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The San Francisco Bay/Sacramento-San Joaquin Delta system is the largest estuary on the West Coast and is central to California's water economy and ecosystem. The Delta encompasses 3000 km² of tidal to freshwater wetlands, agricultural lands, and river/estuarine channels at the confluence of the Sacramento and San Joaquin Rivers (Fig. 1) in central California. Freshwater discharge through the Delta--which captures 42% of California's runoff (Morandi 1998)--feeds San Francisco Bay and partially flushes ocean salt from the estuary's waters. California's Mediterranean climate and its propensity to fluctuate on a wide range of time and space scales play a crucial role in establishing the variability of those discharges, salinities, and the state of the Bay and Delta's ecosystems and other resources.

The Bay-Delta system provides drinking water for two-thirds of the State's population (22 million people), irrigation supplies for at least \$27 billion in agriculture (45% of the Nation's produce), and is a primary water source for California's trillion-dollar economy (CALFED 2001). About 6 km³/yr of freshwater are pumped from the Delta by the federal Central Valley Project and the State Water Plan to supply municipal and agricultural water demands in southern and central California (California Department of Water Resources 1993).

The Bay-Delta system forms a transition zone where freshwater runoff from upland watersheds,

including the Sierra Nevada to the east, meets and intermingles with ocean water to yield variably salty waters, with salinities that fluctuate seasonally and from year to year within both the Bay and Delta (California Department of Water Resources 1993, Peterson et al. 1996). These salinity variations are managed by upstream reservoir releases with the dual purposes of preserving uncontaminated freshwater supplies and ensuring healthy ecosystems in and around the estuary. These remarkable ecosystems have historically supported at least 750 known plant and animal species, including many unique to the estuary environment (CALFED 2001).

At present, though, both the ecosystems and the freshwater supply are in jeopardy. Freshwater diversions have altered the water balance and water quality of the estuary in ways that threaten the ecosystems. In 1993, two fish species in the Delta were listed under the Endangered Species Act, precipitating a crisis that eventually led to the development of the CALFED Bay-Delta Program (Morandi 1998). Recognizing the decline of the system and the urgency of its restoration, more than 20 California State and Federal agencies banded together to establish this long-term, multi-billion dollar program, which is intended to develop and implement a comprehensive plan to accomplish four ambitious objectives (CALFED 2001):

1. Improve the reliability of water supplies in California,
2. Improve water quality in the Bay-Delta system,
3. Restore ecosystems within the Bay/Delta estuary and its watershed, and
4. Stabilize Sacramento-San Joaquin Delta levee systems.

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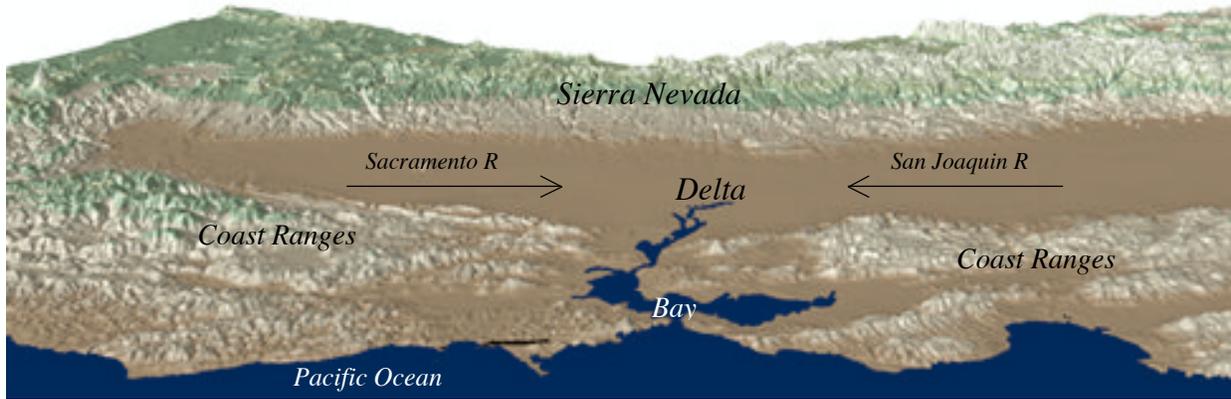


Fig. 1 –Shaded, raised relief view of central California, looking eastward; the figure shows most of the watershed of the Bay-Delta watershed, with San Francisco Bay, the Delta, and the Central (Sacramento-San Joaquin) Valley in the middle, the Pacific Ocean and California's Coast Ranges in the foreground, the Sierra Nevada in the background.

Among the large number of options being considered by CALFED include structural changes in the Delta, wetland mitigations, both reservoir expansions *and* removals, and water-supply operational changes (CALFED 2001).

The success of the CALFED Program depends, among many other natural and societal factors, upon the robustness of its plans and actions to the considerable buffeting that California's highly variable climate will inevitably impose upon it. The watershed that drains to the Bay and Delta encompasses much of central California, including the Central Valley, the Sierra Nevada, and parts of the Coast Ranges (Fig. 1). This broad north-south watershed straddles the transition zone between the wet-Southwest and dry-Northwest influences of the El Niño-Southern Oscillation, as well as their interdecadal expressions in the Pacific Decadal Oscillation and other short- and (especially) long-term influences that are less understood (Cayan and Webb 1992,

Mantua et al. 1997). Superimposed upon these climate fluctuations is a recent observed warming trend in winter-spring temperatures and associated streamflow-timing trends (Dettinger and Cayan 1995). These trends are either harbingers or analogs for future global warming effects in the State. If they continue, the streamflow-timing trends threaten to unsettle crucial aspects of the State's water supply system by adversely impacting the State's snowpacks and snowmelt runoff. Recent studies of California's paleoclimate also provide worrying evidence that the erratic precipitation regimes that have been observed (and largely accommodated) during California's development have been—by and large—benign and small in comparison to natural precipitation variations over the past 1000 or more years (e.g., Meko et al. 2001).

Thus, California's climate has varied in the past in ways that CALFED must acknowledge and somehow accommodate on time scales from

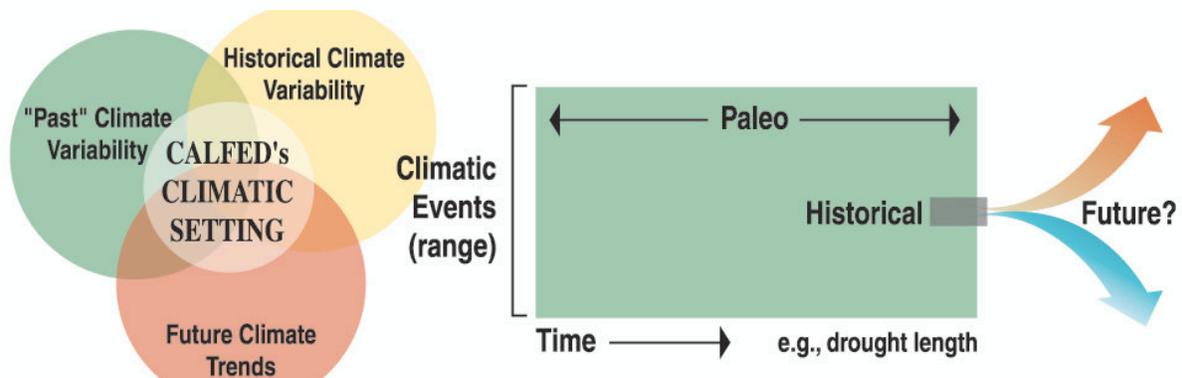


Fig. 2—Conceptual diagrams of the intermingling contributions of past, present, and future climate variability to a realistic depiction of CALFED's climatic setting (left) and relative uncertainties regarding possible ranges of climatic variability as estimated from paleoclimatic sources, historical sources, and global-warming projections (right).

years to decades. The climate that CALFED faces during its planned 30-year lifetime and over the much longer period that it will eventually influence most likely will be some combination of the kinds of climate variability evidenced in California's paleoclimate proxies, in its historical period, and in recent climate-change projections (Fig. 2, left). These climate variations need to be characterized (i.e., monitored, predicted, projected, or described probabilistically, depending on circumstance), and the resulting characterizations need to be communicated to CALFED participants and the public, in order to provide a basis for scientifically sound planning and management actions by the CALFED Program.

The particular combination of past, present, and future-change climate variations that will confront California's water supply and ecosystems is unknown, of course. Possible future climate variations can be drawn from the relatively benign range witnessed in recent history, from the larger range of variations indicated by paleoclimate reconstructions, and from projected warming and the more uncertainly projected changes in precipitation associated with 21st Century global climate change.

To be realistic, all three sources of climate information will need to be considered, but perhaps to varying degrees depending on the climate variables in question (Fig. 2, right). For example, long-term precipitation variations are of particular concern to CALFED because of their attendant effects on runoff, sediment, and biogeochemical budgets of the Bay-Delta system and watershed. Since California's water resources are supplied partly by watersheds outside the State, the climatic status of a region larger than just the Bay-Delta watershed or even the State is pertinent to CALFED. Climate-change projections of 21st Century precipitation change in California are extremely uncertain and model dependent, but generally are small compared to the changes that would attend another of the 50- to 100-yr long California megadroughts evidenced in several paleoclimate reconstructions of the past 1000 years (Stine 1994, Benson et al. 2002). Thus, for precipitation, regional paleoclimate variations present CALFED with possibilities at least as challenging as those projected from global change. In contrast, projected temperature changes associated with global warming in the 21st Century (and even those in the historical period) rapidly rise beyond the range of paleoclimatic reconstructions (Mann et al. 1999). Similarly, projections of future sea-level rise rapidly augment historical and recent paleoclimatic

ranges, and threaten important and delicate freshwater-seawater balances in the Bay, Delta, and associated wetlands. Thus, projections of risk from future temperature variation and sea-level rise may need to rely more on projected global-warming effects than on past trends and variations.

Within this context, some of the key climatic issues facing the CALFED Bay-Delta Program are:

Paleoclimates and CALFED

- How has climate varied in the California region over the past several thousand years on seasonal, interannual, decadal, and centennial scales?
- What effects did past climate changes have on energy, water, sediment, biogeochemical budgets and distributions throughout the Bay-Delta system?
- What effects did past climate variability and physical effects of climate variability have on Bay-Delta and watershed ecosystems?
- How could current water-supply operational programs, water quality, physical hazards, and ecosystem management have coped with past climate variations?

Historical Climate and CALFED

- How does the estuary/watershed system vary in response to climate fluctuations? How much of the current Bay-Delta variability is due to climate?
- What are the main linkages between climate variability and water-supply operations, water quality, sediment transport, and ecosystems?
- How might climate forecasts, ranging from days to decades, be used to benefit and augment CALFED activities?

Climate Monitoring and CALFED

- Is the existing climate-monitoring network in California sufficient, timely, and stable enough to provide CALFED's long-term informational needs?
- Are all physical, chemical, and biological variables needed by CALFED being monitored at necessary temporal and spatial sampling

resolutions? If climate changes, will its effects be evident in the current networks?

- What technical and communication mechanisms are required to provide a sound climate-science basis for all parties in the CALFED decision making process, including the public?

Future Climate and CALFED

- What are the full-plausible--and most-likely--ranges of climate variation, including sea-level rise, in California during the next 100 years?
- How will climate changes vary within the watershed of the Bay-Delta?
- How will future climate variations and changes affect energy, water, sediment, biogeochemical, and contaminant budgets and distributions within the Bay-Delta system?
- How will likely future climate changes, and hydrologic and biogeochemical responses, affect wetlands, water quality, estuarine and riparian systems, and fish populations?
- How will likely future climate changes, and hydrologic and biogeochemical responses, affect water-supply operations and reliability?

Actions to address these issues could include development of transects linking paleoclimatic reconstructions from the Great Basin over the Sierra Nevada to the Delta, Bay, and coastal ocean, allowing the more complete Great Basin and Sierra Nevada paleohistories to more clearly inform Bay-Delta decision making. More strategic monitoring to recognize changes in key hydroclimatic conditions, resources, and habitats using modern sensor and communication technologies should be considered. Establishment of formal mechanisms, including staffing, for regular independent review of California's climate, hydrologic, and biogeochemical data archives and networks may be necessary to ensure adequate data resources for CALFED decision making and future operations. Reasoned assessments of the likelihood of various climate-change projections, using state-of-the-art global and regional models and historical analogs, will be needed to provide more quantitative bases for planning for climate changes. Improved models of past, present, and likely-future responses of California's ecosystems and water systems to climate variations and long-

term changes are needed, with particular emphasis on interdisciplinary linkages.

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