CALFED
BAY-DELTA
PROGRAM

NEWS FROM THE CALFED BAY-DELTA SCIENCE PROGRAM

SCIENCE IN ACTION

BIG PICTURE

Reviving Central Valley Rivers

Merced River, Robinson Reach restoration project. Photo by Diana Jacobs

A river is a band of water you cross on the way to California's capital; a bank where you take the kids fishing; that spelling test word with four s's and two p's.

Most of us have very little sense of the river in its entirety, springing from high mountain rocks, crashing down to the valley, widening and winding out to sea. And many of us think of the Central Valley's rivers, so tightly controlled by dams, pumps, canals, culverts, and levees, as little more than pipes that deliver water to our farms and cities, or worse yet, an inconvenience in the midst of an amazing water delivery infrastructure that, despite all our engineering skill, persists in seeking its own course, something we have to keep "fixing" to stop this flood, or this erosion, or this bottleneck for endangered salmon.

A wave of river research and restoration projects coming out of CALFED points the way to a new view of the many rivers and creeks that flow into the Valley, Delta, and Bay. This new research reminds us that rivers can fix themselves. It documents how giving the river back enough water to recreate the seasonal ups and downs in flows, enough land to flood, enough space to move and migrate, enough sediment to build new land for trees and new riffles for spawning salmon, may be an easier and cheaper path to ecosystem restoration than engineering our way out of trouble.

To get us out of trouble—the kind coming our way from the water wars and the Endangered Species Act — farmers, urbanites, environmentalists, and others have all signed on to the CALFED Bay-Delta Program's effort to provide reliable water supplies and restore the ecosystem. CALFED has since invested tens of millions in good solid science to tell us where, when, and how to invest our restoration dollars. And with the help of stakeholders, it has also raised and spent hundreds of millions on actual river restoration. "We can dare now not only to dream of big things, but also to do them," says the California Department of Fish & Game's Diana Jacobs.

Rivers are big things. Restoring a river is not as easy as breaching a dike on a salt pond to make a wetland. One of the biggest obstacles standing in the way of restoration on 95% of all Central Valley rivers are dams, which store and trap most of their water and sediment, two elements the river needs to build fish and forest habitats. Other obstacles are the levees and riprap lining the banks to keep the river in one place, and the homes and farms standing in old floodplains.

But perhaps the largest obstacle of all is our old idea of rivers as a resource from which we extract water for our taps, gravel for our roads, power for our plugs, and fish for our meals. And the engineering mindset that is the legacy of a hundred years of massive water delivery, flood control, and hydropower projects; a legacy that, according to engineer Phil Williams, mistakenly sees the river as a disorganized system in need of simplification.

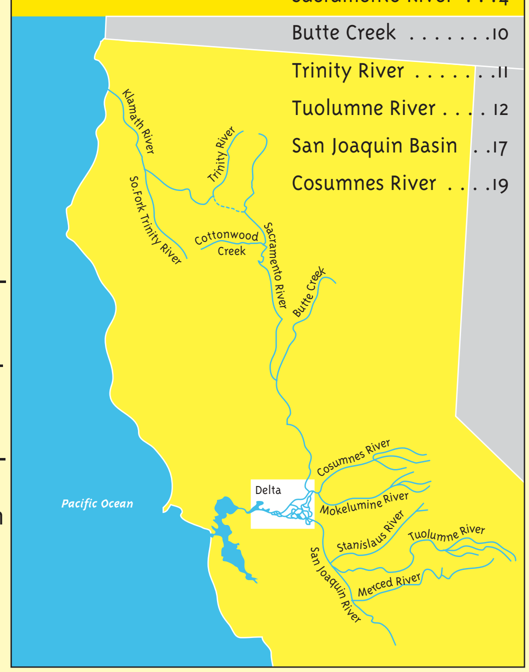
This same mindset has tried to recover our endangered fish by building hatcheries and turning rivers into more and more "efficient" production and conveyance systems to get the fish out to sea, where we can catch and eat them. This same mindset has sought to "mitigate" impacts on the ecosystem with more engineering, rather than attention to the dynamics of the natural system.

The signs are everywhere, however, that our old approach of controlling and harnessing the river may not be sustainable. Levees continue to fail, floods continue to swamp homes, dams never seem to be able to store enough water to slake California's thirst. Young trees are not growing up to replace old ones along the riverbanks, and the new production-line salmon are not as resilient as their wild cousins.

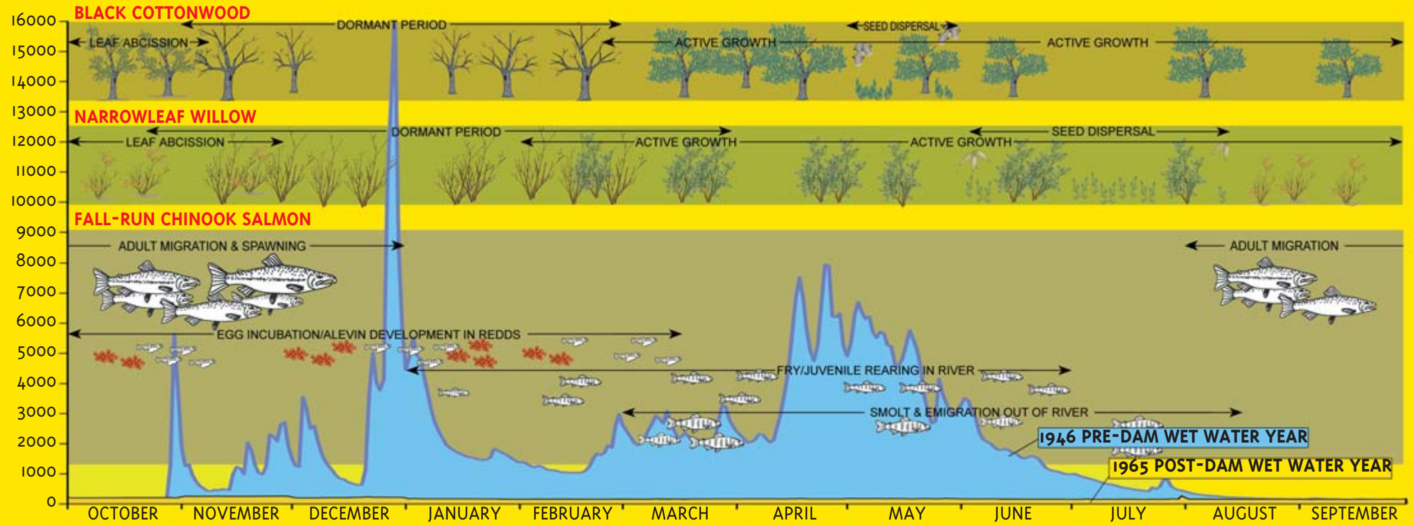
"Our rivers have been bequeathed a legacy of massive engineering projects whose objectives were simplistically defined, whose effectiveness is uncertain, and which were planned in ignorance of long-term impacts on the river ecosystem," says Williams, who has been restoring rivers and wetlands for more than 20 years. "Ultimately, the hardest question, if we commit to restoring our rivers, will not be how to do it, but how long to continue investing resources in perpetuating obsolete riverworks that prevent us from managing rivers in a way that allows them to restore themselves."

Continued page 2

INSIDE: FIVE RIVERS



THE RELATIONSHIP BETWEEN FLORA, FAUNA AND FLOWS ON CALIFORNIA RIVERS



Grand thoughts. Tough choices. While no one's planning to tear down any big dams right now, smaller dams are being removed in places like Butte Creek, with great gains for salmon (see p. 10). Likewise, allowing a levee breach and a flood along the Cosumnes River quickly produced the kind of warm shallow water, good fish food, and fish-friendly vegetation that endangered splittail seem to thrive on (see p. 19)—a sign that not all floods are bad, and that in fact, some floods are very good, at least for the ecosystem.

Elsewhere, along the mighty Sacramento, a failing levee near Hamilton City is not being built up, but rather set back to give the river more room, and an effort to protect a rare stand of valley oak will remove, rather than add, riprap (see p. 4). Here, a growing body of science tells us that allowing the river to erode, deposit, and migrate is critical to the future of the riparian forest and its endangered yellow-billed cuckoo. Farther south on the Tuolumne, restoration designers are trying to rescale the lower river, below three dams, so that it can rebuild its own riffles, pools, and salmon populations (see p. 12). Up north on the Trinity, for the first time in California history, federal mandates are requiring dam operators to recreate the natural seasonal flow variations that make a river a real river in the first place (see p. 11).

"If you understand the patterns and processes of a river, you can see that there is much more order to letting it be free," says U.C. Davis scientist Eric Larsen.

The stories in these pages of efforts to study and restore these five rivers—which range from large to small, and from dammed to straightjacketed to freeflowing—call into question some longstanding assumptions about river restoration and the salmon listings that have driven it to date.

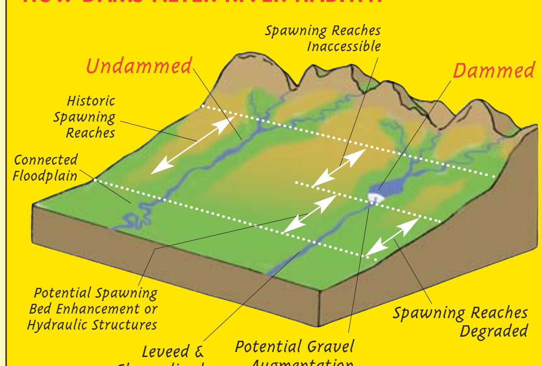
Based on failures to restore salmon in the Northwest's Columbia River basin, the National Marine Fisheries Service's Dan Bottom has come to the conclusion that simplifying the river into a fish transportation speedway from hatchery to sea isn't the answer. In contrast to our efforts to make salmon production more efficient, focusing on one lifecycle at the hatchery and one life strategy for getting the salmon out to the ocean fisheries, salmon themselves are "inefficient," he says. They have multiple life strategies—some are born up a creek, then grow and move out to sea within one year, while others might hang around a year or more before moving from river to ocean, for example. These life strategies evolved in concert with the great variations in their natural environment. "They're not trying to maximize any one thing they do at any one time," says Bottom.

Treating the river like a pipe, he says, favors one life strategy. "We lose all the production potential associated with other life strategies, and the resilience inherent in not all the fish being the same. We need to allow salmon to do what they did best, hedge their bets of survival by expressing the greatest diversity they can. By promoting river processes, you're promoting variation in the environment, and the diversity that comes with it," says Bottom.

The life cycle of cottonwood trees, willows and chinook salmon all evolved in relationship to the seasonal ups and downs of the natural hydrograh of California's Rivers. Large scale alteration of the natural hydrograph by dams has severely interfered with these lifecycles.Source: McBain & Trush

Restoring river processes—how the shape and structure of the river interact with the water that flows through it and the species that grow in and around it—is a priority for the CALFED Ecosystem Restoration Program. Making this a priority

HOW DAMS ALTER RIVER HABITAT



Adapted from Wheaton & Pasternack

reflects a recognition that "fish-centric, species-specific" approaches to restoration will only produce limited successes, according to Tim Ramirez, Assistant Secretary of Water Policy for the state Resources Agency.

It also reflects a recognition that heavy engineering and the river-as-water-supply-pipeline mentality may get in our way. "We still talk about building new dams because water is being 'wasted' by letting it spill from full reservoirs and run down the river out to sea. But these 'spills', the closest thing we have to the small seasonal floods natural rivers once had, aren't a waste, but a great benefit to the ecosystem and fish we are trying to save," says Ramirez.

The priority on processes also necessitates a whole new scale of thinking, planning, and building—a leap from one riffle or boulder weir or fish screen at a time to whole reaches of river, ranging from 10 to 100 miles in length. It is only on such scales that processes, in which water and sediments and seeds and fish interact and change, come into play. It is only on the larger scale that we avoid the pitfalls of "gardening-style" restoration, where benefits are highly localized and often short-lived. For some time now, scientists have been warning us that most restoration projects are too small to have a significant impact on the whole river and lack continuity with other projects within their watershed.

Thinking big isn't easy, and doing it doesn't come naturally to most people in the current constellation of agencies responsible for managing rivers. Nor does it come naturally to the dozens of watershed groups, consultants, river trusts, local irrigation districts, and others working away on their hometown streams and riverbanks. Everyone is now looking to CALFED to provide some top-down leadership, and some conceptual models that will help the people releasing flows from Don Pedro Dam talk to the people restoring spawning gravels below the dam on the Tuolumne, to the engineers worried about flood control around urban Modesto, to the environmentalists and farmers fighting water quality problems in the San Joaquin downstream, and to the managers of the export pumps in the Delta.

"CALFED is testing a rich and creative hypothesis about river restoration," says U.C. Santa Barbara geomorphologist Tom Dunne, who serves on CALFED's Independent Science Review Panel and participated in a recent series of adaptive management forums evaluating work on three rivers. "The hypothesis is that if you manipulate the physical character of the habitat, the biology will follow. We'd like to see gravel move more frequently, water moving across the floodplain more often, the river channel migrating over larger areas. Then we'd like to know how many salmon, how many trees, how many birds, return as a result."

According to Ramirez, CALFED's investment in restoration is more than 400 blue dots on a map. "There's an articulate strategy we've used to make these investments, and science behind this strategy with feedback loops. So wherever you go, wherever people are talking about saving this fish or creating this park, we've given them a new framework for their discussion. We've given them the bare bones they need to start with, the validation they need to continue, and the promise of funding to get it done. Now the burden of proof is on all of us to show that this restoration approach will work." ARO

DEFINITIONS

SALMON 101

Ever since Pacific coast salmon received protection under the federal Endangered Species Act, these remarkable fish have inspired many efforts to protect and restore the California rivers where they live. Because salmon cover so much territory as part of their lifecycles, from mountain streams to deepwater oceans, they are often considered the totem animal of ecosystem protection.

The most notable characteristic of salmon is their ability to change the way their bodies function so they can migrate between freshwater and salt water. A salmon's life begins in the river where its parents were born. The female salmon turns on her side and undulates to create a depression in the gravel where she lays her eggs. She then covers up the nest, which is called a redd. Redds can be more than 10 feet long, although to the untrained eye, they may simply look like piles of gravel.

The eggs hatch after about 50 days in 50°F water, depending on individual species. When they hatch, the tiny fish are called "sac-fry" or "fry". They remain in the gravel for 2-3 weeks while they absorb their yolk sac.

When salmon emerge from the redd they are called "swim-up fry" or "alevins". As they grow and get the silvery gray color and barred pattern on the sides of their bodies, they are called "parrs".

Once they undergo the physical changes that allow them to live in a saltwater environment, they are called "smolt". Most salmon live in the ocean for 3-5 years before returning to their natal streams to spawn.

Because salmon have adapted so well to specific rivers and streams, scientists say there are marked differences between hatchery-raised fish and naturally spawning salmon. Salmon are also divided into runs, depending on when they enter freshwater to spawn. The Sacramento River is the only river in California that is home to all four runs of salmon: fall-run, late fall-run, winter-run, and spring-run. Chinook salmon in the San Joaquin River below Friant Dam disappeared in the early 1950s because of habitat degradation and dams that blocked the fish from reaching their spawning grounds. Currently, seven Pacific Coast chinook salmon runs are listed as threatened or endangered under the federal Endangered Species Act. SZ

Female salmon guarding her redd. Photo by Carl Mesick.

SACRAMENTO RIVER

Forests Round the Bend

Using the "M-word" can be a turnoff to people who live along the Sacramento River. Indeed, for decades the "meander"—in the sense of the winding river—has been as much of a problem to suppliers interested in moving water fast, to engineers protecting home and hearth from floods, and to farmers who've been fighting the river back from their land for generations, as it is now a solution to scientists trying to save the last of the river's birds, beetles, and forests from the long line of riprap along its shores. Slowly but surely, however, longstanding efforts to lock in and line up the mighty Sacramento have been making way for a few meanders.

Meanders come naturally to "the Sac," as locals call it. John Muir once described its lower reaches as "very crooked, flowing in grand lingering deliberation, now south, now north, east and west with fine un-American indirectness."

The Sacramento is different from every other river in the Central Valley for one reason: it's much bigger. "It's a real river, huge and mysterious, just like in *National Geographic*," says the Department of Water Resources' Stacy Cepello, the biologist at the heart of almost everything to do with managing the Sacramento. "It's big, long, and has almost all the fish, all the water, and all the sediment." Indeed, the Sacramento River provides 80% of the Bay-Delta watershed's drinking and irrigation water, 90% of the sediment needed to sustain wetlands and shoreline habitats, and 80% of the chinook salmon caught downstream in ocean fisheries.

Its sheer size and a few other key factors have made the Sac a good candidate for restoration. First, despite all the concrete on its shores and Shasta Dam at its headwaters, at least 100 miles of the river still retain important characteristics of a natural river system. Second, it's at the top of the Central Valley water supply pipeline rather than at the bottom, where the San Joaquin River, for example, cannot avoid what one observer, who asked to remain anonymous, called "the huge river killer sucking all the water," namely the pumps that import the river to kitchen sinks, irrigation ditches, and driplines statewide. Third, the Sacramento gets new water inputs below Shasta Dam from several large, free-flowing tributaries.

Sacramento River. Courtesy The Nature Conservancy

All of this is why a swarm of CALFED-funded scientists have singled out the 100 miles of river between Red Bluff and Colusa for research on how riparian plants and animals benefit from disturbance (floods, erosion, deposition, and meandering) and suffer from stability (concrete culverts, riprap, and reservoirs). And why public entities at all levels—federal, state, county, and city—as well as environmental groups and local landowners, have been working for over 15 years to try to square a desire to restore the river with the realities of local agriculture and recreation.

Monitoring bat use of the riparian forest along the Sacramento River. Photo by Nature Conservancy.

It started in the 1980s, when a huge Army Corps plan to "rock the river" to prevent bank erosion produced a backlash. Opponents of the plan organized a new river trust and filed lawsuits. The resulting stalemate led to the 1986 passage of a bill requiring all interests to cooperate in developing a Sacramento River Management Plan. The planning process spawned an advisory group, CALFED participation, and later the Sacramento River Conservation Area Forum, a nonprofit providing ongoing opportunities for open discussion about how restoration actions along the river may or may not impact local counties, towns, farms, and homes. The forum has since helped facilitate the acquisition or restoration of more than 15,000 acres along the river between Red Bluff and Colusa—jumpstarting what may now be one of the largest riparian forest planting projects in the world.

In addition, Cepello and his agency have built a mind-bending computer map of the Sacramento River, adding layer upon layer of information about land use, soils, hydrology, vegetation, and the like. These GIS (geographic information system) maps identify an inner river zone where the Sacramento once did, and could again, flood and meander, and they have become the first critical building blocks for many other people working to refine humanity's relationship with the river.

"The fundamental issue we're tangling with is how to co-exist with a dynamic system, a forest that needs to burn or a river that needs to meander," says Cepello.

Not so long ago, forest managers were as avidly suppressing fires as engineers were fighting floods and straightening meanders. But just as we've learned that terrestrial forests need to burn now and then to regenerate, so also we're learning that the cottonwoods and willows along the river need the ups and downs of erosion and deposition, the ins and outs of river bends and cutoffs, the flush of winter and spring floods, to thrive.

"The physical dynamic process that drives the creation of the riparian forest is the movement, on a landscape scale, of the river across the floodplain," says Cepello.

How did we learn this? By hiring half a dozen U.C. Davis, U.C. Berkeley, and Cal State Chico scientists to investigate the direct links between physical processes and biological response. These CALFED-funded scientists, and others like Cepello working in state agencies and groups like the Nature Conservancy, are producing a whole new body of research on forest regeneration processes along the Sacramento River, as well as new restoration tools to help us decide how and where to plant new trees, clear weeds, allow meanders, remove riprap, and promote flooding, and what kind of future wildlife habitat to expect from it.

The cottonwood tree, and its willowy compatriots, figure large in all this research. Over 500,000 acres of riparian forest that included these species once bordered the entire Sacramento River, but only about 25,000 acres remain. Today, river processes have been so arrested that many seeds cannot grow from seedlings to saplings to trees. Any observer floating the river will see many more stately, silvery barked, 80-year-old cottonwoods on the upper banks than the middle-aged and younger trees lower down the banks that are meant to follow in their rootsteps.

So why aren't the young trees getting a chance to grow up? As riparian ecologist John Stella explains it, cottonwoods and willows are pioneer species that colonize new land and thrive, like weeds, in disturbed habitats. Their strategy is to get there first in large numbers, and like Jack London and James Dean, "live fast and die young." They release seeds so small, light, and hairy (hence the name cottonwood) that they drift into everything—mouths, tractors, fields—downriver. But these tiny packages of life are only viable for a few weeks, unlike oak acorns, which can lay around for months and still grow a tree.

Cottonwoods evolved to release their seeds in the spring, after flashy winter floods had swept away old vegetation and laid down new sediments, creating perfect seedbeds. They evolved to make the most of heavy spring flows, sending their roots down deeper and deeper so they could reach groundwater by the time summer scorched the earth. But modern-day dam operations have made winter flows less powerful (producing fewer seedbeds) and spring flows less sustained (flows recede so quickly roots cannot keep up with them). These hydrologic changes, and riprap blocking so much of their turf, leave seeds germinating at much lower elevations on the bank, where they often get wiped out by the next winter's storms. As a result, cottonwoods are now producing a good "cohort" of saplings much less frequently than they did naturally (natural regeneration rates are every 5-10 years, in conjunction with wet years). "Their fate is tied to the fate of the river," says Stella.

These ties are not only to the river's flows, but also to its meanders and shape-shifting. "People have historically thought that a migrating, eroding channel meant something was wrong, that a raw riverbank was a bad bank," says U.C. Davis' Eric Larsen. "But the river is not alive unless it's migrating. All its ecological processes are built on the basis of the river moving across the floodplain."

Larsen has documented the Sacramento's movements over the past 130 years. He has also created a numerical model to predict channel migration "tendencies" into the future, and field tested the model, which combines the fundamental physics of fluid mechanics and sediment transport, on several erosion problems and restoration projects.

For the Woodson Bridge area, for example, he plugged four different riprap management scenarios into the model—seeking clues as to how to protect the rare big stand of valley oaks in this state recreation area. But rather than the obvious method of protection—more riprap—his model suggested removing riprap upstream. "Effects translate downstream," says Larsen. "If you riprap the bank in front of your home, you may be sending your erosion problem downriver to your brother-in-law." Larsen's model projects that letting the river go free above Woodson would produce three times as much meander migration and three times as much forest regeneration as no action. Larsen is now trying to tease out how much meander dynamics depends on geology, how much on the sheer force of the water, and how much on people (reservoirs, riverfront development, and riprap).

Riprap certainly thwarts channel migration. This mix of rock and broken concrete armors over 50% of the

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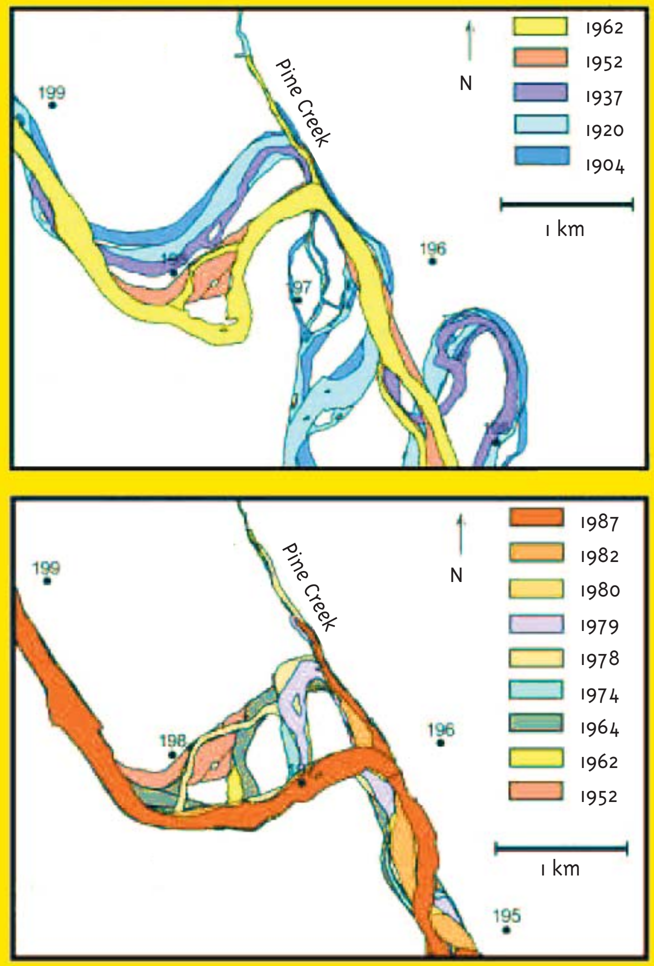
HISTORIC PINE CREEK BEND MIGRATION



Historic migration of the Pine Creek bend on the Sacramento River. The dynamic migration of the channel, as shown between 1904 and 1962, is dramatically limited by the installation of rip rap in the 1970s, as shown in the sequence between 1952-1987 (adapted from a graphic by Ellen Avery). Source: Greco & Larsen

Forests Round the Bend

Sacramento's shores between Red Bluff and Colusa. A recent government whitepaper on riprap documents how point bars opposite a riprapped bank have a steeper angle than natural point bars, producing less cottonwood habitat.

Opposite riprap, floodplains get older and higher over time, rather than providing the young, lower substrates cottonwoods prefer. "When the river is locked up, cottonwood communities just age without being replaced," says U.C. Davis' Steve Greco.

Greco and Larsen have been working together, and with grad students like Alex Fremier, to link the physical variations in the river's size and shape with vegetation growth. "The health of these plant and tree communities is based on disturbance," says Greco. "Just as we used to think all fire was bad, we've thought all erosion was bad, but there's a flip side. When a riverbank erodes, the sand gets redeposited on a point bar, a new substrate where no plants have ever lived before. This is a very special process. Only volcanoes, glaciers, tectonic shifts, and river meanders can make new land."

The river makes new land through bend migration and bend cutoff (see diagram). "A cutoff produces an intense burst of cottonwood regeneration," says Greco, whose research suggests that a full third of the forest regeneration at two sites near River Vista and Wilson's Landing are attributable to cutoffs. Analyzing aerial photos from 1937-1999 through GIS, Fremier found a significant correlation between channel migration and vegetation patch size, among other things.

The age of the floodplain and its elevation also affect cottonwood success. These two variables can help us identify the narrow band along the river where cottonwoods best survive seasonal extremes. In a GIS environment, Greco has mapped the height of the land above the mean summer low flow (about 8,000 cfs) over the past 50 years. He then subtracted the summer low flow elevation from the floodplain surface elevation to get the relative elevation roots need to reach to survive. This elevation model has helped field scientists predict where cottonwoods may occur over a much larger area than they can predict from on-the-ground surveys.

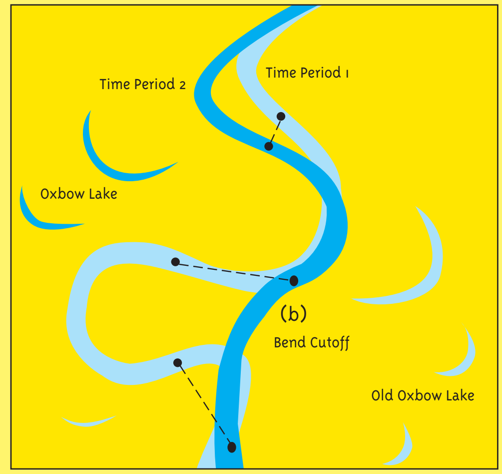
The elevation model is just one of several modeling tools Greco is crafting to help land and water managers assess the restoration potential of river sites. Combining historical maps, old flow gage records, aerial photos, and plant surveys, he's developed a floodplain age model staking out the meander zone over the past 130 years, models of where the water is above and below ground in summer dry periods, and a riparian vegetation community survey and classification, which can help predict habitat suitability for endangered species like the yellow-billed cuckoo.

More clues and tools for fixing the Sac's forests are emerging from research on other rivers. For the past year, John Stella has been examining the lower Tuolumne River, which is smaller than the Sac and in a warmer part of the Central Valley, pushing the seed release period earlier. Part of his work has been with Stillwater Sciences, and part as a U.C. Berkeley doctoral candidate with a CALFED Science fellowship.

Stella's aim has been to field test a "recruitment box" conceptual model describing the window of optimal conditions for recruitment success for cottonwoods and two species of willow. In 2002, the first year of a three-year study, Stella tracked the seed release intensity and timing for all three species at sites along the Tuolumne and San Joaquin rivers. He also collected open catkins (the seed-producing part of the tree) from each of the three species and germinated the seeds in petri dishes to assess their viability period. He installed wells and sensors along the river to measure river stage, water table depth, and soil moisture. He planted 734 seedlings in PVC tubes filled with river sand and subjected them to five different water table decline scenarios (constant and 1, 3, 6, and 9 centimeter, or cm, drop per day)—tracking effects on root growth and mortality. He also surveyed natural growth and survival at three sandbar sites, and canoed up and down the river documenting the composition, density, and topographic distribution of seedlings.

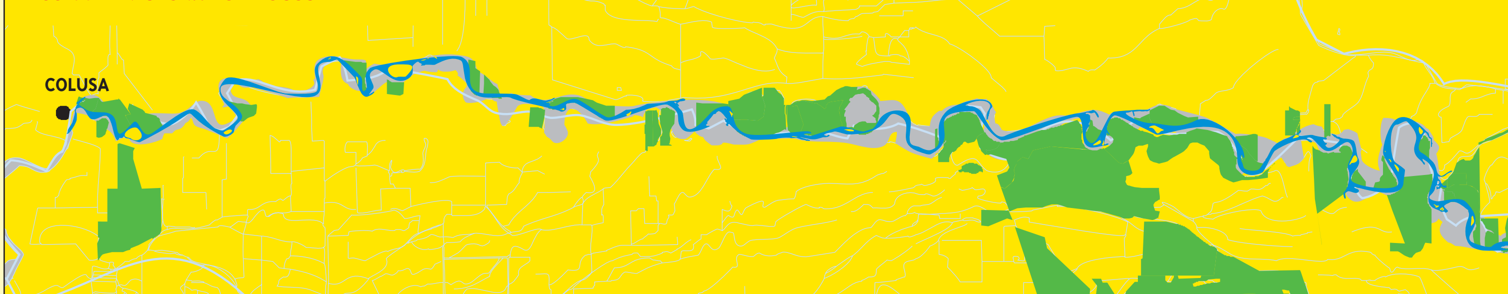
His preliminary results suggest that not enough seedlings took root in appropriate locations along the lower Tuolumne to result in a viable cohort for the next year. A spring flow release, conducted under an agreement to help salmon smolts (Vernalis Adaptive Management Plan, or

RIVER BEND CUT OFF & MIGRATION



Source: Steve Greco

SACRAMENTO RIVER
100-MILE RESTORATION FOCUS



VAMP), came too soon, before the peak seed release period. Stella says the 1,300 cfs maximum smolt release was really too low to place the seeds in more optimal conditions higher up the riverbank. But 2002 was a below-normal year for wetness. Future wetter years might yield VAMP flows (which are pegged to wetness) high enough to benefit the cottonwoods and willows, as well as the fish.

"Using flow as a restoration tool is expensive, and timing is as crucial for these trees as it is for salmon," says Stella. "But knowing the seed release period can be a critical local cue for managers trying to integrate riparian tree restoration with salmon protection and other ecosystem measures."

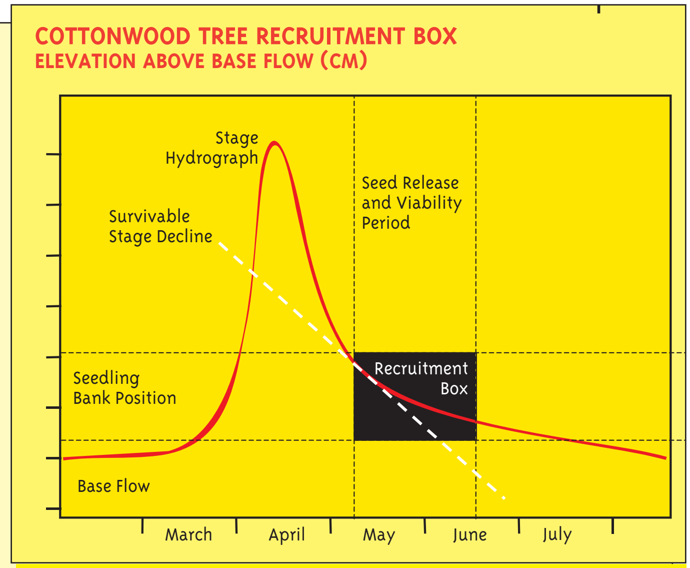
Like Greco, Stella was trying to pinpoint the water levels above and below ground necessary for seed and tree survival. He found that most seed germination in his study plots occurred no more than 35 centimeters above summer base flow—too low on the floodplain, and too susceptible to getting wiped out by next winter's floods. Studies on other rivers, including Stella's work on the Merced, indicate that successful recruitment generally occurs between one and a half and two meters or more above base flow.

In terms of the water table recession rates tolerated by the seedlings in the PVC tubes, 100% died at rates of 6-9 cm per day and 80% at the 3 cm rate, while less than 30% died under the two more gradual drops. By comparison, the VAMP-regulated pulse flow dropped by an initial rate of 7-18 cm per day at sites gaged, or an overall month-long rate of 3 cm per day.

The lack of a gradual drop in the spring flows is also a problem for the cottonwoods along the Sacramento River, but for a much fishier reason. "They shut the river off each spring when the Delta is being managed to protect endangered smelt, at just the time when our trees are releasing their seeds," says the Nature Conservancy's Mike Roberts.

Roberts is conducting field studies at three sites along the Sac to develop his own recruitment box. So far, his work suggests that the bottom of the box lies a couple of feet higher than the level documented for smaller rivers, such as the Tuolumne, where winter scour is not as severe.

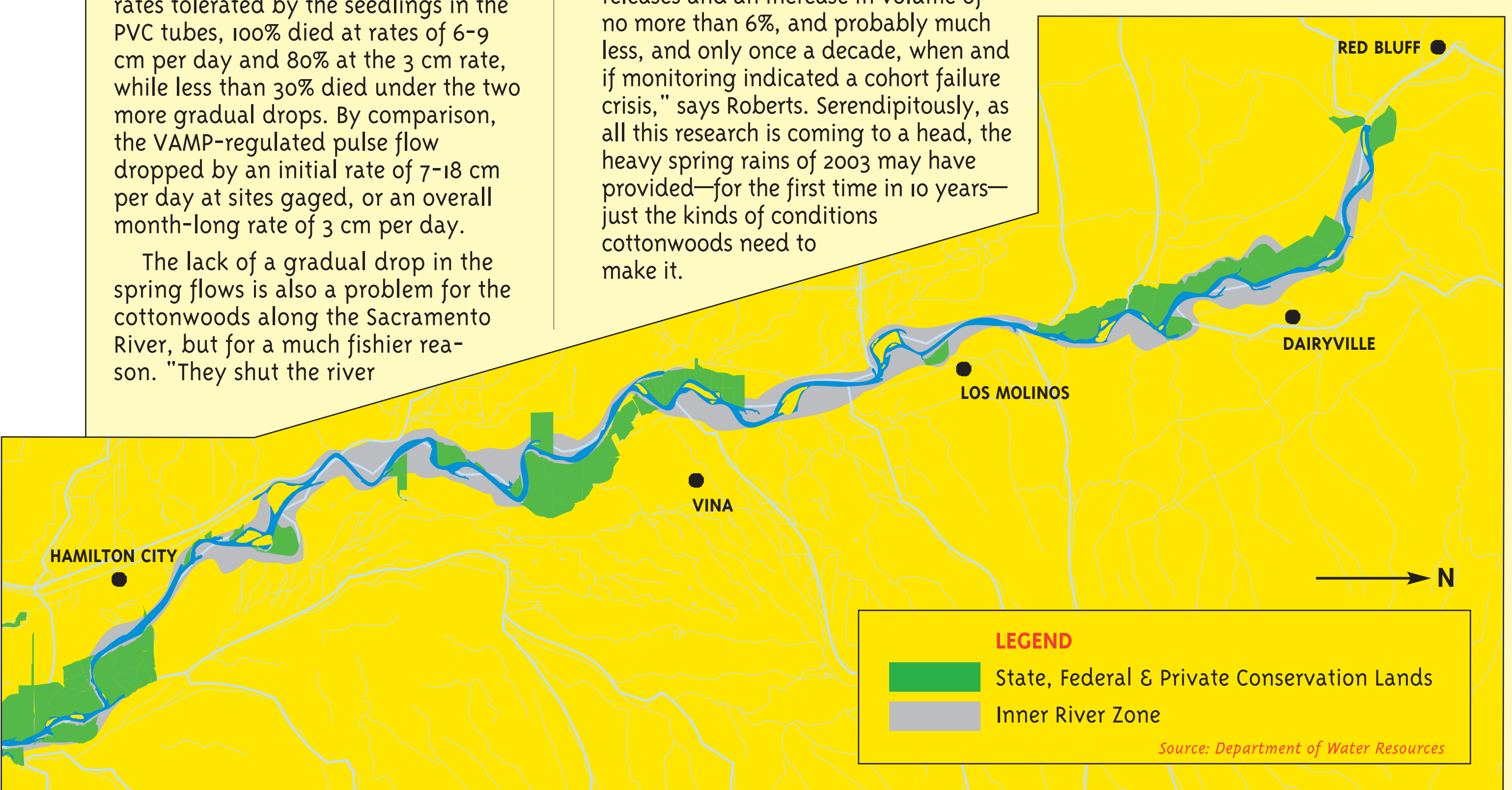
Roberts has also tried to pinpoint what changes water managers would have to make in wet years, when cottonwoods normally recruit, to help the beleaguered trees distribute seeds and put down roots. "The good news is that all we have to do is beef up what the river's already doing in wet years. We're talking a change in the timing of releases and an increase in volume of no more than 6%, and probably much less, and only once a decade, when and if monitoring indicated a cohort failure crisis," says Roberts. Serendipitously, as all this research is coming to a head, the heavy spring rains of 2003 may have provided—for the first time in 10 years—just the kinds of conditions cottonwoods need to make it.



The "recruitment box" conceptual model (redrawn from Mahoney and Rood 1998). The box describes the window of optimal conditions for seedling recruitment and is defined spatially by bank elevation relative to river hydrology and temporally by the spring seed release period. The sloping line within the recruitment box represents the maximum survivable rate of water table decline, which for obligate phreatophytes ("water-loving" plants whose roots need perennial water table contact) is a function of root growth rate, water table elevation, and height of the capillary fringe, the zone of unsaturated soil above the water table. In the recruitment box model, water table declines steeper than the sloped line will not support successful establishment. *Source: John Stella, Stillwater*

(Scientists are still checking.)

Despite the high hopes for this year's cohorts, the long-term trends are disturbing. Greco's models and



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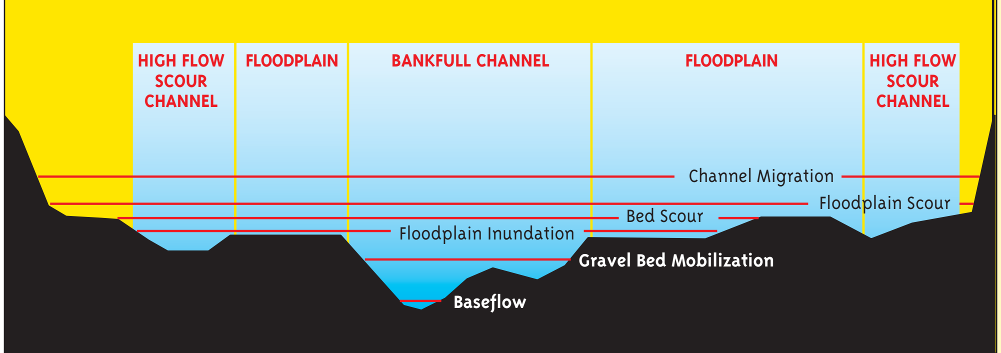
GENERIC GEOMORPHIC RIVER CROSS SECTION



Source: Cain, adapted from McBain

field surveys indicate a major shift in what he calls the "conveyor belt" of succession stages in the riparian forest. First on the belt, colonizing new land, are the willows, followed by cottonwoods in and among them. Once the cottonwoods get older, they should give way to oak. But the oak and the cottonwood both seem to be getting dumped off the end of the belt. "When you don't get cottonwood, you get box elder; and when you don't get oak, you get black walnut," he says. Greco calls the box elder a completely "new forest type" for the lower floodplain, a type that has never been mentioned in historical accounts of the Sacramento River and has much less habitat value.

Pinpointing the value of these projects, both for the ecosystem, and for the taxpayers underwriting them, is also a hot science topic of late. For riparian forests, success has often been assessed by the survival and size of planted trees or the number of yellow-billed cuckoo nests, among other things (see Songbird Surveys p.9). But success measures are getting much more sophisticated. Cal State Chico's David Wood, for example, compared Nature Conservancy restoration sites near River Vista planted in 1993 and 1999 with a 40-year-old remnant riparian forest nearby, and found that soil bulk density and carbon levels proved a better indicator of good ecosystem function than nitrogen mineralization.

Another good indicator could be running around on six legs. One of Wood's students, John Hunt, surveyed ground-dwelling beetles and found 188 distinct "morphospecies" on the Sac River floodplain. Hunt sampled remnant habitats and young and old restoration sites and found species richness increased as habitats aged.

Bats, which roost and forage in riparian forests, also make a notch the success or failure yardstick. Their responsiveness to changes in habitat quality has put them on a developing list of ecological indicators crafted by the Nature Conservancy and Stillwater Sciences. The indicators are part of a larger "Framework for Ecological Health" designed to provide restoration partners with a common standard for all projects (including specific research, follow-up monitoring, and evaluation protocols) —an adaptive management rigor now required for CALFED-funded projects.

Cepello thinks all these indicators are starting to add up to something. "The magic number seems to be 10," he says, looking back over more than a decade of what he calls the "Chinese army" approach to forest restoration on the Sac—hands-on planting of over 5,000 acres on largely higher elevation sites not likely to be eroded by the river in the near term. In other words, after 10 years, the planted forest begins to function more like a natural forest, with all its worms, insects, beetles, birds, and bats.

"Horticultural practices need to go hand in hand with restoring natural processes, because there isn't enough water to go back to the past, pre-dam, environment," says Stella. Indeed, many scientists agree that planting is a critical tool for jump-starting vegetation on such a degraded riverway.

Much of the "cultivation restoration" has been done by the Nature Conservancy. Since 1989, the organization has undertaken 35 restoration projects on 13 different properties between Red Bluff and Colusa. On the Chico Landing reach—20 miles of river fronted by a patchwork of public and private land just south of Hamilton City—the Nature Conservancy has been trying to think big. This thinking big reflects the latest restoration planning and river management shift from working on one river bend or riffle to whole 10-20 mile reaches—a leap in scale that is a natural outgrowth of the new focus on the dynamics of the river's ecosystem.

"We want to restore processes, not just place," says Mike Roberts. "For the first time, we're ignoring boundaries within our own parcels and thinking and planning on a landscape scale. We want to take 4,000 acres and get all the management goals aligned, so we can get the best ecosystem bang for the buck."

In and around Chico Landing, named for one of the last stops on the historic route of the steamboat from the capital, the Conservancy has undertaken a collaborative restoration planning process with county governments, local landowners, and regulating agencies. This "sub-reach" plan, and others for other reaches, seeks to identify large, landscape-scale conservation actions that have minimal impacts on neighbors and other third parties, conserve farming and local economies, and protect

House at the top of failing "J" levee near Hamilton City. City residents and local government are getting a taste of the new approach to restoration along the Sacramento River, working with the Army Corps, the Department of Water Resources, the Forum, the Nature Conservancy, and others to replace an old and failing levee that can no longer protect the city from floods with a setback levee that will give the river more meander room. The project design meets both ecosystem and flood control objectives, and puts restoration dollars to work to protect the homes and livelihoods of local residents and farmers.

flood control and other infrastructure. "It's time to incorporate humans into our landscape conservation efforts," says Roberts.

There were few humans in sight when this reporter visited the Chico Landing area, but a meadowlark flushed with sunset colors chirped a welcome. The visit took us to "before" and "after" restoration sites.

Cottonwood seedlings in new point par

Almond orchards lined up across tidily tilled earth in one quarter of the "before" site, while in another quarter, a freshly furrowed field was being prepped for field crops designed to suppress weeds. In the distance, a thicket of green trees, and happy hopping red-winged blackbirds, were the only hints of the nearby riverbank. For this 670-acre "Capay/RX Ranch" area, the Conservancy hopes to promote more flooding on conservation lands, to take the pressure off neighboring private farms, and one day restore a mosaic of savanna, grassland, and riparian forest habitat.

Downstream at the "after" site, there are tons more trees. Tall cottonwoods, flanked with brambles and brush so dense this 13-year-old riparian forest seemed impenetrable, grace Phelan Island, a federal wildlife refuge. Though planted by the Conservancy in 1989, there isn't a trace of the straight rows of seedlings, carefully irrigated and flooded, that grew up into this jungle today. Nor of the secretive endangered cuckoos nesting somewhere in the treetops.

"Restoring river processes is the most proactive approach yet to long-range species recovery and the avoidance of future species listing and regulation, which is a headache for everyone," says Roberts. "But we can't achieve large-scale restoration without the participation of the communities who live and farm along the riverbanks."

Scientists like Greco are now suggesting that the meander belt is a place where farming should be limited. The target size for any such belt on the Sacramento River, according to CALFED and the forum, should be at least 30,000 acres if the goal is to create a self-perpetuating forest.

Restoration on that scale promises water and land-use conflicts, to be sure. But at the very minimum, all this new science, collaborative planning, and outreach may have translated the M-word into something more positive than nature "out-of-control." ARO

SONGBIRD SURVEYS

Lazuli bunting. Photo by Rick & Nora Bowers

Singing signals of restoration success are the many songbirds that inhabit the riparian forest. The results of 11 years of monitoring the birds' use of 30 sites along the Sacramento River, and of comparing the ways in which they use newly restored sites to the ways they use reference sites—old-growth riparian habitat—are suggesting changes in the way sites are shaped, planted, and managed.

The Point Reyes Bird Observatory undertook monitoring of 30 sites between Red Bluff and the Sacramento River's confluence with the Feather River. Some of the avian parameters Observatory scientists looked for included productivity (number of young per nest), number of breeding territories, nest success, species richness, and species diversity.

One big lesson learned, says the Observatory's Geoff Geupel, is that planting linear strips of trees along the river is not enough to bring back songbirds, and may even harm them by encouraging predators like raccoons to hunt in a "trapline" manner. Instead, songbirds need buffered patches or clumps of habitat with a diverse canopy and understory—a habitat mosaic, says Geupel. Yellow warblers, song sparrows, warbling vireos, and other riparian species all depend on a diverse riparian structure because many of them nest only 3-5 meters off the ground. The Observatory has found that songbirds like to use patches or "clumps" of habitat consisting of shrubby willows, tall cottonwoods, mid-level alders, box elder, and valley oaks, with an understory of hedge nettle, mugwort, native sedges, and other herbaceous species.

Another lesson bird scientists have learned during the past decade of monitoring is that allowing rivers to flood—to experience high-water events—is important, possibly more important than spending $10,000-$20,000 per acre on planting efforts.

Photo by Ron Saldino

"In the past 10 years, we've seen two major flood events on the Sacra-mento," says Geupel. "They do wonderful things for the wildlife populations: they knock back predators, they regenerate the understory, and they change the soil disposition." Restoring hydrology is as important for the river as it is for birds, stresses Geupel. For example, yellow warblers like to nest and establish territories in willows hanging over water. If water levels in the river are controlled, a "bathtub-ring" effect is created, causing the willows to die back and destroying optimal yellow warbler habitat.

The Observatory also recommends a multi-species approach to riparian restoration rather than focusing only on endangered species. Geupel says that by working to help all 14 riparian species—including yellow warblers, black-headed and blue grosbeaks, lazuli buntings, song sparrows, spotted towhees, and others—resource managers can ensure a healthy riparian ecosystem in the future. LOV

BUTTE CREEK

Unbuild and They Will Come

It's no secret that dams and diversions are barriers to bringing back healthy fisheries in our streams and rivers. So restoration on Butte Creek, a tributary to the Sacramento River, has focused on removing those obstacles. Results so far, in terms of salmon numbers, have been heartening. But follow-up monitoring suggests that the life strategies of this species may be more variable, like the marine and riverine systems they evolved with naturally, than we thought.

On Butte Creek, a coalition of stakeholders—including the California Department of Fish & Game, local counties, environmental groups, and farmers—has removed five dams, giving adult fish better access to habitat upstream; built eight new fish ladders where dams could not be removed (six more ladders are in the planning stages); and installed five screens at diversion intakes where juveniles had previously been sucked onto agricultural fields (three more screens are in the works).

But perhaps most importantly, says Fish & Game's Paul Ward, the group acquired from local ranchers the permanent use of instream water rights — 40 cfs from October through June — which allowed it to put more water back in the river. "It's the first time the State Water Code has been put in place for instream use for fish and wildlife," he says.

As a result, the number of spring-run chinook returning to Butte Creek has increased from 1,400 fish in 1996 — and only 635 fish in 1997 — to almost 9,000 in 2002. While several naturally wet years helped, Ward is convinced that the additional guaranteed flows and the structural solutions that were implemented have had a huge impact. Since 1995, almost half a million spring-run chinook were counted in a fish trap installed at the base of the new fish screen at the Parrott-Phelan diversion near Chico, says Ward. Those fish would have been lost to rice and row crops, or to orchards, before.

Seven years ago, Fish & Game started tagging 1.5-inch-long juvenile chinook salmon. Doing this involves capturing the fish at the Parrott-Phelan diversion, taking them to a tagging facility, and then giving them an anesthetic, cutting off their adipose fins, and inserting tiny, coded metal tags into their noses. Once the fish recover from the anesthesia, they are released back into the creek.

Since 1996, over 500,000 fish have been tagged, and biologists are seeing returns from sport and commercial ocean harvests, as well as fish that haven't been caught. The tagging effort has yielded some surprising life history information about spring-run. Says Ward, "We had assumed that spring-run went out primarily as yearlings. But we're finding that the vast majority of them go out as the young-of-the-year." In other words, fish that hatch beginning in mid-November are moving down the creek from then through April, sometimes into May and June.

Another surprise tagging result was that while biologists thought most of the returning fish were three-year-old adults, some of them are four- and five-year-old fish. Ten percent of the fish tagged in 1998 came back as four-year-olds in 2002, says Ward. This is important to know, explains Ward, because historically, Central Valley salmon returned as early as age two and as late as age seven, the older fish as survivors of adverse environmental conditions like multi-year droughts. Human impacts—hatchery practices and fishing regulations that target larger fish—have reduced the returns to mostly age-three fish, says Ward, eliminating the ability of the fishery to survive extended adverse physical conditions.

"Our project, which is the first and only one to tag large numbers of wild spring-run, is showing us that by the time a Butte Creek fish reaches age four, most are harvested in the ocean/sport fishery," explains Ward. "So any return of fish to Butte Creek older than age three is good news."

Fish & Game's Diana Jacobs says that the large-scale tagging effort sets Butte Creek apart. "What's different is that we're learning to build sophistication and continuity into our monitoring. We've gone from just counting carcasses to snorkeling with live fish and tagging."

The next step, says Jacobs, is to figure out the carrying capacity of the creek as it has been recreated. "We've

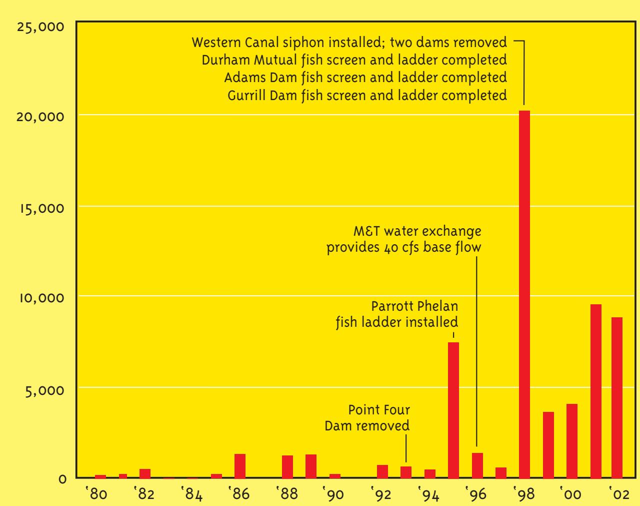
Salmon tagging. Courtesy Paul Ward.

set ourselves up to continue asking these questions," says Jacobs, "and we'll feed our results into national salmon recovery planning efforts."

To Ward, one of the most exciting aspects of restoring Butte Creek has to do with counting heads, not fish tags. Says Ward, "The real story for me is that people who work in this business used to take the attitude that we were doing 'God's work' and that everybody else should get out of the way. With that approach we had some colossal failures." Butte Creek was different, he says. "Before we did anything, we got the local constituents involved—the environmental groups, the ag folks, the counties—we tried to involve everybody. That way, people are generally satisfied that what we're doing is worthwhile." LOV

BUTTE CREEK RESTORATION MEASURES

NUMBER OF SALMON



Recent evalutations, based on new and more accurate counting methods, suggest that the salmon numbers shown above are low. The new methods are still being finetuned.

TRINITY RIVER

Fish Need Rivers

Knocking down a tree might not seem like the start of an innovative scientific endeavor or a way to save salmon, but in the case of the Trinity River, that's exactly what it was. Hydrologist Scott McBain and botanist John Bair toppled about half a dozen trees back in 1995, during their search for ways to restore the natural processes of the Trinity, which flows both into the sea via the Klamath River, and into the Sacramento River via a diversion. What began with a few trees has now grown into a mountain of pioneering science aimed at meeting federal obligations to restore the Trinity's salmon fishery to levels that existed prior to construction of the Trinity Dam in 1964.

The dam reduced Trinity salmon stocks by diverting as much as 90% of the river's water. In addition, it prevented flood flows that once scoured banks, refreshed spawning gravel, and reshaped the river. As a result, willow and alder invaded the banks and trapped sediments, creating what scientists call "riparian berms", or mounds of sand and vegetation. The alders—and the berms—had to be removed to improve fish habitat.

McBain started taking out trees because he wanted to find out whether simply releasing more water from the dam could do the job of removing the river's armor and reconfiguring the river. He rounded up a bulldozer, attached a tensiometer to an alder, and pulled. Then he did it about half a dozen more times.

"We were able to go back and compute how much flow it would take to get rid of those alders and start restoring the river," McBain says. "We found that the dam couldn't release that much water. Essentially, the outflow pipe is too small to remove the mature riparian vegetation with dam releases alone."

This was just one study among dozens conducted on the Trinity River, one of the most studied rivers in California. From 1997 to 1999, a team of scientists from the U.S. Department of the Interior, the state of California, and the Hoopa and Yurok tribes, which hold historic fishing rights, as well as several independent scientists, drew on this abundance of information in a series of week-long meetings to come up with the basis of a plan to restore the river while maintaining deliveries of water to utilities, cities, and farms.

This was a big job. Since construction of the Trinity dam, runs of naturally spawning salmon had declined from an average of 62,000 fall-run chinook to as few as 5,000 in 1991. Many environmentalists wanted to remove the Trinity Dam (and the smaller Lewiston diversion dam below it), but this wasn't politically possible. For their part, water and power users didn't want diversions reduced. The final plan was a compromise laboriously staked out by the science team.

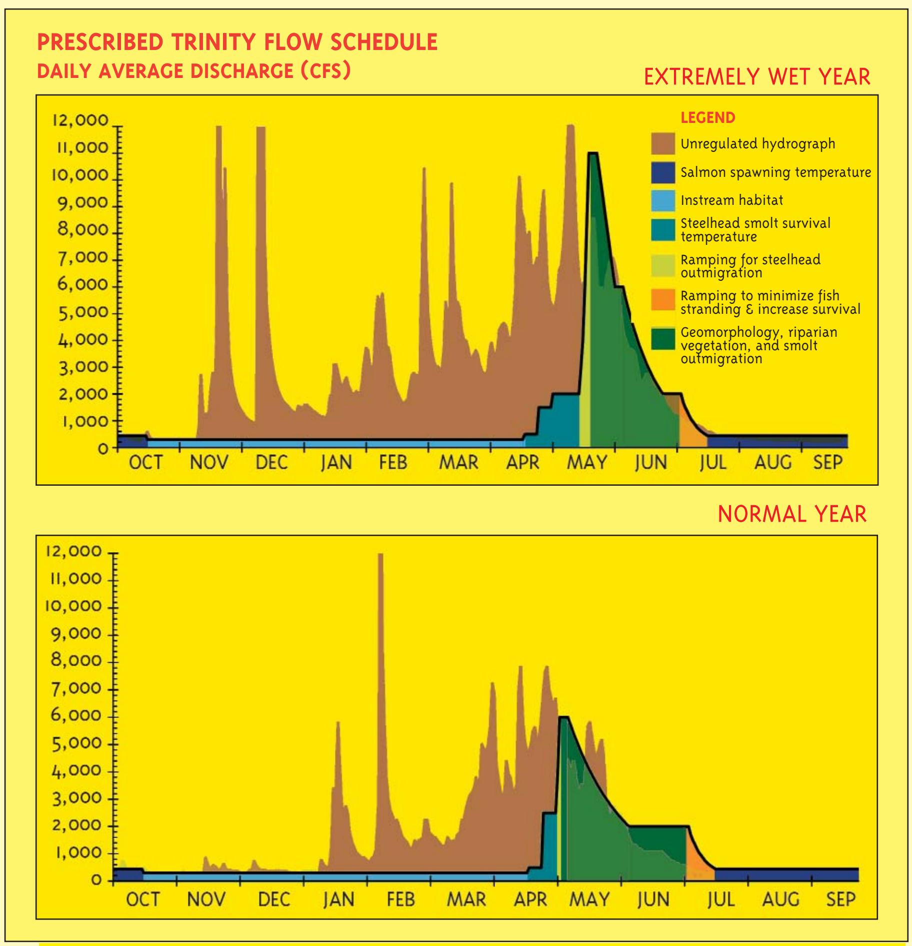
"We sat down and asked, 'What are the objectives for this river?'" says Rod Wittler of the U.S. Bureau of Reclamation. "We looked at goals for the sediment, for the geomorphology, for the fish and fish habitat. How much of each individual type of habitat—the real estate these guys need to hang out in—did we need? What temperatures did we need?"

"The real key part is we established the objectives, and then we asked how much flow is required to achieve them. We literally plotted them out on transparencies and connected the dots. Each point on those hydrographs, each curve, each inflection, each duration, has a reason."

The Trinity River restoration plan is a benchmark in California water history, says Tim Ramirez of the state's Resources Agency. "In California, our approach has always been to take everything we need from a river first, then give whatever's left to the fish and ecosystem," he says. "On the Trinity, for the first time, we've turned this inside out. We've described what the river ecosystem needs first, based on good science, and then we get what's left."

The final plan calls for reducing diversions from the Trinity River to about 50% of the natural flow volume.

Continued page 12



Flow schedules for two of the five water year classses. Source: McBain & Trush

It outlines five different categories of water years, from critically dry to extremely wet (see graphs), and calls for annual peak flows ranging from 1,500 cfs to 11,000 cfs. After construction of the Trinity dam, flow releases had almost always been restricted to 450 cfs or less.

After the experiments revealed that simply letting more water out of the dam wouldn't be enough to reconfigure the river, the science team decided to use bulldozers to remove the riparian berms that were blocking the river's natural processes and to recreate functional floodplain. They also decided to clean and redistribute portions of gravel piles left in the river's floodplain from gold-mining days.

Although less of the river has been diverted in recent years, lawsuits by water and power users have so far prevented managers from implementing the flow regime outlined in the Trinity River restoration plan. This year, for example, spring peak flows will be limited to 2,000 cfs. (Given this smaller volume available by court order, scientists decided the best thing to do was to provide longer suitable temperatures for the remaining progeny of the fish impacted by the lower Klamath fish kill.) Yet 2003 would be classified as a wet year under the restoration plan. If the plan were being fully implemented, this would call for peak flows of 8,500 cfs.

Meanwhile, work has been done to control erosion from culverts and forest roads. A major step may come in the next few months, if Trinity County officials approve the removal of four bridges and several structures that wouldn't be able to withstand higher flow releases from dams. Bureau scientists in Denver are currently running complex computer models tracking sediment and gravel deposition, getting ready to give the river a helping hand once the bridges are removed.

Despite delays caused by lawsuits from water and power users, the Trinity River still promises to be a model for restoration in California, according to Wittler.

"It's a choice we are making as a society," says Wittler. "What makes the Trinity special is that the technical problems are not insurmountable. There are a lot of other California streams that are not coming back no matter what we do." SZ

TUOLUMNE RIVER

River Within a River?

A dam plugs a river. It traps its water and rocks behind a big wall. A trickle escapes to wet down the riverbed, and now and then a downpour or snowmelt forces the dam to break out a little more water. But the river can no longer top its own banks, so it works its way deeper and deeper into a rut.

Tuolumne River at flood

"The question becomes, how far can you scale down a river and still have a river?" explains Scott McBain, one of dozens of planners, engineers, and scientists tasked with restoring the natural processes and salmon habitats of a real "river" in the cramped conditions below California's hundreds of big dams.

The dam that stops the salmon swimming up the Tuolumne River is no engineering marvel of mass and manpower by today's standards. But when masons built the La Grange Dam in 1893, in the first wave of Tuolumne diversions to farms and towns, it was the tallest overflow dam in the country. This historic dam rises a mere 127 feet into the long shadow cast by the newer 545-foot-high New Don Pedro Dam just upstream, and by the Sierra mountains much farther upstream where a third Tuolumne dam, Hetch Hetchy, once broke John Muir's heart. Below La Grange, the Tuolumne flows for 52 nearly flat miles to its confluence with the San Joaquin River. It is for these 52 river miles—fronted by cow pastures and orchards, and pitted and punched by gravel and gold mines—that local irrigation, government, and nonprofit interests have crafted a restoration plan.

"I like to say we're rebuilding the river to maximize its water supply efficiency; the farmers can buy into that," says the Turlock Irrigation District's Wilton Fryer, who has made sure every pebble and plant plug in the restoration plan gets put in the right place. "It's really a multi-dimensional experiment in combining water rights and salmon protection through river restoration."

Of the three largest San Joaquin River tributaries spilling out of the Sierra and down into the Central Valley, CALFED planners think the Tuolumne may be one of their best restoration bets. Like those of its neighbors, the Merced and the Stanislaus, the Tuolumne's former lowland meanders and floodplains have been shrunk by dams, mines, and levees. But the Tuolumne supports the largest natural salmon run in the San Joaquin basin (a hatchery unnaturally inflates the Merced's runs) and still enjoys some variation in the amount and timing of water released from the dams upstream (flows on the Stanislaus are "flat-lined", i.e. low and uniform).

The restoration planning began in earnest around 1995,when a hydropower dam relicensing settlement (FERC) required more streamflow releases and habitat restoration for salmon in the Tuolumne. Since that time, a committee of local water users and agencies has been working on a plan to resize the Tuolumne below the La Grange Dam so that it has enough raw materials (gravel) and space (floodplain) to break out of its rut and act like a river again. More recently, the committee's work has become a focal point of CALFED efforts to promote a science-based adaptive management approach to restoration, and to implement earlier anadromous fish restoration goals created by 1992 federal legislation (CVPIA). Other Tuolumne area interests are also caught up in the restoration fever. A 2003 accounting indicates that a total of 10 nonprofits and agencies are championing over a dozen projects along the lower river to the tune of $54 million (funded) and $36 million (unfunded).

The overarching vision for all this is a habitat restoration plan for the lower Tuolumne River corridor (McBain & Trush, 2000). The plan splits these 52 river miles into two main zones: sand-bedded and gravel-bedded. For the uppermost gravel-bedded miles below the La Grange Dam, the plan focuses on adding the gravel salmon need to spawn and recycling mounds of dredger tailings, while letting the river shape the habitats. In the middle gravel-bedded reach, sand and gravel mining have transformed entire floodplains into huge offshore lakes and instream pits—black holes for both scarce gravel and scarce salmon smolts, because largemouth bass hang out there and eat them. Here the plan emphasizes filling the pits and actually recreating, with levels and bulldozers, the natural river topography of shallow fast-moving riffles, deeper quieter pools, and long-lost floodplains. Finally, for the lower sand-bedded river miles, the plan maps out setbacks and riparian buffers on the banks of urban Modesto, and restoration of riverfront parklands, floodplains, wetlands, and forests. In all reaches, the Turlock and Modesto Irrigation Districts must complete 10 high-priority projects for the FERC agreement by 2005, though many more projects will be needed to realize the habitat restoration vision.

"When I first began working on the Tuolumne, we were mostly talking about no new dams and more places to canoe," says the Resources Agency's Tim Ramirez, who once headed up the Tuolumne River Preservation Trust. "Today, we're all part of a multi-party, multi-interest, multi-million-dollar effort that promises to stretch the frontiers of river restoration worldwide."

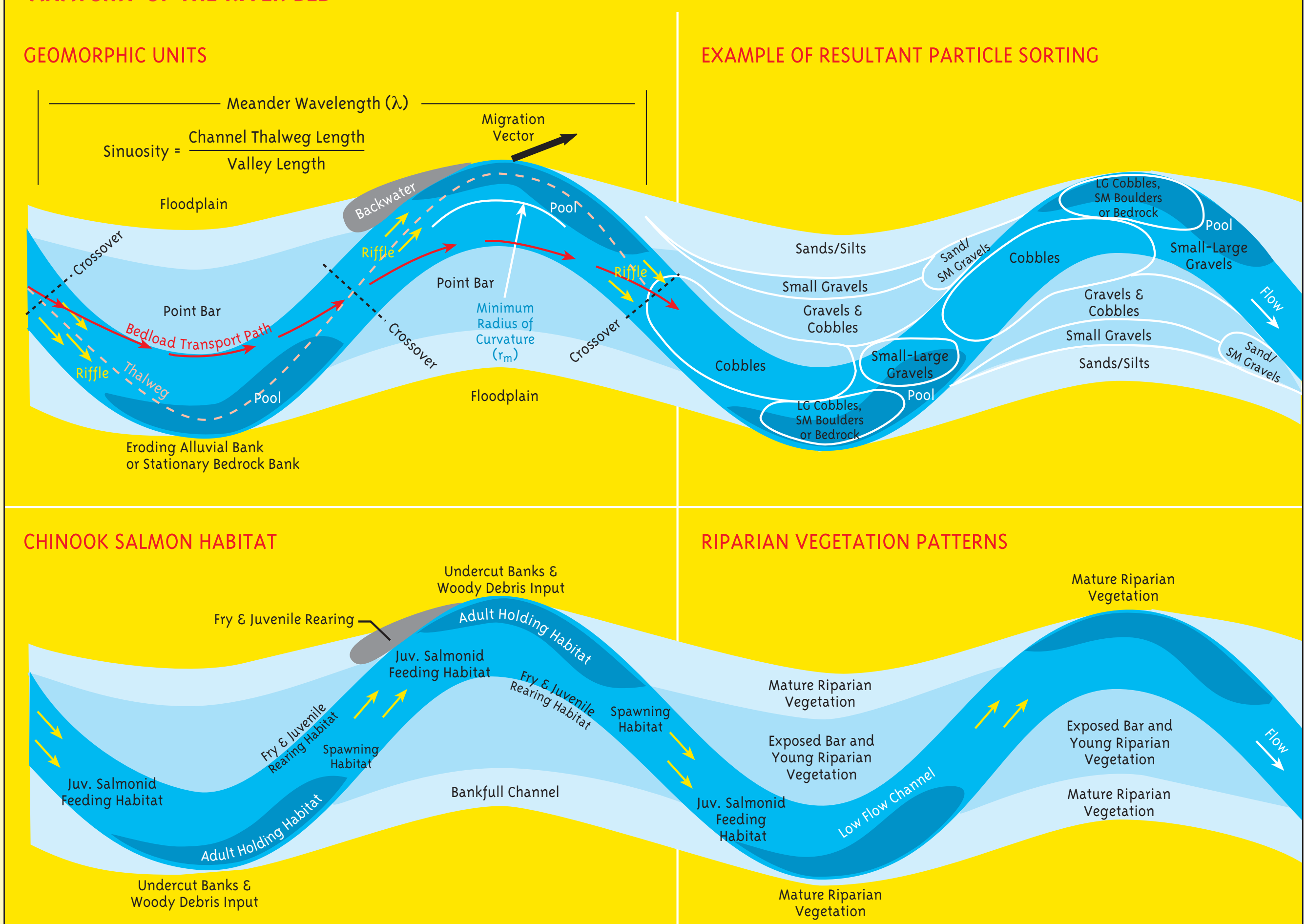
The main building blocks for salmon habitat restoration are water and gravel. Like many other dammed alluvial rivers, the Tuolumne has a gravel deficit. The gravel normally eroded out of the watershed and stored in the riverbed lies trapped behind the dams. The gravel remaining in the floodplain, meanwhile, has been dug out by commercial miners and used to build roads and bridges elsewhere. Low flows don't have the muscle to move the finer sediments up onto the floodplains, where they once nourished plants, trees, and food for fish. Left instead in the half-alive river, the finer sediments fill in spaces, harden the streambed, and suffocate salmon eggs.

Putting gravel in rivers to help salmon is nothing new. At least $8 million was spent on 73 projects involving the injection, cleaning, or ripping of gravel, or construction of riffles, on rivers in the Central Valley watershed below California dams between 1968 and 2000 (with a volume totaling about 800,000 cubic yards), according to research by U.C. Berkeley's Erin Lutrick. Statewide, another study estimates at least $46 million has been spent on building gravel spawning habitat since 1972, putting at least 1.5 million cubic yards of material in rivers.

"When engineers ruled the land and directed river restoration efforts, they took a structural approach," says Scott McBain of McBain & Trush, which undertook the research science and design for Tuolumne restoration plans. "Their idea of a healthy river was one that stayed where it was told and produced oodles of salmon smolts, which kept to perfectly mani-

Continued page 14

ANATOMY OF THE RIVER BED



Source: McBain & Trush

cured spawning areas. But recent restoration science suggests that this Japanese gardening approach is probably not the best way to go. Restoring rivers already confined and disrupted by levees, berms, and artificial habitat structure is like pinching a garden hose. There's going to be damage when flows are too high."

Unexpectedly short lifespans for gravel projects are documented in a 1996 field study of one 122-meter-long riffle reconstruction in the Merced River. The riffle was typical of nine riffle creations along the Merced, Tuolumne, and Stanislaus that involved excavating the existing channel bed, back-filling with smaller gravels, and placing boulder lines to retain the imported gravel. The study found that rather than the riffle lasting the planned 15 years and hosting the projected 575 salmon redds, a flow that occurs on average every 1-2 years was sufficient to scour the riffle back to, and even below, the pre-excavation level. This manmade riffle was just one of many spots along California rivers where habitat construction projects didn't live up to expectations because their design did not account for geomorphic processes, according to the study.

"It's widely accepted now that re-initiating geomorphic processes in the river, rather than creating permanent structures, is the way to go," says watershed planner Jennifer Vick, who worked on the Merced study with Tim Ramirez and U.C. Berkeley's Matt Kondolf.

It's also widely known that there has been very little scientific evaluation of the success or failure of different gravel augmentation and habitat restoration methods in the past, that every river has different needs, that there's still a timing toss up between the benefits of building permanent habitat now versus allowing gravel injection to provide it later, and that there is thus little agreement yet on the best ways to fill the gravel gap.

One thing is sure: in the past, most projects have been designed to stay in place; when high flows moved them, they were perceived to fail. "We need to realize that sediment movement can be a criterion of success, not failure," says McBain. The Tuolumne restoration plan acknowledges that the river is dynamic, not static, and will move around. "So what we need to do to achieve sediment continuity throughout the Tuolumne is four main things: add gravel and cobbles, better manage high flows, fill in channel pits, and give the river some space."

To guesstimate how much gravel of what size to add to the Tuolumne, biologist Darren Mierau, who works with McBain & Trush, began by looking at what was left. Comparing amounts of spawning gravel documented in 1988 by the Turlock Irrigation District with field surveys in 2000, he found a 57% loss, some of it blown out by the 1997 flood. He then "drew big circles" on aerial photos of the river around pits, erosion spots, and other areas in need of gravel, and added them all up. Altogether, he estimates the lower Tuolumne's gravel-bedded miles need as much as 2.8 million cubic yards of coarse sediment to replenish spawning gravels, fill in the mining pits, and scale down the river channel to suit post-dam flows.

To do this will require "emergency room" style procedures over the next five years. "It's like a patient who has lost a lot of blood," says McBain. "The river needs a transfusion to

Measuring flow effects on sediment movements. Courtesy McBain & Trush

make up for over 100 years of sediment supply lost to the dams." The restoration plan's transfusion will add gravel and cobbles in riffles, on point bars above the water on the insides of bends, or on bedrock shelves, "where the river can recruit it as it needs it," says McBain.

After a short-term transfusion on the order of 300,000 cubic yards, the plan will move the patient onto life support—adding as much back as the river transports downstream. In drier years, when the river doesn't have enough flow to move it, no gravel will be added. In wet years, several thousand cubic yards might be added to replace what's scoured out. The amount of gravel added every year may often be substantially higher than it was in the past 30 years, but the amount of engineering of new structures will be much lower, under the plan. In terms of the scale of the whole sediment management regime, it's much smaller than a pre-dam regime, much larger than a post-dam regime, and scaled to restore a balanced sediment budget under today's regime.

"The new approach mimics natural processes and allows gravel to recycle over miles of the river," says McBain. "If you do the Japanese gardening approach, the benefits are site specific, over only 100-200 feet of river channel."

TUOLUMNE RIVER RESTORATION

Differing kinds of gravel will be used in different reaches of the river. In general, gravel size for salmon spawning habitat ranges from 1/2"-5" in diameter, and should be placed to create water depths of 1-2 feet and velocities of 1-3 feet per second, according to Mierau. Other cheaper gravel mixtures can be used to fill relict pits and replenish gravel bars.

Some say the gravel must "season" for a year or more—namely roll around, interact with the water, release minerals, accumulate algae — before it smells just right to the salmon. Carl Mesick, who has built 18 riffles on the neighboring Stanislaus since 1999, and plans to build 33 more, found in one experiment testing gravel sources and sizes that the Stan's salmon used gravels scooped from their own Stanislaus first, and only used gravel imported from the Tuolumne after a year or more. Mesick's research also suggests that finer gravels 1/4"- 3/8" in diameter act as an essential "lubricant" for bigger gravel as salmon dig and build their redds.

With the shortage of habitat, Mesick's seen too many fish crowded into too few riffles, and spawning nearly on top of each other. One female's eggs may thus be "entombed" and smothered by fine sediments released by another female digging just upstream, leading to egg mortality. "I've seen 150 females swim in and move the entire top 12 inches of my riffle downstream," he says. Mesick noted that the salmon prefer spawning in upstream versus downstream riffles, and favor the "tails of pools," where there is easy access to both gravel and deeper, quieter places to hide when they get spooked.

Moving gravel costs money and pollutes the air, so Tuolumne River restorers have been eager to secure a local source. That source may be the "old Delaney Ranch," near the town of La Grange, a 250-acre cobbled moonscape whose mining rights CALFED is helping Fish & Game to buy for use as a gravel blood bank for the restoration work. According to Mierau, the property may contain many years' worth of gravel in the form of old dredge tailings from gold mining days. The plan is to wash and process the gravel to remove sand, silt, and boulders, and then place it instream, eventually leaving a seasonal wetland and riparian forest behind on the Delaney Ranch, and achieving two restoration projects for the price of one.

Once the gravel is in the river, how do we get enough water to move it downstream and shape it into salmon habitats? More than half the river's 1.9 million acre-feet of runoff is captured and diverted, leaving a 32-year (1971-2002) annual average of about 774,000 acre feet in the 26 miles below the New Don Pedro Dam. To see what it would take to move the gravel, researchers requested a modified flood control release in spring 2000. Instead of one long, low magnitude release, the irrigation districts slowly stepped up the release over a period of days from 3,000 to 7,000 cfs.

Researchers found that gravel starts moving at around 4,500 cfs, and that more moves as flows increase (see chart p.18). Flows between 5,500-15,000 cfs every few years would be enough to restore several critical geomorphic functions, says McBain, but getting such flows won't be easy. "Right now there is no requirement on any Central Valley river that specifically calls for high flows that are geomorphically significant," he says. "But with a little cooperation and creativity, and with minimal impacts on water supply and power generation, flood control releases could be reoperated to help the river be a river again." (See also Trinity p. 11 and Reservoir Reop p.17.)

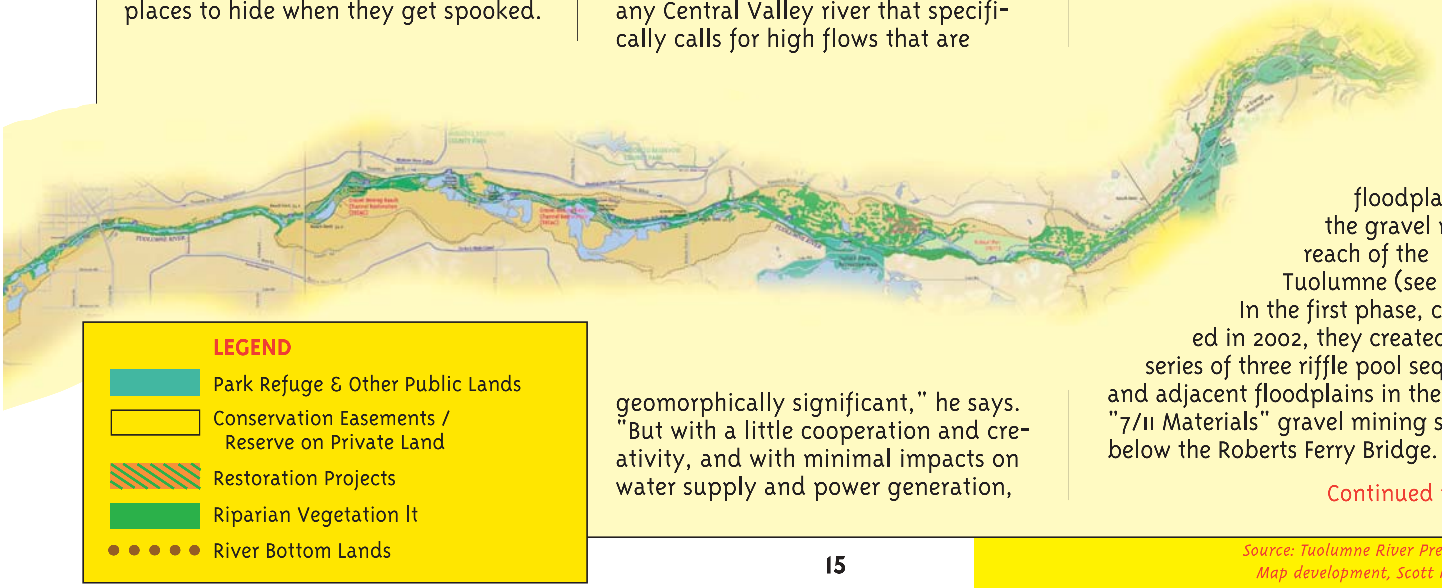
Mierau acknowledges the experimental aspects of their Tuolume River restoration design. "We're testing a huge hypothesis here, that we can scale down the size of a river and restore its dynamics under a regulated flow regime," he says.

Resizing the river not only involves more gravel and better flows, but also giving the river some space to move around. For the Tuolumne, designers are working toward at least a 500-foot or greater river corridor width. In the river's most constricted spots around gravel mines and along the banks of urban Modesto, this new corridor would more than double current widths. Increasing the width at key locations will yield mutual benefits for flood control and environmental restoration by extending riparian habitat, allowing channel migration, reducing floodwater energy and damage, and improving public safety. It will also give reservoir operators more options for handling everything from annual flow peaks to catastrophic floods like the one that occurred in 1997, says McBain.

Despite these benefits, Fryer thinks it's unrealistic to think that the river can be rebuilt from A to Z. "What is achievable is rehabilitating fluvial functions in segments scaled to the smaller flows that will prevail in the future," he says.

The irrigation districts have already gotten started on resizing the river corridor along seven miles of channel and floodplain in the gravel mining reach of the Tuolumne (see map). In the first phase, completed in 2002, they created a series of three riffle pool sequences and adjacent floodplains in the "7/11 Materials" gravel mining site below the Roberts Ferry Bridge. Farther

Continued page 16



Source: Tuolumne River Preservation Trust
Map development, Scott Noren, Lodestar

River within a River

BEFORE

A recent restoration project recreated the original Tuolumne River channel by filling in an inchannel gravel mining pit called Special Run Pool 9, pictured here in the lower right corner; and plugging the hole between the river and the big offchannel mine pit to the left.

DURING

To ease excavation, the restoration design called for the creation of a temporary river bypass channel, so the equipment could more easily fill in the pool and recreate the old channel.

AFTER

The filled and planted pool left — now riparian floodplain and forest — and new channel right. Courtesy Turlock Irrigation District

downstream at "Special Run Pool 9," workers filled and reshaped a 24-foot-deep instream gravel mining pit, using the technique of creating a temporary bypass for the river so the dozers could work on dry ground. What was once a wide deep pond in the river, full of predatory bass and bounded by aging cottonwoods and a popular local tire swing, is now a shallower pool and meander bounded by a new floodplain terrace complete with riparian plantings. The district has almost enough CALFED and local funding to complete two more planned projects within the next two years.

These recent projects follow on a sizable riffle creation (10,000 cubic yards) below the La Grange Bridge by the California Department of Fish & Game in 1999, in a favored salmon spawning spot scoured out by the 1997 flood. The 1999 effort didn't quite come off because the riffle proved too wide and the flows too slow to attract the salmon. Later, Fish & Game successfully added a point bar to narrow the river and increase the velocities, producing salmon habitat future flows may recycle downstream.

Such steps toward "adaptive management" are important to CALFED. Through a set of adaptive management forums and outside expert advisory councils held in 2001-2002 for the Tuolumne and Merced rivers and Clear Creek, CALFED has been asking restoration teams to tighten up their scientific shoelaces—in terms of evaluating outcomes—so that lessons may be learned and perhaps even exported elsewhere.

"What they're trying on the Tuolumne is a huge departure from what's been done statewide in the past, i.e., dumping truckfuls of gravel and driving away," says environmental scientist Dr. Michael Healey of the University of British Columbia, an expert advisor for the forums. "Their concept of creating a single-thread, mobile channel river is pretty novel in national river restoration, which is why it's important to implement it in ways that deliver the most information."

Healey and other forum leaders have urged all three river restoration teams to get better baseline data, set clear quantitative goals (this many salmon in this many years will spawn on this riffle, or escape being lunch for this many bass in this pit, etc.), and be rigorous about follow-up monitoring, among other things. They've also asked all the teams to break out of their reach-by-reach approach to problems (lack of spawning gravel here, too much bass predation there) and try to create models of how they want the river to work as a whole, and to think about how specific efforts in each reach will work for or against each other. They hope to help the teams bridge the gap between research science and project design and construction, and, given the millions of dollars invested in these projects, better evaluate bang for the buck.

"No matter what restoration approach you choose, the most important thing to do before you start is to be transparent about your predictions of the outcome," says U.C. Davis' Greg Pasternack. "This is the difference between science and gardening."

Pasternack has been integrating the creativity of the "folklore" of fishers, biologists, geomorphologists, engineers, and other habitat builders with new computer models of river hydraulics and sediment transport to create an interdisciplinary framework for designing and testing salmon habitat creations. "Most people use models for assessment, not design, and they use old models developed to manage floods, not guide restoration," he says. But these new models can help with adaptive management. "It's only when we add up and check every little prediction we made about flows or velocity or oxygenation that we gain an idea of whether the fish went there because all the pieces were in place, or not."

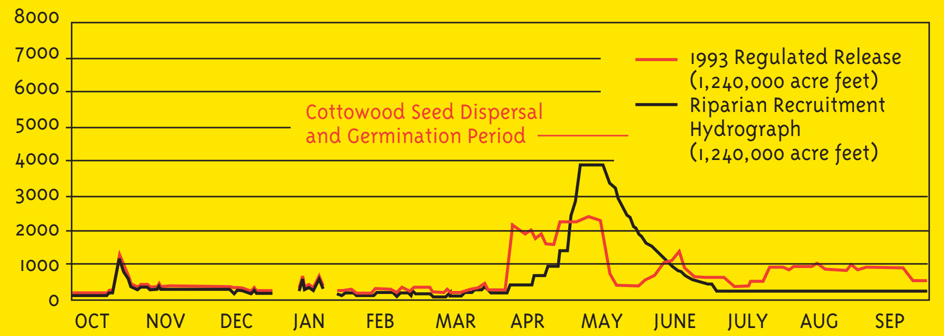
CALFED wants to compare and contrast outcomes on many river projects using approaches like Pasternack's, says Jill Marshall, river science coordinator for CALFED. Asked what CALFED thinks it's learned about gravel and river channel sizing, she says, "We learned that if you put gravel in the river and it stays there, the fish use it, and we've matured in the sophistication of our approaches to placement. We've also learned that in many cases, flows expected to mobilize bedload haven't, and that more knowledge of ecosystem function is needed to complement gravel placement."

The way Healey sees it, "We'd like these rivers to function as active environmental systems, rather than imposing a rigid template on them. The Tuolumne team has moved an awful lot of dirt around, and redesigned some of the riverbed with a great deal of imagination. The trick now is to make this an experiment other people can learn from." ARO

SAN JOAQUIN BASIN

Reoperating Reservoirs

REGULATED & TARGET RIPARIAN TREE RECRUITMENT FLOWS



Source: Cain

As the San Joaquin River flows from the mountains to the sea, there are two places where so much water is diverted to canals and farms that the river actually goes bone dry. In another place, the state and federal water projects sometimes pump so much that the river flows backward. Trying to restore some semblance of natural river conditions to such an altered waterscape can only be described as daunting. But John Cain sees a glimmer of hope, if we change the way we operate the four largest reservoirs in the San Joaquin's watershed.

"These reservoirs have always been managed for very limited objectives, namely water supply, flood control, hydropower, or recreation," says Cain, who works for the Natural Heritage Institute. The Institute has a CALFED grant to evaluate the feasibility of "reoperating" the reservoirs to achieve increased flows not only for fish, but also for moving gravel, rebuilding channels, and nurturing riparian vegetation. "There's room to add more objectives without reducing deliveries to existing water users," says Cain. Not much room, he adds, but enough to make it worthwhile.

Cain's reoperation feasibility analysis zeroes in on four reservoirs: Millerton (mainstem San Joaquin), New Exchequer (Merced), New Don Pedro (Tuolumne), and New Melones (Stanislaus). The first step in his analysis was to single out the ecological and geomorphic objectives of reoperation, especially those detailed in the CALFED Ecosystem Restoration Plan. He then estimated the instream flows necessary to meet those objectives based on modeling, literature review, and an analysis of historical hydrologic patterns.

Cain worked with the Nature Conservancy's Brian Richter and McBain & Trush Consultants to analyze pre- and post-dam hydrology using two separate but complementary analytical methods—the hydrograph component analysis (HCA) and the index of hydrologic alteration (IHA). They found two big changes in the hydrograph: reductions in late spring flows, which help keep waters cool enough for salmon smolts and outmigration; and reductions in peak annual flows, which help cleanse spawning gravel and shape channel habitat.

Cain and Institute staff then estimated flow targets necessary to help restore vegetation, habitats, and processes (see other articles), based on prior studies, modeling, and fieldwork. To test the feasibility of achieving these new environmental flow targets, researchers created a new hydrologic accounting model and plugged in ("gamed") different reoperation strategies for the reservoirs. They used the model to test three general strategies: 1) reshaping the flood hydrograph; 2) reshaping the flood hydrograph and increasing the maximum allowable flood release downstream from reservoirs; and 3) reshaping the flood hydrograph and implementing groundwater banking. In all, the Institute performed over 1,150 "runs" encompassing 16 combinations of strategies and conditions on all four tributaries for a 16-20 year time span.

The screening-level analysis produced the following major conclusions. First, it is possible to reoperate the reservoirs to increase the frequency with which geomorphic and riparian flow targets are met without reducing deliveries to existing water users. Second, the short, high-magnitude flows necessary to move gravel and shape habitats, which once naturally occurred in the winter and spring, are much easier to recreate than the lower magnitude yet longer, sustained flows necessary to meet salmon needs in the spring, summer, and early autumn, when irrigation demands on the river are highest.

"We couldn't find a way to meet ambitious fish flow targets requiring prolonged flows without significant water supply impacts," says Cain. But in one multi-year analysis, Cain found that groundwater banking was able to contribute greatly to spring fish flow targets.

Working with winter flood releases proved a little more promising. First, the analysis suggested that floodplain inundation flow targets could be met more frequently on all four tributaries by simply increasing the peaks of existing controlled flood releases. Flow targets that would move the riverbeds of the Merced, Tuolumne, and Stanislaus could also be met by reshaping flood release hydrographs without increasing the maximum allowable flood release, according to the analysis. On the San Joaquin, however, the maximum allowable flood release is too restrictive to meet such targets. On all four tributaries, it was not water supply obligations, but these maximum allowable flood releases that prevented improvements in meeting geomorphic flow targets.

Flexibility in reoperation is, in part, a function of storage. New Melones Reservoir on the Stanislaus River has over 2.4 million acre-feet of storage space and is most flexible in reoperation. Millerton Reservoir on the San Joaquin has only 520 thousand acre-feet of storage space and thus any reoperation would be extremely constrained.

"Reoperation has to have flexible targets, because flows change from wet to dry years, and should focus on recreating the desired elements in our hydrograph only when it is possible, and as often as it is possible and helpful to the ecosystem, not all the time," sums up Cain.

Continued page 18

Reservoir

The best opportunity for improvement, says Cain, is in reshaping wet-year flood releases. Such releases, to relieve full reservoirs, are usually about 4,000 cfs over a few weeks. A beneficial "reoperation" would be to ramp releases up to 8,000-12,000 cfs, but let them out over a shorter period of time. "It wouldn't be releasing more total water, but increasing the magnitude of the flows enough to mobilize the riverbed," says Cain.

A second good reoperation opportunity would be to ramp down large spring releases more gradually. "Abrupt cutoffs are very bad for riparian tree seedlings, whose roots are adapted to keeping pace with a gradually declining water table," says Cain. Longer or larger spring outflows might also benefit salmon smolts, which prefer the cooler water temperatures of a snowmelt that once lasted through June, but now ends on May 15.

Hurdles to such new approaches are many, among them Army Corps' regulations limiting flood releases on each of the tributaries to prevent overbank flows. But overbank flows are exactly what we need to restore these rivers, says Cain. "We need to manage reservoirs to create small floods more frequently," says Cain. These smaller controlled releases, aided by some floodway expansions, would provide important ecological services without harming humans.

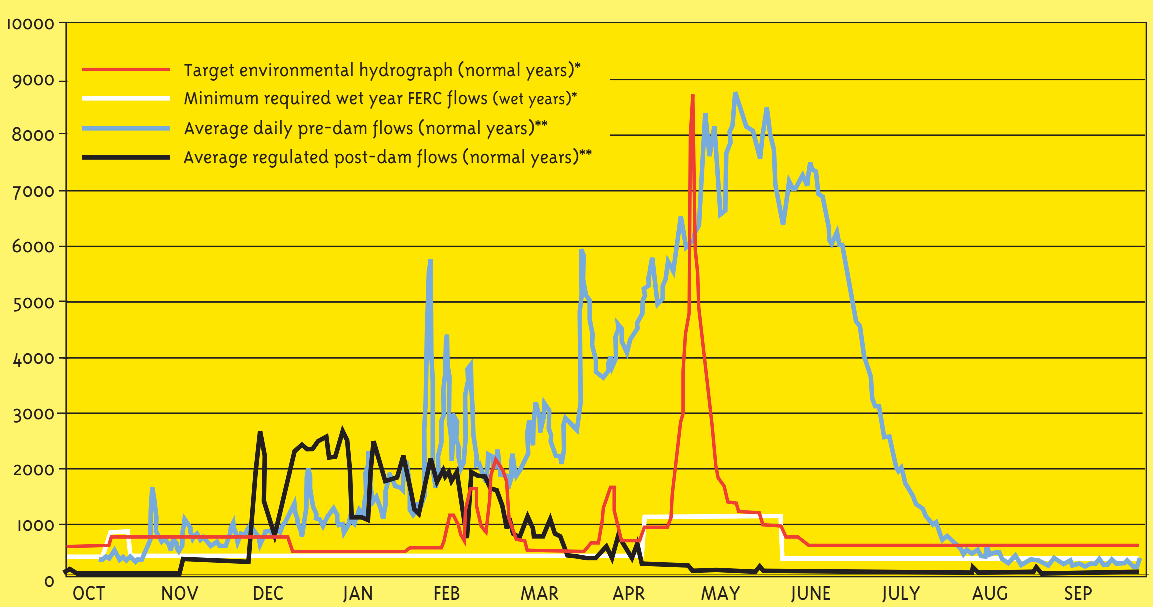
Reshaping flood hydrographs comes with some risk of reducing water supplies for agriculture in some years, as reshaped flood releases for the environment might occur over shorter timeframes than the current longer, more gradual releases. "If we spiked up the release and then got some unanticipated dry weeks, then it might impact future supply," says Cain. "But by just reshaping the flood peak, a river might get an immediate 30,000 acre-foot release for the cost of the few thousand acre-feet of future supply risked."

The Natural Heritage Institute's work on creating a multi-objective hydrograph isn't new to science or planning (see Trinity, p.11), but it is new to those managing the waters of the heavily used San Joaquin system. "People have been reluctant to evaluate what kind of flows it will take to restore these rivers because it seems like water costs would be so great," says Cain. CALFED'S big challenge, once the Institute's work is complete, will thus be how to create incentives that encourage water districts to go to the trouble of reoperation. ARO

GLOSSARY
River Words

Bankfull Discharge The channel-forming discharge responsible for the active channel that erodes and deposits, creates pools, riffles, and meanders.
Base Flow The flow that a perennially flowing stream reduces to during the dry season.
Bedload Sediment particles that slide and roll along the bottom of a streambed.
Catkin Spike of unisexual flowers with inconspicuous petals.
Channel Migration The balance between erosion on one side of a channel and deposition on the opposite side that is the driving force behind lateral migration of channels.
Cohort A group of individuals born during the same short period.
CFS: cubic feet per second A unit expressing rate of discharge, typically used in measuring stream flow. It equals a rate of approximately 7.48 gallons per second.
Floodplain The flat, low-lying portion of a river valley, adjacent to the river channel, which is built of sediments deposited by the river and which is subject to periodic inundation.
Hydrograph A graph illustrating changes in the flow of water or in the elevation of water level over time.
Incision Extensive degradation or down-cutting of a stream or river bed.
Levee A natural or manmade earthen obstruction along the edge of a stream, lake, or river.
Meander A looplike bend in the course of a river.
Phytoplankton Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.
Point Bar A crescent-shaped accumulation of sand and gravel deposited on the inside of a meander.
Recruitment The process of adding new organisms (known as a cohort if the organisms were born at the same time) to a population.
Redd A type of fish-spawning area associated with flowing water and clean gravel.
Riffle Shallow rapids where the water surface is broken into waves by obstructions such as shoals or sandbars wholly or partly submerged beneath the water surface.
Riparian Pertaining to the banks of a river or other flowing body of water, as well as to plant and animal communities along such bodies of water.
Riprap A protective cover of stones placed to prevent erosion or the sloughing off of a structure or embankment.
Setback Levee A levee placed a substantial distance from a stream, allowing it to meander without consequences to the levee and to accommodate a floodplain that can store and convey flood flows.
Succession The change in composition and structure of biological communities due to external environmental changes, such as floods or climate change, and biotic forces, such as competition and predation.

COMPARISON OF HISTORIC, EXISTING, AND TARGET HYDROGRAPHS: TUOLUMNE RIVER



** single year example*
*** composite averages of several "normal" years.*
Source: Cain

COSUMNES RIVER

Floods of Food and Fish

Laser-level flat may be the topography of choice for farmfields, but not for floodplains. While floodplains—the places a river spreads into when its waters overflow its banks—may seem flat, the elevation of historic floodplains along the Cosumnes River, for example, once varied by up to three meters. Such natural nuances are the subject of intense scrutiny by scientists studying two levee breaches along the Cosumnes. They want to find out how these reconnections of the river to its old floodplain—a CALFED restoration priority for the Central Valley watershed—may benefit salmon, splittail, cottonwoods, and other riverine life.

"The benefits of getting water on floodplains are woefully under-appreciated," says Jeff Mount of U.C. Davis, who is leading the Cosumnes research. "Floods are only natural disasters when we get in the way."

There aren't many mansions or malls standing in the way of Cosumnes floodwaters: most of the land along its banks grows grapes, wheat, rice, and tomatoes. More importantly, the Cosumnes is free of big dams, unlike other California rivers. "It's a unique test river for floodplain research because no flows are being stored and swiped, so it has a reasonably natural hydrograph with both winter and spring floods, plus small levees," says Mount.

Levees restrain the river to one channel and separate it from its former floodplain. But before humans began farming along the Cosumnes, the river had multiple channels, large tule marshes, dense patches of riparian forest, and many lagunitas (floodplain lakes). In more recent years, the Nature Conservancy has been partnering with local farmers and public agencies to create the 40,000-acre Cosumnes River Preserve, which combines wildlife and flood-friendly farming with restoration of riparian, wetland, and floodplain habitats.

"The Cosumnes is the only undammed river flowing out of the Sierra into the Central Valley," says the Preserve's Keith Whitener. "Every year's flows have a variability you just can't get on other rivers when you call up the dam operator and ask him to release 5,000 cfs. That's why we're restoring it, and why so many scientists are out here studying it."

A small breach on the floodplain at the Cosumnes River (but not one of the two breaches studied). Photo from U.C. Davis

In the 1990s, local biologists noted that an earlier accidental break in the levee about three miles upstream from the confluence with the Mokelumne River soon laid down a nice new patch of sediment in an adjacent farmfield, where a forest quickly grew up. "A breach acts like a fire hose, spraying sand onto the floodplain, constructing splays that expand outwards, creating a topography that produces a mosaic of plant communities," says Mount.

This "accidental" forest inspired two more intentional holes in the levees: the Accidental Forest Breach of 1995, close to the original breach, and a 1998 Army Corps breach on a farmfield upstream (which secured a natural breach from the 1997 floods). At these interconnected sites, Mount's team has been monitoring sediment buildup and topographic change; the production of phytoplankton, zooplankton, and other aquatic food; the growth of vegetation; and the use of the newly flooded areas by native and alien fish. They've also been looking very closely at how the timing and duration of the floods affects all these factors. Since the breaches, there have been immense variations, from the big El Niño floods of 1997, to the drought of 1998, to the wet years of 1999-2000 and the drier years since.

The wet years produced enough water (big episodic floods) to import new sediment and create new floodplain topography; in later drier years, topography didn't change much, but native flora and fauna benefited from smaller, more sustained flooding. "Allowing a flood is passive-aggressive restoration," says Mount. "It's aggressive about reintroducing riverine processes, but passive about introducing form. It's moving away from the yellow metal madness of pushing a lot of ground around to remake rivers."

Mount's team began studying the two breaches in 1999. Starting from the ground up, U.C Davis' Joan Florsheim documented changes in the shape of the river bottom and floodplain in and around the breach site, and the formation of sandsplay complexes (see diagram). The number of non-consecutive days water flowed through the breaches ranged from 3 to 86 between 1999 and 2002. To find out how much sand these flows brought in and where it was deposited, Florsheim surveyed the site with an electronic distance meter, measured high water marks, inferred flow directions in the flooded areas, and took sediment samples (new deposits of soft light brown sand were easily distinguished from older, finer, harder gray and red silt and clay).

"It went from mostly flat to having a lot of diverse topography within a few large storms," says Florsheim. Over the two-year study period, maximum deposition on the splay surface measured 0.36 meters per year. New splay complex channels formed in the floodplain, with a maximum scour rate of 0.27 meters per year. Topographic relief, which ranged by 1.6 - 0.25 meters, developed in the formerly laser-level floodplain and was highest near the breach, decreasing with distance down floodplain. In a resulting paper, Florsheim concluded that sandsplay complexes sequester and increase the residence time of sediment in off-channel storage areas, and provide a diverse topography that creates variability in flow strength, depth, and

Continued page 20

velocity and inundation duration and frequency. "It's not just about getting water onto the floodplain, it's about recreating the physical processes that contribute to floodplain ecology," she sums up.

The new bare soil surfaces on the splays also proved to be at the right elevation for cottonwood willow forest to establish itself naturally, concluded Wendy Trowbridge, another on the U.C. Davis team (see also p.4). She compared the growth and density of plants and trees at breach sites with sites elsewhere along the river and found, among other things, that flooding allowed native wetland plants to outcompete invasive agricultural weeds in lower areas away from the breaches, and that dry years help get valley oaks started (oaks can tolerate flooding after their first year); thus interannual variability is important to the natives. "This form of process-based restoration has shown that it is not always necessary to hand-plant native plants to restore the riparian forest," says Trowbridge. "If you create the right conditions, the plants will come back on their own."

Next, team member Ted Grosholz hauled out his plankton nets to see how much food the breaches and floods produced, and how long it lasted. He got a little bogged down trying to find this food—the tiny plants and animals called phytoplankton and zooplankton—largely because most plankton nets are made to be dragged through open water rather than the fast-growing vegetation around the breach sites. After switching to smaller nets, he compared his food haul from the flooded area with one from the river. "The shallow, slow-moving waters produced 100 times more plankton than the channel," he says.

The sequence from rain to flood to food also interested Grosholz, who noted that it begins with a transition from a "riverlike to a lakelike system." Then within a week or two of a storm or melt, as soon as the floodplain starts to fill up, food production "just explodes," he says. Then the fish arrive and chow down (enough so that zooplankton levels drop).

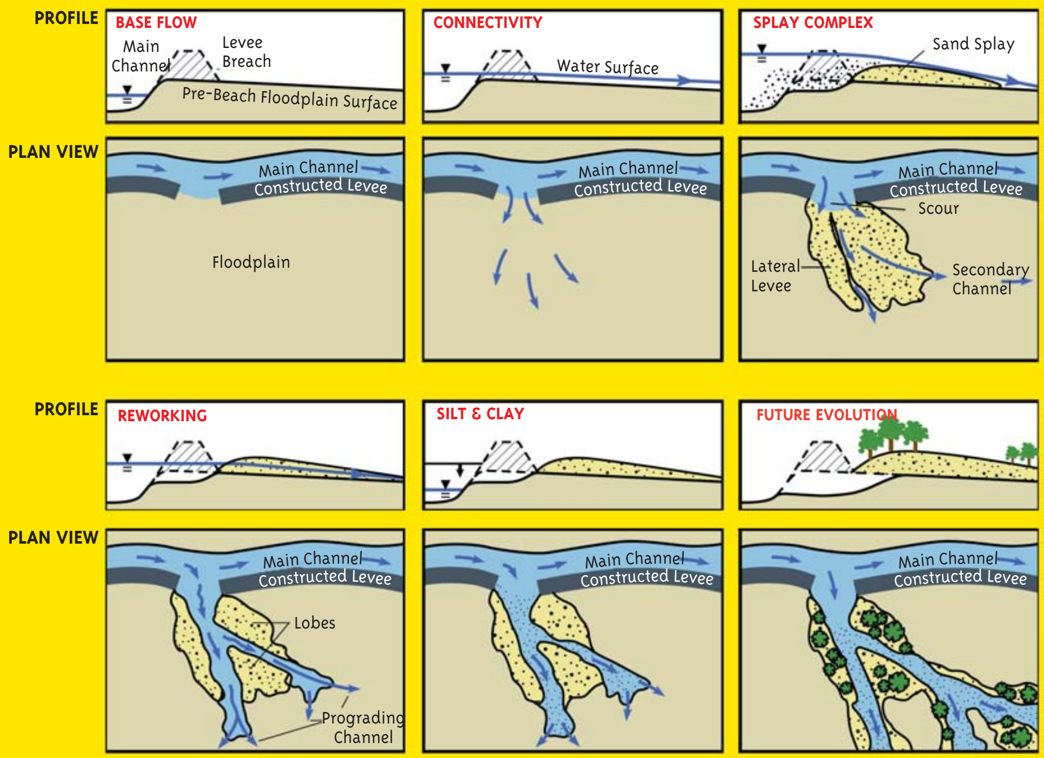
It's not just the amount of water that arrives with a flood, but also how long it sits there that's important to plankton and those that eat it. In some years, winter rains produce early flooding, which ebbs, and then recurs with later rains and spring snowmelt. "Reflooding reinvigorates productivity," says Grosholz. "If it doesn't reflood, the system seems to run through its nutrient base and some plants begin to crash." Grosholz found correlations between variations in water residence time and the new sand-splay and floodplain topography, which in turn influenced zooplankton biomass and made it "patchy."

This April's late floods produced big "yummy" zooplankton and a floodplain "chock-a-block" with feeding larval and juvenile fish, including salmon, according to Grosholz. But more interestingly, "The zooplankton densities, the ones you can actually see with the naked eye, that look like little Rice Krispies, are 10-100 times denser in the forest than in the sunny, warmer, open floodplain. This change from high-density fish to high-density fish food is striking, and occurs over 20 meters."

Indeed, Grosholz was surprised to find so much food and organic matter in the flooded forests surrounding the open floodplain. For years, these areas have been thought of as more of a liability (because they're so dark and cool) than an asset for fish and sunlight-driven food production. But Grosholz now thinks forested floodplains may not only support the aquatic food web by exporting organic matter and nutrients to plankton growing in more open floodplains, but also by sustaining many insects and large zooplankton under the trees. "Our findings suggest that we can't just construct open floodplains in isolation, but [we] need to create strong, long borders with forests, and place all these elements side by side."

So as flooding comes and goes through these habitats, how do the fish fare? The locals certainly fare far better than immigrants from out of town. Peter Moyle says he can tell

EVOLUTION OF SPLAY AND CHANNEL COMPLEX



Modified from: Florsheim, J.L., and Mount, J.F, 2002. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California, Geomorphology (44):67-94.

Source: Florsheim

from their behavior that native fish evolved with these shallow, slow-flowing floodplains, and that they know when to get on and off, unlike alien invaders, which prefer quieter, deeper waters and often get stranded in pools when floodwaters recede.

Moyle used seine nets and electrofishing to explore how native salmon and splittail, the latter a listed fish CALFED is trying to help, were using the breach sites. The first few years of monitoring were really wet, with the river staying connected to the floodplain, and Moyle saw a gradual but distinct succession of fish from natives to aliens, with the natives staying much longer and the aliens spawning later than in drier years. But in later drier years in the study, when the floodplain connected and disconnected from the river several times, the succession was much more dramatic.

Salmon appeared early, almost as soon as the flooding started, fattened up, then left as floodwaters receded. Splittail came later, spawning on the floodplain in March and April. "The splittail moved up the river, felt the signal of the water coming off the floodplain, then swam through the breach," says Moyle.

The new sandsplay offered temporary habitat for the splittail, which spawn and rear juveniles in the annual vegetation. "The fish really like cockleburrs, because they have strong stems and lots of leaves eggs can stick to," says Moyle

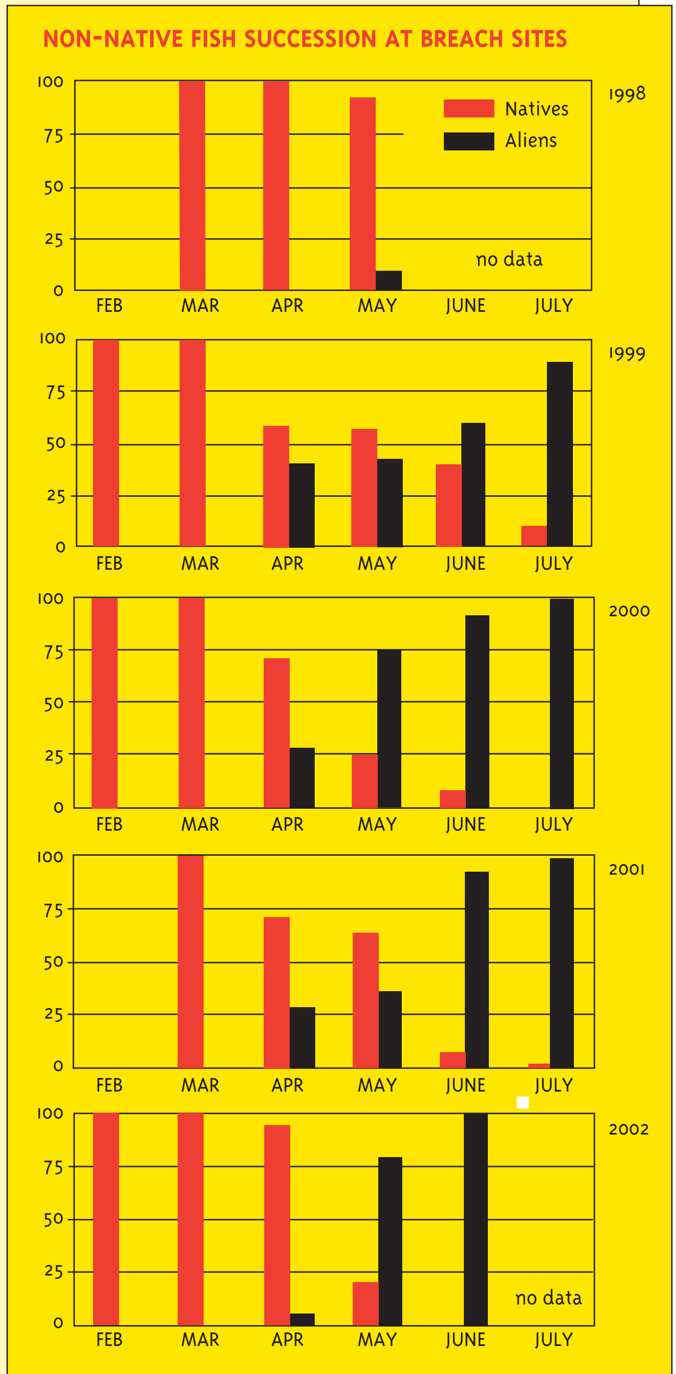
Trowbridge downloading data from a sensor measuring depth and temperature of the surface water on the floodplain. Photo from U.C. Davis

(scientists and farmers hate them, because their burrs get stuck to everything).

In March and April, the native fish clearly detected impending change. "The temperatures got warmer, the water got clearer and lower, and the fish started bailing out," says Moyle, whose samples showed decreasing numbers in the floodplain and increasing numbers in the river channel at this time.

Over the course of the research, only tiny numbers of listed fish—for whom each individual death evokes a management failure—got stranded in the floodplain as waters receded, not enough to threaten species survival. "Five years ago, when floodplain research started up, everyone was freaking out about stranding, but it just doesn't seem to be the case here on the Cosumnes or on the Yolo Bypass," says Whitener.

Moyle says his Cosumnes studies confirm Yolo Bypass research (with the Department of Water Resources' Ted Somer) about the value of floodplains to native fish. Though the bypass is basically a large engineered overflow channel for the Sacramento River, it showed the same patterns of fish use. "If you want to manage floodplains to help native fish, get the water on them early, then get it off—the less permanent water you have, the better," says Moyle, who recommends draining floodplains completely by mid-May.



Source: Moyle

Scientists all seem to agree that getting floodplains reconnected with rivers should figure more prominently in all Central Valley river restoration efforts, and that flooding for the ecosystem can be timed to be compatible with dry-out periods for farming. "Floods are the single most effective way to introduce sediments and nutrients onto the riverplain," sums up Mount. "You can do all the planting and use all the yellow metal you want, but the Cosumnes tells us what an extraordinary and instant change happens when water is simply reintroduced to the landscape." ARO

OUTLOOK

Integrating Creativity, Science, and Responsibility

TOM DUNNE, GEOMORPHOLOGIST
CALFED ERP INDEPENDENT SCIENCE BOARD

"CALFED is the most creative, most diverse, most likely to be productive, large-scale river restoration program anywhere in the world, which is one of the reasons why it's so intensely important for it to be done right. We need to recruit to CALFED the best ideas and the best outside reviewers, and we need to continue to try to imagine things in the longer term, outside the box.

"CALFED needs to do three things to improve its Ecosystem Restoration Program for rivers, and the science and adaptive management approach that it's built on: think, plan, and manage on a whole river scale; make the connection between physics and biology; and [not shy] away from the water problem.

"Let's start with scale. So much of the river work is being done on a single scale, typically individual reaches of channel, a mile or so in length, and specifically targeted at helping one kind of fish or animal. But restoring rivers means thinking about everything from the dam on the tributary to the Delta, thinking from the fishes' point of view. Unfortunately, the person managing the dam is not talking to the person restoring the spawning beds in the upper river, who is not talking to the person filling the gravel mining pits in the lower river, who is not talking to the people worrying about water quality on the San Joaquin, or the people pumping water out of the Delta. It's nobody's fault, everybody's just concentrating on his or her responsibilities. But the fish, and the river, need to be taken care of all the way down the flowline.

"So all the creative people working on rivers are surrounded by a lot of other people trying determinedly not to be creative, trying to hold on very tightly to their responsibilities, and that's what we pay them for—to keep us safe from floods, or bad water quality, or challenges to water rights.

Spring-run salmon in Butte Creek. Photo by Allen Harthorn

"CALFED needs to integrate the creativity with the responsibilities, along the whole river. It needs a new level of staff with responsibilities for a broader scale of issues—whole rivers, whole water supply systems—and for addressing emerging competition between flood control and ecosystem restoration programs.

"The scale problem should also be addressed by developing more top-down conceptual models of whole rivers, put together by teams of biologists, geomorphologists, hydrologists, and riparian ecologists. There's a real dearth of measurement, data analysis, and assimilation of data into models that would allow us to predict restoration results. New, larger-scale conceptual models, and new high-level CALFED staff with authority to shepherd them, should help provide more top-down integration of restoration science and actions. CALFED's current bottom-up approach, in which local agencies, stakeholders, and watershed groups suggest and implement restoration projects, makes the Program creative and diverse, but poorly integrated.

"Second, CALFED needs to make the connection between its work to reshape the physical habitats along rivers—also a byproduct of bottom-up localized approaches—to the fish and trees that may or may not return as a result. Biologists and restoration managers need to tighten up their predictive abilities. We need more concrete, quantitative predictions of what the biological results of manipulating the physics of these habitats, to make up for the water that's gone away, will be.

"Third, CALFED should understand that working within a paradigm that accepts that all the water is already allocated is limiting the effectiveness of our long-term restoration experiment. It is sobering, as an outsider, to see such scale and diversity in a program, tempered with so much tension and fear over water supply. Everyone seems to hope that if we just do all this physical restoration, we won't have to talk about water. But one day soon, we will have to quietly and constructively address the underlying issue of the water itself, for example by improving ways of predicting and organizing mid-winter water releases from reservoirs. Only through detailed, ambitious, flow release experiments and data analysis will we be able to assess the crucial question of the tradeoffs between habitat reconstruction and simply securing more water for the environment.

"This is a giant research experiment, all the way from the policymaker down to the person dumping the gravel into the river. Nobody's ever done 'restoration' on this scale before. The public needs to know that what CALFED is doing holds the promise of tremendous benefits for the people of California, but it is hard, unprecedented, and is going to require patience."

Thomas Dunne is a professor at the Donald Bren School of Environmental Science and Management, at the University of California in Santa Barbara, and recently participated in three CALFED adaptive management forums evaluating the restoration approach on the Tuolumne and Merced rivers and Clear Creek. He co-authored a book with Luna Leopold entitled "Water In Environmental Planning," and another with Leslie Reid of the U.S. Forest Service entitled "Rapid Evaluation of Sediment Budgets." He has studied rivers and restoration in South America, New Zealand, the Pacific Northwest, California, and Spain, and currently studies the Amazon and the Mesopotamian Marshlands.

MANAGEMENT

Frontiers for Change

Going back to Nature on Central Valley rivers, to some pristine pre-dam, pre-levee, pre-development state, is beyond anyone's wildest dreams. But many scientists believe these much-altered rivers can heal themselves, to some degree, with better management.

"We need to give water users and resource managers good reasons why they need to have a dynamic river system," says U.C. Davis scientist Steve Greco. "Restoring processes could be construed as expensive or unnecessary or damaging. But we're trying to show that these processes can help reduce endangered species pressure in the future."

Getting the water and goodwill to restore river processes may be among the most obvious management challenges. Some water can come from buying it, as CALFED is doing with its environmental water account and program. Dedicating water to recreate a more natural hydrograph will help put the ecosystem on a more equal footing with farmers, cities, and other water users, say environmentalists.

Some of the water should come from "reoperation" — namely changing the timing and volume of current reservoir releases, especially in wet years when there is plenty of water to go round. But the Turlock Irrigation District's Wilton Fryer says this won't come easy. "We really need to think through all the pieces that go into this," he says. "There's going to be operational challenges, regulatory challenges, and lost income in terms of electricity generation."

Other water managers, like Tim Quinn of Southern California's Metropolitan Water District, see the answer in system-wide improvements. "The new science underlines the importance of adding flexibility to the system, so we can manage for both ecosystem processes and water supplies," he says.

Certainly restoration managers promoting riparian processes would like to see more flexibility when it comes to state and federal flood control regulations: the State's Reclamation Board limits encroachments onto the floodplain, including tree planting, and the U.S. Army Corps sets maximum allowable flood releases for each river. According to habitat builders like Carl Mesick on the Stanislaus River, "All of us are operating under a huge constraint: Every time we put a pebble in the river, the Reclamation Board screams because it raises the water level during a flood."

Many of those who want to recreate the small-to-medium-sized beneficial floods that once spiked the hydrograph of today's "flat-line" rivers every 2-10 years (such floods move gravel and grow fish food) face the fear factor of the 100-year flood, around which most flood control facilities and regulations are designed. Maximum allowable floods are set too low for some restoration objectives, and regulation change to allow more flooding is far from reality. In addition, today's lawsuit-happy society makes flood control agencies, as well as reservoir operators and some restoration managers, nervous about any deviation from flood control norms.

Yet many restoration projects actually increase our safety from floods and our rivers' ability to absorb floodwaters. Indeed the integration of flood management with ecosystem restoration offers tremendous cumulative benefits not yet realized. The most stark example, says engineer Phil Williams, is the poor marriage between CALFED's restoration plans and the U.S. Army Corps' recent comprehensive flood control study for the Valley. "We need government agencies that have the mission, mandate, resource authority, and skills to effectively manage whole rivers," he says. "This means rethinking the role of flood control agencies and natural resource management agencies. The former were established over 100 years ago to build levees, but are now being asked to save endangered species and provide community recreation. It just doesn't work. In too many instances, flood control criteria override ecosystem restoration, without necessarily resulting in better flood management. We need a genuine, multi-objective approach where we can achieve both."

The Trinity River may provide one model of a multi-objective river management approach (see p. 11). In a letter to Clinton's Interior Secretary Bruce Babbitt, famed geologist Luna Leopold wrote: "Useful as your dam destruction is, we will still be faced with the task of improving the management of those we cannot take out. I have spent much of my career working on rivers, and this Trinity methodology is the best thing I have seen in three decades."

Implementing the Trinity approach, however stellar, has been rocky politically and legally. Achieving institutional change, so that we can better manage whole rivers, promises to be equally rocky. A July 2003 report summing up a series of adaptive management forums on restoration work on three rivers, undertaken by U.S. Fish & Wildlife's Anadromous Fish Restoration Program (an outgrowth of the CVPIA) and CALFED's Ecosystem Restoration Program, says negotiating regulatory exemptions or modifications for the new breed of river habitat restoration projects should be of the "highest priority." Another area of institutional conflict, identified in the forum report, involves aggregate mining in streambeds. One state department is encouraging counties to go mine their rivers while another state department tells them to go fix the holes and restore the rivers.

Everyone seems to recognize that the current top-down regulatory process, which is largely geared to individual fish and individual pollutants and individual mandates, is out of sync with CALFED's ecosystem approach.

"We can no longer manage problems in isolation, the Delta for smelt, the rivers for salmon, the water supply for water users alone," says the Bay Institute's Christina Swanson. "If we don't restore processes and biota all the way through the system, from river to Delta to Bay, we are bound to fail."

Patrick Wright, CALFED's director, believes the single agency, single purpose project era is over. "CALFED is rapidly moving into a role of facilitation and support for locally based, collaborative efforts, rather than having the fish and wildlife agencies go in and do restoration projects in a vacuum. We get the state and federal agencies together to identify their highest priority kinds of projects. Local groups and agencies send in project proposals and we evaluate them based on these priorities, and on scientific rigor. Our bar is so high now, that only 10% of the last round of proposals made it through the first cut."

The high science bar makes water managers like Tim Quinn happy. "Water suppliers fear we'll wind up losing water on the basis of shoddy science," he says. "So the quality of the science

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emerges as an important variable in the political arena."

Funding sound science and long-term monitoring will be another management challenge, as many river restoration projects may take decades to prove or disprove their worth.

Everyone is clearly looking to CALFED to sustain the restoration work, champion the science and monitoring, and tackle the institutional challenges. Promoting CALFED's leadership in all this is one reason Tim Quinn "sweated" to get the bill passed which created the California Bay-Delta Authority in August 2002 — CALFED's new implementing body. "Having the new authority greatly ups the stakes for coordinated decision-making, and makes CALFED much more visible and accountable," says Quinn.

Part of the accountability will come from embracing the uncertainties of river restoration, and from promoting experimentation, say the scientists. CALFED's outside science advisors have been pushing hard to create a "culture of investigation " for the river work, so that lessons learned on one river can be applied to others. Unlike research and restoration in the Delta and Bay, which have been coordinated for a long time by big agencies like the U.S. Geological Survey and the Interagency Ecological Program, river work is much more localized.

"Each river has it's own culture," says Jill Marshall, river science coordinator for CALFED. "People are working at wildly different scales, from small non-profits to big university science teams to district-driven consultants. Choosing different approaches isn't bad, except there is no clear mechanism for people who work on all these rivers and all these scales to communicate with each other. More collaboration will help us tear down institutional and regulatory barriers to change."

The Bay Institute's Peter Vorster agrees. "Cross fertilization is critical. We need to identify common issues in river restoration, such as cottonwood recruitment or the altered groundwater-surface water relationships in lost river reaches, and be forced to share ideas and data around a table with blackboards in a workshop setting." The adaptive management forum report reinforces such cross fertilization, both within river teams and among them, calling for more regular meetings and communication, stronger adaptive management protocols, stronger conceptual models of whole rivers, and more integration of science, design, and construction from the project to reach to tributary scales.

Such communication will be critical in optimizing the management of flows for all users. "Using flow as a restoration tool is expensive and politically sensitive," says riparian ecologist John Stella. "The spring pulse flows we need for trees come at a sensitive time of year, when water managers don't want to waste water needed for irrigation later on, or hold onto water too long and lose flood storage. The value of some of the new river research is to help integration of riparian tree restoration with salmon and other ecosystem measures, to bring more information to the table in setting flow schedules, giving floodplain managers more input on how to prioritize sites for cottonwood and willow restoration, and what to do in terms of site preparation and grading."

All the hallmarks of a new era of resource restoration, rather than extraction, seem to be present in these tales of thinking outside the box, beyond the bulldozer, and across property and policy lines, on our Central Valley rivers. We have been striving to better understand how Nature created and sustained our rivers, and now we must find ways to balance the hardware of our old interventions with the software of our new process-based approach. Clearly, it's no longer a matter of just trying to find more water or build more habitat for the salmon and splittail and cottonwoods and cuckoos. "Salmon need more than just water, they need rivers," says Ramirez. "Our investment in river science over the last few years has built a solid foundation. Now we must find the courage to translate the science into management changes."
ARO

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This publication was paid for by the CALFED Science Program. Special thanks to Tim Ramirez, for his extraordinary vision for this river restoration publication, and to all the story sources and reviewers for their insights and time.

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