A Primer on Delta Salinity: Natural and Human Influences

Information Sheet

Delta Science Program

DELTA STEWARDSHIP COUNCIL

- Salinity, by definition, is the saltiness or amount of salt dissolved in a body of water.
- Salinity levels in Sacramento-San Joaquin Delta water have far-reaching impacts, affecting municipal, industrial, agricultural, and ecological water uses.
- Seasonal and daily salinity levels are driven by the amount of fresh water and ocean tides flowing into and through the Delta. Climate, hydrology, and human actions (drivers include tidal forces, rainfall, agricultural run-off, water diversions, and reservoir operations) also affect salinity.

Background

As with all estuaries, the Delta (the inland region of the San Francisco Estuary) is characterized by a gradient of water salinity. However, **in the Delta, freshwater flows are carefully managed to ensure that most of the Delta is fresh year-round.** Water in the South Delta must meet a salinity objective of 700-1000μS/cm to support beneficial uses such as farming in the Delta and freshwater exports to large urban and agricultural regions south and west of the Delta. **During California's recurring severe droughts, additional management actions such as the construction of salinity barriers have been required to keep the Delta fresh.**

Another risk to keeping the Delta fresh comes from aging Delta levees surrounding deeply subsided Delta islands. Failure of these levees can lead to rapid saltwater intrusion from the ocean. These risks to a freshwater Delta are expected to become more severe as the effects of global climate change become more pronounced by the end of the century.

Climate change exacerbates the likelihood and severity of drought by decreasing snow and rain and increasing evaporation thereby decreasing freshwater supply. Additionally, sea-level rise increases the amount of fresh water needed to prevent excessive salinity intrusion into the Delta.

Glossary

- Bathymetry: the measurement of depth of water in oceans, seas, or lakes
- Conductivity: the ability of water to conduct an electrical current based on the concentration of dissolved ions (i.e., salts)
- Discharge: in hydrology, the volume rate of water flow
- Diversion: in hydrology, taking water by gravity or pumping from a surface waterbody into a canal, pipeline, or other including impounding water in a reservoir
- Inflow: in hydrology, the source of water in a waterbody
- Outflow: in hydrology, the discharge of water from a waterbody
- Salinity: the saltiness or amount of salt dissolved in a body of water
- Subsidence: the gradual sinking of an area of land

Major Factors Driving Delta Salinity

Delta salinity is influenced by many factors including climate, hydrology, and water infrastructure operations, such as reservoir and water export operations.

Environmental Salinity Drivers	Fresh Water Management Drivers	Other Human Drivers of Salinity
1. Rainfall and runoff a. Climate change b. Evapotranspiration 2. Tides 3. Sea-level rise	4. Regulations 5. Reservoir operations a. South Delta CVP and SWP Pumping Operations 6. In-Delta diversions 7. Salinity Management Tools within the Delta b. Barriers c. Operable gates	8. In-Delta discharges a. Agricultural drainage b. Point-sources c. Groundwater effluence 9. Bathymetry d. Channel depth and interconnectivity e. Subsidence 10. Tidal Marsh Restoration

Environmental Salinity Drivers

The main environmental drivers of Delta salinity are saltwater brought in from the Pacific Ocean by tidal currents and fresh water flowing into the Delta from the surrounding watershed.

1. Rainfall and Runoff

Precipitation in California varies more dramatically from year to year than anywhere else in the continental United States and the wettest 5% of wet days contribute about a third of precipitation (Dettinger 2016). The Delta and the upper watershed is similarly highly variable on an interannual basis, and the wet season occurs largely between October and April of every year.

a. Climate Change Influences

A framework developed to forecast California precipitation showed that atmospheric rivers are more likely to occur due to climate change, with implications for water and flood management as a result (Huang et al., 2020). Accordingly, modeled projections of the hydrology of the Delta watershed under climate change scenarios forecast an increase in precipitation yet snowpack water equivalent declined sharply, which is associated with a major shift toward earlier unimpaired runoff timing (Knowles et al. 2018). This "hydrological drought" results from warmer temperatures that decrease snow storage and reduce snowmelt runoff (He et al., 2021). Additionally, the rainy season has become progressively "shorter and sharper" with rain concentrating in the winter months and lessening in the fall and spring months (Lukovic et al., 2021). Further, interannual variability of precipitation will increase for California due to climate change with an increased incidence of extremely dry years despite the increased incidence of extreme wet years (Swain et al., 2018).

b. Evapotranspiration

As climate change proceeds, temperatures are expected to be warmer thus increasing evaporation and reducing snowpack and runoff, making the dry season longer, even when the wet season has relatively high flows (Knowles et al., 2018). The increasing temperatures associated with climate change have increased drought risk for California (Diffenbaugh et al., 2015) exacerbating evaporation during the dry season.

2. Tides

The Delta experiences tidal fluctuations on a semidiurnal pattern with two high and two low tides every 25-hour cycle. The high tides bring in saline ocean water and mix in the estuary with fresh water from rivers. The primary historical driver of salinity intrusion into the Delta was the amount of fresh water that flowed into the estuary system (Ghalambor et al. 2021) resulting in large salinity variability from year to year. When high tides are coupled with sea-level rise, the risk for flooding increases.

3. Sea-Level Rise

The State of California Sea-Level Rise 2018 Guidance projects a 66% probability of sea-levels in the San Francisco Bay-Delta Estuary to rise between 0.6 to 1.1 feet by 2050 (OPC

2018). Sea-level rise increases salinity intrusion and flooding hazards for levees and other water infrastructure (DSC 2021). Furthermore, the 2022 Sea-Level Rise Technical Report estimates that coastal sea-level rise could be as high as 7 feet by the end of the century if emissions are not curbed (Sweet et al., 2022).

Freshwater Management Drivers

Due to fresh water being the major environmental driver for reducing salinity in the Delta, the management of fresh water in the Delta watershed is a major objective for resource managers.

4. Regulations

Over the 20th century, numerous dams were built to impound over 30 million acre-feet of water in the tributaries to the Sacramento and San Joaquin Rivers. Beginning in the 1940s, the California Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) constructed large dams and water conveyance networks as part of two major water conveyance projects in California: the State Water Project (SWP) and the Central Valley Project (CVP) which provide fresh water to the Central Valley and southern California.

DWR and USBR manage the SWP and CVP reservoirs and water exports in the Delta watershed and are water right holders for the SWP and CVP. Water quality and flow requirements for managing salinity in the Delta are established in the State Water Resources Control Board's (State Water Board) Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta (Bay-Delta Plan). DWR and USBR operate the SWP and the CVP, respectively, in accordance with the State Water Board's Water Right Decision 1641 (D-1641) (see Regulatory fact sheet for more information).

Despite the dams being built and operated to manage fresh water for the SWP and CVP, a study evaluating salinity intrusion over the 20th century found that the expansion of dam storage and irrigation diversions may have led to an increase in salinity intrusion (Hutton and Roy 2019).

5. Reservoir Operations

The high level of management in the Delta and upper watershed has changed the timing and magnitude of freshwater flows into the Delta (Ghalambor et al. 2021) and DWR and USBR control salinity intrusion with reservoir releases or reductions to CVP and SWP exports to comply with D-1641. Reservoir releases vary according to in-Delta salinity and hydrology- during wet weather months there is a reduced need for reservoir releases, but in the dry summer and fall, water is released to keep the Delta fresh.

a. South Delta CVP and SWP Pumping Operations

The CVP and the SWP provide fresh water to the southern Central Valley and southern California by pumping water from the South Delta. The water that enters the CVP and SWP must have adequately low salinity to be distributed. Because of the placement of the pumps in the South Delta, pump operations impact channel flows and sometimes result in negative flows. Water from reservoirs must be released to maintain fresh conditions in the South Delta. Under extreme drought, drought barriers have been installed to allow less reservoir releases and maintain salinity objectives (see Emergency Drought Barriers fact sheet for more information).

6. In-Delta Diversions

In addition to the two Projects, water diverted in-Delta has remained relatively constant at about 4% (0.9 million acre-feet) of Delta inflows over the past century (DSC 2018). The majority of in-Delta diverted water is used for agricultural irrigation. Over 1,800 in-Delta diversions remove water directly from channels and sloughs for irrigation use.

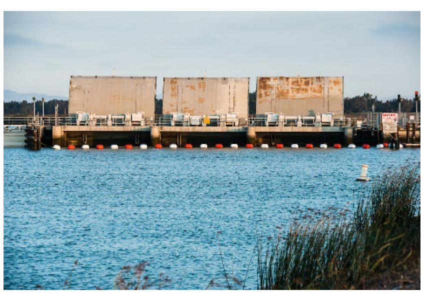
DWR and the North Delta Water Agency (NDWA) have a contractual agreement that DWR will ensure a dependable water supply of suitable quantity and quality for agriculture use in the north Delta, from where NDWA diverts water, except under drought emergency conditions.

7. Salinity Management Tools within the Delta

a. Barriers

Emergency drought barriers were first placed during the 1976-77 drought in six places in the Delta to quell salinity intrusion (DWR 2015). A barrier was used again in 2015 and 2021 in False River to stop saline water from entering Franks Tract which is located near waterways used to convey fresh water to the CVP and SWP (see Emergency Drought Salinity Barrier fact sheet for more information).

b. Operable Gates



The use of operable gates on waterways that are used for freshwater conveyance can reduce salinity intrusion by redirecting the flow of fresh water. The Delta Cross-Channel (DCC) is a constructed channel with two operable gates that can divert water from the lower Sacramento River into the Central Delta via the Mokelumne River. The operation of the DCC redirects the flow of fresh water into the Central Delta and towards the export pumps. The DCC is also operated for flood control and must be kept closed for migrating Chinook salmon during many parts of the year.

The Suisun Marsh also has three Salinity Control Gates (SMSCG) on the eastern portion of Montezuma Slough which are operated to mitigate the salinity effects of the CVP and SWP in the marsh. The SWP Incidental Take Permit requires the use of the SMSCG to manage freshwater supply to support aquatic habitat (see Regulatory Fact Sheet for information on SMSCG operation requirements) and have also been experimentally operated to support favorable habitat for Delta smelt (Sommer et al. 2020).

Other Drivers of Salinity

In addition to the major environmental and management drivers of salinity in the Delta, other factors can also influence salinity.

8. In-Delta Discharges

The South Delta experiences consistently high salinity. Some of this high salinity can be explained by the origin and makeup of the underlying soils that contribute salts to water draining from these soils into the South Delta. The resident soils in the southernmost part of the Delta are composed of eroded, heavily mineralized, marine sedimentary rock from the Diablo Range (DWR 2007).

Additionally, the sheer number of saline discharges that occur in the South Delta compound the relatively high salinity. There are approximately 74 discharge sites situated along South Delta waterways upstream from the CVP and SWP. Most discharges are from agriculture, treated wastewater, urban runoff, and groundwater effluence.

a. Agricultural Drainage

The majority of discharge sites identified in the South Delta are agricultural. Agricultural drains in the South Delta are particularly saline compared to others around the Delta. Conductivity, a common measure of salinity, in South Delta agricultural drains ranges from 350 to 4,500 μS/cm with an overall average of 1,496 μS/cm (DWR 2007). SWP deliveries average approximately 430 μS/cm, and the water quality objective for conductivity in the South Delta is 700-1000 μS/cm at compliance stations in the interior South Delta.

b. Point Sources

Point-source discharges in the South Delta are municipal wastewater treatment plants and pit drainage from a historic sand excavation company. A DWR study from 2007 estimated that discharge volumes from all point-sources average 0.6 and 5.7 million gallons per day with conductivity ranging between 1,099 and 1,753 μS/cm (DWR 2007).

9. Bathymetry

a. Channel Depth and Interconnectivity

European settlers changed the physical structure of the Delta waterways to reduce flooding and allow farming in the floodplains and tidal marsh. “Reclaiming” the floodplains and tidal marsh was accomplished by constructing or reinforcing levees on the banks and creating new straight channel cuts, which increased channelization and modification of channel bathymetry. Over time, channels in the Delta have been deepened and straightened to accommodate shipping and land conversions, as well as to build levees for flood management (DSC 2021). This alteration removed complex networks of dendritic streams and sloughs which would otherwise slow tidal salinity influences, thereby requiring more fresh water to push out the saline wedge.

b. Subsidence

Half of the volume of organic peat soils in the Delta has been lost due to disturbance and oxidation (Deverel and Leighton 2010), lowering some Delta islands by as much as 25 feet below sea-level. The height differences between water and land levels risk further amplifying the effects of channelization by increasing flooding hazards that would lead to permanent flooding of Delta islands and salinity intrusion (DSC 2021).

10. Tidal Marsh Restoration

Tidal marsh restoration projects are not typically designed to manage salinity but do affect Delta flows and salinity by changing the geometry of the river flow and tides, either increasing or decreasing salinity intrusion depending on the location and design of the restoration project. Strategically placed and designed restoration actions can change channel geometry or otherwise help alter salinity patterns in the Delta. For example, a project called “Franks Tract Futures” evaluated alternative geometries of a potential restoration project in the central Delta with salinity control as one of the multiple benefits being considered in the design (see Franks Tract Futures fact sheet for more information).

Future Responses

Computer models can provide managers with information to mitigate and adapt to the changing salinity regime in the Delta and respond to various climate change pressures. The management tools currently in use may provide some opportunities to continue addressing salinity intrusion; however, additional tools and management methods may be necessary to address sea-level rise and climate change-induced precipitation and temperature changes.

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