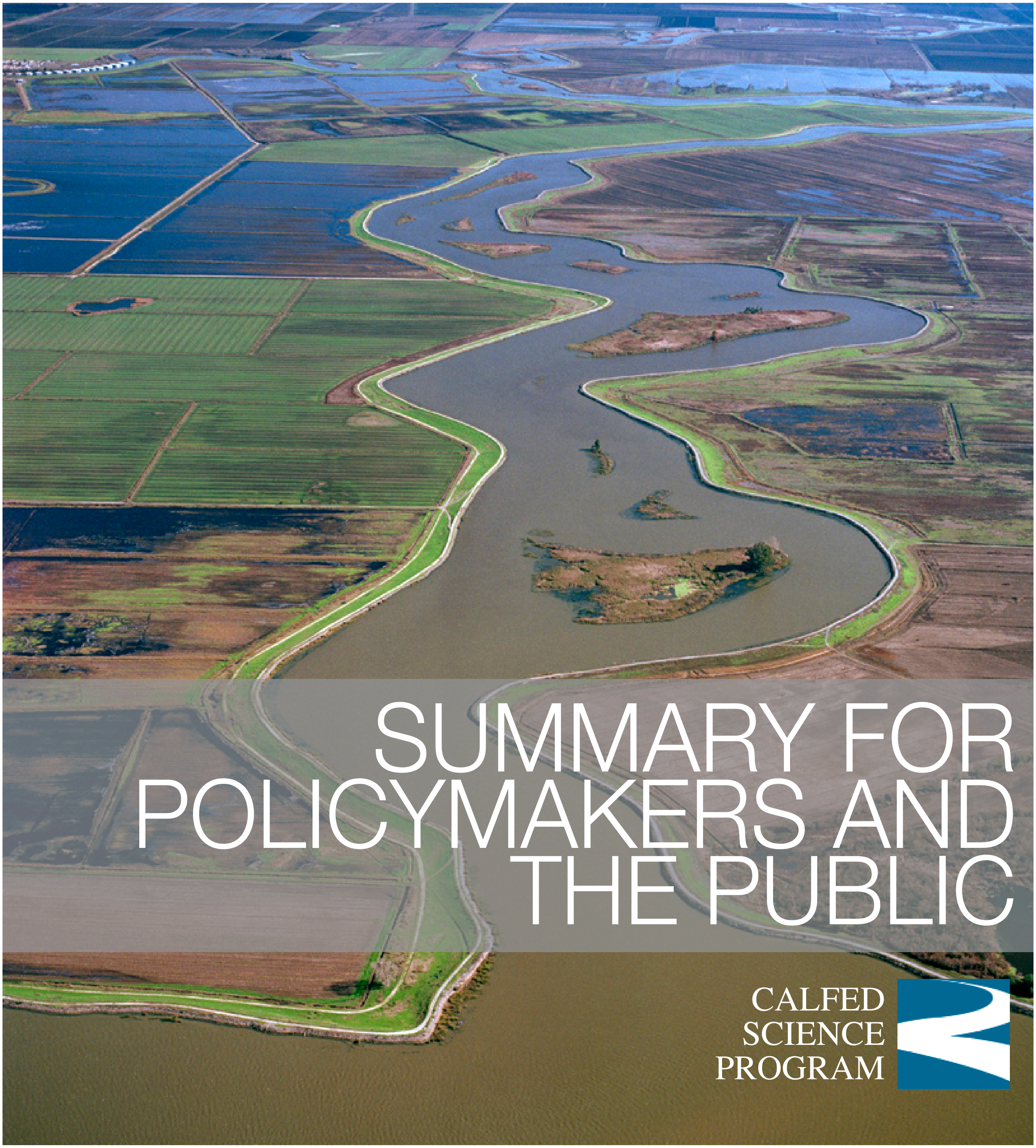
THE STATE OF BAY-DELTA SCIENCE 2008



SUMMARY FOR POLICYMAKERS AND THE PUBLIC

CALFED SCIENCE PROGRAM

The State of Bay-Delta Science 2008

Summary for Policymakers and the Public

November 2007

CALFED Science Program

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Technical support for this summary will be found in the full ***The State of Bay-Delta Science 2008*** to be released early in 2008.

Preface

The State of Bay-Delta Science 2008: Summary for Policymakers and the Public presents important new policy perspectives arising from recent advances in how scientists now understand the Bay-Delta ecosystem. These perspectives both challenge the way we once understood the Delta, and our policies for managing it. We describe these advances more completely in the full, State of Bay-Delta Science 2008 report, scheduled for publication in early 2008. The summary report synthesizes our current scientific understanding of the Bay-Delta ecosystem in easily assessable, nontechnical terms.

The amount of scientific information about issues in the Bay-Delta has increased dramatically in recent years, stimulated by creation of the CALFED Bay-Delta Program in 2000. Research promoted by CALFED and other science agencies has increased our understanding of how the Bay-Delta functions and has challenged some long-held beliefs about the Bay-Delta. Problems of water management, environmental protection, and levee integrity continue to intensify, however, and are being further complicated by climate change and sea level rise. Several high level planning and evaluation processes are underway to find solutions to these problems, including Delta Vision, the Bay-Delta Conservation Plan, and the Delta Risk Management Strategy. These processes all depend heavily on scientific understanding of the Bay-Delta. Policymakers and the public need to be well informed about current scientific understanding of the Bay-Delta ecosystem to be able to assess alternative policies and to make sound decisions about water and environmental management. This summary provides an overview of our scientific understanding to help guide policymakers in finding solutions. The CALFED Science Program staff will update and revise the full State of Bay-Delta Science report from time to time as new information becomes available.

Michael Healey
Lead Scientist, CALFED Bay-Delta Program
Sacramento, CA, January 2008.

Introduction[1]

The environmental resources of the San Francisco Bay and Sacramento-San Joaquin Delta have long contributed to the state's diverse society and its prosperous economy. However, in pursuit of wellbeing and prosperity, over the past 150 years, Californians have dramatically changed the Delta's geography, hydrology, and ecology. Today, the Bay-Delta is degraded and its capacity for providing all the environmental and societal benefits the public demands (viable populations of desired species, wild habitats for recreation and solace, land for agriculture, and the conveyance of reliable and high-quality freshwater) continues to decline.[2]

As the Delta has changed, science has played an increasingly important role, contributing to the way people perceive and respond to problems. As our science of the Bay-Delta has progressed, our understanding has improved. Our comprehension of how the Delta functions is today quite different from that of a few decades ago. We now know that change is constant, that it is neither possible nor desirable to "freeze" the Delta at any point in time, that the challenges of water and environmental management are inextricably intertwined, and that the capacity of the Delta to deliver environmental and water supply expectations is likely at a limit.

The problems of the Bay-Delta are broad based and do not easily fit within traditional discipline-based problem solving. Looking to the future, we now no longer consider earthquake-induced levee failures and "Katrina-style" flooding to be science fiction. Realistic views of the future include dramatic changes such as accelerated sea-level rise, changes in the availability of fresh water, and continued species invasions. The scientific community is grappling with the implications of these complex problems for designing research projects, interacting with and learning from other scientists, and communicating their findings to policymakers.

The establishment of the CALFED Bay-Delta Program in 2000 helped to address the problems of water quality, reliability, levee integrity, and ecosystem restoration in the Delta and its tributaries. Since then, CALFED-supported science has helped to clarify the extent and seriousness of the problems in the Delta, and has identified a spectrum of potential solutions. These solutions and how to implement them are now under debate as part of the Delta Vision process.

The New Science of the Bay-Delta

Routine scientific monitoring of the Bay-Delta began more than three decades ago under the auspices of the US Geological Survey and the Interagency Ecological Program. The long-term data sets provided by this monitoring, combined with recent problem-focused research and analysis stimulated by CALFED has greatly increased our understanding of the Bay-Delta system. Nevertheless, much still remains to be learned, and changing background conditions (e.g., climate change, population growth, species invasions) are continually challenging our ability to predict the future from the past. Problems that policymakers must address are increasing in complexity, and solutions call for new forms of collaboration among scientists from different disciplines. Helping in this collaboration, the CALFED Science Program has acted to expand and facilitate communication among scientists, and between scientists and policymakers through its journal *San Francisco Estuary and Watershed Science*, newsletters like *Science News*, model-development, biennial science conferences, and many workshops. CALFED has helped scientists to look beyond their

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1 Technical support for this summary will be found in the full *State of Bay-Delta Science 2008 report,* to be released early in 2008.

2 Explored further in chapters 1 and 2 of the full *State of Bay-Delta Science 2008* report, in preparation.

specific disciplines and see the Delta as a whole – laying the important groundwork for the Delta Vision,[3] Delta Risk Management Strategy,[4] and the Bay Delta Conservation Plan.[5]

The result of all this scientific activity has been a new perspective of the Delta, and recognition that the environmental services provided by the Delta will continue to degrade with some disappearing if we continue our current policies for water and environmental management. Our policy framework of the past has served California well, but our enhanced understanding of the Delta shows that we need new policies if the Delta is to continue to provide the range of services that Californians demand. This summary of the *State of Science for the Bay-Delta System* is framed around our new perspectives arising from recent Delta science. It highlights the most important changes in how we now understand the Delta and provides the principal policy implications (see Table 1).

3 For more information on the Delta Vision, visit *www.deltavison.ca.gov*.

4 For more information on the Delta Risk Management Strategy, visit *www.drms.ca.gov*.

5 For more information on the Bay-Delta Conservation Plan, visit *www.resources.ca.gov/bdcp/*.

Table 1. New perspectives on the Delta derived from recent science

Perspective One: The Delta is a continually changing ecosystem. Uncontrolled drivers of change (e.g., population growth, changing climate, land subsidence, seismicity) mean that the Delta of the future will be very different from the Delta of today.

Perspective Two: Because the Delta is continually changing, we cannot predict all the important consequences of management solutions. The best solutions will be robust but provisional, and will need to be responsive and adaptive to future changes.

Perspective Three: It is neither possible nor desirable to freeze the structure of the Delta in its present, or any other form. Strengthening of levees is only one element of a sustainable solution and is not applicable everywhere.

Perspective Four: The problems of water and environmental management are interlinked. Piecemeal solutions will not work. Science, knowledge, and management methods all need to be strongly integrated.

Perspective Five: The capacity of the Sacramento-San Joaquin water system to deliver human, economic, and environmental services is likely at its limit. To fulfill more of one water using service we must accept less of another.

Perspective Six: Good science provides a reliable knowledge base for decision-making, but for complex environmental problems, even as we learn from science, new areas of uncertainty arise.

Perspective Seven: Accelerated climate change means that species conservation is becoming more than a local habitat problem. Conservation approaches need to include a broad range of choices other than habitat protection.

Perspective One

The Delta is a continually changing ecosystem. Uncontrolled drivers of change (population growth, changing climate, land subsidence, seismicity) mean that the Delta of the future will be very different from the Delta of today.

Despite the fact that change is what characterizes the Bay-Delta, our policies and even some of our science have often assumed that the Delta of the future would be much the same as the Delta of today. A growing body of science, however, shows that large-scale changes are commonplace in systems like the Bay-Delta. Powerful external forces are driving change in the Bay-Delta. A more realistic viewpoint is that change is inevitable, and is necessary for the proper function of the system. Estuaries and deltas are dynamic, constantly changing ecosystems. The present Delta formed when the sea level rose following the last ice age, which ended 10,000 BCE. As the rivers of the central valley carved away at the fringing mountains, the Delta approached its precolonial geometry about 5,000 BCE. In the past 150 years Californians have imposed rapid changes on the Delta creating islands and channels where there had been marsh and tidal creeks, changing freshwater flows and sedimentation patterns, discharging chemical wastes, and introducing new species. This rapid change continues today with human populations increasing, land uses and associated discharges changing, species from other regions invading, native species struggling with new challenges, the climate warming, and the sea level rising.[6]

Continual environmental change must be accommodated in any program to sustain valued species. Instead of seeking some constant, optimal conditions, sustainable management of the Delta's ecosystem will rely on habitats that go through repeated or uncertain cycles of change. Broadly speaking, we understand that our native organisms evolved in a variable environment and are better adapted to the large temporal and spatial variations more characteristic of California's natural landscapes than to the static conditions provided in heavily engineered settings.

The muting of natural habitat rhythms is not the only influence to which Bay-Delta organisms must respond. A rising sea level implies that the location

6 Explored further in chapters 1 to 4 of the full *State of Bay-Delta Science 2008* report, in preparation.

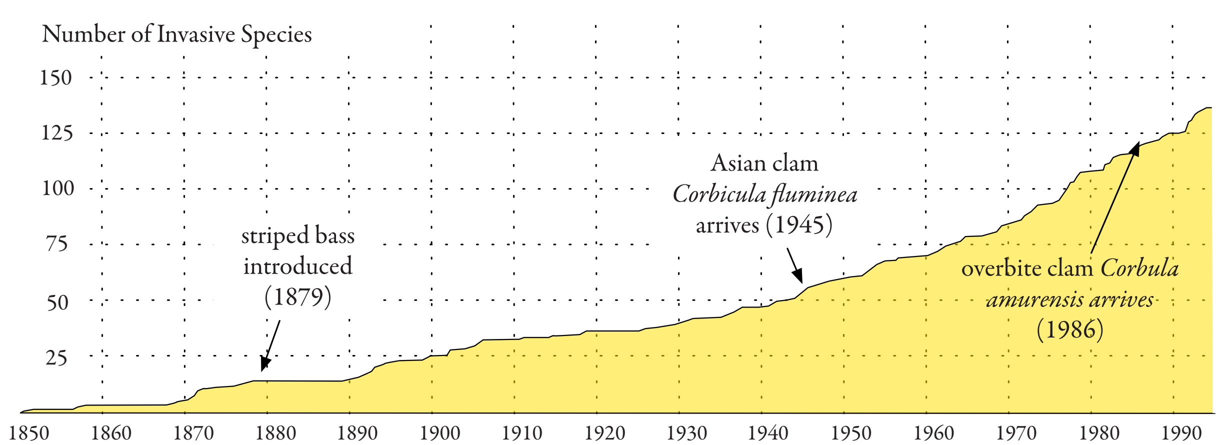

Figure 1. The estimated number of invasive species in the San Francisco Estuary from 1850 to 1995. (Adapted from Cohen, A. N., and J. T. Carlton, "Accelerating Invasion Rate in a Highly Invaded Estuary," *Science* 279 (1998): 555-558.)

of certain habitat types that we typically think of as fixed will change. Our system of land and water management as a whole must be able to respond to sea level rise, which could be 3 feet or more over the next century. From a scientific perspective, changing background conditions means that our measurements of the Bay-Delta system will never converge toward any "normal" values. Furthermore, as environmental change continues, the problem a scientist starts out to address may change into a new problem for which hard won measurements and analyses of the past may no longer be relevant. For example, the invasion of the overbite clam in Suisun Bay changed the structure of the food web, making historic understanding of food web dynamics less relevant to emerging conservation problems. As California warms, and precipitation in the mountains changes from snow to rain, as sea level rises, and water quality constraints continue to evolve, many of today's water-supply problems may be barely addressed before they are subsumed by the next challenge. Science needs a finite period to understand any natural process or trend, usually several years for environmental problems. For example, precipitation patterns vary from year to year and decade to decade. Several years of data are required for the scientist to understand local hydrodynamics and water supplies. In times of sporadic change, science may be hard pressed to understand what is happening well enough to inform policy. A stronger infrastructure and firmer support for science will help narrow this gap in capacity.[7]

One of the main contributions of science to discussions of the future Delta has been precisely this realization that neither the undisturbed past, nor an armored current condition can resist the continually evolving conditions and problems in the Delta. We now have a much clearer picture of how quickly the system is changing, the direction of change, and how uncertainties about future change limits firm statements about ecological cause and effect or management outcomes.

For science, this means improving our capacity to monitor and evaluate change. For policy, it means identifying and implementing policies that are both robust to change yet flexible and adaptable.[8]

Perspective Two

Because the Delta is continually changing, we cannot predict all the important consequences of management solutions. The best solutions will be robust but provisional, and will need to be responsive and adaptive to future changes.

The desire for permanent, or at least very long term, solutions is commonplace in environmental and engineering designs. No one wants to repair a broken system repeatedly. CALFED's Ecosystem Restoration Program is unique in its emphasis on using physical and ecological processes to help rebuild sustainable ecosystems that would produce the services we desired (e.g., viable species populations, particular habitat types) yet with little required maintenance. Recent science in the Delta, however, has led to the perspective that continual environmental change is itself a key to sustaining valued aquatic species. This means that any management plan for the Delta must retain or restore flexibility and variability if key species, processes, and services are to be maintained. The desire for permanent solutions has pervaded other elements of CALFED, but this is changing. Levees were once viewed as permanent bulwarks against flood, but we now recognize that levees are only one tool in the management of flood flows and that some levees should be designed to fail or be overtopped. In the past, we designed water supplies for urban and agricultural to be stable and reliable, but now we recognize that

7 Explored further in chapters 4 and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

8 Explored further in chapters 4, 6, and 7 of the full *State of Bay-Delta Science 2008* report, in preparation.

both supply and quality change with time, so that reliability derives from the capacity for adaptation.[9]

In the face of pressures from growing human populations, from aging levees, from degrading land surfaces, and from climate change and sea-level rise, we can only expect that solutions that seem reliable today will become unreliable in the future. Our ability to predict those challenges is unlikely to improve enough to make permanent decisions possible any time soon. These challenges limit our ability to manage and control the Delta ecosystem. They even limit our ability to monitor and identify changes. Under these circumstances, no single once-and-for-all solution for Delta problems can realistically be expected. Rather, water and environmental management designs that will be most cost-effective and most likely to succeed will be practical, robust to anticipated changes, yet capable of adapting. The need for adaptability recognizes that all solutions are temporary; procedures and diverse options for adaptation need to be built in. To satisfy these needs we should formally establish adaptive management procedures and strategies within agency policies.[10]

As we acknowledge the temporary nature of solutions, we increasingly recognize that the best policies are enabling instead of prescriptive. To increase potential for learning and likelihood of success, the most valued policies will be those that allow a diversity of responses and can evolve as conditions change. Since future conditions are uncertain, surprise is inevitable, and engaging a variety of policy solutions can help to spread the risk.

Perspective Three

It is neither possible nor desirable to freeze the structure of the Delta in its present, or any other form. Strengthening of levees is only one element of a sustainable solution and is not applicable everywhere.

The Delta's levees grew with agricultural development of the vast marshlands, meandering channels, tidal sloughs, and muddy islands that existed before the Gold Rush. Laborers first raised the low natural levees that surrounded Delta islands by hand, then by dredging sands and silts from channels. The resulting levees are haphazardly engineered, with heavy mineral sediments commonly sitting on top of less stable peat. Despite the levees' structural weakness, they define the Delta's geography, water channels, land uses, habitats, flood flows, and tidal patterns.[11]

Until recently, we believed that stable levees were the foundation of a sustainable Delta. We viewed levee stability as absolutely necessary for water-supply reliability, a crucial determinant of water quality, and the protector of the Delta's ecosystems and agriculture. Meanwhile, exposure of the islands' peat soils to air, fire, wind, and compaction, has resulted in the ground surface in many Delta islands subsiding as much as 25 to 32 ft below the water level of adjacent channels. The levees themselves have aged and weakened, breaking regularly, despite the development of massive flood control systems upstream. Channelization of tidal and riverine flows by the levees has created artificial salinity and mixing conditions that favor invasive species over native species.[12]

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9 Explored further in chapters 3, 4, and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

10 Explored further in chapters 3 to 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

11 Explored further in chapters 2 and 5 of the full *State of Bay-Delta Science 2008* report, in preparation.

12 Explored further in chapters 3 to 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

Recent analyses of levees and levee risk show that the likelihood of levees failing in the future are high, that levees are limiting our options for ecosystem restoration, and are a weak link in the State's water and flood management system. Maintaining them in their current form would be very costly and difficult, even if historical conditions continued. But Delta conditions are changing in ways that heighten the risks posed by our dependence on levees. The levees may be shattered in an earthquake, face increasing pressure from floods and rising sea level, and continue to weaken with age and land subsidence. Decision-makers increasingly recognize that the present levee system is not a dependable foundation for the future Delta. Given the mounting pressure on the levees, it is likely that future levee failures will be multiple, flooding many islands, posing a severe risk to human life, and disabling the State's water system for months or possibly years.[8]

For these reasons, sustainable policies for managing the Delta need to discard any remaining belief that we can strengthen levees enough everywhere to protect Delta lands and infrastructure into the future. The use of levees are just one of several ways of managing and maintaining critical landscapes in the Delta, such as human uses and settlements. In some places, we should strengthen levees to provide reliable long-term protection for existing urban development, or critical water supply channels, for example. In other places, levees could hamper ecosystem restoration, effective flood management, and other long-term goals. We need more holistic and comprehensive approaches to floods, emergency preparedness, and habitat restoration. Levees and other hard engineered works will be part of the solution, but using multiple approaches is likely to provide more reliable and sustainable solutions to the wide range of Delta problems. We should design much of the Delta's levees and land use to absorb occasional overtopping and failure. Land use policies reflecting such realities as subsidence, the rising sea level, and the impracticality of assuring the same level of flood protection everywhere are more realistic than policies built solely on levee strength. Urban planning that acknowledges the risks, directs development from the most flood prone areas, and promotes flood-safe construction is also part of a sustainable solution.

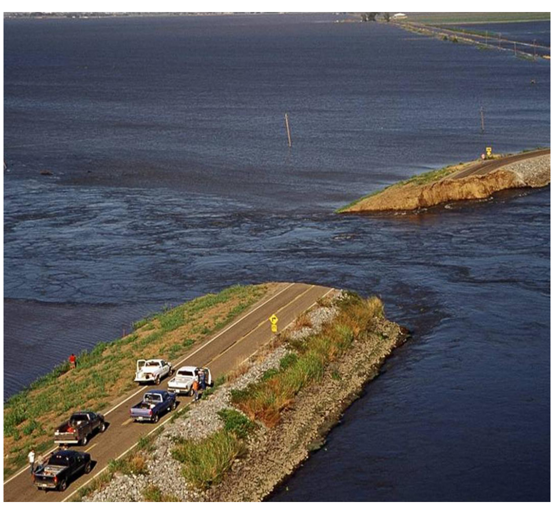

Figure 2. A "sunny day" levee failure in June 2004 results in the flooding of Upper Jones Tract.

Perspective Four

The problems of water and environmental management are interlinked. Piecemeal solutions will not work. Science, knowledge, and management methods all need to be strongly integrated.

Western science has succeeded by breaking problems into their constituent parts and conducting research to understand each part in isolation. We expect to understand the whole from understanding the parts. The success of this approach in both the physical sciences and engineering has even influenced the way we organized governmental agencies: hydrologists in water agencies, fisheries biologists in fisheries agencies, etc. But the success of the reductionist approach in the physical sciences has not been paralleled in the environmental sciences. A clear understanding of the whole has not emerged from our understanding of the parts. "Environmental problems" can arise and persist because of weaknesses in the application of reductionist science to problems in complex ecological systems.

Science in the Delta has used both reductionist and interdisciplinary methods and research. To address the complex issues of the Bay-Delta, scientists from different backgrounds have learned to share information and to look at problems in new ways, much as numerous disciplines including physicists, ecologists, and economists have come together in the study of climate change. CALFED's research funding across agencies to bring scientists from many disciplines together with resource managers in workshops to address particular topics mirrors the most recent developments in science worldwide. An example of this integration is the research conducted to understand the Pelagic Organism Decline (POD). Researchers designed a multifaceted conceptual model that has connected declines in pelagic organisms to a spectrum of interlinked causes ranging from water exports to agricultural practices, and from invasive species to sediment transport. The interlinking of Delta science on water supply, water quality, and ecosystem health with land uses, flood management, and levee engineering are heavily influencing planning for a sustainable vision of the Delta.[13]

Much environmental science in the Bay-Delta comes from the long-term monitoring programs conducted by the Interagency Ecological Program, the San Francisco Estuary Institute, and other programs and agencies. This monitoring has provided the data for nearly all the crucial analyses of trends and variability in the estuary's ecosystems. However, the monitoring has been based on the assumption that simply measuring the numbers of organisms, or the quality of water will allow proper ecosystem management and restoration. We now realize that to understand changes in the abundance and distribution of particular species, we must also understand the dynamics of their predators and prey. To understand the impact of water quality on species and the ecosystem, we must also understand the processes that distribute chemicals in the environment and through the food chain. Furthermore, entire groups of organisms, important physical parameters, and important contaminants have gone unmonitored. Recent scientific successes have shown that a mixture of multidisciplinary monitoring, modeling, and field and laboratory studies is needed to synthesize, track, and understand changes in the Delta. Attempts to understand the POD have shown both the strengths and the weaknesses of existing databases and monitoring. As science has integrated more aspects of the system into its analyses, it is becoming clear that to understand the Delta, we must mobilize the full range of tools and methods of science ranging from ecotoxicology to genetic fingerprinting, from biotelemetry to systems modeling. [14]

Problems of the future will be as multifaceted and complicated as those we face today. Research supporting management, as well as management itself, will be most successful if they embrace this complexity in search of effective and adaptive solutions. Our limited ability to predict the results of management actions in the Delta reflects our inexperience with linking the methods from the many separate disciplines that contribute to Delta science. Building these linkages remains an important area for scientific progress in the future. Collaboration that brings together researchers and managers in interagency research and workshops to build linkages has been very influential in advancing Delta science and management. Bay-Delta science also provides a model for scientific management efforts elsewhere. However, we can do much more to encourage and strengthen the integration of disciplines and the integration of science into management.

13 Explored further in chapters 4 and 7 of the full *State of Bay-Delta Science 2008* report, in preparation.

14 Explored further in chapter 4 of the full *State of Bay-Delta Science 2008* report, in preparation.

Perspective Five

The capacity of the Sacramento-San Joaquin water system to deliver human, economic, and environmental services is likely at its limit. To fulfill more of one water using service we must accept less of another.

Since European settlement, California's streams have been tapped to meet ever-increasing human demand for water. In the Twentieth Century, federal and state water projects increased storage and conveyance capacities resulting in spectacular prosperity for the state. Now, California has grown to a population of 36 million with an economy that is the 7th largest in the world, largely on the strength of its large-scale integrated approach to water management. However, opportunities for increasing supply to satisfy growing demand are becoming limited, and environmental problems are creating a growing need to reallocate water to the ecosystem. As California's population grows, increasing urban water needs will have to be met mainly by improving water management instead of by developing new supplies within the Sacramento-San Joaquin system.[15]

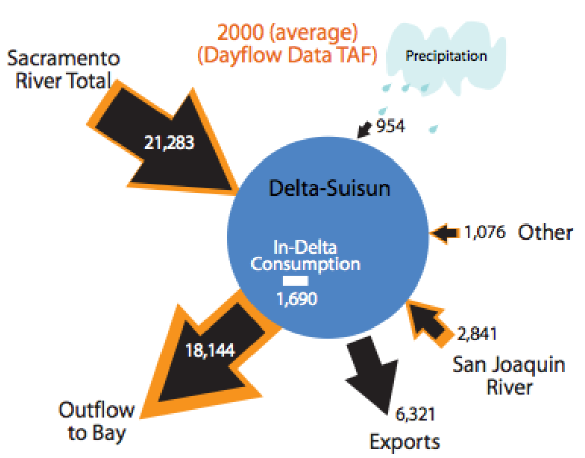

Figure 3. Delta Water Balance showing inflows and outflows during an average water year, in thousand acre-feet. (Source, California Department of Water Resources. *Status and Trends of Delta-Suisun Services*. By URS Corporation, Sacramento, 2007: 18.)

The transition from a belief in growth through water development to growth by working within water limits began during the last quarter of the 20th century as Californians reached real limits and became increasingly aware of the environmental impacts of water development on habitat loss, species declines, and water pollution. Severe droughts in 1976-1977 and 1987-1992 brought home the fact that water is precious while also showing the possibilities for water conservation. We have replaced our old way of thinking about water as flowing "wasted to the sea" with the recognition that every drop of water flowing in a river to the sea contributes to valuable ecosystem functionality. Today, individual water consumption is less than it was 30 years ago, and water planners are often more concerned with water reliability and quality than with increasing supply.[16]

Frequently, conflicts between water limits and the water needed to meet societal and environmental goals come to a head in the Delta. Priorities have changed in recent years, and water deliveries are now timed to meet environmental functionality as well as the needs of water users. Proposals for improving water supply reliability increasingly recognize that reliability will depend on having multiple supply, storage, and conveyance choices. Waste products of the human economy are also discharged into water, and the far-reaching impacts of certain wastes are becoming increasingly clear. Stimulated by concern over the impact of selenium and mercury on fish and birds in the Bay-Delta, science has shown the complex environmental and ecological impacts of these contaminants. Selenium is released during oil refining and from soil irrigated along the west side of the San Joaquin Valley. Irrigation drainage waters

15 Explored further in chapters 4 and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

16 Explored further in chapters 1, 2, and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

poisoned waterfowl in Kesterson Reservoir. When redirected into the San Joaquin River, this selenium flowed into San Francisco Bay where it poisoned bottom feeding fish and ducks. Today, we have virtually eliminated selenium from refinery discharges, and we have reduced selenium contamination from agricultural runoff through better land and water management. However, completely eliminating selenium discharge into the San Joaquin River would be very costly and most proposed solutions simply transport the problem elsewhere. Mercury is a naturally occurring contaminant in California's Coastal Ranges, but during the Gold Rush, it was mobilized and widely distributed through mining processes. Mercury is a pervasive contaminant in water, sediments, and biota of the Bay-Delta. It is also a serious obstacle to wetland restoration as restoration can remobilize mercury locked in sediments. Comparable conflicts between contamination of drinking water and ecosystem needs have also emerged for organic carbon and bromide. Carbon and bromine are natural components of Delta waters, but during disinfection of drinking water, they form cancer-causing byproducts. Drinking water standards are becoming more restrictive, and removing these contaminants from the Delta's water is extremely costly, making the Delta an increasingly poor source of drinking water. Yet, alternative sources of drinking water pose their own problems and raise other hard choices.[17]

There are multiple policy challenges in satisfying the demand for water. Demand itself changes as our population and economy grow and change, but we are limited in our supply of water. Water must meet different quality standards depending on its intended use, and these standards are changing. The quality of available water is also changing in response to land use and waste discharge. Rising sea level, changing hydrology, and risks to levees from earthquakes, among others, make the Delta a poor source of high quality water in the long run. While environmental needs for water remain ill defined, future policies will likely put greater priority on environmental water, further constraining alternative uses. Given the limits of the Sacramento-San Joaquin water supply, water policies that emphasize efficiency of use, flexibility of allocation, and local self-sufficiency may provide the most likely pathways to real water supply reliability.

Perspective Six

Good science provides a reliable knowledge base for decision-making, but for complex environmental problems, even as we learn from science, new areas of uncertainty arise.

In a complex system like the Bay-Delta that is changing rapidly, scientific uncertainties will always be present. Chaos and complexity theory tell us that, even if we had a perfect description of the Bay-Delta's condition at a single moment in time, any prediction of its condition in the future would become increasingly inaccurate the further we tried to look ahead. This is the ecological equivalent of weather prediction. We can be very certain that the weather a minute in the future will be as it is now. Predicting tomorrow's weather is more uncertain, even with sophisticated models. Predicting weather two months or two years from now is highly uncertain. Furthermore, we cannot know all the details of any complex system at any moment in time – partly because most of the system is invisible to us. The Delta farmer, for example, does not actually see his land subsiding. The increased risk of levee failure is also invisible, until the levee fails. Local conditions, problems, and available solutions in the Delta are always changing – often in ways we do not understand or have not yet imagined. The prospect of continual change means that a definitive understanding of important aspects of the system is virtually impossible. We are limited in our ability to reduce this uncertainty because the time required to gain scientific understanding is comparable to the time span

17 Explored further in chapters 3 and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

over which the system itself is changing (and when decisions that impose still more changes).[18]

Early in the Twentieth Century, science came to be seen as the foundation of reliable long-term solutions to society's problems. Levees and water supplies were engineered with the confidence that any problems resulting from their design or installation could be addressed as needed. Water quality problems are often discovered long after we begin discharging contaminates instead of being anticipated at the time discharge begins. Habitat loss and species declines have also frequently been addressed incrementally with little reflection on the gaps in knowledge that mask underlying causes. We now recognize that these approaches are a recipe for long-term failure.[19]

Ecosystems are complex adaptive systems that respond to outside influences in unexpected ways. For a time, the ecosystem may absorb a stressor seemingly without response only to suddenly change or collapse. The POD may be an example of such a sudden response. Ecosystem science is currently not good at predicting when stress will trigger these sudden responses. This results in significant scientific and management challenges. Flexible and adaptive management systems are the best defense against such surprises. The type of multiagency and multidisciplinary integration of science that CALFED has promoted has helped institutions to interpret and respond to new information in a timely way. Events leading up to the decision to stop the State Water Project pumps on May 31, 2007 illustrate this collaborative process. Monitoring on May 12 showed high numbers of Delta smelt captured at the pumps causing the Department of Water Resources to reduce pumping. Further data collected on May 25 and 31 showed continued high catches and scientists and managers agreed to the shutdown on May 31.[20]

Recent scientific studies have suggested that new kinds of uncertainty about the Delta system are emerging. From a coarse scale, global climate models suggest that precipitation patterns, river discharge patterns, and storm events affecting the Delta will change in the future, but regional projections of these events are highly uncertain. From a finer scale, historic data showed a relationship between outflow from the Delta and the abundance of some pelagic fish species, a relationship that was the basis of the X2 management regime. However, data collected since the POD suggest that the relationship has changed, or broken down, confounding the

18 Explored further in chapters 1, 3-5, and 7 of the full *State of Bay-Delta Science 2008* report, in preparation.

19 Explored further in chapters 1, 3, 5, and 6 of the full *State of Bay-Delta Science 2008* report, in preparation.

20 Explored further in chapters 4, 6, and 8 of the full *State of Bay-Delta Science 2008* report, in preparation.

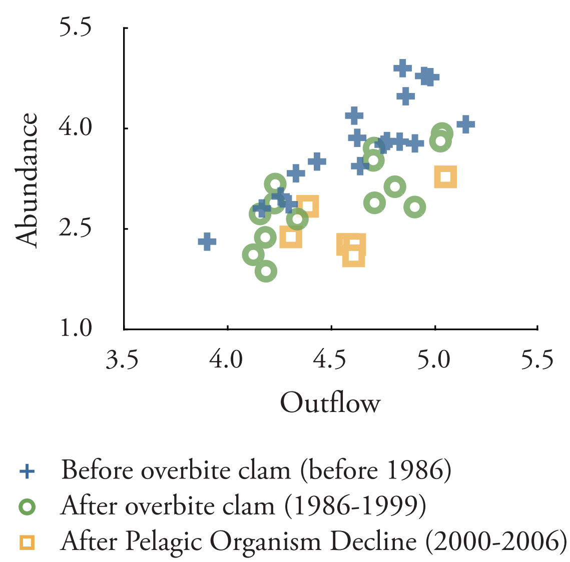

Figure 4. The changing relationship between longfin smelt abundance and Delta outflow. (Adapted from Kimmerer, Wim, "Effects of Freshwater Flow in Abundance of Estuarine Organisms: Physical Effects or Trophic Linkages?" *Marine Ecology Progress Series*, 243 (2002): 39-55.)

hypotheses that linked outflow to fish populations (see Figure 4, previous page).

We now understand that policies must accommodate these underlying uncertainties. An example of such an accommodation is the multibarrier approach for drinking water-quality maintenance, where — in the face of uncertain sources, threats, and needs — we develop multiple, redundant safeguards on water quality. Integrated approaches to water-supply reliability that draw on several different sources and conveyances to mitigate the uncertainties and risks of each are another example of accommodating inherent uncertainties through a diversity of management options. Similarly, flexible approaches need to be developed for ecosystem restoration and levee integrity. Adaptive experimentation to maximize learning opportunities and a precautionary approach to management decisions would help to avoid the overuse of resources that has characterized past water management.

Perspective Seven

Accelerated climate change means that species conservation is becoming less of a local habitat problem. Conservation approaches need to include a broad range of choices other than habitat protection.

The recovery of species listed as threatened or endangered is the main driver of today's science and conservation planning in the Delta. Although the problems of the Bay-Delta are ecosystem level problems, we see them revealed through the disappearance of individual species or habitats, and it is these losses that capture our attention. When CALFED began, listed races of Chinook salmon were the primary focus of research and management. Shortly after all parties signed the Record Of Decision (ROD), the POD emerged, and after 2004, began to drive science and water management decisions. As a listed and an included POD species, the Delta smelt has received a great deal of attention. Although the causes for the decline of Delta smelt remain uncertain, (they are quite likely multiple causes including export pumping, toxic substances, and food web changes), there is also a growing recognition that global warming may make the future Delta intolerable to Delta smelt and other valued species, undermining local attempts to protect them. Even as science increases our ability to manage the changes that we can control, it also shows us the implications of such uncontrollable changes as climate. In the face of such externally imposed challenges to Delta species, conservation becomes more than a local problem of habitat management. Instead, it engages wider questions such as whether we should establish refuge populations of smelt, or other species where the physical environment remains suitable; whether cryopreservation of DNA, or maintenance of captive populations need to be part of our conservation tool kit; and whether artificial genetic modification to change the environmental tolerance of a species should be attempted.[21]

Invasion of the Delta by non-native species is also an issue of great concern that is linked to native species loss. We know, for example that the invasive overbite clam appropriates most of the primary production in Suisun Bay, starving the food web leading to Delta smelt. We also know that the invasion

21 Explored further in chapter 4 of the full *State of Bay-Delta Science 2008* report, in preparation.

Figure 5. As the climate changes and water temperatures warm, the Delta may no longer be able to support the imperiled Delta smelt.

of Brazilian waterweed has enhanced the habitat of largemouth bass and sunfish to the disadvantage of native species. Under the United Nations convention on biodiversity, invasive species are a primary threat to biodiversity, and signatory nations, though the United States is not one, must develop plans for preventing and managing the adverse impacts of species invasions. In our changing global environment, we may need to adopt a broader perspective on species introductions. The Bay-Delta is already one of the most invaded estuaries in the world, and further invasions are almost certain to occur. As climate changes and the Delta becomes inhospitable to native species, it may nevertheless provide a refuge for species from warmer habitats that are themselves facing intolerable local conditions. Relocating species for conservation purposes may become as important as protecting local habitats.

The kinds of environmental changes expected for the Bay-Delta in the near future call for a rethinking of both policy and management of native and alien species. Critical habitat, as required under the Endangered Species Act, may no longer be where a species lives today, but somewhere further north, at a higher elevation, or in an unexpected setting. Conservation policy will have to be open to exploring many ways to preserve biodiversity.

The Way Forward

These new scientific perspectives on the Bay-Delta and its environmental challenges highlight the growth in scientific understanding of the Delta and of ecosystem management that has occurred during the past decades. These perspectives highlight the impending globally and locally driven changes to the Bay-Delta to which policy must respond. Globally, climate change is expected to raise sea level three feet or more over the next century, change precipitation and storm patterns, and raise local temperatures several degrees. Locally, population growth, land subsidence, earthquakes, and species invasions will drive ecological change and increase risks of flooding. Scientifically, we now recognize that change and uncertainty are essential characteristics of our local ecosystem dynamics. We often manage natural resources under an assumption of permanence, that the future will be like the present, and that management should aim for the "optimum" condition. This is not an achievable goal. Future infrastructure, both for management and for science, needs to be robust but flexible, inclusive and adaptive, resilient and sustainable in the face of change. Uncertainty is pervasive and although absolute solutions are unlikely to be found, science will continue to be a main source of information for policymaking. Building and maintaining the scientific infrastructure to help meet future challenges is essential to any sustainable way forward.

Scientific input to water and environmental management has a long history in California. CALFED has brought science more fully into the policy processes. The Science Program has introduced a new and forward-looking approach that integrates the broad spectrum of scientific and technical advice needed to address the highly complex problems of today. Tools used by the Science Program have included interdisciplinary workshops, support for research that cuts across agency mandates, and integration of science with the practical knowledge of resource managers. These tools have strengthened our understanding of challenges in the Delta, as well as the options available to address them. When CALFED began, expectations were that we could resolve ecosystem issues through modest changes in water management and minimal reallocation of water. The POD has now forced water management agencies to consider significant water reallocations. Initially, CALFED considered Delta stabilization and levee integrity a primary goal: now the Delta Visioning process is imagining a mixture of levee protection in some areas, and alternative land and flow management options in others. The evolution of policy from an emphasis on engineered solutions to an emphasis on engineered natural designs that work with natural processes reflects advances in ecosystem science, new environmental conditions, and changing societal expectations.

Within the above context, the way forward appears to include several extensions of the goals and strategies that CALFED began with. Generally, science provides three important elements to the debate about resource management problems: (1) objective information about the system and how it behaves; (2) models of physical and biological systems that illustrate how different policies might affect the problems; and (3) a shared, formalized language and a forum that permits informed debate. The way forward for CALFED science is to strengthen its capacity to make these contributions (see Table 2, previous page).

Science as a source of objective information about the system and its behavior

There are systemic weaknesses in the science infrastructure that supports water and environmental management in the Bay-Delta. One of these weaknesses is a lack of consistent support for targeted research on key unknowns in the Bay-Delta ecosystem. CALFED Science has begun a competitive program of research grants for critical research, but has lacked the secure funding to carry this program into the future. Given the pace of change, future management decisions will be increasingly dependent on scientific synthesis, insight, and advice from scientists with hands-on experience in the Delta. Assured support for policy relevant research is the best way to ensure that information and advice will be available when needed.

Since its inception, CALFED has striven to enhance and extend observation networks, including development of the Comprehensive Monitoring Assessment and Research Program (CMARP): unfortunately, CMARP has yet to be implemented. More recently, the Science Program has been working with the implementing agencies to develop performance indicators for their CALFED initiatives: but this effort is still at a conceptual stage. We also see a desperate need to monitor existing and future project performance objectively. More comprehensive monitoring would provide the raw materials for timely decisions about project direction and contribute to improved physical and biological models of the Delta. The CALFED Science Program is working to develop a feasible, more integrated framework for monitoring across implementing agencies.

The ROD specifies that adaptive management should be the tool for integrating science more fully into management. CALFED agencies have made considerable progress in implementing adaptive management, but weaknesses remain. Support for monitoring and assessment, which is central to the adaptive process, is intermittent, as is the use of prospective analysis to explore policy alternatives. CALFED science has the capacity to help agencies make further progress in formally establishing adaptive management.

CALFED has a strong Bay-Delta focus, but is addressing a set of problems that exist in various guises throughout California. Nationally, there are several major projects focusing on water and environmental conflicts, for example the Upper Mississippi, Great Lakes, Everglades, and Columbia Basin projects. These projects would benefit from statewide and national networks of information sharing. CALFED is regarded as a successful model in science coordination and integration and could be a leader in establishing such a network.

Science as a set of tools for evaluating system responses to policy alternatives

The complexity and interlinked character of the Bay-Delta system and all its most vexing problems call for a new generation of system-scale, cross-disciplinary models. CALFED has supported several steps toward developing such tools including an ambitious attempt to develop interlinked species con-

Table 2. Future directions for CALFED science

Scientific contribution to environmental problem solving	**Strengthening CALFED's capacity**
Objective information about the system and its behavior	1. Secure long-term support for CALFED Proposed Solicitation Package program at about $20 million annually to support research that targets key unknowns 2. Support development and implementation of a comprehensive strategy for monitoring and assessment that takes advantage of rapidly emerging technology 3. Integrate adaptive experimentation and adaptive management into design and implementation of Delta Vision strategic plan and Bay Delta Conservation Plan so that program performance can be assessed in a timely manner 4. Integrate the CALFED Bay-Delta Program more fully into statewide and national networks of information sharing and instrumentation to support ecosystem management and restoration
Evaluation of system responses to policy options	1. Support development of cross-disciplinary, systemwide models of physical and biological processes in the Delta (e.g., US Geological Survey's CASCaDE project) 2. Establish CALFED Science as a focus for high level, integrative modeling of system response (e.g., through elaboration of Delta Regional Ecosystem Restoration Implementation Plan models, linkage to regional databases, etc.) 3. Strengthen the capacity for objective policy analysis through use of these models in conjunction with adaptive management and performance measures
Formalized and informed debate about science and policy for environmental and water management	1. Strengthen existing tools (e.g., workshops, discussion papers) for engaging science and policy 2. Strengthen capacity to translate science into policy relevant knowledge 3. Strengthen public outreach about science issues to inform the broader debate about science and policy

ceptual models, and various efforts to link physical models with ecosystem responses. Such modeling needs to be strongly supported so that policymakers can be informed by mature scientific models of Delta processes. Forecasting the consequences of policy choices will always be uncertain, but models provide the most objective means of bringing complex ecosystem data into policy analysis.

At present, there is little capacity in CALFED, or the implementing agencies, for cross-disciplinary modeling of ecosystem behavior. For the future, CALFED science should serve as a node or catalyst for the development of integrative models. As part of the Science Program, such models would have legitimacy and would provide another avenue for coordination and communication among diverse interests in the Delta. Policy analysis is becoming increasingly reliant on quantitative risk analysis and numerical analysis. For the CALFED Science Program to remain relevant, it will need to build its capacity to apply these tools and to connect them in ways that provide a complete picture of ecosystem response.

Science as a facilitator of informed policy debate

Finally, CALFED needs to expand and strengthen its ability to bring science into policy debates. Notably, as the Delta Vision Blue Ribbon Task Force completes its new vision, and following its debate and implementation, it will be all the more important that independent scientific information and methods are near the center of decision-making.

CALFED Science uses a variety of communication and outreach tools for scientists these include the on-line journal *San Francisco Estuary and Watershed Sciences*, and the biannual science conference; for policymakers, workshops and discussion papers; and for the public through newsletters like the *Science News*, as well as public lectures. These avenues need to be strengthened and expanded in the future to ensure a smooth and effective flow of scientific information to policymakers and other interests.

Science is crucial to any policy debate and objective, peer-reviewed science provides the most reliable basis for policy decisions. Making reliable science available to policy debates has always been a weak link in the science-policy process. The Science Program has a good track record of facilitating this information flow, but it needs to be sustained and improved.

CALFED and the CALFED Science Program were created in recognition of a need for stronger coordination, integration, and communication to address problems of water supply, water quality, levee integrity, and ecosystem performance. CALFED science has had considerable success facilitating these processes within the scientific community and has also stimulated new science to address important gaps in knowledge. As a result, our understanding of Delta processes has improved and policymakers are better informed. These science-based activities will be even more important in the future.

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