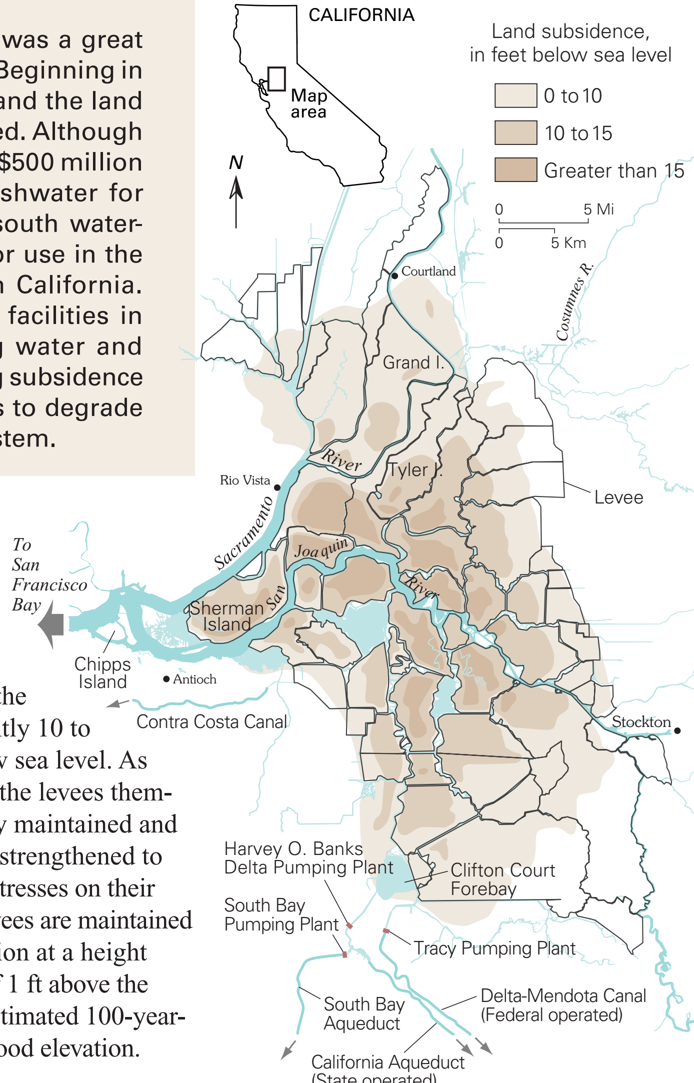
Delta Subsidence in California

The sinking heart of the State

The Sacramento-San Joaquin River Delta of California once was a great tidal freshwater marsh blanketed by peat and peaty alluvium. Beginning in the late 1800s, levees were built along the stream channels, and the land thus protected from flooding was drained, cleared, and planted. Although the Delta is now an exceptionally rich agricultural area (over a $500 million crop value in 1993), its unique value is as a source of freshwater for the rest of the State. It is the heart of a massive north-to-south water-delivery system. Much of this water is pumped southward for use in the San Joaquin Valley and elsewhere in central and southern California. The leveed tracts and islands help to protect water-export facilities in the southern Delta from saltwater intrusion by displacing water and maintaining favorable freshwater gradients. However, ongoing subsidence behind the levees reduces levee stability and, thus, threatens to degrade water quality in the massive north-to-south water-transfer system.



The Delta, located at the confluence of the Sacramento and San Joaquin Rivers, is blanketed by peat and peaty alluvium deposited where streams, originating in the Sierra Nevada, Coast Ranges, and southern Cascade Range, enter the San Francisco Bay system. In the late-1800s, large-scale agricultural development in the Delta required levee-building to prevent frequent flooding. The leveed marshland tracts then had to be drained, cleared of wetland vegetation, and tilled. Levees and drainage systems were largely complete by 1930 and the Delta had taken on its current appearance, with most of its 1,150-square-mile area reclaimed for agricultural use (Thompson, 1957).

(California Department of Water Resources)

Today the Delta includes about 57 islands or tracts that are imperfectly protected from flooding by more than 1,100 miles of levees. Reclamation and agriculture have led to subsidence of the land surface on the developed islands in the central and western Delta at long-term average rates of 1–3 inches per year (Rojstaczer and others, 1991; Rojstaczer and Deverel, 1993). Many of the islands in the central Delta are presently 10 to nearly 25 feet (ft) below sea level. As subsidence progresses, the levees themselves must be regularly maintained and periodically raised and strengthened to support the increasing stresses on their banks. Currently, the levees are maintained to a standard cross section at a height of 1 ft above the estimated 100-year-flood elevation.

An extensive network of drainage ditches prevents islands from flooding internally and maintains groundwater levels deep enough for agricultural crops to grow. The accumulated agricultural drainage is pumped through or over the levees into stream channels. Without this drainage, the islands would become flooded.

The dominant cause of land subsidence in the Delta is decomposition of organic carbon in the peat soils. Prior to agricultural development, the soil was waterlogged and anaerobic (oxygen-poor). Organic carbon accumulated faster than it could decompose. Drainage for agriculture led to aerobic (oxygen-rich) conditions that favor rapid microbial oxidation of the carbon in the peat soil. Most

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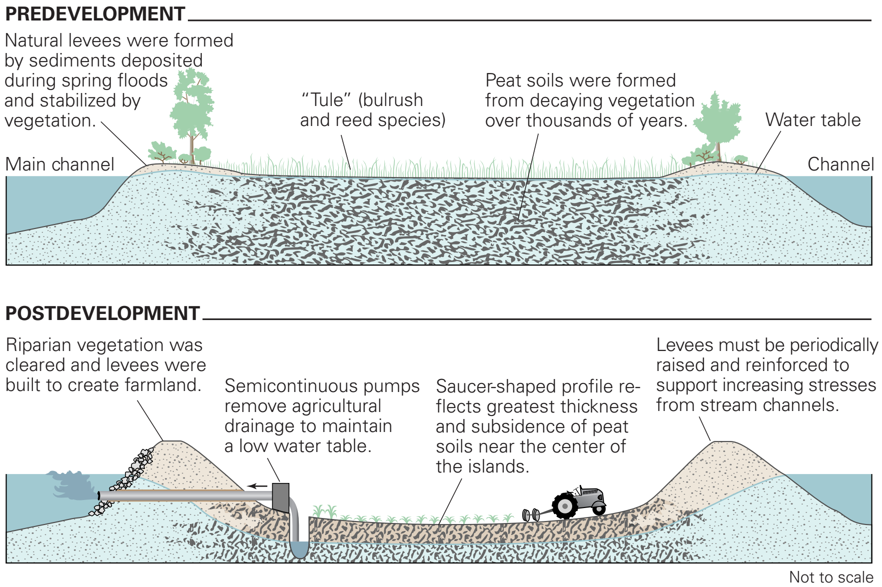


of the carbon loss is emitted as carbon-dioxide gas to the atmosphere (Deverel and Rojstaczer, 1996).

The Delta's unique value as a source of freshwater

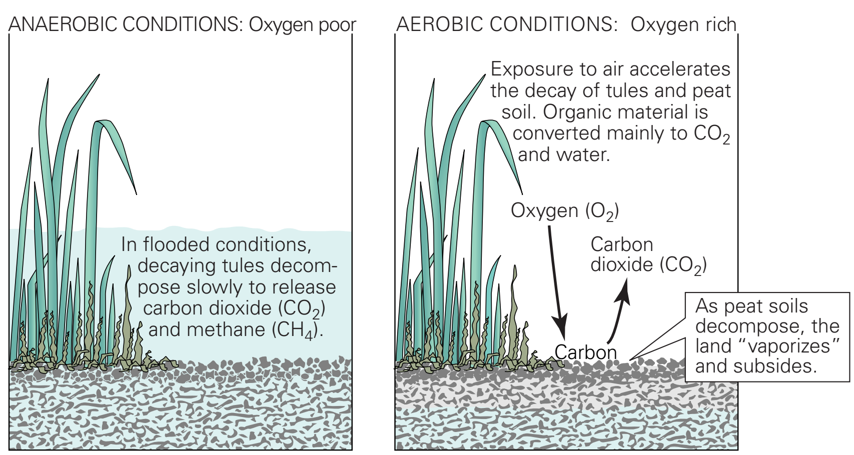
The Delta receives runoff from about 40 percent of the land area of California and about 50 percent of California's total streamflow. It is the heart of a massive north-to-south water-delivery system whose giant engineered arterials transport water southward. State and Federal contracts provide for export of up to 7.5 million acre-feet per year from two huge pumping stations in the southern Delta near the Clifton Court Forebay (California Department of Water Resources, 1993). About 83 percent of this water is used for agriculture and the remainder for various urban uses in central and southern California. Two-thirds of California's population (more than 20 million people) gets at least part of its drinking water from the Delta (Delta Protection Commission, 1995).

The waterways of the Delta are subject to tidal action. Ocean tides propagating into San Francisco Bay are observed 5–6 hours later along the Cosumnes River in the eastern Delta. The position of the interface between the saline waters of the Bay and the freshwaters of the Delta depends upon the tidal cycle and the flow of freshwater through the Delta. Before major dams were built on rivers in the Delta watershed, the salinity interface migrated as far upstream as Courtland along the Sacramento River (California Department of Water Resources, 1993). Today, releases of freshwater from dams far upstream help reduce the maximum landward migration of the salinity interface during the late summer. In the spring, however, reservoirs and Delta exports consistently act in concert to increase the landward migration of the salinity interface over that expected under conditions of unimpaired flows[1] (Knowles, 2000).

Land subsidence of Delta islands indirectly affects the north-to-south water-transfer system, which is predicated on the available water supply (annual inflows to the Delta), the viability of aquatic species populations, and acceptable water quality in the southern Delta. The presence of the western Delta islands, in particular, is believed to effectively inhibit the inland migration of the salinity interface between the Bay and Delta. If these islands were to become permanently inundated with saline water, the water available to the massive pumping facilities near the Clifton Court Forebay might become too saline to use. The timing of levee breaks and flooding is critical in this regard. Fortunately, most flooding occurs in winter and spring, when major saltwater intrusion is less likely. However, there are occasional levee failures under low-flow conditions. These failures can cause major short-term water-quality problems, even if the flooded areas are later reclaimed. During one such incident, an island was flooded under low-flow conditions, and chloride levels reached 440 parts per mil-

> The leveed tracts and islands help to protect water-export facilities in the southern Delta from saltwater intrusion by displacing water and maintaining the salinity balance.

Field studies (Deverel and Rojstaczer, 1996) determined that the increased flux of carbon dioxide gas from the drained peat soils was sufficient to explain most of the carbon loss and measured subsidence. The dissolved organic carbon pumped from the islands in agricultural drainage could account for only about 1 percent of the carbon loss. The studies also showed that rates of carbon-dioxide production increase with increasing temperature and decrease with increasing soil moisture.



[1] Unimpaired flows refer to the hypothetical flows that would occur in the estuary without water storage diversions and exports, upstream and in the Delta, but in the presence of the existing channels and levees.

lion (ppm) at the Contra Costa Canal intake, which is well above the California standard for drinking water of 250 ppm (California Department of Water Resources, 1995).

The statewide water-transfer system in California is so interdependent that decreased water quality in the Delta, whether due to droughts or levee failures, might lead to accelerated subsidence in areas dependent on imported water from the Delta. How might this happen? Many areas of central and southern California that are dependent on Delta water also are susceptible to another kind of subsidence. Historically, over-pumping in the San Joaquin and Santa Clara Valleys compacted critically stressed aquifer systems, resulting in land subsidence (Galloway and others, 1999). Before imported Delta water became available in the mid-1970s, nearly 30 ft of subsidence had been measured in the San Joaquin Valley and up to 14 ft in the city of San Jose in the Santa Clara Valley. Estimated damages were in the hundreds of millions of dollars, largely due to costs associated with construction of flood control structures and well damage. Both the Santa Clara and San Joaquin Valleys now rely, in part, on imported water from the Delta to augment local supplies and, thereby, reduce local ground-water pumpage and arrest, or slow, subsidence. Degradation of the Delta source water could lead to increased ground-water use and renewed subsidence in these and other areas in California.

The Tyler Island levee was breached in a 1986 flood. Such levee failures have been common in the Sacramento-San Joaquin Delta since reclamation began in the 1850s. Each of the islands and tracts in the Delta has flooded at least once, with several flooding repeatedly. About 100 levee failures have occurred since the early 1890s. Initially, most of the failures were caused by overtopping during periods of spring flooding. Although construction of upstream reservoirs since the 1940s has reduced the threat of overtopping, it has not reduced the incidence of levee failure.

(California Department of Water Resources)

The Sacramento-San Joaquin Delta: The heart of California's water systems

An artificial balance is maintained in the water exchanged between the Delta and the San Francisco Bay. Freshwater inflows regulated by upstream dams and diversions supply water to the Delta ecosystems and to farms and cities in central and southern California.

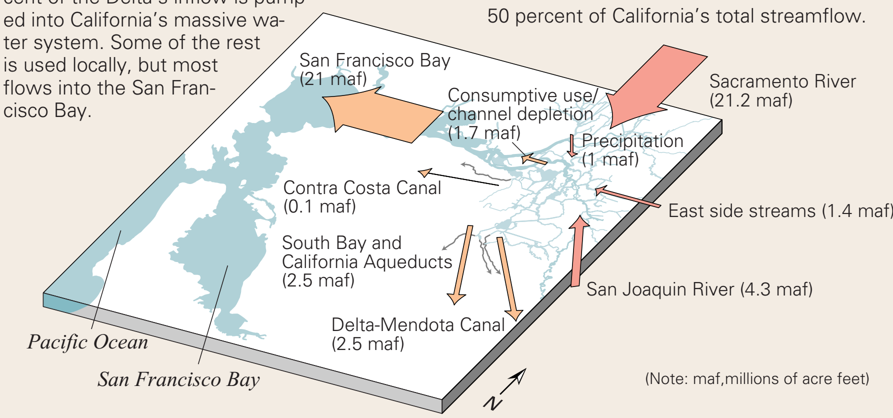
Subsidence of Delta islands threatens the stability of island levees and the quality of Delta water. Delta levee failures would tip the water-exchange balance in favor of more saltwater intrusion, which can ruin the water for agriculture and domestic uses. Several aqueducts would be affected. Any reductions in the supply of imported Delta water could force water purveyors in many parts of the State to meet water demand with ground-water supplies. This, in turn, could renew land subsidence in the Santa Clara and San Joaquin Valleys and exacerbate subsidence in Antelope Valley and other areas that currently are reliant on imported Delta water supplies and prone to aquifer-system compaction.

Annual Outflow[1]

An amount equivalent to about 25 percent of the Delta's inflow is pumped into California's massive water system. Some of the rest is used locally, but most flows into the San Francisco Bay.

Annual inflow

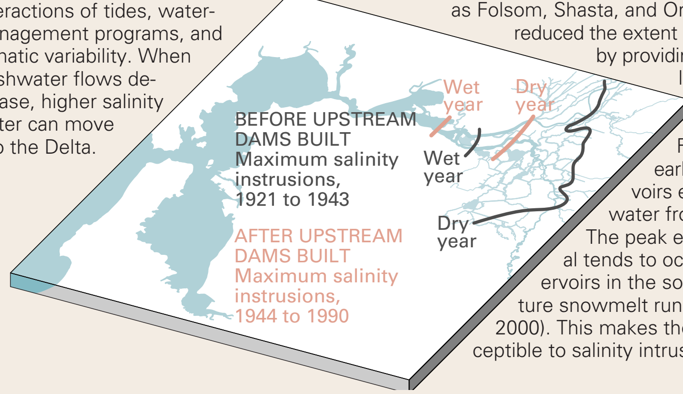
The Delta receives runoff from about 40 percent of the land area of California and about 50 percent of California's total streamflow.



(Note: maf,millions of acre feet)

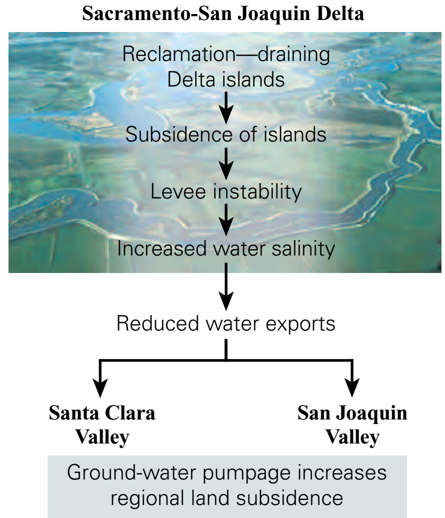
Salinity

Salinity intrusions are linked to the interactions of tides, water-management programs, and climatic variability. When freshwater flows decrease, higher salinity water can move into the Delta.



On average, upstream control structures, such as Folsom, Shasta, and Oroville Dams, have reduced the extent of salinity intrusions by providing freshwater releases during the summer and fall. However, from February through early June the reservoirs effectively remove water from Delta outflow. The peak effect of this removal tends to occur in May as reservoirs in the southern Sierra capture snowmelt runoff (Knowles, 2000). This makes the Delta more susceptible to salinity intrusions in the spring.

[1] Flow data from 1980–1991 (California Department of Water Resources, 1993)



The statewide water-transfer system in California is so interdependent that subsidence in the Delta might lead to accelerated subsidence in areas dependent on imported water from the Delta.

The future of the Delta poses many challenges

Delta-island subsidence caused by peat oxidation only can be controlled by major changes in land-use practices. The continuation of agriculture in the Delta depends on a sufficient peat thickness. In much of the cultivated area of the Delta, substantial thicknesses of peat remain so that there is great potential for further subsidence.

The Delta currently is the subject of a major Federal-State-stakeholder effort (called CALFED) to develop a long-term plan to restore ecological health and to improve water management of the Bay-Delta system. This plan includes restoring wetland and riparian habitat along the outside of the levees and on several of the smaller, less subsided islands.

Presently, there are no planned restoration activities in the heavily subsided areas within the central Delta islands. Much of the extensively subsided area is impractical to restore and will continue to require some monitoring and, perhaps, maintenance. As subsidence progresses, the levee system will become increasingly vulnerable to catastrophic failure during floods and earthquakes. The interrelated issues of Delta land subsidence, water quality, and wildlife habitat will continue to pose a major dilemma for California's water managers.

—S.E. Ingebritsen, Marti E. Ikehara, Devin L. Galloway, and David R. Jones

FUTURE STRATEGIES

Possible long-term management strategies for various Delta islands include:

1. Shallow flooding to mitigate subsidence by slowing peat oxidation and allowing growth of wetland vegetation that contributes biomass accumulation.
2. Shallow flooding combined with thin-layer mineral deposition (a possibly beneficial reuse of dredge material).
3. Continued use of agricultural areas with shallow peat and (or) low organic-matter content, under the assumption that the additional subsidence will not destabilize the levees.
4. Addition of thick layers of mineral soil, possibly using controlled levee breaches or deposition of dredge material, to slow peat oxidation and raise land-surface elevation.
5. Deep flooding to create freshwater reservoirs.

These strategies may be implemented in a mosaic throughout the Delta that creates a substantial diversity of wildlife habitat—uplands, open water, shallow permanent wetlands, and seasonal wetlands.

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