CALFED BAY-DELTA PROGRAM

NEWS FROM THE CALIFORNIA BAY-DELTA AUTHORITY SCIENCE PROGRAM

SCIENCE IN ACTION

Demystifying the Delta

Scientists plumbing depths, gauging tides, and chasing fish have been unveiling the underwater landscape and life of the Delta. How best to manage this 800,000 acre tangle of canals, cuts, levees and islands — a place that hardly resembles any past ecosystem but certainly serves the farms and cities of modern day California with its drinking and irrigation waters — has stymied scientists, engineers, environmentalists and government agencies for decades. Yet its users and managers remain deeply engaged in a long-term effort to find a "thru-Delta" solution to persistent conflicts between water supply, water quality and endangered fish, rather than doing a concrete end run around the Delta's complications. And they're making progress.

The Sacramento-San Joaquin Delta formed when two great rivers meandered across a vast inland marsh toward the sea. But humankind tinkered endlessly, and without a central plan, with this landscape — diverting water, building levees, planting crops, growing towns. And as we strove to take only the freshest waters out of this naturally salty estuary, year after year, we arrived at a point not long ago when we also began "taking" too many of the last few winter-run chinook salmon and delta smelt on the planet.

As one century rolled into the next, a five- year old cooperative state and federal program called CALFED (now overseen by the California Bay Delta Authority) decided on the thru-Delta approach to managing these water conflicts. The idea was to work towards optimization of the existing channels, pumps and fish facilities in the Delta, rather than sending out the guys and gals with the hardhats and backhoes to build bigger and better ones. And as the teams of scientists CALFED assigned to this task intensify their studies, they're suggesting some new twists to old concepts about how the Delta works, and some innovative ways to manage how tides, river flows, fish and salt interact in this complex system.

"In the Delta, we've learned that water doesn't flow like a river, that fish don't simply travel from point A to point B, and that channel and island geometry affect salt transport," says Kim Taylor, deputy director of science for the Authority. "It's a whole different ballgame thinking of our water and fish as moving through a mixing bowl, rather than through a series of one-way canals."

As CALFED explored opportunities to optimize the Delta system, its research began to suggest that our longtime leaning on the "net flow" model of the Delta, which measures direction and rate of water movement after removing tides from the equation, may be limiting our management options. Scientists also began to question our focus on screens, salvage, and take limits as the primary tools for protecting fish (when "incidental take" limits of endangered fish are exceeded at the water export pumps, regulatory red lights stop the turbines).

Researchers now think we may find more opportunities in tapping the tides rather than turning to already tapped out rivers. They've produced new ideas for how to do this at three critical waterway junctions in the Delta. They've also developed new ways to count and track fish, new cameras for seeing underwater, new water budgets to minimize the take of salmon and smelt at the pumps, and new 3-D models simulating the transport of water, salt, and fish through key flooded islands. The result is a whole new frontier of understanding of the Delta's internal dynamics and how its natural processes interact with our unnatural efforts to withdraw its least salty waters.

"It's really hard to understand something you can't see," says Diana Jacobs, Deputy Director of the California Department of Fish & Game. "You can see the salmon spawning in the clear creeks and rivers upstream. But the Delta is turbid and tidal. All this new technology and research is allowing us to go underwater in the Delta and study what's really going on."

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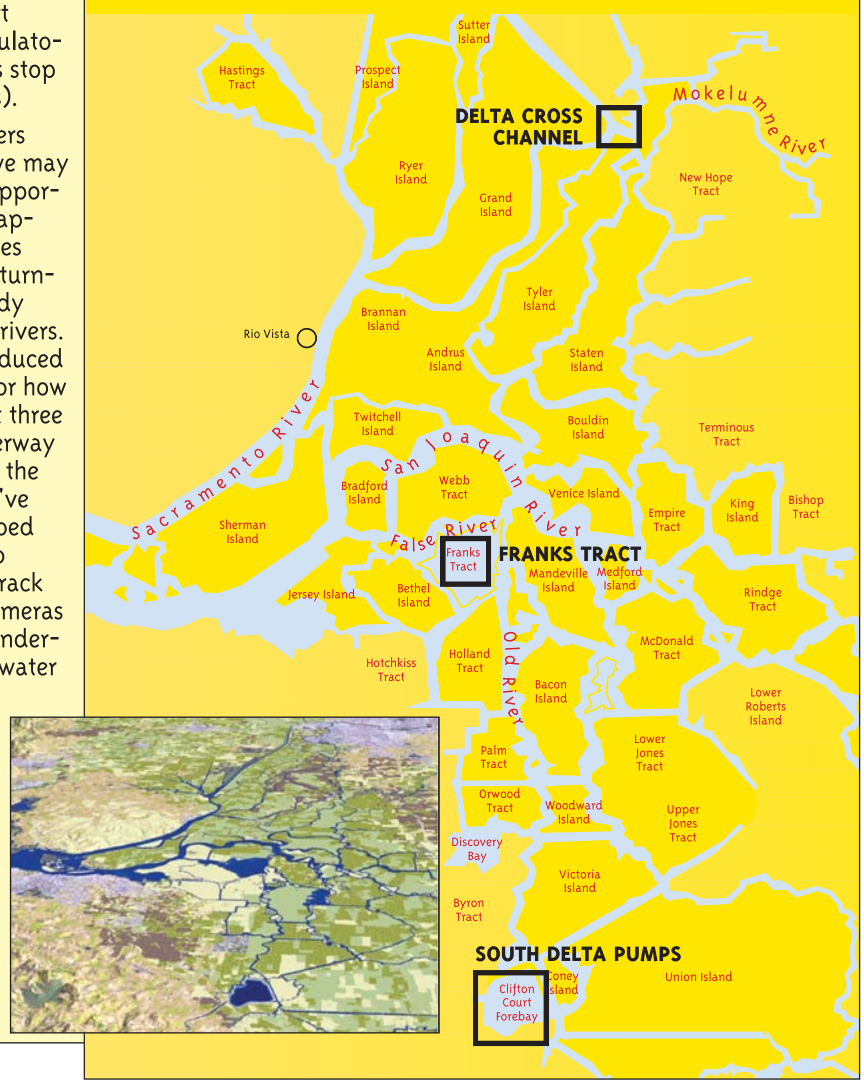
THREE PLACES TO OPTIMIZE DELTA DYNAMICS



Demystifying the Delta

This new wave of Delta research has profound implications for how we manage the system and suggests different tools for human tinkering — scientists say fixing a few levees at Franks Tract, for example, could improve water quality at drinking water intakes by up to 30%. "For all these years, we may have been turning the wrong knobs in the wrong places, because we saw the system as a river, not an estuary," says Tim Quinn of Southern California's Metropolitan Water District, which draws a lot of its water supply from the Delta.

Deciding which are the right and the wrong knobs is all about site specifics, and delving deeper into the dynamics of different Delta junctions (see Research pp. 3-7). It's also about optimizing use of our freshwater (see EWA, p. 8) and tidal tools and use of our existing infrastructure. And finally, optimization has to do with understanding how timing affects any actions we take, bringing timing down from a monthly to a daily scale, and even down to the difference between night and day, which scientists suspect plays a role in where fish are in the water column.

"We're moving into a new paradigm for managing environmental assets like water and species," says Sam Luoma, CALFED's retiring lead scientist. "The old paradigm was 'control' nature. The new paradigm is to manage our assets and reduce our impacts by working with nature. But to work with nature we need to know how nature works. Science and management must move forward together."

Clearly, some details of Delta dynamics now being explored by scientists suggest a thru-Delta solution which applies and integrates river, tide, fish, and facilities management on a much more localized scale. They also suggest that it may be possible to achieve some water supply and ecosystem goals at the same time.

"The ultimate test of whether this new knowledge will pay off is in our effort to make the thru-Delta approach work," says California Bay-Delta Authority director Patrick Wright. "The centerpiece of that effort is the 2004 Delta Improvements Package, which calls for increased exports to improve water supply reliability, together with additional protections for fish and water quality. Some are skeptical as to whether we can increase pumping without undermining our restoration goals; others believe that we can increase protections for fish, water quality, and water supply by optimizing Delta operations. All this new research will be enormously important in the debate."

OPERATING PRINCIPLES

NINE NEW TWISTS

1) OLD CONCEPT: The Delta is an extension of the rivers that flow into it. In terms of water circulation, the net flow component of water movement is the most important aspect to consider.

NEW TWIST: Tides, moving in two directions two times a day, have as much, or more, influence on water movement and transport processes in the Delta as export pumps or river flows.

2) OLD CONCEPT: Delta salinities are largely determined by freshwater inflows.

NEW TWIST: The Delta is a complex mixing bowl in which localized geometry interacts with complex flow patterns. These interactions may play a bigger role in salinity conditions than once thought.

3) OLD CONCEPT: Releasing freshwater from reservoirs is the only way to rapidly reduce tidal salts in Delta drinking water supplies.

NEW TWIST: Better management in key Delta locations, such as the flooded island Franks Tract, which may act as a tidal trap of saltwater in the Central Delta, could provide new tools for managing salinity at export facilities.

4) OLD CONCEPT: A new isolated canal or other developments of large infrastructure may be the only ways to improve water supply reliability while protecting water quality and saving fish.

NEW TWIST: Coordinating inflow operations at the Delta Cross Channel, Clifton Court Forebay, and other existing facilities with tidal cycles may offer opportunities to improve water quality and reduce impacts on fish without extensive new engineering.

5) OLD CONCEPT: Drainage from Delta peat islands is the primary source of dissolved organic carbon (DOC) in exports.

NEW TWIST: Most of the DOC in exports is coming into the Delta from rivers and watersheds.

6) OLD CONCEPT: Delta net flow is a major determinant of fish movement in the Delta.

NEW TWIST: Fish movement in the Delta is more closely tied to local flow structure, which is affected by tides and river inflow and their interactions with local geometry. It can no longer be assumed that the majority of the fish will go with the majority of the water.

7) OLD CONCEPT: Moving all salmon quickly through the Delta via the main channels is key to protecting them, because the interior Delta is hazardous to their health.

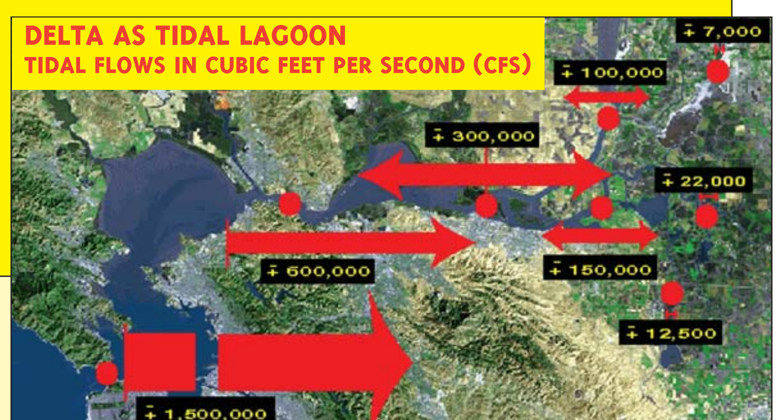
NEW TWIST: Some salmon races may benefit from their time in the Delta. Chinook salmon and steelhead exhibit a diversity of life history strategies, which require a diversity of habitats and multi-purpose management.

8) OLD CONCEPT: Mortality resulting directly from exports affects populations of salmon, delta smelt, and splittail. Reducing mortality at the export pumps by improving salvage screens will protect these populations.

NEW TWIST: One size fish salvage and screens does not fit all. Benefits vary from species to species and possibly among life stages. Reducing direct mortality at the pumps may require a combination of modifications to both infrastructure and operations. Species recovery will take a systemwide effort that reduces many different stressors and supports diverse improvements in habitat conditions.

9) OLD CONCEPT: Fixed, monthly standards set by regulatory agencies are essential to protect fish and water quality.

NEW TWIST: More flexible management tools are needed to optimize the system and operate on a real-time basis.



DELTA AS TIDAL LAGOON
TIDAL FLOWS IN CUBIC FEET PER SECOND (CFS)

RESEARCH

The Junction Jigsaw

Everyone knows that water flows downhill. But the Delta — that lowlying tangle of canals, cuts, and islands — flatly defies this notion. It also defies that other hydrologic tenet, that water flows one way from the river to the sea. Add an estuary, and the push of its tides upstream, plus the diversion of much of the river water to our taps, and *poof*, no more downhill, no more one way. Pour it all onto a landscape as convoluted as the Delta, and you have hydrologic complexity to the nth degree.

"Every corner of the Delta is a junction where water does weird things," says biologist Bruce Herbold of the U.S. EPA, referring to the dozens of waterway intersections cross-hatching the Delta. "It's simple geometry — water can't all be flowing downstream and going in a circle around islands at the same time. Where fish, salt, and water go at any and every split in the Delta is much more complicated than we ever imagined."

Scientists armed with drifters and beepers and computers and meters have been honing in on these complications at a handful of critical Delta junctions and producing a slew of new research, still very much in progress. They've discovered large-scale regional differences in how things move from place to place in the Delta channel network, and see many more options for management improvement in the ebb and flow of the tides than in the downward flush of rivers.

"We've gotten every drop of water we can out of managing the Delta as a river system on a seasonal time scale, and now the heart of our opportunities for improvement lie in the tidal time scale," says one of the scientists at the heart of the new research, the U.S. Geological Survey's Jon Burau.

Almost all of the Delta infrastructure — gates, dams, pumps, canals — is tied to seasonal variability, capturing and storing water when the weather is wet, redistributing it when it's dry, and measuring and adjusting our supply in terms of net flow. But "we're pretty much maxed out on managing the system like a river," says Burau. "We have to remember that rivers only hold sway in most of the Delta for about two months of the year. The rest of the time, tides are the big deal, a whole different territory and timescale for management."

Big deal for those fluent in the lingo of Delta operations means big "knob." Nothing makes a water manager smile more than the prospect of new "knobs" to turn at the controls of gates or dams or pumps that can send water where we want it in a big way. A freshwater knob, the Environmental Water Account, has offered resource managers a new tool and greater leverage in their efforts to help fish (see p. 8). A saltwater knob in a location like False River near Franks Tract (see cover map) could send as much as 50,000 cubic feet per second (cfs) in two directions, two times a day, a knob a hundred times bigger than the net flow knobs we've had to play with for years.

Though estuary managers and pump operators have worked with the tides for years, they've had little data about how tidal knobs might be micro-managed to keep either endangered fish or drinking-water-tainting salts moving around in the Delta mixing bowl from ending up in the wrong places.

"We always knew the harder we pumped, the more salinity and fish would show up at the pumps," says California Department of Fish & Game deputy director Diana Jacobs. "What we didn't know is what we could do about it. New modeling, monitoring and camera technology is allowing us to go underwater and get some new ideas."

The ideas are pouring out of the computers of researchers like hydrologist Burau, engineer Chris Enright, and biologist David Vogel, who have been coordinating flow, salt and fish research in three places where adjusting tidal knobs might make an enormous difference: the Delta Cross Channel to the north, Franks Tract in the Central Delta, and the state and federal pumping facilities to the south, (see cover map).

"It's all about the way tidal motions interact with the shape of the land," says Enright, who works for the state Department of Water Resources.

The shape of the Delta, and its salinity regime, are a product of how humans have reworked the landscape. We have dredged deepwater ship channels, built levees that enabled widespread subsidence, added many straightline cuts and channels, and allowed breaches on islands, all of which have changed the way salinity moves through the Delta. But this salinity regime is not static. Subtle changes — like shoring up a levee, taking out a cut, or closing an island — can dramatically change how fish and salt are transported around. For example, a levee breach in Suisun Marsh can cause a salinity shift in the South Delta, says Enright.

So maybe we don't need to build a big new canal or add another million cubic yards of concrete to the Delta infrastructure to get a hold of some big new knobs. And maybe it's time to update our water management mindset so that old ideas don't get in the way of new opportunities.

Scientists believe the Sacramento River's bend at the Delta Cross Channel plays a role in whether fish are drawn into the channel or not. Thus the magnitude and direction of velocity structure (complex water currents in a 3-dimensional perspective) are determined by the geometry of the junction and continuous changes in tides and freshwater flow. The interaction of velocity structure and variable fish behavior (such as position in the water column) determines where the fish go. Source: USGS

DELTA CROSS-CHANNEL

One old idea in need of updating, for example, might be the belief that the only way to keep the bad salty water in the South Delta away from the pumps is to flush with good clean water from the north. In the past, that water has always come from reservoir releases upstream at times when operators are loath to part with it, and from opening the Delta Cross Channel gates. But in 1999, a combination of drought, heavy tides, and

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closed gates (to protect outmigrating salmon) caused a water quality nightmare no one ever wants to relive. Since then, CALFED research has shown that if suppliers only close the gates at night during flood tides, they can still grab nearly as much good water from the Sacramento River as they can by keeping the gate open for weeks at a time. Opening the gates in broad daylight on an ebb tide may not only minimize fish getting sucked in (scientists suspect that fish are higher in the water column, or more active, at night), but also maximize boater access to the Delta Cross Channel. One big knob found and more in the works.

FRANKS TRACT

Another big knob materialized recently when the science shifted from getting good water to keeping out the bad. But rather than erecting a 4,800-foot-wide gate across the Carquinez Strait to keep the seasalts bayside, as proposed in the 1950s, the gate may span a small 700-foot-wide channel known as False River.

The False River runs from the San Joaquin River into, and then along the northern edge of, Franks Tract — which at about 3,100 acres is one of the biggest flooded islands in the Central Delta. During a four-month experiment here in 2002, while tracking tidal flows with drifters and measuring salinity and bathymetry, Burau noticed an amazing thing. "Water sloshes back and forth but what's in the water doesn't," he says. "In fact what goes out False River is fresher than what went in."

The shape of Franks Tract, and the specific locations of its many levee breaks, is key, he found. The sequence is this: the flood tide from the west side pushes salty seawater along False River and into Franks Tract. But when the ebb tide goes out, it pulls ambient water from all over the Tract — not just the seawater — back out to sea. Meanwhile other openings on the east side of the Tract along Old River allow the salty leftovers to mix with precious freshwater coming down from the north (via the Delta Cross Channel and Georgiana Slough) on its way to the South Delta pumps (see cover map and opposite).

"Franks Tract is a mixing machine; it's the perfect size and has the perfect openings to mix salt into the system," says Water Resources' Enright.

Fixing the salt trap problem may be a matter of geometry and physics, both scientists say. The distance from the San Joaquin through False River into Franks Tract is shorter than the distance a tide may reach in one cycle, or what scientists call "the tidal excursion." Extending the length of False River is a mere matter of fixing the northeastern levee. Once fixed, the tides coming in would never fully discharge into the Tract, reducing the exchange and storage of salinity on the island. Exacerbating the mixing problem are several major levee breaks along False River that act as nozzles,

MODEL MAGIC

To most of us, the idea of water movement in the Delta evokes that little map with arrows all over it. That map, and the net freshwater flow from river to sea it describes, is based on an old model of the Delta that for decades has helped inform operations decisions. One dimensional models, like DSM2, have long been used to describe this net flow in the Delta. While useful for some questions, scientists, engineers and technicians increasingly understand the need to make their projections about the impacts of different management actions more precise.

Driving this change, at first, were 1990s studies of the fresh-salt water interface (X2 and entrapment zone), followed by research on hydrodynamics and fish movements in the Delta Cross Channel — both of which got managers thinking in 3-D. According to Bruce Herbold, who coordinated the latter research, the Cross Channel studies showed us just how important things are that lay outside our conceptual boxes.

The key to using models effectively is to match their capability to the questions being asked. For large statewide planning questions, like 'what will adding Sites Reservoir and operating the pumps differently do to supply and salinity over years' — the 1-D model is entirely adequate, says Chris Enright. But 1-D models start to break down when we ask them more site- or time-specific questions such as 'what is the importance of velocity structure at a certain junction on a daily basis?' For this we need 2-D and 3-D models that can give high-resolution descriptions of how the transport of water and biota changes up and down the water column.

The main challenge in creating these new models is to accurately describe the system to the model. Modelers need to calibrate the model to reality based on accurate measurements of local geometry and boundary conditions. Models need to be able to tell us if a ten foot change on this bank or at this channel bottom will make a difference in their ability to answer questions. "The feedback loop between models and data and more modeling and more data is critical," says Enright.

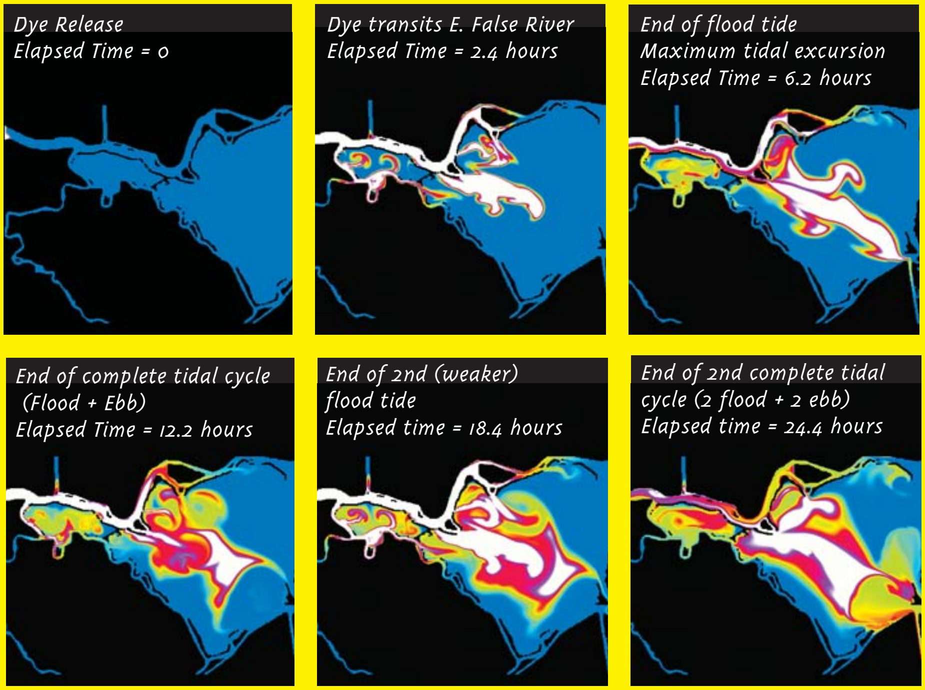
Jon Burau has made it his mission to collect that local data for several years now, and then worked with Enright and others to plug it into multi-dimensional models with an unprecedented level of specificity like the one for Franks Tract (see opposite). "Our model applications have grown more and more fine-tuned as the available geometry data has improved, evolving from net flow to tidal to velocity structure levels," says Enright

Herbold says the new models have "leveled the playing field between engineers and biologists," who were always reluctant to use such engineering tools because of all the uncertainties they had about the ecosystem. Indeed California Urban Water Agencies is now spearheading a biology-based model for salmon which may one day be able to interact with reservoir operations models.

"We're going in the direction of models that can talk to each other. Once we have models that everyone around the table believes in, then we get to start to use them to problem solve," says Herbold.

Franks Tract, fed by tides from the False River at left, and by the San Joaquin River at top, and the Old River at right.

COMPUTER SIMULATION: TIDAL TRANSPORT OF SALT INTO FRANKS TRACT



Time sequence of color plots representing dye concentrations over two tidal cycles based on numerical model simulations in the computer (TRIM2D, Casuli and Cheng, 1992). Dye (white), which can be thought of as representing salty San Joaquin River water, is released in False River at the beginning of a flood tide. Prior to the release, the whole area is initialized in the computer model as blue. Thus variations between white and blue indicate dilution of the dye through dispersive mixing processes. In the sequence above, the dye enters Franks Tract, mixes into the fresher ambient water and stays there. This is almost completely a tidal process and thus has virtually nothing to do with the river flows and export rates. (See p. 12 for Weblink to sequence animation).
Source: Burau & Enright

spraying salty water into the Tract like the "jet" setting on a garden hose.

All this comes to life in blue-green color on Burau's computer screen. He and Enright have plugged their field data on Franks Tract's bathymetry, geometry, and hydrodynamics into a cutting edge 2-D model. Using this model, they can simulate various management approaches to the salt trap problem, and highlight how fixing northern versus eastern levees, or adding a new tide gate that could be closed during the fall period of water quality nightmares, would affect salt transport (see Weblinks for animations). Burau thinks levees could be repaired incrementally and cheaply, and conditions checked as improvements are made. At best, Enright projects a 30% improvement in the quality of water sucked toward the pumps. But even if solutions proposed in Franks Tract don't work out as planned, the principles learned of using the tidal timescale can be applied to different locations throughout the Delta.

"Franks Tract is not necessarily the cure for cancer, as many people have been quick to believe. It's just one more example of how we might do a better job throughout the Delta in managing on a tidal timescale," he says.

And don't forget that what may be something of a cure for people — rearranging salt transport or changing the geometry of flooded islands — may not be any such thing for native fish and biota adapted to the natural variability of an estuarine ecosystem. That variability is what keeps natives thriving and exotic species on the run, says Bay-Delta Authority fish biologist Zach Hymanson. "It may be that we need to let the Delta be salty every so often," he says.

SOUTH DELTA

There is one place in the Delta, however, where working with tides is almost sure to help fish. For decades, managers have thought of the South Delta as a dead-end slough. Fish and water beware, what goes in doesn't come out. Think of this place, and its state and federal water projects, and words like "giant sucking sound" come to mind.

While the state water project facilities were originally set up to work with the tides, and South Delta improvements in the form of tidal barriers will soon help manage problem water levels in channels around the pumps and near local irrigation intakes, Jon Burau thinks more can be done to bring big tides to the aid of small fish.

Burau and a team of other scientists and state water managers are designing a series of experiments using the Clifton Court Forebay gates where water and fish are taken in by the State Water Project and held before the water is pumped south and the fish are salvaged and trucked back to the river. He speculates that simple timing changes in gate operations, informed by careful monitoring of local conditions, could save a lot of fish and could draw better-quality water into the pumps. It's all a matter of when the gates are opened and how wide, and of taking water when fish are out of the "zone of influence" of that sucking sound.

Right now, the state facility opens the gates into the Forebay mostly at night, drawing in as much water as possible, as quickly as possible. The team wants to experiment with a different approach, such as opening one or two gates instead of all six, and taking water more slowly over a longer period of time. "When you're not pumping at capacity, you have more flexibility to grab water at different times, but when you open the gates at midnight and go full throttle, it can be a dead end for fish," says Burau.

"The goal should be to move fish by the pumps while we take little sips," says Enright.

Moving the fish past the Forebay on a bypass flow is another possible approach. Opening the gates on monster tides could leave enough water out in the river to maintain a bypass flow that fish can hitchhike on, instead of getting drawn directly into the Forebay. Water project engineers, and the CALFED plan, have long proposed big expensive screens at the Forebay gates to keep the fish out. But

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Burau's team may be able to show that natural hydrodynamic features could give us bypass flows that might do just as good a job, at a much lower cost.

Gate openings could also be micro-managed to avoid taking water from areas where fish are particularly abundant at that moment, or from areas with poor water quality. "When you take water can mean where you take water from," says Burau. For example, if the Forebay gates are opened only on a flood tide, water is pulled preferentially from the North Delta (see below). On an ebb tide, the pumps pull water from the South and East Delta. "Grabbing the water at a time that pulls from a fish-free zone could help."

ZONE OF INFLUENCE SOUTH DELTA PUMPS

The water supplies drawn into Clifton Court Forebay at the State Water Project come from different regions of the Delta, depending on the tidal cycle. Coordinating timing with flood or ebb tides could help minimize salt or fish intake.

"All of these ideas are current avenues of research, not slam-dunk givens, " Burau explains. "But in essence, we want to capitalize on what nature is giving us by extending the current fish facilities management activities of keeping salmon and smelt out of the pumps, and applying bypass flow ideas long used by fish screen managers, to the channels leading to the pumps."

Actually making these ideas work will depend on getting all the details right. Managers will need to balance the relative magnitude of flows outside the Forebay against the magnitude of flows being drawn in. They will also need to juggle the timing of fish position in the water column with junction geometry and flow rate.

TAILING THE FISH

Now that we're getting a better picture of junction geometry and zones of influence of tides and pumps, we need to know how the fish react to all this underwater action. Several studies planned and underway will explore these links. One study, funded by the federal Bureau of Reclamation, will examine how far the effects of pumping extend into the Delta, and then look at fish populations in those areas. "We will use acoustics to find out what fish are doing in the water column and build that information into models of how fish move," says the agency's Mike Horn.

Small fish such as salmon smolts or delta smelt are the most susceptible to the velocity structure in junctions and at intakes throughout the Delta. They can't swim against a strong flow. To track just exactly where these small fish (3-5 inches long) go in the Delta and what they do when tides change or gates open at junctions, Dave Vogel has been saddling smolts with one-gram-radio transmitters. More importantly, this biologist with the firm of Natural Resource Scientists has been carefully coordinating his work with Burau's so that when the fish move, scientists know exactly how the water has moved too — fulfilling a CALFED mandate for integrating science research across disciplines that first proved itself invaluable in 2001 studies of the Delta Cross Channel.

Vogel's more recent studies, though they use hatchery not wild fish, are also yielding insights into the relationship between tides, fish, and Delta geometry. "The most dramatic result from our telemetry on smolts is the sheer magnitude of the distances they move each day, twice a day, up and downstream, with the tides. We can no longer think that smolts move in a linear fashion," he says.

Vogel clocked smolts traveling the tides over distances of 10-15 miles in a single day, depending on where they were in the system. When a salmon gets to a junction where the flows split, it doesn't always go with the biggest flow or the straightest migration route. " What determines whether a fish turns right or left are site-specific conditions — velocity changes in the water over minutes and seconds related to tides and

The U.S. Geological Survey's Cathy Ruhl and Jim George (standing) following a drifter on the San Joaquin River in the Delta. Drifters, tiny sailboats, are used to track flow directions and velocities. The drifter that should be in this photo has just been pulled underwater temporarily by intense vertical velocities in the bend immediately downstream of the head of Old River barrier. Source: Burau

channel geometry and time of day," says Vogel.

Time to question another axiom of fish management, the assumption that any diversion of a certain percentage of flow will take an equivalent percentage of fish with it. "There's no rule of thumb for the Delta that works," says Vogel.

Vogel's research shows smolts traveling every which way (see p.7), and not necessarily in packs, challenging another long-held belief: that salmon exhibit strong schooling behavior. Historic attempts to track salmon involved the release of large groups all at once and their recapture in nets shortly thereafter. "Chinook salmon don't work well as test organisms when you dump them out in a mass, because it takes days for them to disperse," says Vogel. His telemetry suggests that "salmon don't migrate through in a huge wad in unison."

Local geometry and hydrology continue to play an interesting role in whether smolts chose to go left or right. Confronted with the three-way split at the Cross Channel, for example, Vogel found that a surprising number of smolts ended up in Georgiana Slough. "Flow alone doesn't explain why this happens," he says. Along the San Joaquin River, Vogel found many smolts sidetracked into Turner Cut, and elsewhere in the Delta, funneled into flooded islands by high-velocity flows through narrow levee cuts.

"I'm beginning to think that the high mortality of smolts in the interior Delta is not so much the compounded problem of many factors — pumping, contaminants, habitat loss, small unscreened diversions — but the much simpler problem of localized microhabitats that favor predatory fish," says Vogel. "This is something we can physically fix."

Teasing out the site-specific conditions of every problem flow split and junction in the Delta, and fixing them so fish have a better chance of survival, is something Vogel is confident we can do. But each split will require its own overlays of data on fish behavior, physical geometry, and hydrodynamics. And each region within the Delta may exhibit different fish behaviors. For example, Vogel found that San Joaquin River salmon behaved distinctly differently from their Sacramento River counterparts, largely because the channel geometry in their habitat is much more complex.

Failing tricks with geometry, tides, and fish behavior, we can always go back to that long-held pillar of Delta fish protection: screens. Although the CALFED Record of Decision specifically calls for new state-of-the-art fish screens at the South Delta pumps, scientists and engineers are increasingly dubious about whether they are really the best use of limited funds — or indeed whether they will work at all to protect some species (see p. 10).

Several studies should yield more concrete information on whether screens are a viable option in the future, especially for delta smelt, which as one biologist says "die if you look at them funny." Three studies launched this spring will examine smelt survival and injury rates, predation losses, and stress levels during the collection, handling, transport, and release phases of the salvage process. "Screening fish in the South Delta is extremely challenging," says Department of Fish & Game biologist Bob Fujimura. "We are not comfortable making assumptions about how well they do, especially juvenile smelts, which are particularly sensitive."

Wired fish showing antenna and stomach sutures.

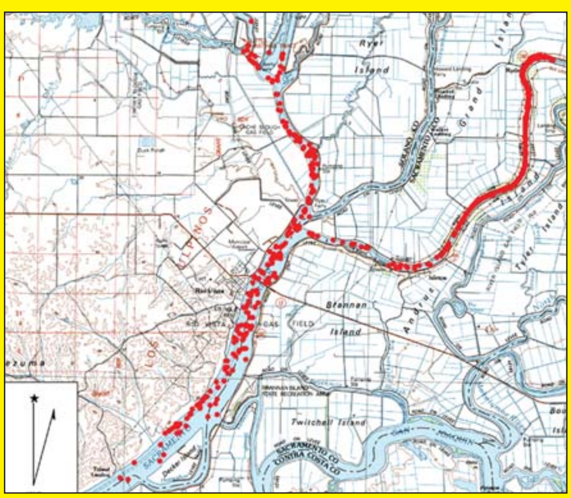
Another study is taking an underwater peek at what actually happens at release sites for salvaged fish from the Skinner Fish Salvage Facility. Staff release these fish at two Delta sites, using 13-inch pipes to transfer the salvaged fish from a transport truck back into the water.

The first test of the underwater camera, which employs the Dual-Frequency Identification Sonar (DIDSON) to see clearly regardless of the water's turbidity, revealed predator fish keying in on the pipe during a release. Researcher Roger Churchwell of the Department of Water Resources says the large three-year study he hopes to start sometime this year will employ numerous methods, but the new technology of the DIDSON will be instrumental in understanding fish behavior and documenting conditions during release. Churchwell's agency has been first in California to deploy this new technology, which was developed by the Navy for inspection of ship hulls for mines and harbors for intruders. The DIDSON can view out to 40 meters and provides an image of fish as they swim through the water, but the camera seems to have no effect on fish behavior. "We hope to see if we need to modify existing fish release sites to improve survival, and if hydraulic conditions in the release pipe are affecting the fish," says Churchwell.

All this research, and our increasing 3-D understanding of Delta junctions and hotspots, confront the concept of irresolvable conflicts between water quality and fish, and of the interior Delta as a deathtrap for smelt and salmon. They also raise questions about the necessity of "hardwiring" in any solution in a system whose flexibility and flux may be our biggest management asset (see p. 10-12).

"For 20 years, we've generalized about everything in the Delta," Vogel says. "Now we know that to succeed, we have to be much more site-specific in our management."

RADIO-TAGGED SALMON SMOLT TRAVELS IN THE DELTA



NORTH DELTA, 2001
Telemetered locations of approximately 50 radio-tagged smolts released at Ryde in the lower Sacramento River. Note the large distances salmon smolts move north into Cache Slough and to Liberty Island with the flood tides. Source: Vogel, D.A. 2001, USFWS Report

CENTRAL DELTA, 2004
Telemetered locations of approximately 100 radio-tagged smolts released near Fourteenmile Slough in the lower San Joaquin River. Note salmon smolt movements into the interior and south Delta through Turner Cut. Source: Vogel, D.A., 2004, CALFED Report

CARBON CULPRIT

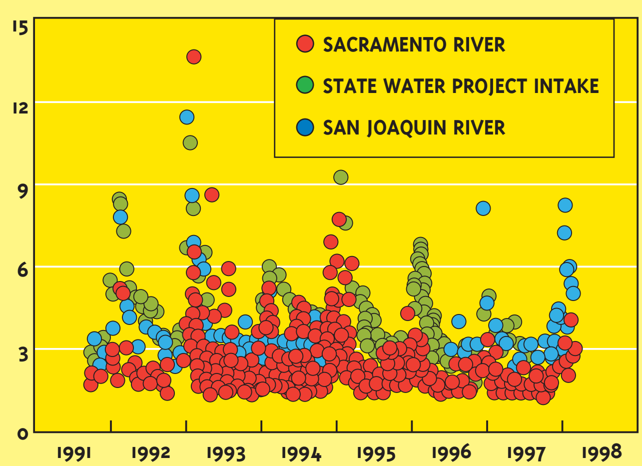
Delta drinking water suppliers furrow their brows over many substances, ranging from bacteria to pesticides, but two substances cause particular problems, bromide, a salt in seawater (see other stories) and dissolved organic carbon (DOC), formed by the natural degradation of soil and plant matter. Upon chlorination or ozone disinfection at treatment plants, these substances can form different byproducts (such as trihalomethanes, or "THMs", and bromate) harmful to human health and regulated by the EPA. For decades, water managers have pointed the finger at the Delta's peat islands, and their agricultural drains, as the biggest culprits behind elevated DOC concentrations. But new science shows that the bulk of the DOC (approximately 75%) comes not from the Delta itself, but from upstream rivers and watersheds.

As waters cross the Delta, the quantity of DOC added amounts to a quarter of the total, rather than half as long thought. More importantly, the vast majority is added in the wintertime — summertime increases are almost undetectable. In both the Sacramento and San Joaquin river valleys and the Delta, DOC concentrations are highest in the early spring, showing a stronger relationship with increasing amounts of spring sunlight and higher water temperature than with rainfall or runoff. So during the periods of high export in summer and fall, most of the DOC being exported by the pumps comes from the rivers, not the Delta.

"If you're worried about DOC from the Delta itself, you should be more worried about open tidal wetlands than peat islands," says researcher Brian Bergamaschi of the U.S. Geological Survey, who has been able to track DOC sources via chemical signatures. A recent CALFED-funded study of a furrow-irrigated corn field located on Twitchell Island in the Delta revealed that only 4% of the net primary production was transported off the field as DOC in the irrigation drainage waters. Wetlands export up to 10%.

"The bad news is that wetland-derived DOC is the worst kind. The good news is that it's fresher material and degrades more quickly in the environment," says Bergamaschi. The fresher the organic material, the more THMs it forms upon chlorination, he explains. Likewise the fresher the material, the more quickly and completely it degrades. "DOC that may be a problem for Contra Costa Water District and its Rock Slough intake is not the same problem for 'MET' down in LA, which gets its Delta water months later," he says.

INTAKE & RIVER CARBON COMPARED



Time series of DOC showing similar timing and magnitude of peaks at SWP intake and major Central Valley rivers

Dealing with Delta DOC could be a matter of geometry and hydrodynamics, in which planners redesign how wetlands interact with adjacent channels. Dealing with DOC from rivers and watersheds will require altering the flow path of water so it spends more time percolating down through, or flowing under, the ground and thus degrades before tainting our taps.

It should be noted that while DOC may be bad for drinking water, it may be good for estuarine foodweb in that it supports microbial productivity.

EXPERIMENT

Making the Delta More Fish-Friendly

Tuning in with the tides may offer some powerful future tools for conflict resolution in the Delta, but tuning into the more immediate needs of salmon and smelt is working in the here and now. The Environmental Water Account (EWA), for example, is now in its fourth year of proving itself an invaluable freshwater tool.

"Our old tools for protecting endangered fish used to be take limits and fighting, so we operated on the edge of jeopardy all the time," says Fish & Game's Diana Jacobs. "Now, we're much more pre-emptive and collaborative. When real-time monitoring shows fish in the vicinity, we say, 'Turn down the pumps,' and they do it immediately, because we have EWA to pay them back for lost water later. There's no fighting, no arguing, no delay. People who managed fish before and after EWA just love it, because we all work together."

Between 2000-2004, EWA purchased over 900,000 acre-feet of freshwater at a cost of about $140 million to replace exports, when concerns about fish led to curtailed pumping, and to provide improved fish habitat upstream.

The success of this cooperative, real-time, interagency action created a culture in which high level managers of fish and water agencies were quick to accept new counting methods for chinook winter-run salmon critical to assessing incidental take limits — another important tool. Federal incidental take limits for winter-run allow up to 2% of 'juvenile production' to be lost at the pumps. The formula for setting take limits combines the number of offspring produced ('juvenile production') with the number of adult fish returning to spawn each year ('adult escapement'). The latter number — based on how many fish passed through the Red Bluff Dam fish ladders — became questionable in recent years as the dam gates remained open for longer periods and fewer fish had to use the ladders. An alternative method, counts of spawned female carcasses upstream, backed up by earlier surveys, revealed a variation up to a factor of five in the total estimates of spawning adults. The new higher estimates of adult escapement translated into a higher estimate of juvenile production and meant that the take limit was never reached in 2001, for example — changing the need to reduce pumping and use EWA resources to protect fish.

"EWA allows us to take new knowledge and apply it much more quickly than we could ever do with prescriptive standards," says Jerry Johns, deputy director of the Department of Water Resources.

When monitoring in 2003 revealed large numbers of delta smelt in the Delta in late May, managers continued export reductions longer to allow the fish to move out of the interior Delta before water temperatures rose too high. "We are using better monitoring to determine day-to-day operations," says Johns. "It makes an EWA-type approach much more effective if you can target your resources."

Perhaps the biggest revolution wrought by EWA has been on the agency side. "Making fish agencies into water managers in the system gives them a stake in the outcome. The feedback loop is really tight here, because the fish agencies are franchised into the process of spending water assets wisely through EWA," says Johns.

Yet EWA still needs to be more flexible, say biologists. "Fish use the Delta differently in different years, so the risks are different," says U.S. EPA's Bruce Herbold. "The EWA is trying to use comparable resources in every year. But in some years, we may not need all of them, and in some years they may not be enough." Finding ways to make EWA more effective year-to-year is part of the reason why it was set up as a four-year CALFED experiment, complete with its own annual technical review by a panel of outside experts (the next review is planned for November 2004).

New tools and new monitoring have also brought into question the view of the Delta as a dangerous place that managers had to herd migratory fish through as quickly as possible. According to this so-called "leaky pipe model," anything that interfered with the salmon's swift commute — be it predators, entrainment in the Central Delta, or diversion into floodplains or tributaries — was seen as a problem for the fish. However, recent findings are beginning to change that view.

"We now think that salmon hedge their bets — they spread out risk like a mutual fund does," says the Department of Water Resource's Ted Sommer. Under this model, salmon do not come down the river in lockstep; rather, they spread out, with some making their way into floodplains, and others making for tidal wetlands or tributaries.

Sommer and others say the management implications of this new paradigm for salmon life history should be obvious: It may be time to worry less about reducing losses to predation, diversions, and stranding, and instead put more attention on creating diverse salmon habitat.

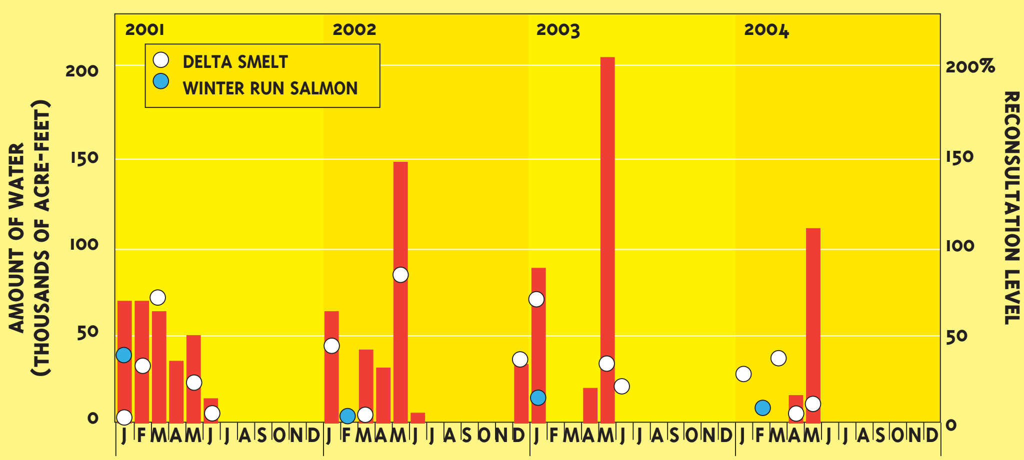
"EWA is a great complement to the flow, habitat improvement, and water quality protection actions we still need to take to make the Delta good habitat again, but it's not a substitute for them," says Gary Bobker, program director of The Bay Institute. "It will take the whole menu of actions to recover sustainable endangered fish populations. Maybe then we can start to worry less about direct diversion effects."

EWA IN A NUTSHELL

The Environmental Water Account (EWA), one of the tools within the CALFED Water Management Strategy, was established to provide water for the protection and recovery of at-risk fish species beyond water available through existing regulatory actions related to the operations of the state and federal water projects. It is based on the concept that flexible management of water can achieve fish and ecosystem benefits more efficiently than a completely prescriptive regulatory approach. EWA's purpose is to provide protection to at-risk fish species through environmentally beneficial changes in water project operations at no uncompensated water cost to the projects' water users. This approach requires the acquisition of alternative sources of project water supply, called "EWA assets," that are to be used to augment stream flow or Delta outflow or to modify exports, to provide fish benefits, and to replace the regular project water supply interrupted by EWA-driven changes to project operations. The EWA is intended to provide sufficient water, combined with the benefits of implementing the Ecosystem Restoration Program and the environmental protection provided by the regulatory baseline, to address CALFED's fish protection and restoration-recovery goals.

ENVIRONMENTAL WATER ACCOUNT EXPENDITURES

JAN 2001 THRU SEPT 2004



EWA expenditures are used to take proactive measures (release water from reservoirs and/or ramp down Delta pumping plant rates) to AVOID the reconsultation levels (100%, or "red light) for delta smelt and winter run chinook salmon. In previous years - without the EWA - protective actions could not be taken UNTIL the reconsultation levels were reached. Note that a single EWA action often provides benefits to more than one listed species (including spring run chinook salmon and steelhead).

MANAGEMENT

Which Knobs Do We Turn Next?

Imagine a Star Trek-style flight deck with real-time streaming video of Delta flows and salt movement. Then imagine this flight deck in the lobby of the Department of Water Resources, and available on the Web, so that anyone could log on and wade right in to watch changes in the system as we open and close gates, release water from upstream reservoirs, and change pumping operations.

According to the California Bay-Delta Authority's Kim Taylor we are "inches away" from making this dream a reality. Such technology and data at our fingertips could certainly enhance our ability to respond to hourly changes in the Delta system and to optimize our management of its facilities and waters. But we are still miles away from understanding what this stream of new data and ideas means for management. "The complexity makes is difficult to know what the best thing to do is, but it's also exciting because we have more options for what to do," says EPA's Bruce Herbold.

"We'll go wherever the science leads, but it certainly seems to be leading us toward greater flexibility, which is what we've been calling for from Day One," says the Metropolitan Water District's Tim Quinn. "If it says we can pump more and do no harm then we will; if it says don't pump, it's a bad day, we won't. We'll never eliminate the conflict and competition between fish, water quality and water supply, but we'll get smarter about how to reconcile our differences through good management."

Certainly we've gotten a lot smarter since the early 1990s. According to California Bay-Delta Authority senior advisor Tim Ramirez, there's not only been an extraordinary acceleration in our level of understanding of the nuances of the ecosystem, but also in the degree of cooperation among agencies working to save fish and deliver water. "It's become an 8-5 part of our agency culture," he says. "We've evolved from management based on a non-native fish on a monthly timeframe with limited tools for helping the ecosystem to a finely tuned daily management model based on the critical life stages of many native species and a new flexible tool, the Environmental Water Account, for avoiding the red light at the pumps."

The mood now seems hopeful that by continuing to experiment with system changes in small reversible increments, and by being open to surprises and learning from them, we can all get better together in the CALFED way. Franks Tract is a case in point. When Burau first started setting his drifters out there, his CALFED research goal was to discover the fate of a contaminant (selenium) on the island and whether it would pose a problem for future restoration. The "surprise" was discovering how the Tract was hoarding salt from tides and redistributing it in unsavory ways. So an island that began as a restoration target is now being reconsidered as a water conveyance and salinity reduction project.

"We had no idea there could be a tool sitting right in the middle of the Delta that might help us untie the Gordian knot between water quality and water supply without asking Friant Reservoir to send down more water," says Quinn.

Certainly the 30% improvement in water quality that scientists estimate might result from corrective measures at Franks Tract would help urban water purveyors extend their existing supplies. According to Steve Macauley, Executive Director of the California Urban Water Agencies, the reduction in salinity in Delta exports resulting from any work on the Tract would let them reclaim more of the water later (if the source water is too salty in the first place, it can only be reused once).

Another urban drinking water purveyor, Richard Denton of the Contra Costa Water District, sees a bigger picture. "The new research tells us we shouldn't be in a hurry to pour concrete all over the Delta or plug up certain channels," he says. "It tells us we should let tidal actions work for us rather than against us."

Despite the promise of working harder at working with the tides, many people have concerns. Denise Reed, a tidal marsh geomorphologist on CALFED's Independent Science Board, cautions that we shouldn't expect to be able to manage tides the way we manage rivers, because the timescale is so much more compressed and human interventions would need to be so precisely tuned to daily ebbs and flows. She feels we should be very careful with the idea that tide gates everywhere might solve all our problems. "It's not about adding more controls on the Delta; that goes against the grain of everything we've been working for. It's about exploring new opportunities to achieve both water supply and ecosystem goals at the same time by working in concert with the landscape," says Reed.

The Bay Institute's Gary Bobker worries that "People jump on small fixes, anything new like Franks Tract, that shows it's not an export pumps problem." He points out that all the hype about tides deflects the debate

In June 2004, a levee along Jones Tract (ten miles west of Sacramento) failed without warning, flooding almost 12,000 acres of farmland and illustrating the continued long-term risk of the existing Delta levee system. Its failure forced a brief change in normal Delta water project operations, and provoked increased water quality and fisheries monitoring. Soon after the breach occurred, U.S. Geological Survey scientists measured a maximum tidal discharge of 19,000 cfs at the opening. By the time workers had almost completed closing the breach, maximum tidal flows had decreased to about 10,000 cfs . Data from the long-term flow station located on Middle River showed substantial increases in the tidal velocities after the failure, a potential threat to other weak spots. More in-depth analysis of the impacts will be shared at a special session of the CALFED Science Conference in October 2004. Source: DWR from the most critical piece of science knowledge of all, that the more flow we have in spring, the more fish we have. "Maybe the socio-political-economic reality is that CALFED cannot fully restore flows and habitat quality in the Delta, and that it will have to rely on these real time interventions, but that's not science — that's policy based on tradeoffs," he says.

Water Resources' Chris Enright is concerned about too much of the "all get better together" approach on Franks Tract. "There's a tendency to try to make every project everything for everybody. We need to think more regionally and integratively about these projects. In my view, Franks Tract is so far gone, it's a hole in the ground with levees all around and eight feet of water in the middle. We should concentrate on water quality there and move our ecosystem restoration initiatives away from the pumps," says Enright.

Franks Tract and other Delta research do seem to have pushed some hot buttons about where to spend restoration dollars, with many concluding that more bang from the buck may come from investments upstream and downstream rather than in the black hole in the middle.

"The Delta is plumbed as a flood control and water delivery system, with channels that have hardly a vestige of natural bathymetry, and all of a sudden we're asking it to function as an ecosystem. Where you find the trade off between the Delta working well as one or the other is the billion dollar question," says the Geological Survey's Jon Burau.

Other management trade-offs are coming to the fore with the buzz on Franks Tract. Whereas managing on a tidal time scale has been a "win-win situation" at the Delta Cross Channel, according to Richard Denton, tidal tweaks at Franks Tract could easily turn in to a win-lose situation.

Denton says that if Franks Tract works as hoped, and improves water quality by removing salinity, we have to make sure the improvement for downstream urban intakes isn't cancelled out by more pumping upstream at the water projects. Denton says new assurances will be necessary to ensure this balance between water supply, water quality and ecosystem improvements.

OUTLOOK

DR. JOHNNIE MOORE
LEAD SCIENTIST
CALFED

"This new job presents an incredible opportunity to work in a completely modified system to the benefit of both the ecosystem and water supply. There are very few free-flowing rivers left in the lower 48; they're all channelized, dammed, and used for irrigation. We'll be managing them forever. If we can make an experiment like this work in the Sacramento-San Joaquin river system, we can do it anywhere.

"We can't give up on the Delta if we want species like salmon and smelt to continue. We may need more hardware or we may need more software; we may need both. We must accept that we're now in an era dominated by humans, an era Nobel Laureate Paul Crutzen calls the 'anthropocene,' where human forcings are at play at all levels (water use, climate change, pesticides, etc.). The world got this way incrementally — no one back in the 1800s planned our water system, for example, as a whole. So we need to go back to basic principles and processes to determine the best path forward.

"The challenge for California will be how to restore process, because we can't restore pre-1800s geography. Projected population growth will require big banks of water unless we dramatically change our consumption practices. CALFED has made a big investment in science to understand processes, and how best to manipulate them for benefit to ecosystems within the context of human needs.

"The exciting thing about all this tidal and related science (see pp. 3-7) is how clear it is that when you do integrated research, you end up with a much deeper understanding of the ecosystem. We've learned that the Delta is not static, how small changes like levee breaches or gate operations can have a big effect on circulation in the long term. This science shows how important it is to use the natural system as a laboratory, so we can test our ideas and models about possible manipulations through in-the-water estuarine experiments.

"Nationwide, big water management projects are not known for using the bulwark of science: peer review. CALFED is an exception. It pushes a more immediate kind of peer review than the kind that takes place through publication in journals. It facilitates expert feedback at all levels, through its independent science panels, boards, and workshops, as well as the more traditional peer-reviewed outlet for science in the online journal, *San Francisco Estuary and Watershed Science*. It is critical to use these tools to incorporate the most recent science into pressing management needs, and adapt our actions to changing knowledge. We can't be doing 2004 management based on 1995 science, but if we're using 2003 and 2004 science, it has to be well substantiated.

"We aren't going to fix this system in five or 10 or 20 years and then say, 'We're done.' What's critical is creating a culture of developing peer-reviewed science and then using it to make decisions that are embedded in all agencies, regardless of politics or economics or whatever the future may hold."

As of July 2004, Dr. Johnnie Moore, Professor of Geology at the University of Montana, replaced Sam Luoma as CALFED's lead scientist. Dr. Moore has a Ph.D. in geology from the University of California, Los Angeles. In Montana, he founded the Environmental Geochemistry Laboratory and co-developed the Center for Riverine Science and Stream Renaturalization. He specializes in the transport and fate of metals and metalloids in wetland, river, and reservoir systems. While most of his research has been conducted in Montana, he has also worked in Northern California and Utah and in other countries examining contamination from historical mining operations and agricultural runoff.

Turning up the pumps and making maximum use of the existing water project infrastructure was envisioned in the CALFED Record of Decision (ROD, August 2000), but only if other interests — including in-Delta farmers, endangered fish, sport fisheries, and water quality for exporters — could simultaneously be protected. Concern from all sides drove the CALFED staff to develop the 2004 Delta Improvements Package as an update to schedules in the ROD, so that all of the actions related to water project operations and potential increased exports could be viewed in the context of new science, new funding constraints, and new management options.

Continued page 12

Which Knobs?

The package outlines conditions under which the State Water Project would be allowed to increase its permitted export capacity from 6,680 to 8,500 cfs. Besides the commitments in the CALFED ROD to avoid adverse fishery impacts and to protect in-Delta water supply reliability, these conditions include: construction of permanent operable barriers in the South Delta to help mediate water level problems; development of a salinity management plan for the San Joaquin River; improvements to protect water quality near the Contra Costa canal; environmental protection for important native fish species, including implementation of the Ecosystem Restoration Program; and a long-term Environmental Water Account.

Another possible mid-course correction to the ROD is being considered for the long-standing and pricey proposal to build monolithic new fish screens at the pumping plants. While the screening approach may work well on river diversions, the benefits to fish populations of expanded screening at the pumps remain uncertain. "Each fish is precious, and my duty is to minimize their loss to the extent that it's reasonable, and therein lies the rub," says Fish & Game's Diana Jacobs. "For what we're thinking of spending on screens, we could probably send a Delta smelt to the moon, or at least buy a lot more water for EWA or do a lot of river restoration," she says.

Quinn, who co-chairs the South Delta Fish Facilities forum with Jacobs, says this group is "not rushing headlong" into multi-billion dollar investments in screens when so much of the new science says it may not be worth it. That wouldn't be an investment in flexibility, he says.

Indeed when it comes to investing in new science, top managers and scientists excited about the new tidal data and models would like to see equivalent energy dedicated to the fish side of the equation. Not enough is known about fish behavior, not enough analysis has been done of the wealth of existing fish data in terms of water management implications, and many technical problems remain to be solved in terms of the gear and methods used to study smelt, for example.

"We need to know the population effects of our salvage efforts, and more about how fish navigate using salinity gradients, currents, tides and flows," says Jacobs. "Salinity may be a bad thing for Frank's Tract but a good thing for a lot of native fish. If we overlay variation in fish behavior with variation in habitat and salinity, we may begin to get a clearer idea of what to do."

Gates designed to help manage salinity and tides already exist in the San Francisco Bay-Delta Estuary, such as these built in 1988 in Suisun Marsh to freshen the marsh for waterfowl habitat.

Good science should continue to help provide clarity and new management choices, as it has on the Delta Cross Channel and Environmental Water Account. "Today's advances would not be possible if CALFED had not been able to marshal the time and talent to build instrumentation, test concepts, tap the long root of existing knowledge (IEP, DWR, and USGS) and bring all this effort to pay-off point," says CALFED's retiring lead scientist Sam Luoma. "But we are clearly under-invested in the long-term effort."

It's not as if science funding equals a lot of money, compared to bigger-ticket items like dams and fish screens. In the CALFED Record of Decision, only 3.5% of the program's $8 billion projected expenditures was slated for science. CALFED has set aside about 5% of its funds from Proposition 50 for science. "But bond funding only gets us a couple of more years, and then we have nothing," says Ramirez.

Another big challenge is to better integrate the practice of science into all of the program elements under CALFED. "We need to break down barriers and establish new conduits that maximize information transfer from scientists to managers and policymakers," says the Authority's Zach Hymanson. Such closer connections with day-to-day management and policy should also encourage state and federal agencies to provide their share of the financial support for science.

Some find it hard to imagine that this way of doing business — what Ramirez calls "well-funded research with multidisciplinary teams working on priority policy issues" — will ever end. Others know that it cannot end if we are to meet the lofty expectations established in the CALFED ROD. Every year promises to produce new challenges — droughts and deluges, levee breaks, more or less fish, more people and farms, earthquakes, political upheavals, economic upturns and downturns, climate change and sea level rise.

The way California Bay-Delta Authority director Patrick Wright sees it: "Flexibility, combined with good information and communication, must remain at the heart of Delta management. CALFED's ROD, and the new Delta Improvements Package, attempt to do this. If we can't sustain a program that's proven to be so beneficial to us all, and so adaptable, we have no business in the water business."

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WEBLINKS

California Bay-Delta Authority	www.calwater.ca.gov
ESTUARY Newsletter	www.estuarynewsletter.com
Franks Tract Animations	http://baydelta.wr.usgs.gov
San Francisco Estuary Project	www.abag.ca.gov/sfep/sfep.htm
Smolt Movement Studies	www.resourcescientists.com

Delta Improvements Package
www.calwater.ca.gov/DeltaImprovements/DIP/DeltaImprovementPackage.shtm

CALFED Science-in-Action Publications

Scrutinizing the Delta Cross Channel, June 2001
Puzzling over the Shallows, December, 2001
Reviving Central Valley Rivers, June 2003

This special publication was paid for by the California Bay-Delta Authority's Science Program.

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