic estimates do not include Tulare Basin (figure after data from E. Andrews and A. Mueller-Solger).

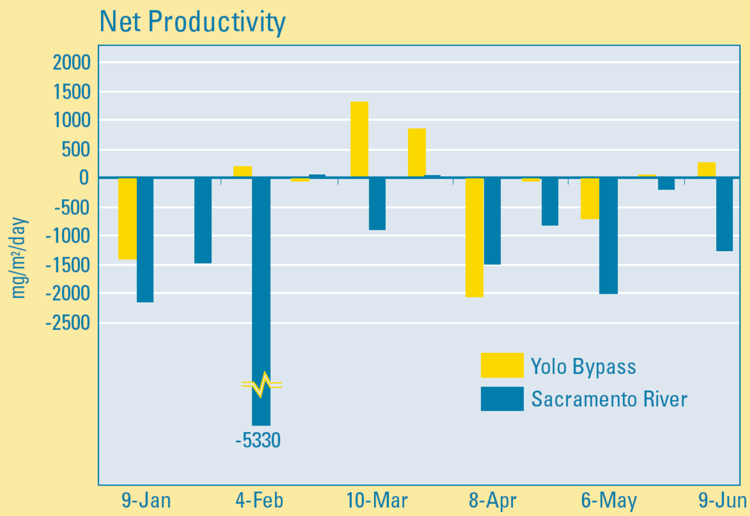
- At a riparian re-vegetation project on Clear Creek, transported mine tailings were used to re-contour a dredge-mined riparian area, resulting in poor and highly permeable soils. In active re-vegetation areas, riparian hardwood cuttings successfully survived and established a patchy distribution to provide habitat for nesting songbirds and other wildlife. Passive re-vegetation success was more variable. Overall, plantings are causing floodplain development during overbank flow events (Souza).
- Substantial changes have occurred in the lower Mokelumne River corridor since 1910. Seasonal lakes and secondary channels observed in 1927 have been removed, eliminating floodwater retention sites that would normally recharge groundwater and provide habitat for juvenile fish, amphibians, invertebrates, riparian bird species, riparian mammals, and reptiles. Most of the floodplain has been cleared of ripar-

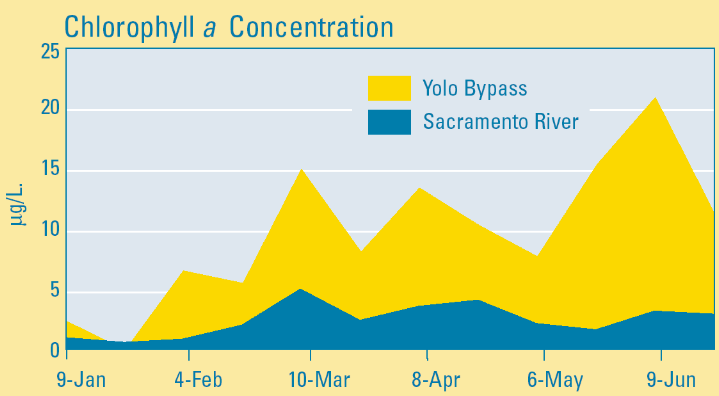
ian forest and shrub communities and converted to agriculture. Substantial fragmentation of riparian habitats has occurred (Edwards).

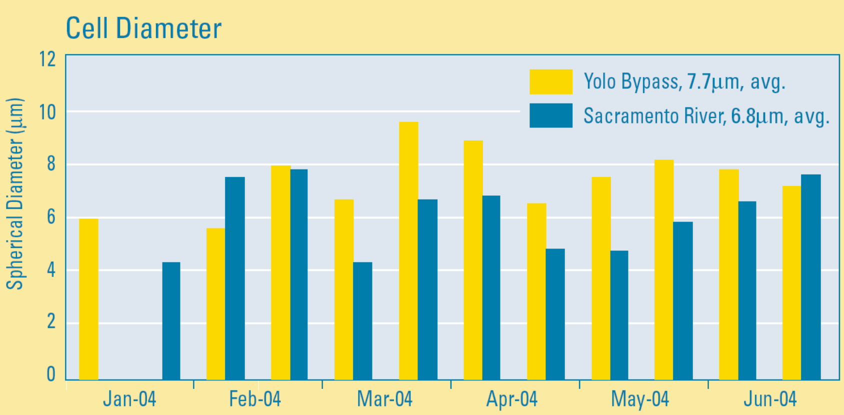
- 76,000 elderberry shrubs (*Sambucus mexicanas*) have been planted on the Sacramento River National Wildlife Refuge since 1989 to provide habitat for the federally threatened valley elderberry longhorn beetle. Almost all of the elderberry shrubs remain alive, and are actively used by the beetles. Beetles choose shrubs based on stem height (Swagerty).

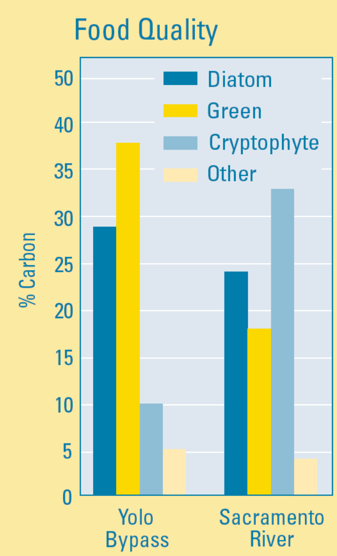
Birds

- In Central Valley restored riparian areas, riparian bird species richness was most strongly related to tree size (positive), tree cover (positive), and cottonwood cover (negative). Bird indicator species were not identified, but establishment of riparian tree and shrubs is a good indicator that birds will succeed in restored riparian areas (Nur).
- Early results from a Clear Creek restoration project suggest more recently vegetated restoration sites appear to have higher densities of songbird species than remnant reference sites. Key factors limiting populations seem to be nesting success and cowbird parasitism. While Clear Creek supports many riparian bird species that are rare to absent elsewhere in the Central Valley, the health and long-term viability of these populations may be at risk (Burnett).
- Along the San Joaquin, Mokelumne, and Cosumnes rivers, the highest bird species diversity was found in mature forest. Several riparian species are more abundant and in some cases have higher nest success in early successional restoration sites (Wood).









Sampling from January to June 2003 suggests the Yolo Bypass had greater productivity than the adjacent Sacramento River, and the quality of the food was higher as well (figures courtesy P. Lehman).

Watershed Perspectives

Ted Frink and Stefan Lorenzato
(DWR)
Session Chairs

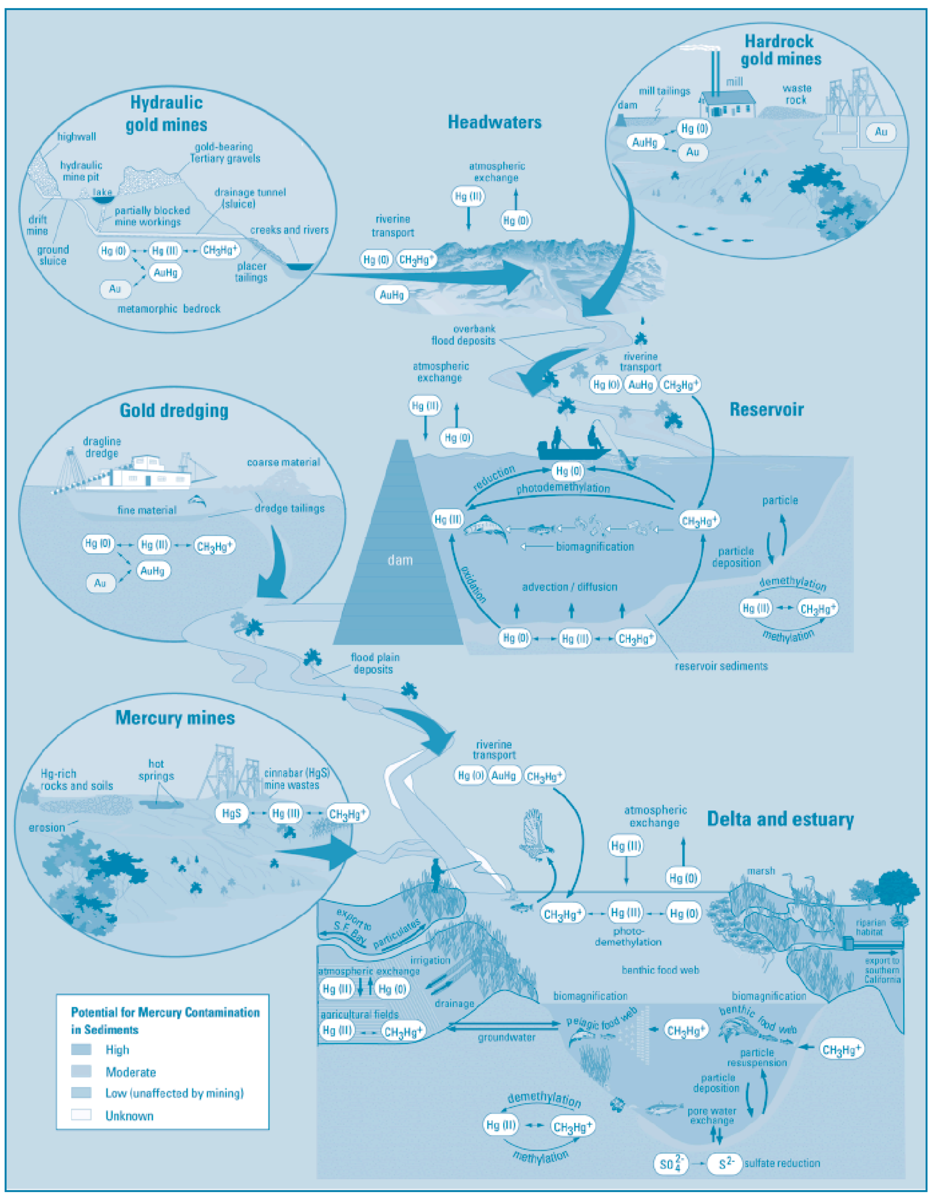
Background

All of the science presented at the 2004 CALFED Science Conference is ultimately relevant at a watershed scale. However, restoration professionals do not always step back to the "30,000 foot view." Even when looking at the big picture, one can focus on different things. Talks in this session alternatively discussed big-picture natural science and the collaborative processes inevitably required to put it to work in areas with diverse stakeholders and management issues.

Half of the talks in this session involved the Yuba River watershed, a large (1560 km^2) Sierran watershed draining to the Sacramento River. Research and study efforts in the Middle and South Yuba rivers are framed around the potential to introduce wild spring-run Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*O. mykiss*) into the river upstream of Englebright Dam. The multi-stakeholder collaborative program is evaluating the ecological, biological, and socioeconomic feasibility of these introductions, which may or may not include removal of the dam. Sediment remaining from hydraulic mining is an issue in this watershed from both flood capacity and water quality/ecosystem health perspectives. And with the remaining historic mining debris comes concerns about mercury (see page 56 for more background on mercury). The Cosumnes River is the only river running from the Sierra to the Delta that has escaped major water development, and is thus a prime candidate for restoration.

Lessons from this and other complex integrated human-landscape-ecosystem research and stakeholder supported efforts can help inform future CALFED efforts for restoration and watershed management.

One common theme is that in our efforts to consider larger ecosystem-watershed restoration scales, social and economic aspects of a system become just as, if not more, important than the technical ones.



This conceptual model of transport and transformation of mercury in the Bay-Delta system emphasizes the need to manage this problem at a watershed scale. See page 56 for more information (figure courtesy C. Alpers, M. Hunerlach, J. May, R. Hothem and M. Stephenson (USGS Fact Sheet 2005-3014)).

SCIENTIFIC INFORMATION

Cosumnes River

- In the Cosumnes River watershed, cropland area in the watershed has decreased since 1974, while vineyard, orchard, and residential development have increased. These land uses, along with roads, logging, dairies and cattle grazing, and mining contributed to surface soil disturbance. Overall, however, there have been no major changes in annual suspended sediment load since the 1970s (Platenkamp).

- Since 1907, the lower Cosumnes incised on average 12 feet, but incision has become very slow in the last decade. Levee construction and poor grazing practices have contributed to bank erosion. Granlees diversion dam also traps sediment, leading to increased incision (Platenkamp).

Yuba River

- In the upper Yuba River from 2001-3, bedload represented less than one percent of total sediment load. Suspended sediment concentration (SSC) data revealed distinct seasonal variations resulting from changes in suspended-sediment supply and hydrologic events. High SSC over time can have lethal and sub-lethal impacts on fish. Throughout the study period, SSC was generally less than the sub-lethal threshold (Curtis).
- Results from coring in Englebright Lake on the Yuba River show that the sediment is thickest in middle section, thinner near the dam, and thick in the upper area, with coarser sediments at the upstsream end. Authors estimate that 25 million metric tons of sediment have accumulated over 61 years, filling over 25 percent of the original capacity of Englebright Lake (17,750 of 70,000 acre-feet) (Snyder).
- In the South and Middle Yuba rivers, there were positive correlations between discharge, suspended sediment concentration, and mercury in unfiltered water. Mercury and methylmercury are transported primarily in storm events in the Yuba watershed. The highest concentrations of mercury and suspended sediment concentration relative to discharge occurred during rising limbs of storms, an observation that helps to explain much of the variability in the overall relations between mercury, suspended sediment concentration, and discharge (Alpers).
- In Englebright Lake bed sediments, both mercury and methylmercury concentrations varied over several orders of magnitude. Mercury concentrations in shallow bed sediments match concentrations in recent suspended sediment in the major tributaries to the lake. Higher concentrations of mercury and other trace elements were found in deeper sediments deposited in Englebright Lake during the 1940s-1960s (Alpers). (see also Mercury, p. 56)

Columbia Basin

- Replicated, smaller scale studies of habitat restoration effectiveness, if properly designed, can provide insights on watershed and regional scales. Available historical data on annual fish survival, habitat restoration actions, and other potentially influential factors were used to quantify the effects of restoration

actions on fish survival across multiple watersheds in the Columbia River basin over the last 20-30 years. Restoration actions had variable effects on fish survival patterns over space and time. More precise survival metrics showed more positive correlations with habitat actions (Marmorek).

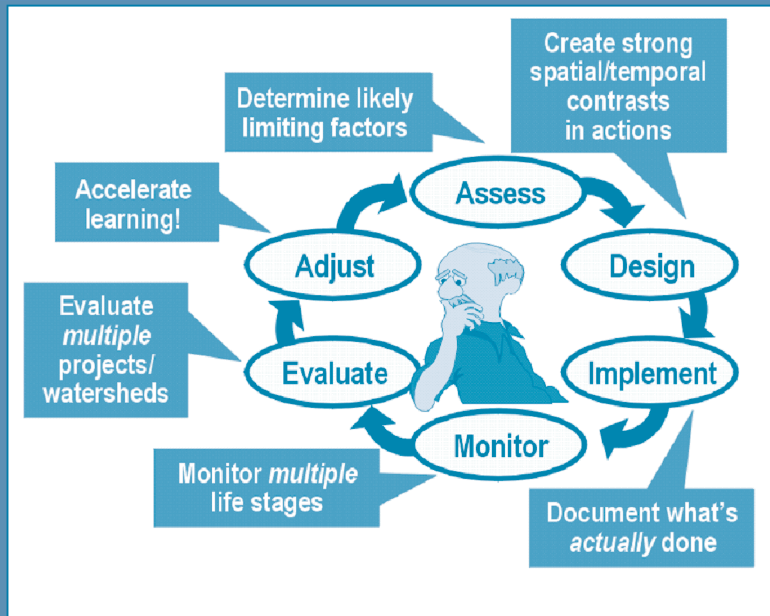
Landslides

- Three case studies showed how landslides in different watersheds can have different, but generally detrimental, effects on salmonid habitat. In one, sediment from landslides filled pools and caused channel aggradation, decreasing habitat value and limiting salmonid migration even though the sediment was of the appropriate size for spawning. In another, landslides provided mudstone rocks to the channel. Weathering of the mudstone embedded and cemented existing spawning gravels together, impeding spawning. In a third, fine-grained landslide debris caused a larger problem through extended high concentrations of suspended sediment than through pool infilling (Pearce).

MANAGEMENT IMPLICATIONS

Watershed Restoration Planning and Evaluation

- Local involvement is critical to success in watershed stewardship plans. Without it, implementation of restoration plans may not be possible, no matter how strong the science. Key components of one such successful effort included patience, listening to other stakeholders, and continued involvement through the multi-year process (Reeves).
- Assessment of restoration efforts can benefit from shifting from opportunistic retrospective analyses of individual watershed projects towards rigorously designed and monitored, multi-watershed, adaptive management experiments. This necessitates good coordination and documentation of restoration projects (Marmorek).
- Restoration projects need to state hypotheses and structure monitoring in order to test their effectiveness across multiple scales. Location and timing of restoration projects and reference areas can affect how they can be used for such analyses (Marmorek).
- Lessons from the Yuba River suggest stakeholders' commitment, a clear decision process, and the technical framework that integrates science are all central to restoration success. Ultimately, a facilitated collaborative process is as important to project success as having credible scientific results and expert review of findings (Christophel).
- Modeling technology has advanced to the point where it can help in assessing possible consequences of restoration actions, including complex ones in heterogeneous watersheds. Now, managers may be able to use such tools even in the absence of copious field-gauged data (Kavvas, Flint).
- If managers focus on reducing sediment inputs from a few significant land-use types and address the effects of Granlees Dam and levees, sediment inputs to the Delta will be reduced, and salmonid spawning habitat in the Lower Cosumnes improved (Platenkamp).
- Field-based management is important for improving salmonid habitat in landslide-prone watersheds. There are no broad-brush, uniformly applicable management methods because of variability among watersheds (Pearce).



Closing the adaptive management loop. Action effectiveness studies are needed as part of an adaptive management framework (figure courtesy D. Marmorek).

Specific Implications for the Yuba Watershed

- Suspended sediment concentration on the Yuba River in 2001-3 was not a limiting factor for potential long-term reintroduction of Chinook salmon and steelhead to the upper watershed (Curtis).
- Exposure levels of methylmercury in the upper Yuba River watershed may pose a risk to aquatic species. Potential methylmercury exposure and associated risk should be considered in anadromous fish reintroduction scenarios above Englebright Dam. If a high concentration were released downstream, as from dredging, it could be a concern. Any future dredging of sand and gold must be weighed against risk of mercury and methylmercury release downstream (Alpers).
- In the South Yuba River, there is excellent correlation of mercury with suspended silt and clay. This indicates the potential for measuring turbidity as a proxy for mercury (Alpers).

Managing Big Rivers Below Big Dams

Scott McBain (McBain and Trush),
Bruce Orr (Stillwater Sciences)
and Tim Ramirez (CBDA)
Session Chairs

Background

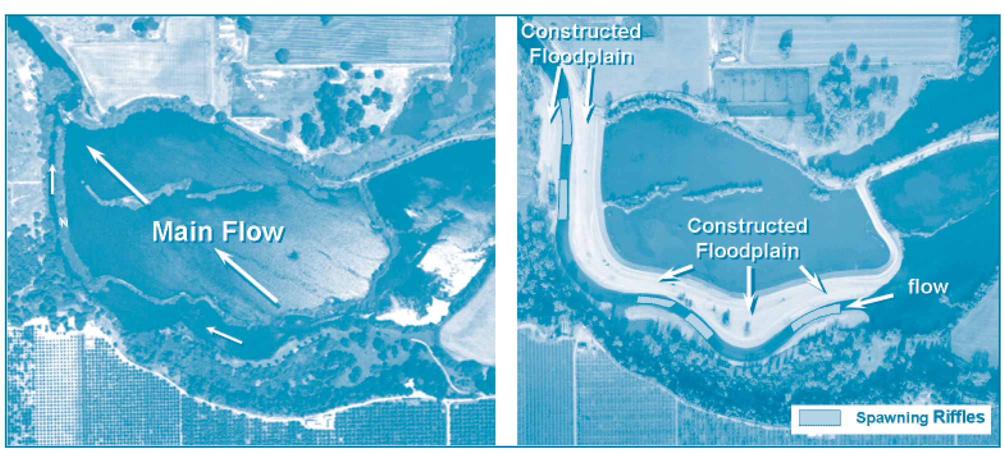
Salmon and other fish species of concern drive many large-scale restoration efforts because dams block upstream fish passage, trap sediment and alter flow regimes. Each of these impacts affects the ability of fish to reproduce and rear. The key to restoring big rivers and their native fishes is to better mimic the seasonal variation under which these species evolved and thrived. Large-scale restoration projects in these systems increasingly attempt to alter geomorphology and hydrology to elicit positive physical and ecological responses that will benefit species of concern and other ecosystem constituents. Tools include manipulation of the high flow regime, coarse sediment regime, fine sediment regime, and channel/floodway geometry. In practice, predicting cascading geomorphological effects against a backdrop of variable hydrology is challenging. Big rivers are fundamentally different physically and biologically than creeks and streams. Some, but by no means all, of the hydrologic and geomorphic lessons can be successfully up-scaled to big rivers.

Trees are among the many species other than fish affected by dams. The absence of young cottonwood stands in the Central Valley is usually indicative of a riverine ecosystem whose hydrology and geomorphology is fundamentally broken. Cottonwood is a pioneer species that begins a successional process leading to the development of complex and diverse riparian forests. Therefore the lack of recruitment of new cohorts of cottonwoods indicates there may be no future regeneration of riparian forests. Ultimately, restoring cottonwood recruitment usually requires improvements in the geomorphology and hydrology of an alluvial river. Active re-vegetation has typically been applied in situations where process-based restoration has not been considered. More recently it is receiving attention as a tool to jump-start natural recruitment and provide sources for recolonization while restoring hydrologic and geomorphic regimes.

We are involved in a grand experiment to restore regulated rivers. The main constraints on successful restoration of big rivers are currently lack of water and sediment, exacerbated by development and population pressures. These constraints usually prevent restoration to unimpaired conditions, but substantial rehabilitation can occur. What are the measurable benefits with incremental rehabilitation? Is there a minimum threshold of flow and sediment inputs where a dynamic, healthy alluvial river cannot be achieved? An adaptive approach will be necessary given these and other unanswered questions. Monitoring is critical, not only for understanding the effects of previous restoration efforts, but also to calibrate existing models for use in future efforts. Ultimately, a holistic view of big rivers as systems that extend beyond their floodplains will need to be taken, linking them to the watersheds of which they originate.

Historic restoration approaches have focused on mechanical rehabilitation of the physical habitat in river systems, but CALFED Ecosystem Restoration Program is increasingly funding projects that attempt to rehabilitate the physical underpinnings of alluvial rivers. This approach, while intuitive, often breaks new ground in the restoration field, and needs to be informed as much as possible by previous efforts. This session brings together information from relevant efforts, in hopes that tomorrow's restoration practitioners can learn from others as they rehabilitate the physical systems of bigger alluvial rivers in the Central Valley.

Pre-Project **Post-Project**



Pre- and post-project aerial photographs of Ratzlaff Reach. Before restoration, main channel flow was through a deep pond with salmon predator habitat. Restoration created spawning riffles, and a dynamic floodplain and channel (figures courtesy R. Mager).

SCIENTIFIC INFORMATION

Clear Creek

- A model of Chinook salmon spawning and juvenile rearing habitat predicted a substantial increase in spawning habitat after restoration on Clear Creek, and mixed results for fry and juvenile rearing. On the Merced River, the model appeared to overestimate pre-restoration spawning habitat, but predicted decreases in spawning and rearing habitat were validated (Gard).
- Floodplain rehabilitation on Lower Clear Creek has been partially successful. Large flows in 2002 caused significant alterations to the geometry of the reconstructed area. Point bars, mid-channel bars, and transverse riffles developed, the threshold of bed mobility increased, gravel-injected banks eroded, and some pools deepened. Sediment deposition onto the floodplain indicated successful channel design, and geomorphic alterations have prevented the degradation towards the undersired channel conditions that existed prior to the project (Pittman).
- On Clear Creek, after channel re-construction average annual Chinook salmon spawning area increased from 427 m^2 to 1,534 m^2. During this same period, spawning areas in sixteen control reaches in Clear Creek almost doubled, and juvenile densities increased (Newton).
- Improving habitat quantity and quality are each important. Increased suitability of salmon habitat on restored reaches of Clear Creek was attributed to increased cover at channel bends, retention of the old channel as a backwater, and channel migration that captured mature vegetation (Newton).
- Since the removal of Saeltzer Dam on Clear Creek in 2000, over 3,000 m^3 of sediment eroded from the former reservoir deposit. Downstream aggradation at Renshaw Riffle approached 10% of this eroded volume. Erosion from high flow periods ultimately lead to desiccation and high mortality of riparian trees (Miller).
- Dredge mining in northern California released fine mercury-contaminated sediments throughout Clear Creek and Trinity River drainages. While coarse clasts are at near background concentrations, finer sluice tailings of sand lenses could contain more than 100 times background mercury levels (Ashley). (Also see Mercury, page 56).

Tuolumne River

- The 1995 FERC relicensing agreement for New Don Pedro Reservoir included increased summer base flows for the lower Tuolumne River. This has increased wetted area for riffle habitat by 30% or more in the study reach. In the years since, overall invertebrate density appears to have declined slightly since the new flow regime was initiated and showed reduced year-to-year variability. Community composition has generally shifted away from pollution tolerant organisms and towards those with higher food value for fish (Orr).
- While River 2D habitat modeling predicts a substantial reduction in largemouth bass habitat, preliminary analysis after the Tuolumne Special Pool Run 9 (SPR9) restoration project indicates that the density and abundance of largemouth bass were not reduced relative to control sites. Bass abundance monitoring is not sufficient to link the effects of the project to juvenile Chinook salmon survival and recruitment. The SRP9 monitoring by itself is insufficient to provide the larger-scale context needed to interpret effects on a river-wide scale or population level (Keith).

Sacramento River

- Results from the Indicators of Hydrologic Alteration (IHA) model showed that some of the most significant alterations to the Sacramento River hydrograph from regulation of the river (since operation of Shasta Dam) include a 104% increase in mean August flow, a 78% increase in the number of hydrologic reversals, and a 49% decrease in the magnitude of peak flows (Snowden).

Friant Dam

- Regulation of the Sacramento River has resulted in reduced peak flows and a flattening of the hydrograph; summer flows have increased and spring flows have decreased. This impacts cottonwood recruitment. Seedling recruitment failed due to 1) absence of spring peak flows, 2) limited area available for recruitment, and 3) repeated inundation and limited growth of the seedlings due to hydrologic reversals (Snowden).

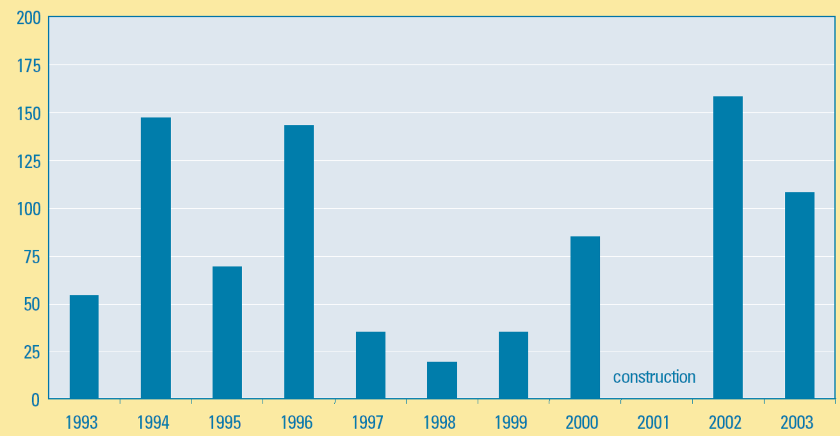
San Joaquin River

- "Recruitment box" models provides a conceptual basis for the necessary conditions (seasonal timing of seed release, suitable bank elevation, and hydrograph timing and rate of stage recession) for seed germination in pioneer riparian trees such as cottonwood and willow. Seed release timing varies between years, likely cued to factor(s) other than river flow. Cumulative heat load based on local air temperature was not a better predictor of seed release timing than calendar time alone for comparisons among sites, but it did predict interannual timing within sites better than simple calendar time (Stella).
- Peak flows on the San Joaquin River have been reduced by an order of magnitude from pre-Friant dam levels. Gravel mining has removed orders of magnitude more gravel than pre-dam annual coarse sediment flux. Channel incision in areas up and downstream of the mine sites suggests there is active bed mobility and transport in the channel at flows below 15,000 cfs (Cain).

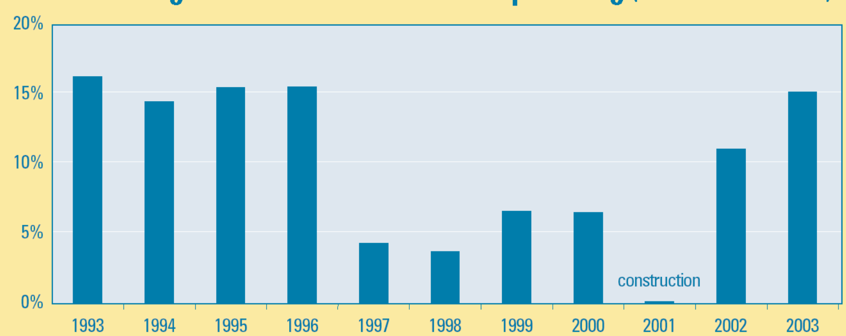
Merced and Feather Rivers

- Salmon are using constructed riffles for spawning approaching pre-1997 levels within the Robinson Reach of the Merced River Salmon Habitat Restoration Project. There was large variability between riffles both in the pattern and distribution of redds (Mager).
- Using January 1997 flood events at O'Connor Lakes restoration project on the Feather River to calibrate a model of water surface elevations and flow velocities, the authors examined three alternative restoration designs. Altering the species composition from trees to low shrubs at one bend in the river changed modeled flow patterns such that high velocity flows were directed to the center of the channel and away from levees (Griggs).

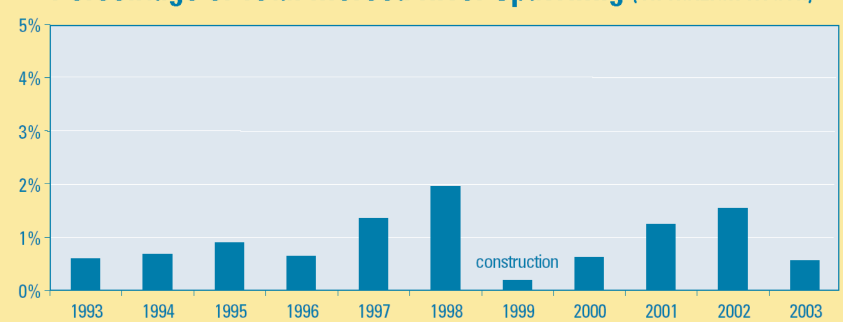
Number of Redds on Robinson Reach



Percentage of Total Merced River Spawning (on Robinson Reach)



Percentage of Total Merced River Spawning (on Ratzlaff Reach)



Salmon spawning on the Merced River has increased following riffle construction on Robinson Reach and Ratzlaff Reach (figure courtesy R. Mager).

MANAGEMENT IMPLICATIONS

- When "downscaling" a river, managers need to consider the width of the floodplain corridor, sediment and flow regime, and balance these with cost and ecological benefits. To achieve CALFED goals we must do better than treat rivers as conduits for moving fish up and down to and from spawning grounds (McBain).
- To set priorities managers need information that allows them to define scale in an ecologically significant manner. For example, a river corridor not only needs to be wide enough for floodplain processes, but also wide enough that the floodplain is ecologically significant (McBain).
- Modeling analyses that are not calibrated by field observations have limits. Standard bed mobility models may understate bed mobility on low gradient rivers and oversimplify complex channel features which affect bed mobility. The San Joaquin River can mobilize sediment at flows less than predicted by the models currently used to make management decisions regarding restoration potential on the river (Cain).
- Models can be used to help test ideas for habitat design, and are a cost effective way to test hypotheses as part of an adaptive management framework. However, is important to validate habitat predictions at several scales (Gard).
- Flow-based restoration strategies could be more feasible and cost-effective if flows can be timed to coincide with seed release patterns. Such high flows may only need to occur one to three times each decade. The most cost-effective approach would be to manage seedling recruitment in wet years (Stella).
- Changes in the flow releases from Shasta Dam to mimic pre-dam hydrology could increase cottonwood recruitment opportunities between Red Bluff and Ord Bend (Snowden).
- Engineered riffle designs can provide suitable salmonid spawning habitat if they are monitored for a suite of attributes that could influence habitat suitability (Mager).
- On Lower Clear Creek, channel rehabilitation has created an appropriately sized, single thread channel that may anticipate future sediment transport and flow regimes. Restoration may require additional gravel injections to create desired geomorphic attributes, and modifications may be necessary to improve floodplain function (Pittman).
- Large-scale restoration efforts need evaluation over multiple years to better understand how hydrologic and geomorphic shifts might inform future project phases and monitoring efforts (Newton, Miller).
- High flows can lead to substantial channel changes years after passive restoration efforts are carried out and funded monitoring periods end. Monitoring periods need to encompass variation between water years (Miller).
- Field recognition of sluice sand in tailing stratigraphy can identify potential sand/gravel sources of mercury before tailings are used for project restoration (Ashley).
- Bulk dredge tailings used for floodplain restoration have had no obvious effect on mercury in biota because methylation does not occur in areas where dredge material is most often obtained (areas of flow or sediment from dry sources) (Ashley). (See also Mercury, page 56)
- Riverine monitoring could be improved by more macroinvertebrate studies. Benthic macroinvertebrates are an indicator of general aquatic ecosystem health, an important food foodweb component, and a key component of natural biodiversity. The California Stream Bioassessment Protocols will likely facilitate long-term monitoring and comparisons both within and among rivers in the Central Valley (Orr).
- Lessons learned from the Tuolumne River SPR9 project include: (1) make sure that monitoring can link project effects to the anticipated ecological response; (2) understand the big picture (i.e., the river-wide or population-level context of the project); (3) don't rely on untested methods for baseline or post-project monitoring; (4) conduct monitoring at multiple spatial scales, nest site-specific monitoring within river-wide or regional monitoring, and (5) minimize and clearly understand constraints posed by different components of the project (Keith).
- 2D hydraulic models may allow for maximizing riparian restoration without compromising the functions of a designated floodway. Effective planting may help direct flows away from infrastructure and reduce potential floodway maintenance costs (Griggs).