Color Contour Maps of Delta EC

Figures 17-20 show daily average Delta EC contours in false color. Generated by Resource Management Associates (RMA), these images show the output of a two-dimensional Delta hydrodynamics model based on historical EC and flow data. These four figures are snap shots in time of average flow and salinity for a single day under differing Delta conditions to illustrate the wide variation in salinity regimes that can occur. These images are a powerful tool for visualizing the distribution of Delta salinity. When coupled with other observations and studies, these distributions point to the sources and processes that drive Delta salinity. They help to illustrate the relative importance of different sources and the underlying water movement (hydrodynamics) of the Delta.

Figure 17 shows a typical early summer salinity distribution for the Delta. Seawater intrusion is evident in Suisun Bay and extending into the western Delta. Salinity from the San Joaquin River is seen impinging on the southeastern part of the Delta and the very fresh water of the Sacramento can be seen coming in from the north. The combined influence of Sacramento River inflow and export pumping at the Banks and Tracy pumping plants is thought to be the cause of the “freshwater corridor” extending across the central Delta from north to south.

Figure 18 shows high EC conditions (737 µS/cm) at the Banks and Tracy pumps. This was near the period of maximum EC for the year at the end of a series of dry to critically dry years (1987-1992). This is near the worst case for export salinity experienced in recent years.

EC at Banks was poor on the date represented in Figure 19 (~600 µS/cm) even though this was a wet year. This is thought to be due to closure of the Delta Cross Channel (DCC) gates to protect juvenile Chinook salmon migrating downstream. With the expected delay due to travel time across the Delta, an EC spike at the pumps coincided with the DCC closure. Subsequent studies of the effects of the DCC on salinity at the Banks and Tracy pumping plants have reinforced the association of DCC closure with high intake EC, especially when Delta outflow is relatively low.

Figure 20 shows the Delta during conditions of high Delta inflow. San Joaquin River inflow was greater than 15,000 cfs. EC at Banks was very low (~115 µS/cm). Computer “fingerprint” modeling of Delta flows suggests that nearly all of the water at the South Delta pumps was from the San Joaquin River on this date.

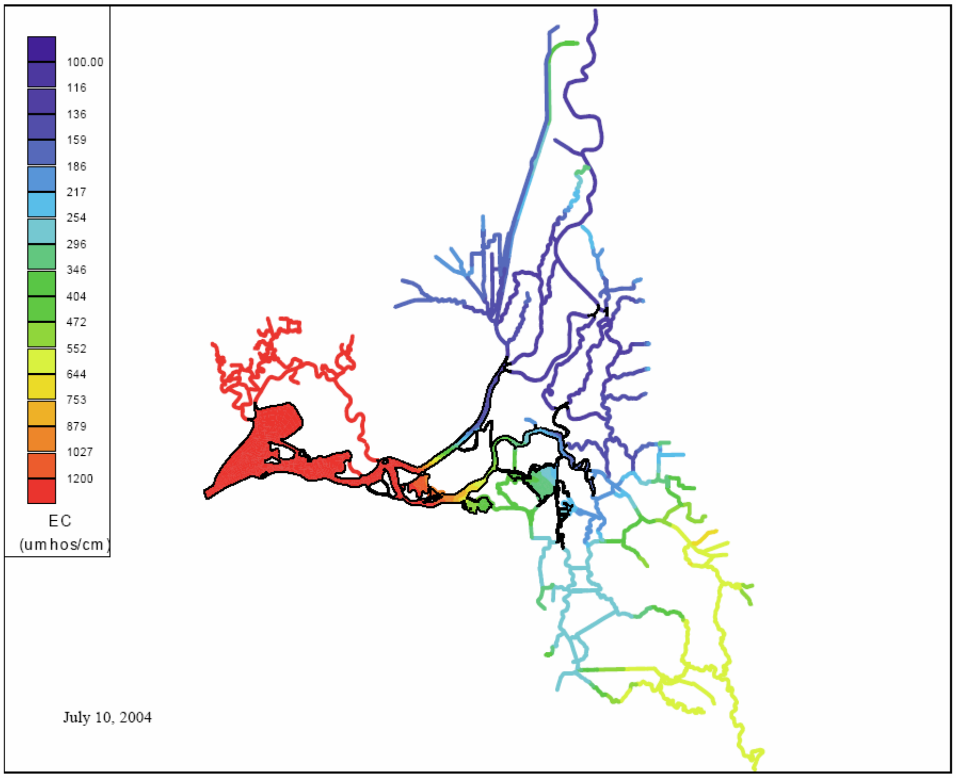


Figure 17: Tidally averaged Electrical Conductivity (EC) contours for July 10, 2004 (courtesy of RMA).

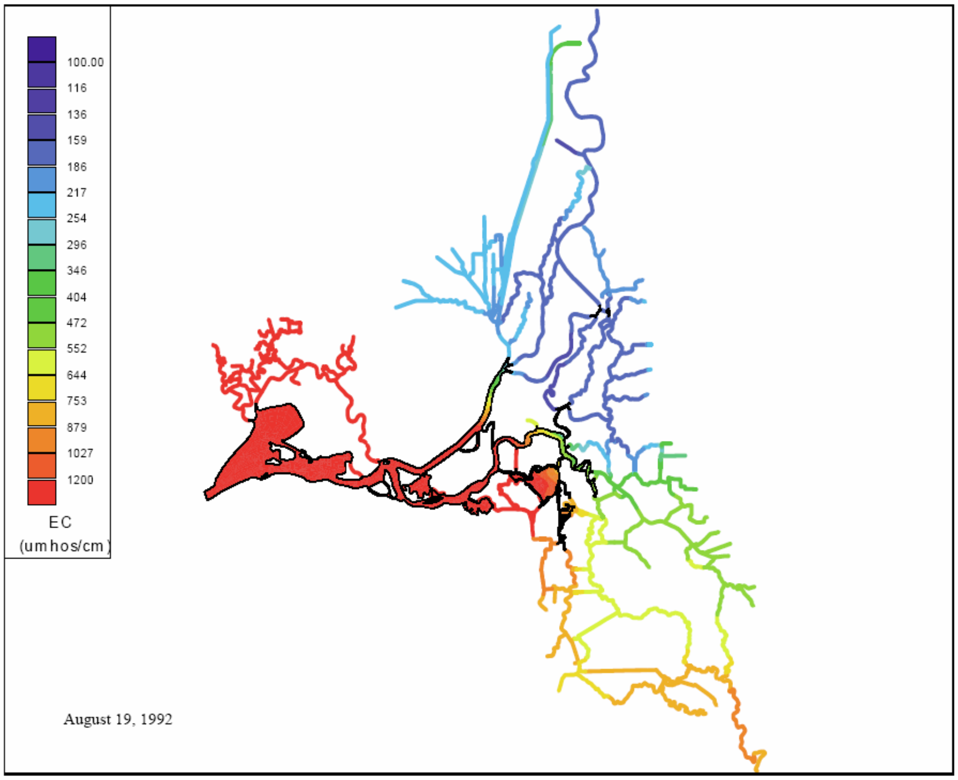


Figure 18: Tidally averaged EC contours on August 19, 1992.

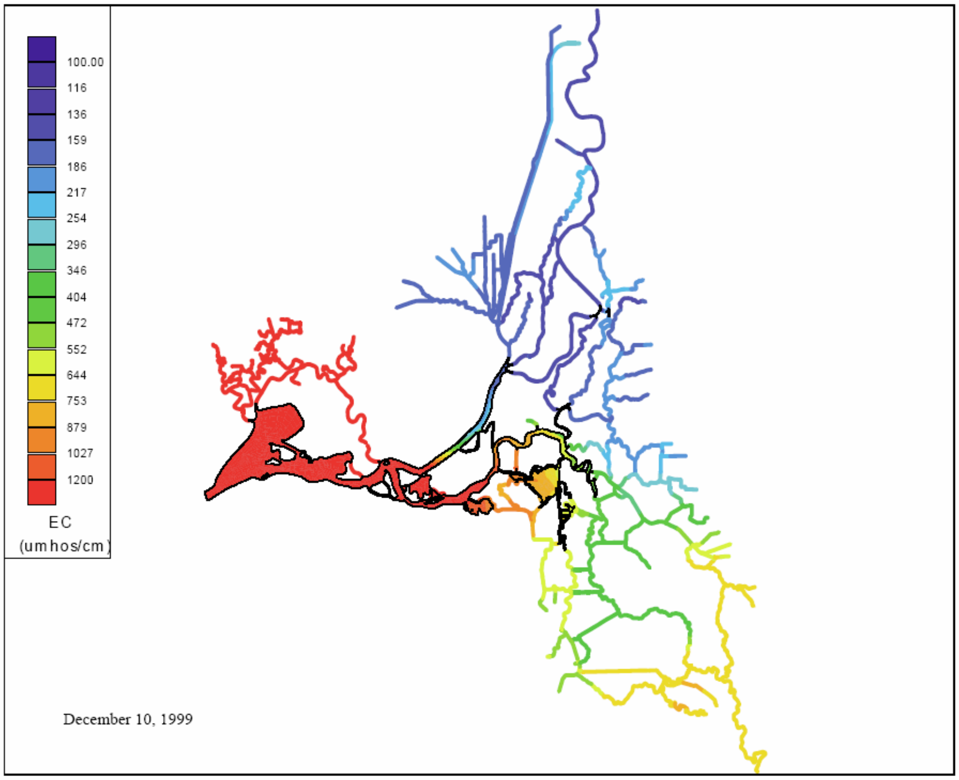


Figure 19: Tidally averaged EC contours on December 10, 1999.

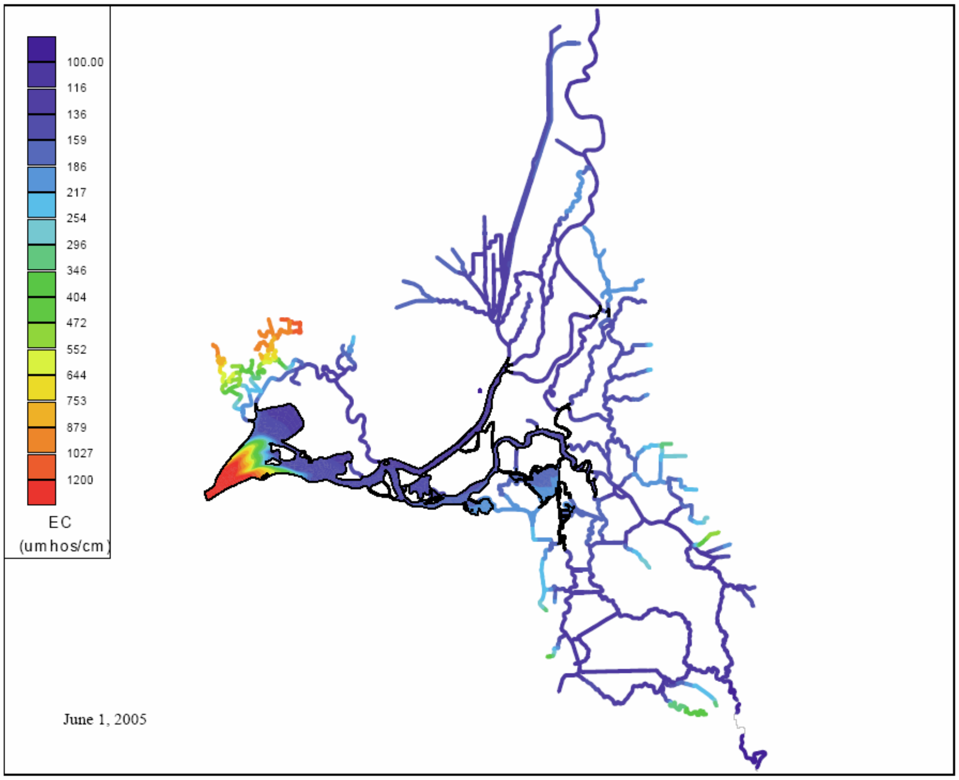


Figure 20: Tidally averaged EC contours on June 1, 2005.

CONCEPTUAL MODEL

This conceptual model differs to some extent from the usual quest for environmental knowledge in the wealth of monitoring data available and the depth of understanding that exists. Knowledge of the dynamics of salinity in the Delta has grown to the point where a sophisticated system of continuous monitoring equipment and computer models are used to operate the water projects' pumps and reservoirs to meet salinity objectives with a high degree of accuracy. We can plot the salinity at nearly any point in the system and we can model where the water and the salt that reaches the pumps comes from. In some critical locations we can even model the movement and mixing of salt in three dimensions with high spatial and temporal resolution. This "conceptual model" is an attempt to capture the current thinking about the factors that drive salinity at the municipal water supply diversion points and to put this knowledge into a simplified and understandable framework.

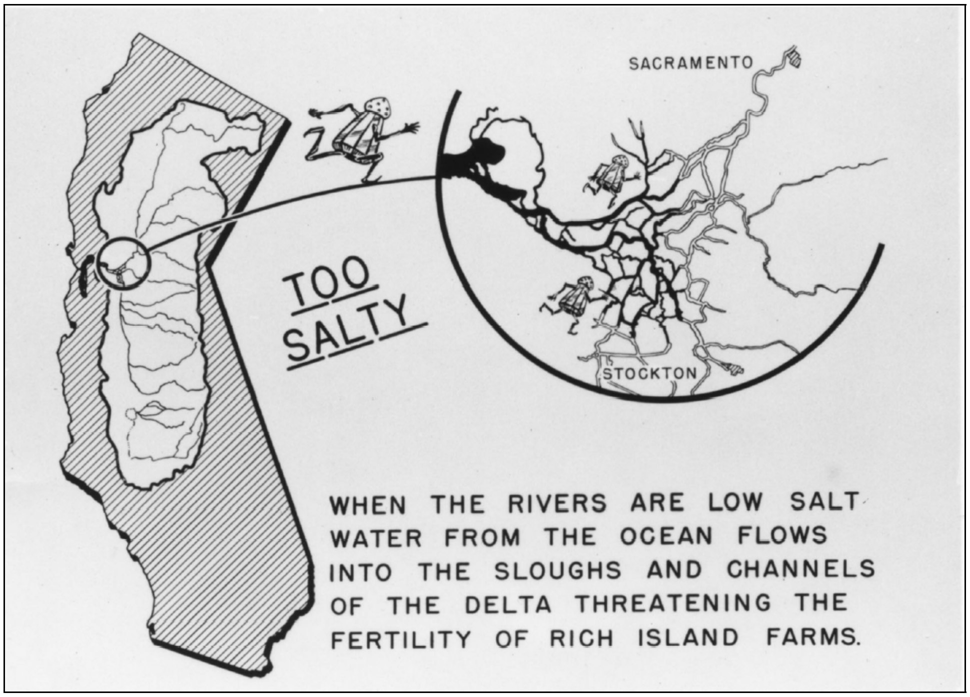


Figure 21: 1945 USBR depiction of Delta salinity intrusion.

At its simplest, the salinity in the Delta can be viewed as the movement of salt from San Francisco Bay into the Delta. Figure 21 is from a 1945 document on the history of the Central Valley project. This early public information piece conveys a basic understanding of salinity in the Delta and one of its effects.

Salinity Drivers and Outcomes

We now know that salinity at the municipal supply diversion points at any given time is the result of a number of factors. Figure 22 shows these "drivers" and the outcomes, salinity at the five major diversion points for drinking water supply. Factors are identified as uncontrollable (hydrology) or partially controllable (water operations, hydrodynamics, and watershed sources). Hydrology (precipitation and runoff) varies seasonally and year to year and is beyond our control. Water operations, reservoir releases, channel barrier operations, and diversion pumping rates, are our primary means of controlling flow in the system, and thereby salinity, but operations are driven by regulatory factors other than water quality so are only partially controllable for water quality purposes. Together hydrology and water operations determine Delta inflow, the most important determinant of salinity distribution in the estuary. The changes in maximum salinity intrusion after construction of Shasta dam in 1949 (Figures 3 and 4) are an indication of the powerful effect of water operations on salinity. Hydrodynamics, the movement of water, in the Delta is another important driver of salinity. We have been able to influence movement of water through the Delta to some extent through construction of channels (the Delta Cross Channel), barriers (south Delta temporary barriers, Suisun Marsh Salinity Control Gate) and, although not designed for this purpose in most cases, the Delta levees.

Watershed sources are only partially controllable; a certain amount of the salinity of the Delta's tributaries is the result of natural solution of minerals in rocks and soils. Non-point sources such as agricultural drainage and runoff have recently been subject to additional regulatory requirements but do not yet have limits on salinity. Municipal wastewater discharges have typically been subject to narrative limitations that prevent the discharge of excessive amounts of salt but have not been given numeric limitations on salinity or salt loads. Some industrial discharges have been regulated for salinity.

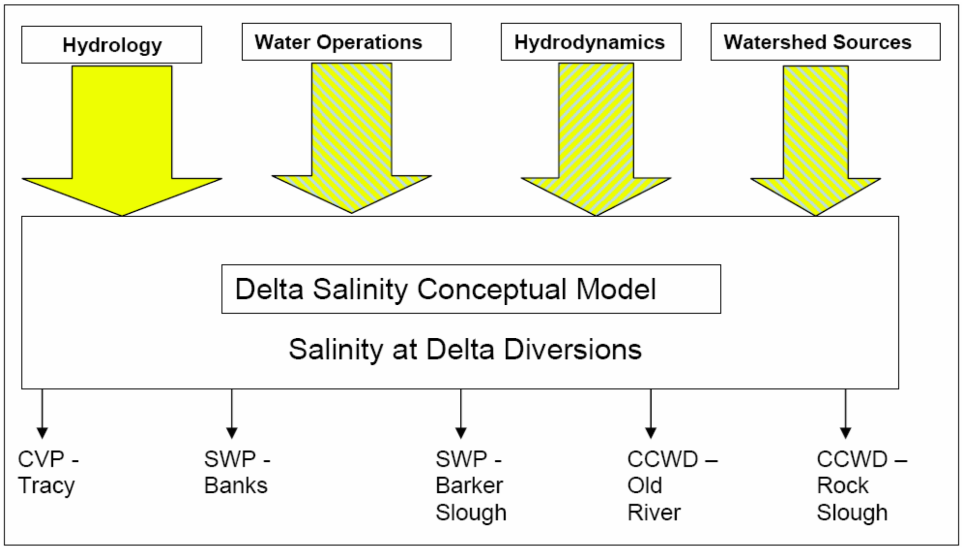
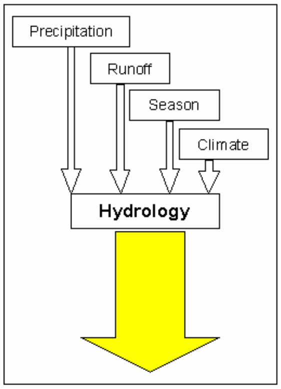


Figure 22: Drivers and Outcomes model of Delta salinity.

Hydrology



The amount of water flowing into the Delta is the single most important determinant of salinity at the export pumps and the amount of inflow is largely determined by hydrology. During very wet years average salinity at the SWP pumps is low. The average EC at the Banks Pumping Plant for the 1983 water year, one of the wettest on record, was 276 µS/cm. In the critically dry 1991 water year, EC at the same location averaged 589 µS/cm. Figure 23 shows the relationship between water year indices for the Sacramento and San Joaquin Rivers and annual conductivity at the Banks Pumping Plant. The water year index is calculated using a weighted formula based on current and the previous year's runoff. Higher water year index means more Delta inflow and therefore lower salinity.

The seasonal variation can be even greater. EC can vary from less than 200 to more than 750 µS/cm in a single water year. The highest salinities occur during the fall and early winter when Delta inflow is lowest. The amount of precipitation that falls in a given year, where it falls, when it falls, how much runs off, and other aspects of hydrology drive these changes and are generally beyond our control.

One of the key features of California hydrology is the difference in precipitation and runoff between the northern and southern parts of the state. There is much more runoff coming from the northern part of the Delta watershed (Sacramento River) than the southern part of the watershed (San Joaquin River). The annual inflow and outflow statistics for the Delta from the 1980 to 1991 period (DWR 1995) are shown in Table 2.

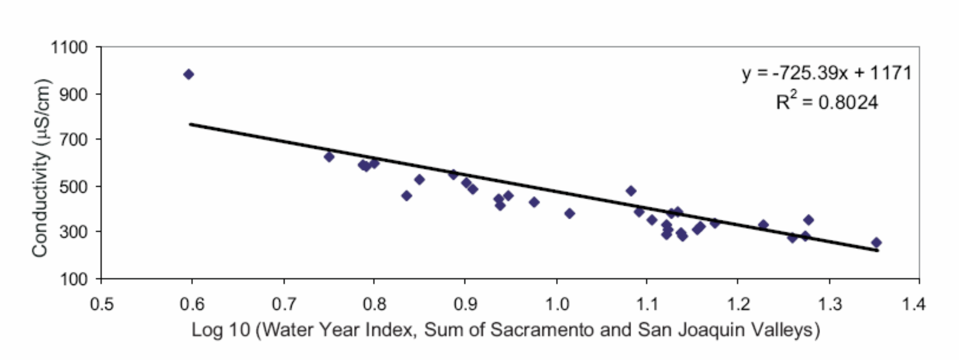


Figure 23: Relationship between water year index and annual average conductivity at the Banks Pumping Plant (DWR, 2004).

Table 2: Inflow sources, and outflow/diversions of California Delta water in thousands of acre-feet (TAF).

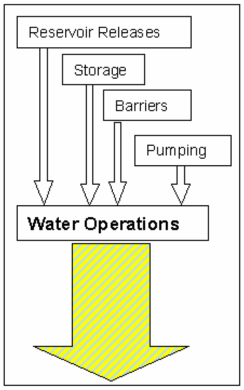
Inflow	Volume (TAF)
Sacramento River	17,220
East Side Sierra Streams	1,360
San Joaquin River	4,300
Delta Precipitation	990
Yolo Bypass	3,970
Total Inflows	**27,840**

Outflow/Diversion	Volume (TAF)
Delta Outflow to Bay	21,020
Consumptive Use and Channel Depletion	1,690
Tracy Pumping Plant	2,530
Banks Pumping Plant	2,490
Contra Costa Pumping Plant	110
Total Outflows	**27,840**

On average, during this period, approximately two thirds of the Delta inflow came from the Sacramento River and the Sierra streams draining into the east side of the Delta (the Cosumnes Mokelumne, and Calaveras rivers). However, the majority of water demand in the State is south of the Delta. The main purpose for the State and federal water projects is to modify the natural hydrology of the state by storing water when and where it is most available so that it can be used when and where it is needed. Water from winter and spring runoff in Northern California is stored in reservoirs and conveyed to Southern and Central California throughout the year.

Water Operations

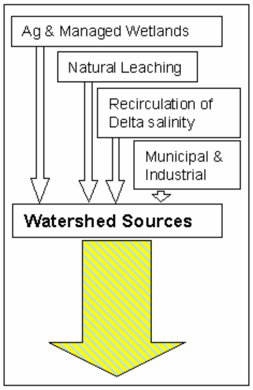
Even though we physically have control over all of the structures and processes, operations are represented as only partially controllable relative to water quality because they are subject to other constraints. For example, dam license provisions may require maintenance of flood reserve capacity at a time of year that reduces the amount of water available to meet water quality goals later. Reservoir releases may be driven by in-stream flow and temperature requirements. Delta barrier and pumping operations are regulated to protect fish and in-Delta agricultural water diversions.



At times, water project operations can be the dominant driver of Delta salinity. During periods of low natural inflow, the combination of reservoir releases and Delta diversion pumping governs salinity. Fall Delta outflow can be less than 4000 cfs while combined SWP and CVP diversions are near 10,000 cfs. It is during these periods, when the majority of Delta inflow is diverted, that salinities at the pumps are usually highest. When Delta outflow increases with the late fall and winter rains, salinities begin to decrease.

Installation and operation of Delta barriers can also have a significant effect on salinity at the SWP and CVP pumps. Installation of the temporary barriers in the south Delta can cut off the flow of high salinity San Joaquin River water through Old River, Middle River, and Grant Line Canal reducing the average salinity at the State and Federal pumps. Operation of the Delta Cross Channel (DCC) gates can also have a significant effect on water quality particularly in the fall months when Delta outflow is low. (This is in fact why the DCC was constructed.) The DCC gates are generally opened for the summer sometime in late June, allowing higher quality Sacramento River water into the central Delta by way of the Mokelumne River channels, and closed in December. However, the DCC gates are operated in accordance with water rights permit conditions issued by the SWRCB and are frequently closed to protect migrating fish or because of high flows at various times in the fall, winter, and spring. They are also sometimes opened expressly to improve water quality in the Delta.

Watershed Sources



Included here are salts added through material inputs to agricultural, municipal, industrial, and natural processes. These sources of salt are as varied and complex as land use and water use in the watersheds. Only the sources that monitoring and studies indicate are most important are discussed here. The salt from seawater entrained at the Delta export pumps, used for irrigation, and ultimately finding its way back to the San Joaquin River and the Delta is one of these sources. Another significant source in the San Joaquin River watershed is naturally occurring salt in soils that are mobilized by irrigation practices.

Soils on much of the west side of the San Joaquin Valley are derived from ancient marine sediments and are naturally high in gypsum and other salts. Irrigated **agriculture** in these areas dissolves these naturally occurring salts and moves them downward into the groundwater. Addition of fertilizers, soil amendments, and land application of animal wastes also contribute to this salt load. This groundwater eventually finds its way to surface water either through accretion to streams, groundwater use, or through specially constructed drains (tile drains). Both agriculture and **managed wetlands** concentrate the salts in supply water and soils through the process of evapotranspiration. This salty water is often discharged through drainage canals, sloughs, and creeks.

Natural leaching of salts from rocks and soils occurs everywhere in the watershed. This gradual increase in dissolved substances in water as it flows downstream through a watershed is normal and depends on factors such as geology and plant communities.

Because water is pumped upstream from the Delta and used in the lower San Joaquin Valley, salts there (which may be of seawater or watershed origin) can be **recirculated** within the system. Salts in water diverted from the Delta at the Banks and Tracy export pumps can travel through the Delta Mendota Canal and the California Aqueduct, through agricultural supply canals in the San Joaquin Valley, through agricultural fields, groundwater, or wetlands, through the drainage system, and back to the Delta by way of the San Joaquin River. The exact pathways for this recirculation are no doubt highly variable and the time it takes for salts to make this circuit is also highly variable.

Municipal and **industrial** use of water is known to both add and concentrate salts in supply water. These discharges of salt are easily quantifiable because they are monitored in accordance with discharge permit requirements. These discharges contribute much less salt to the system than agriculture and managed wetlands but they are increasing along with development in the Central Valley. It is also sometimes difficult to differentiate salt sources in a watershed because of mixed land uses and reuse of water within the system. For example, municipal and industrial wastewater is often land applied to grow crops. This is often the case with food processing wastewater.

Table 3: Source category salt loading (WY 1985-1995).

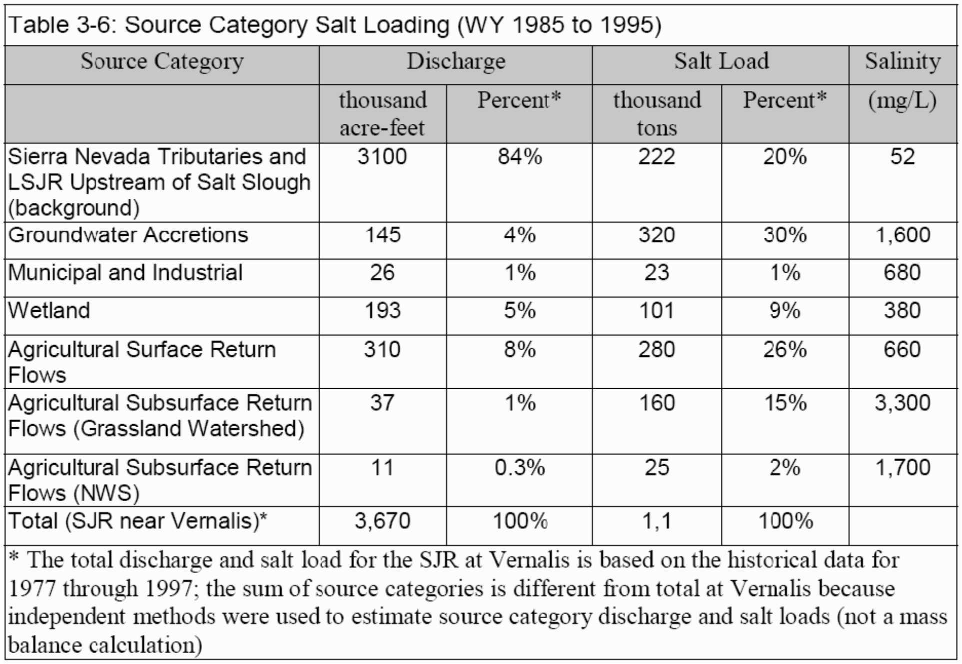


Table 3-6: Source Category Salt Loading (WY 1985 to 1995)

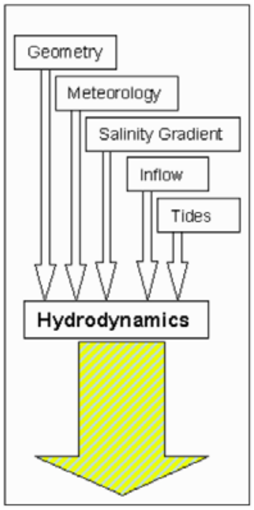
Source Category	Discharge		Salt Load		Salinity
	thousand acre-feet	Percent*	thousand tons	Percent*	(mg/L)
Sierra Nevada Tributaries and LSJR Upstream of Salt Slough (background)	3100	84%	222	20%	52
Groundwater Accretions	145	4%	320	30%	1,600
Municipal and Industrial	26	1%	23	1%	680
Wetland	193	5%	101	9%	380
Agricultural Surface Return Flows	310	8%	280	26%	660
Agricultural Subsurface Return Flows (Grassland Watershed)	37	1%	160	15%	3,300
Agricultural Subsurface Return Flows (NWS)	11	0.3%	25	2%	1,700
Total (SJR near Vernalis)*	3,670	100%	1,1	100%	

* The total discharge and salt load for the SJR at Vernalis is based on the historical data for 1977 through 1997; the sum of source categories is different from total at Vernalis because independent methods were used to estimate source category discharge and salt loads (not a mass balance calculation)

The Central Valley Regional Water Quality Control Board estimated the salt loading from different source types in the San Joaquin Valley shown in Table 3 (CVRWQCB 2004).

For the Sacramento River, municipal wastewater plant discharges contribute approximately 7% of the salt load at Hood. Municipal sources make up a higher percentage of the salt load than in the San Joaquin River because of the large population of the Sacramento metropolitan area and low background concentrations.

Hydrodynamics



As used here, hydrodynamics includes the major physical attributes and forces that govern the movement of water within the Delta and Bay. One indication of the importance of hydrodynamics is that the geographic extent of the Delta is largely defined by the upstream extent of tidal water level fluctuations. Although tidal hydrodynamics is important throughout the Delta, its impact on salinity is most important in the central to western Delta and less important as one travels upstream. Tides are the primary engine driving water mixing (dispersion) in the Delta. A parcel of water can move up and downstream several miles with the ebb and flow of the tide. This causes complex patterns of mixing and water movement and makes sophisticated computer modeling programs a must for understanding Delta water quality.

Geometry refers to the layout of bays, channels, rivers, sloughs, and flooded islands in the Delta and the depth profiles of these features. There are approximately seven hundred miles of interconnected channels and at least five permanently flooded islands in the Delta's 738,000 acres. The importance of geometry is illustrated by several key projects that improve water quality by changing the routing of water through the Delta. The Delta Cross Channel was constructed as part of the Central Valley Project in 1951 to divert high quality Sacramento River water into the central Delta and towards the south Delta pumps. Another project, the Suisun Marsh Salinity Control Gates seek to lower salinities within Suisun Marsh by restricting upstream movement of brackish water and increasing freshwater flows into Suisun Marsh.

Controlling the flow of water at strategic locations in the Delta can have a major effect on salinity. Channels that branch off into flooded islands are much more effective at trapping and moving salty water into the Delta than are straight and uniform channels. Computer modeling of various options for restricting water movement in and around Franks Tract have shown that, under certain conditions, salinity at the south Delta pumps could be reduced by as much as 30%. Related studies indicate that constructing a screened diversion near Hood on the Sacramento River and discharging the diverted water into the South Fork of the Mokelumne River could further reduce salinity at the SWP and CVP pumps. Changing the way that the Delta Cross Channel is operated could also reduce salinity at the SWP and CVP pumps. The Department of Water Resources is conducting studies and planning a pilot project to further analyze these findings.

The depth profile (bathymetry) of a channel is important both across the width of the channel and in the upstream-downstream direction. Recent modeling studies have shown that bathymetry is an important factor in determining where density driven movement of seawater occurs. In several areas, shallow flats adjacent to deeper channels increase the tidal mixing and spread (dispersion) of salinity in the system. Bathymetry is also an important factor in the propagation of tides into the Delta.

The movement of water in the estuary can also be driven by the **salinity gradient** between fresh and salt water. The difference in density between the more saline waters of San Francisco Bay and fresher water flowing out of the Delta is an important force determining the extent of salt water intrusion into the Bay-Delta system. Rather than mixing immediately, less dense (fresher water) tends to ride up over the more dense saline water and the saltier water pushes upstream underneath. This effect is most pronounced in the deeper reaches of San Pablo Bay and the Carquinez Straights. Significant density driven water movement (baroclinic flow) occurs primarily downstream of Sherman Island.

As stated earlier, freshwater **inflow** into the Delta is highly correlated with salinity at Delta diversions pumps and is thus an extremely important driver. Water flows downhill into the Delta from its tributaries. The effect of this inflow is partly due to the volume of water entering the Delta and partly due to water surface elevation (stage). This flow of water downstream primarily driven by the gradient of water surface elevation is known as advective flow. At high water inflows during the winter and spring, the water surface of the Delta and its tributaries is higher, reducing tidally driven water movement. At the same time the increased volume pushes brackish water out of the Delta.

As stated above, movement of water due to the **tides** is a definitive characteristic of the Delta. The Delta is the freshwater tidal portion of the San Francisco Bay-Delta estuary. Much of the land surface in the Delta is at or below the elevation of the mean high tide. The twice daily high and low tide signal can be seen in stage (water surface elevation) measurements in most of the rivers, sloughs, and channels of the Delta for at least some part of the year. This tidal fluctuation can clearly be seen in stage recorded at the I Street Bridge on the Sacramento River and at Mossdale Bridge on the San Joaquin River when flows are low during the late summer and fall. However, this does not mean that flow reversals (upstream flow due to the tide) occur this far upstream. For example, there is strong upstream and downstream tidal flow at Rio Vista on the Sacramento River but usually not at Freeport. Conversely, tidal flows in the main channels of the western Delta are often many times higher than the net downstream flow.