

CHAPTER 5.0

ORGANIC CARBON CONCENTRATIONS AND LOADS IN THE DELTA

Over the past three decades, the Sacramento-San Joaquin Delta has been the focus of monitoring and computer modeling studies of organic carbon. Organic carbon data have been collected at numerous locations in the Delta and its tributary watersheds. Assessment studies, including computer modeling, have used these data to improve the understanding of organic carbon concentrations at drinking water intakes and the role of organic carbon quantity and quality in both disinfection byproduct formation and in Delta ecosystem function. Recent computer modeling techniques allow tracking of tributary and in-Delta sources of organic carbon and relate them to concentrations at the drinking water intakes.

The key issues pertaining to organic carbon chemistry and ecological processes, summarized from recent research, are presented in Chapter 2. This chapter is focused on evaluating the sources of organic carbon in the Delta in a manner similar to that used for the tributaries in Chapter 4 and summarizing key findings of source-intake relationships from a published numerical model of the Delta. Recent research has emphasized the range of reactivity of organic carbon from different sources, as discussed in Chapter 2; however, detailed organic carbon characterization is only available at very limited spatial and temporal resolution. Until better data are available, the loads of organic carbon from the tributary and in-Delta sources, combined with the modeling studies that relate loads to concentrations at the drinking water intakes, provide a useful measure of the relative importance of different sources. This information will be refined in future efforts to quantify sources and potential drinking water impacts based on additional data.

5.1 DELTA INFLOWS AND OUTFLOWS

Characterization of flows is central to estimating loads of constituents in moving water bodies. Daily water flows entering and exiting the Delta at various locations, shown in Figure 5-1, were obtained from the DAYFLOW model. DAYFLOW is a computer program developed in 1978 as an accounting tool for determining historical and current Delta hydrology at the boundaries. Inflows in all tributaries, outflows to the San Francisco Bay and diversion by the water supply intakes are represented in the model. However, DAYFLOW does not characterize internal flows in the channels of the Delta and cannot be used to understand the mixing processes of different tributary and internal sources of individual constituents. DAYFLOW output is used extensively in studies conducted by the Department of Water Resources (DWR), the Department of Fish and Game (DFG), and other agencies. Model output is available electronically at <http://www.iep.ca.gov/dayflow/index.html>.

Annual water supply diversions at the Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Contra Costa Water District's Rock Slough and Old River pumping plants (CCC), and the North Bay Aqueduct's Barker Slough Pumping Plant (NBAQ) are shown in Figure 5-2. The naming conventions on this figure are consistent with the DAYFLOW model diversion names shown in Figure 5-1. Over 95% of the water diverted from the Delta is diverted at the Banks and Tracy pumping plants. The sum of water diversions from the Delta is shown as a percentage of annual flows from the major tributaries (Sacramento and San Joaquin Rivers) in Figure 5-3. Over the water years 1983-2004, the average amount of water diverted was 5.2 million acre feet, varying between 3.1 and 6.3 million acre feet. Compared to the variability of tributary flows into the Delta, the diversion volumes are relatively uniform. In dry years, such as the late 1980s and the early 1990s, diversions by the projects can be nearly 50% of Delta inflows. In more recent years, because of higher tributary inflows, the diversions have been a smaller fraction of the inflows, but even so, diversions of 30-40% are common.

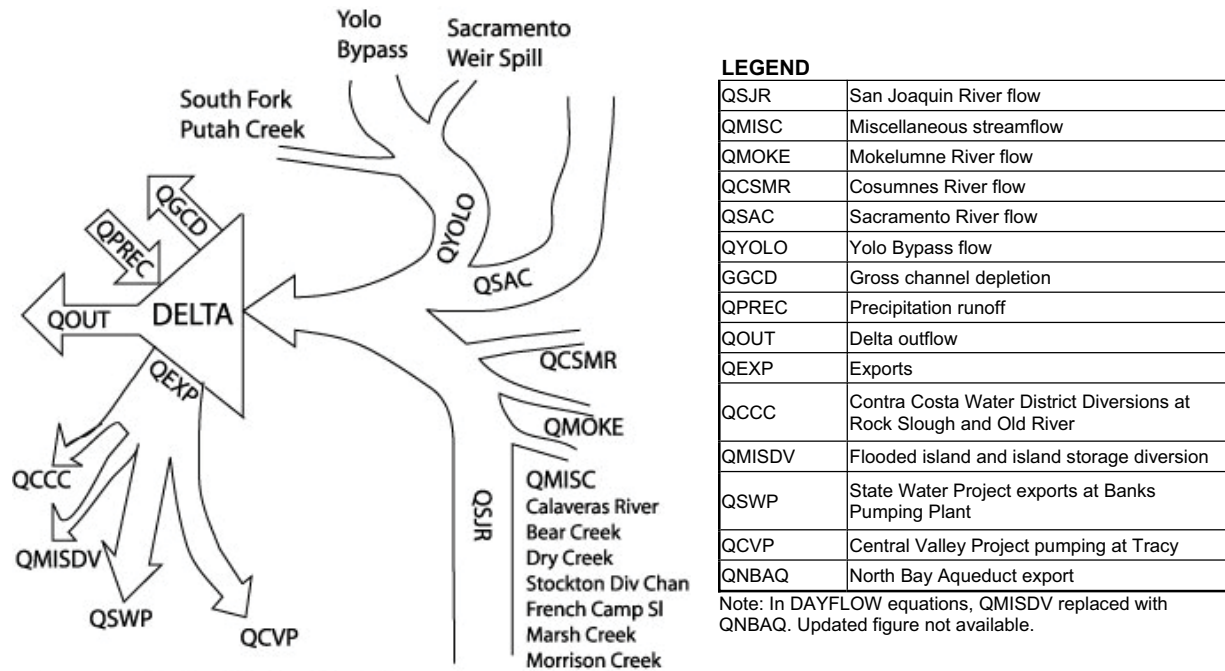


Figure 5-1. Delta locations with daily flow data reported in the DAYFLOW model. (Figure reproduced from <http://www iep.water.ca.gov/dayflow/documentation/fig2.jpg>).

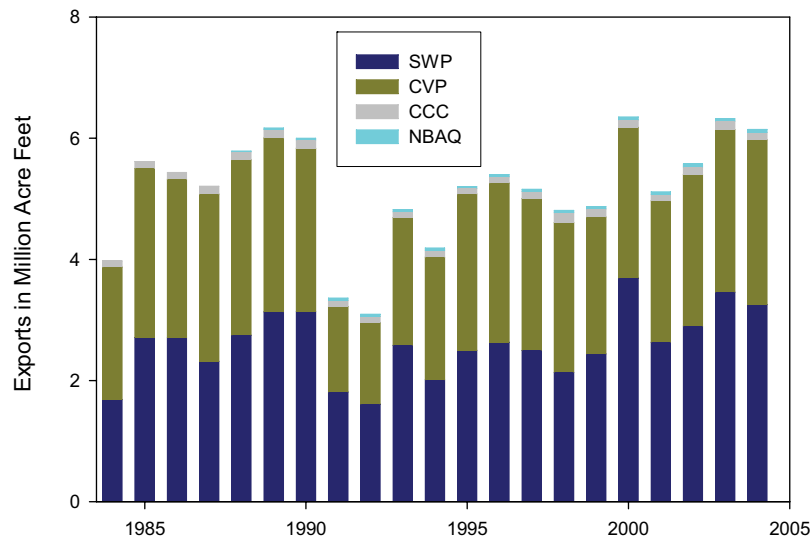


Figure 5-2. Annual water supply diversions (Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Contra Costa Water District’s Rock Slough and Old River pumping plants (CCC), and the North Bay Aqueduct’s Barker Slough Pumping Plant (NBAQ) as reported in the DAYFLOW model.

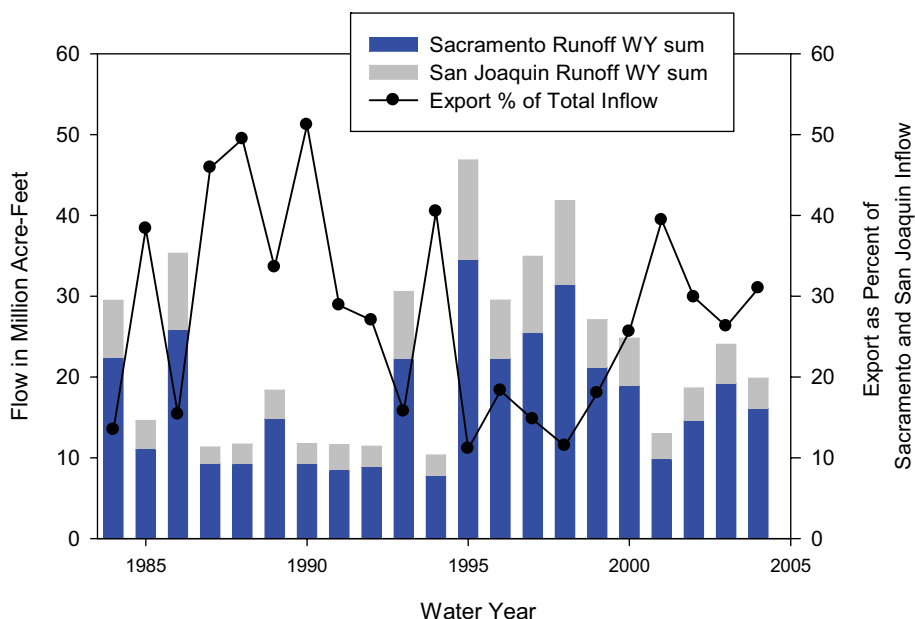


Figure 5-3. The sum of project diversions as a percentage of annual flows from the major tributaries (Sacramento and San Joaquin Rivers) to the Delta.

5.2 PATTERNS IN ORGANIC CARBON CONCENTRATIONS

This discussion of organic carbon concentrations is based on data collected by the MWQI Program. This program obtains grab sample data on TOC, DOC, and UVA₂₅₄ at 10 locations around the Delta. In previous years, MWQI also collected data from Delta agricultural drains. Dissolved and total organic carbon concentrations from all sources to the Delta are well correlated, with most of the organic carbon being in the dissolved form. This is true of both tributaries and agricultural drains on Delta islands (Figure 5-4). UVA₂₅₄ data, a general measure of organic carbon reactivity as discussed in Chapter 2, are also well correlated with DOC concentrations over the range of concentrations obtained in the tributaries and agricultural drains. However, this relationship is dominated by the agricultural drain data, especially at high concentrations. Over a narrower range of concentrations, more typical of what is seen in the Sacramento and San Joaquin Rivers, the relationship is far more noisy (Figure 5-5 upper and lower panels). These data are in agreement with past work (e.g., Fujii et al., 1998 and others discussed in Chapter 2) that suggests locations with varying sources of organic matter are more likely to have variable UVA responses than locations with a relatively homogeneous source of organic matter.

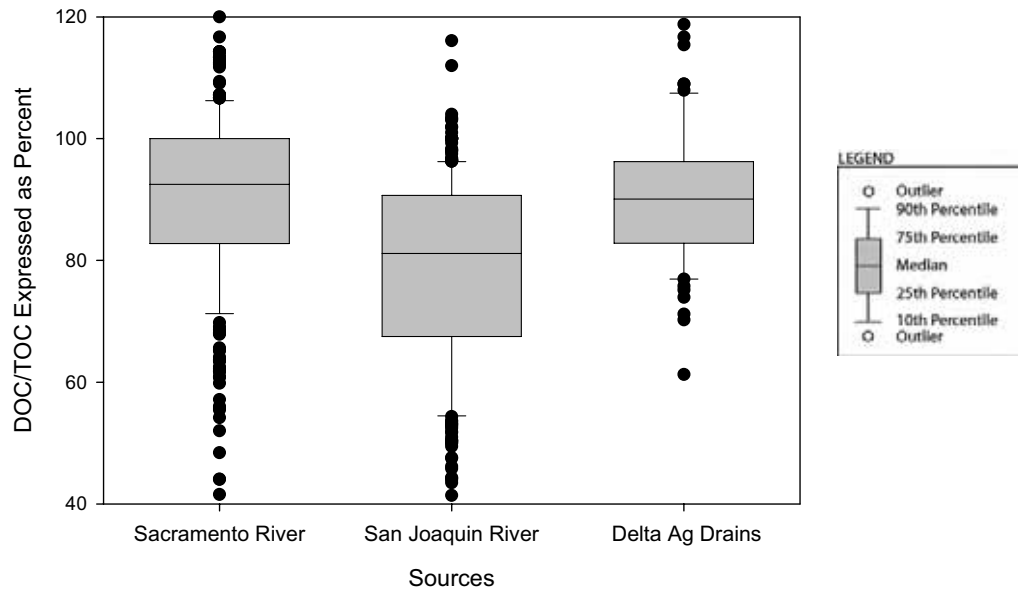


Figure 5-4. Relationship between dissolved and total organic carbon concentrations at key Delta locations.

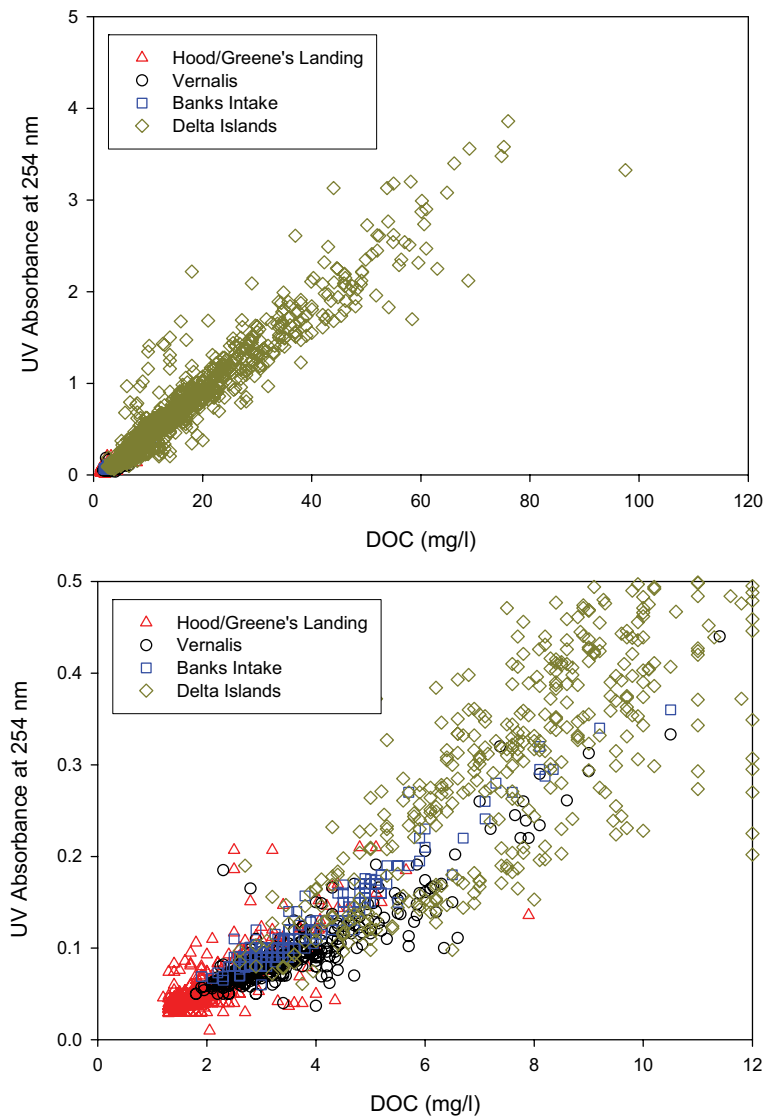


Figure 5-5. Dissolved organic carbon concentrations and UVA at 254 nm at key Delta locations.

The SUVA₂₅₄ values (where the UVA is normalized by the DOC concentration) for the Sacramento River at Hood are similar to the SUVA values for the San Joaquin River at Vernalis (Figure 5-6). This indicates, albeit at a gross level, little systematic difference in the DOC structure between the two sources. However, the values at the Banks Pumping Plant are somewhat higher, indicating a marginally more reactive source that is consistent with in-Delta supplies of more labile organic matter from primary production.

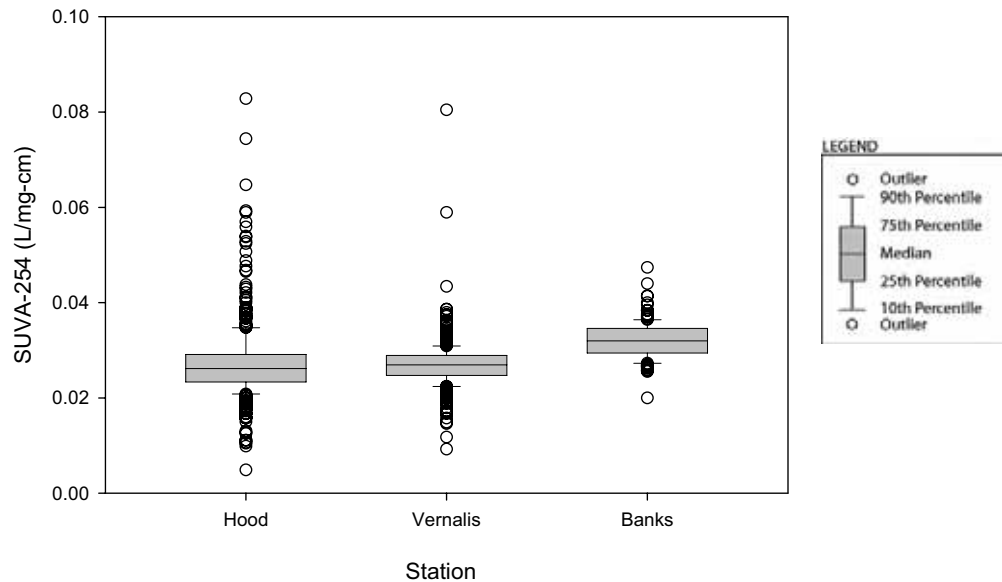


Figure 5-6. SUVA₂₅₄ values (UVA normalized by the concentration of organic carbon) at Sacramento River (Hood), San Joaquin River (Vernalis) and Banks Pumping Plant.

Some of the longest records of organic carbon concentrations exist at the Sacramento River at Greene's Landing/Hood, San Joaquin River at Vernalis, and the Banks Pumping Plant. The two river locations are important because they constitute the majority of the flow into the Delta, and the Banks Pumping Plant is the largest water diversion from the Delta. Figure 5-7 presents water column concentrations of DOC at these locations from 1990 to 2005. Several interesting observations result:

- Concentrations in the Sacramento River are almost always substantially lower than in the San Joaquin River.
- Concentrations in the Sacramento River rarely fall below 1.5 mg/l, and those in the San Joaquin River rarely fall below 2 mg/l.
- Concentrations at the Banks Pumping Plant are almost always higher than in the Sacramento River, and are usually similar to the concentrations in the San Joaquin River.

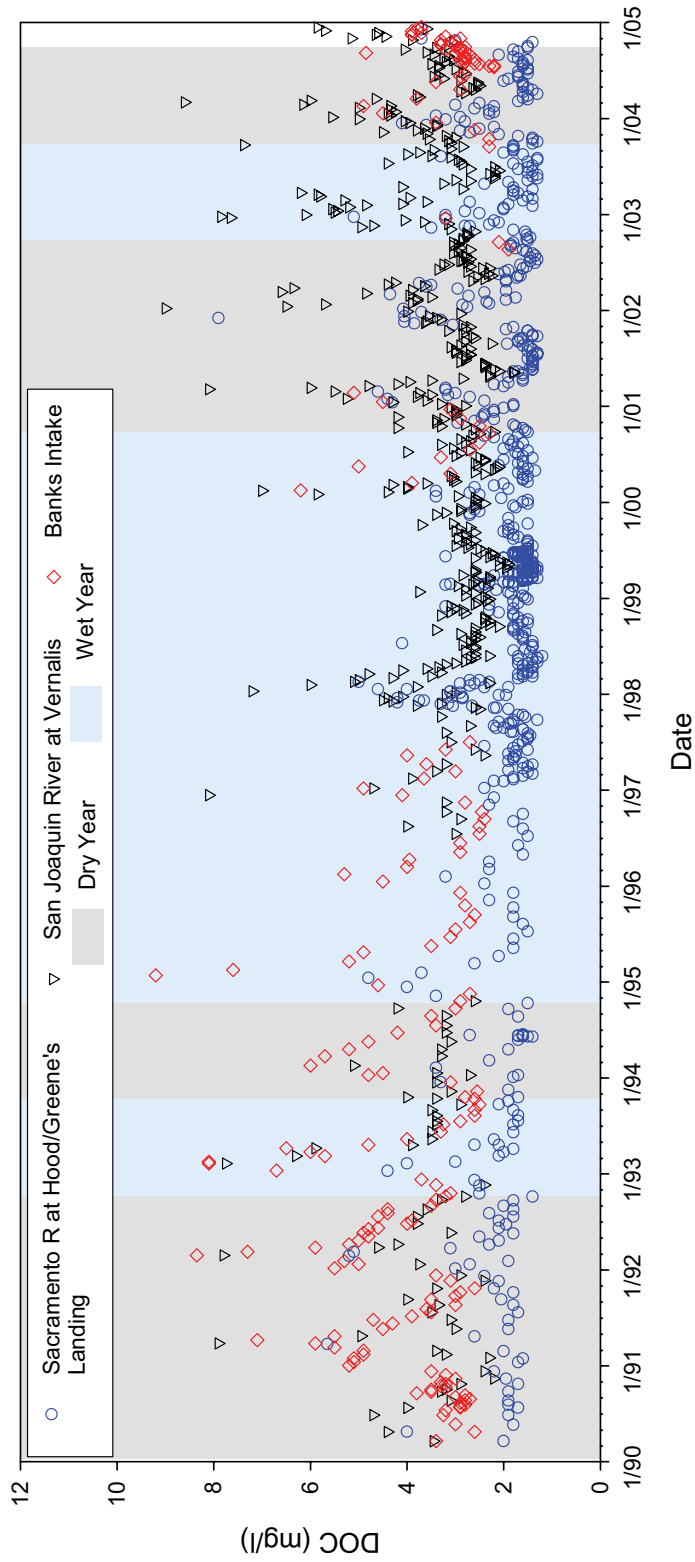


Figure 5-7. DOC concentrations at Sacramento River (Hood), San Joaquin River (Vernalis) and Banks Pumping Plant.

A further plot of DOC at the tributaries and DOC at Banks (Figure 5-8) shows a somewhat stronger correlation between San Joaquin and Banks concentrations than between Sacramento and Banks concentrations. However, the correlation coefficients in Figure 5-8 are not high enough to suggest that either of the tributary concentrations can adequately explain what is observed at the Banks intake. The higher coefficient for the San Joaquin flows, as compared to the Sacramento River flows, may in part be due to the proximity of the two locations and/or preferential flow paths. The occasional elevations of concentrations at the Banks Intake even above the San Joaquin River concentrations, are indicative of in-Delta sources, although the data in Figures 5-7 and 5-8 alone are insufficient to quantify their significance. The concentrations at the Banks Pumping Plant, and at other diversions in the Delta, are due to a complex mixture of the Sacramento River, the San Joaquin River, and in-Delta sources. The relative contribution of each of these sources is discussed in more detail in Section 5.5.2.

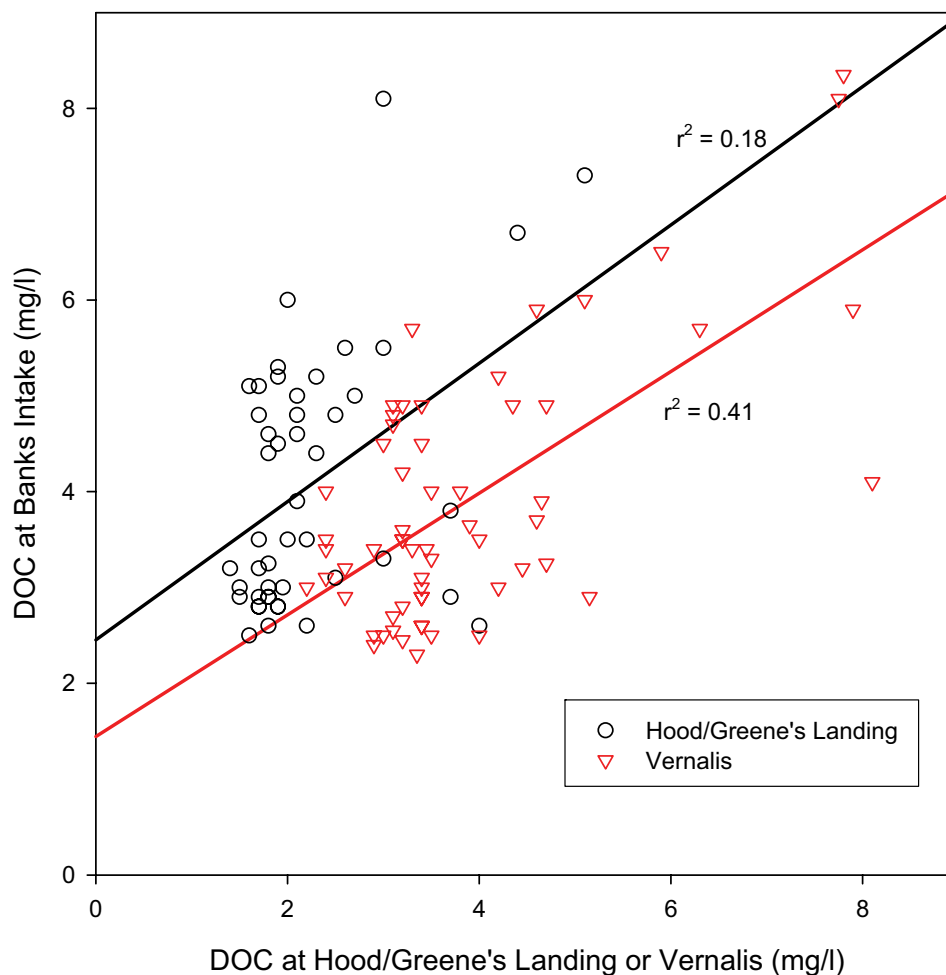


Figure 5-8. Correlation between DOC at the tributaries and DOC at Banks Pumping Plant.

Automatic organic carbon analyzers have recently been installed in the Sacramento River at Hood, the San Joaquin River at Vernalis, and at the Banks Pumping Plant. The analyzers measure TOC and DOC by a combustion method and the Hood location also has a wet-oxidation method analyzer. Real time data for Hood and Banks are plotted with grab sample monitoring data for comparison in Figure 5-9. In the future, the real time data will provide a more comprehensive understanding of organic carbon concentrations and will allow a more refined estimate of loads during the wet season when concentrations change rapidly. Another goal of real time monitoring is to inform water utility managers so they can adjust their operations to adapt to carbon fluctuations and spikes.

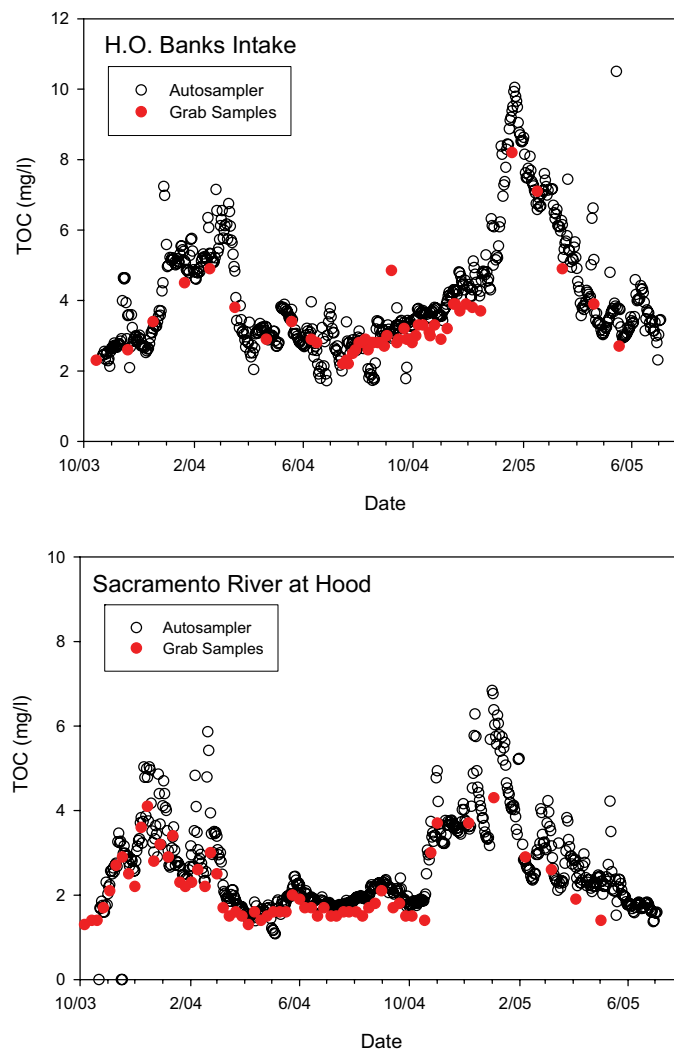


Figure 5-9. Real-time TOC data compared with grab sample data at Sacramento River (Hood) and Banks Pumping Plant.

5.3 ORGANIC CARBON LOADS

To account for the various inflows and outflows of organic carbon in the Delta, the inputs from tributary and in-Delta sources and the exports to San Francisco Bay and water supply diversions were quantified. The tributary inputs and the exports to the Bay were estimated in Chapter 4. This chapter describes the approach used to estimate organic carbon exported in water supply diversions and in loads generated within the Delta.

5.3.1 EXPORT IN WATER SUPPLY DIVERSIONS

Organic carbon concentration data from four of the water supply diversions in the Delta (expressed as TOC in three out of four cases), are paired with flow rates to estimate the exported organic carbon loads. Loads are calculated in the same manner as described in Chapter 4 for the stream loads, using monthly average concentration and flow data. The monthly average organic carbon concentrations for the water supply diversions, along with the data count, are shown in Figure 5-10. These concentrations were used to estimate monthly loads of organic carbon using DAYFLOW flow data. The annual organic carbon exports over the water years 1984-2004 are shown in Figure 5-11. Because the flow volumes in the exports are relatively uniform, the estimated annual loads vary over a fairly narrow range, 20,000 to 35,000 tons/year.

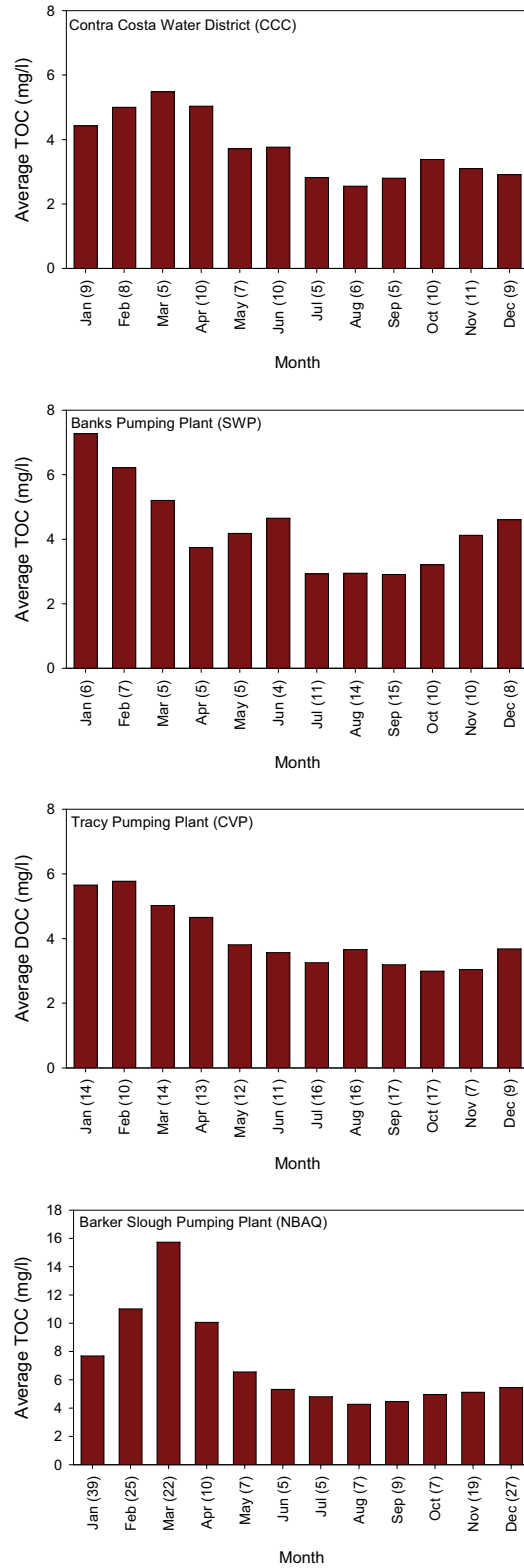


Figure 5-10. Organic carbon concentrations at water supply diversions. The number of data points is shown after each month.

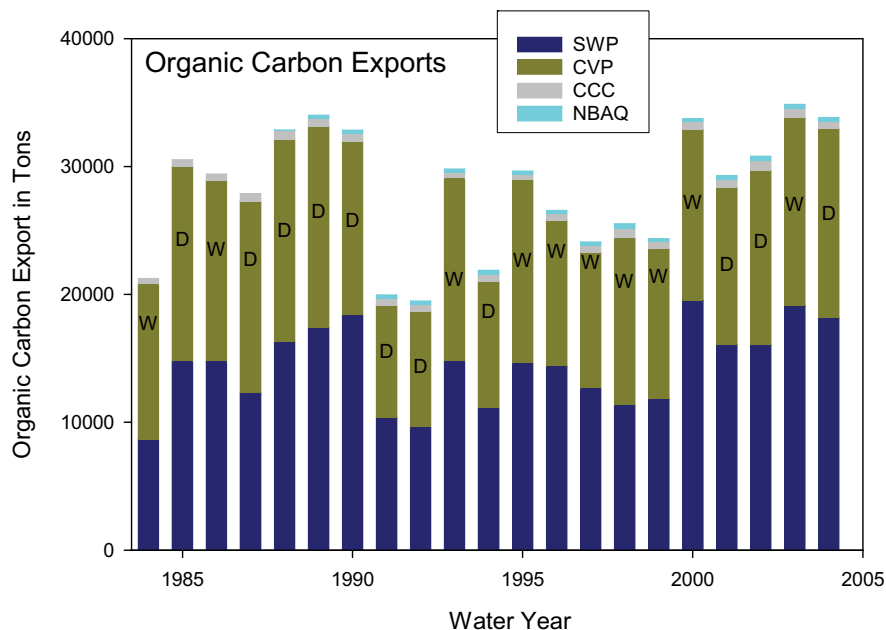


Figure 5-11. Annual organic carbon exports over the water years 1984-2004.

5.3.2 ORGANIC CARBON SOURCES IN THE DELTA

The Delta contains three major known sources of organic carbon: primary production in the water column, export from agriculture on Delta Islands, and export from tidal marshes. In addition, urban areas are rapidly developing along the fringes of the Delta. At this time there are insufficient data to characterize the load of organic carbon from urban runoff and wastewater discharged into Delta channels.

Primary productivity in the Delta was estimated using direct measurements of productivity on a small number of dates (Jassby et al. 2002). The direct measurements of primary productivity were related to a model of productivity that was a function of water turbidity and solar radiation. A long-term record of radiation and light attenuation was used to estimate an average primary production of 70 g C/m²/yr. With a Delta water area of 24,000 acres this translates to roughly 7,000 tons/year of carbon due to internal primary productivity in the waters of the Delta. While this estimate is useful for comparison with other sources of organic carbon in the system, there was also a significant year-to-year variation in primary productivity reported, with the highest estimate five times the lowest estimate. In addition there is a generally declining trend in primary productivity in the Delta. There are several hypotheses for this inter-annual variability and long-term decline. Changes in water residence time due to variability in the flows of the Sacramento and San Joaquin Rivers, changes in populations of primary consumers (such as the exotic clam, *Potamocorbula amurensis* after 1987 as well as other filter feeding primary consumers), and reductions of suspended solids concentrations due to dam construction may all be factors affecting productivity.

Tidal marsh organic carbon export rates have not been estimated directly in the Delta. Based on a review of the literature, Jassby and Cloern (2000) estimated an export rate of 150 g C/m²/yr (150 tons C/km²/yr), a value far greater than the export rates of any of the land uses considered in Chapter 4. USGS is conducting a study on Twitchell Island in the Delta and has estimated an export rate of 110 gC/m²/yr (Personal Communication, Roger Fujii). Using the literature values and assuming a marsh area of 8150 acres (Jassby and Cloern,2000), this translates to 4950 tons of organic carbon released from the Delta tidal marshes to the surrounding waters. Additional research is needed on Delta tidal marshes to better quantify these export rates.

Contributions from Delta agriculture were estimated using agricultural drain concentration data and total flow approximations from the Delta Island Consumptive Use (DICU) computer model. There are substantial DOC data from Delta agricultural drains collected by MWQI, as shown in Figure 5-12. There are less TOC data on Delta agricultural drains so DOC was used to approximate TOC loads. In general, MWQI data show that DOC represents approximately 90 percent of TOC. The Delta agricultural drainage concentrations are substantially higher than the agricultural drainage concentrations from the Sacramento River watershed (Colusa Basin Drain) and the San Joaquin River watershed (Harding Drain) discussed in Chapter 4. As shown in Figure 5-13, the highest concentrations occur during the wet months.

The DICU model was developed to estimate the diversions and return flows of Delta waters into agricultural land on Delta islands. The model is calibrated from a detailed hydrologic study on Twitchell Island conducted in 1960. DICU estimates of flow for each month were coupled with mean monthly DOC concentration data observed at all island drains from Figure 5-12, to estimate the load of organic carbon from Delta agricultural drainage. The average annual load is estimated to be 14,800 tons/year. As shown in Figure 5-14, the highest concentrations of DOC occur in the wet winter months (January through March) which correspond with a peak in calculated discharge from the islands. Flows are also elevated in June through July, although these are associated with lower concentrations. Existing information does not allow consideration of year-to-year variability.

It is important to note that aqueous export of organic carbon from Delta islands constitutes less than 1% of the carbon loss from these islands, with much of the rest being exported as gaseous carbon dioxide (Deverel and Rojstaczer, 1996).

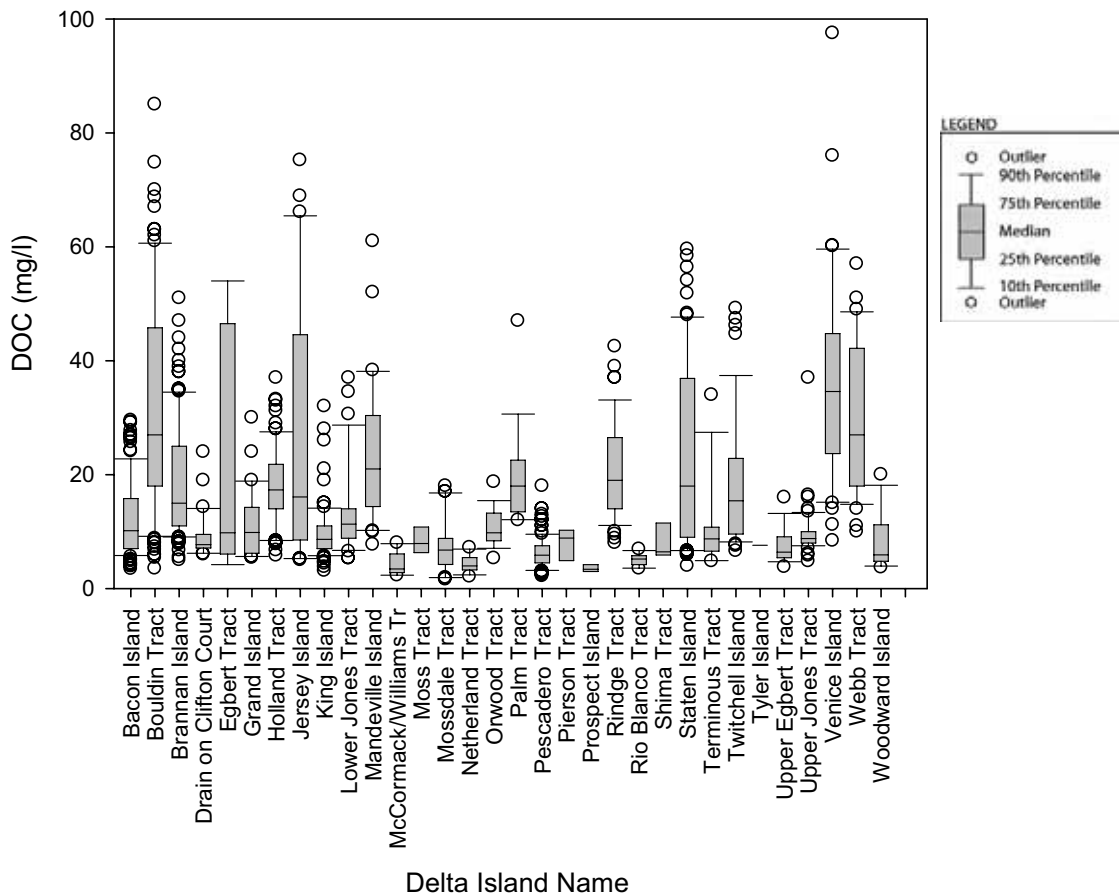


Figure 5-12. DOC concentrations in Delta agricultural drainage.

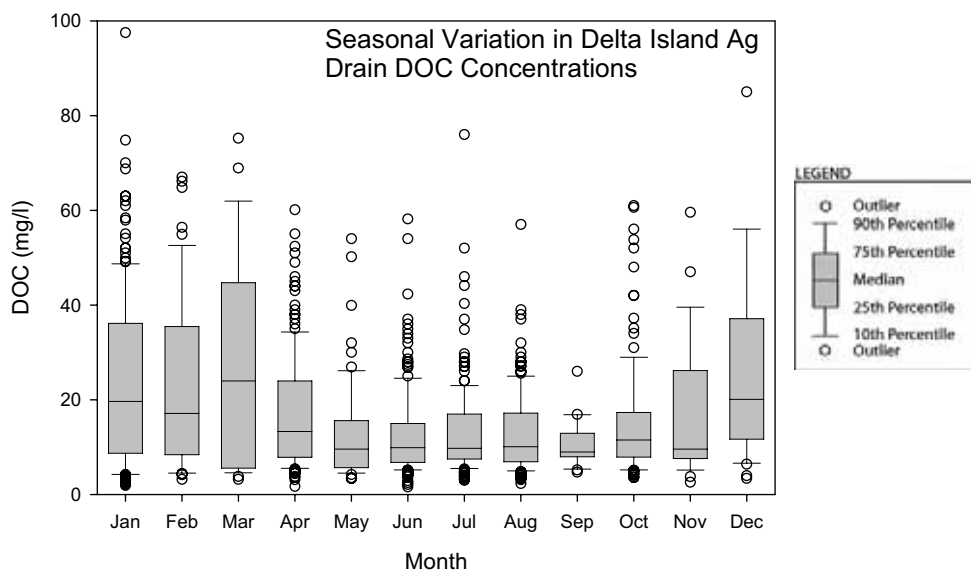


Figure 5-13. Seasonal variation in Delta agricultural drainage DOC concentrations.

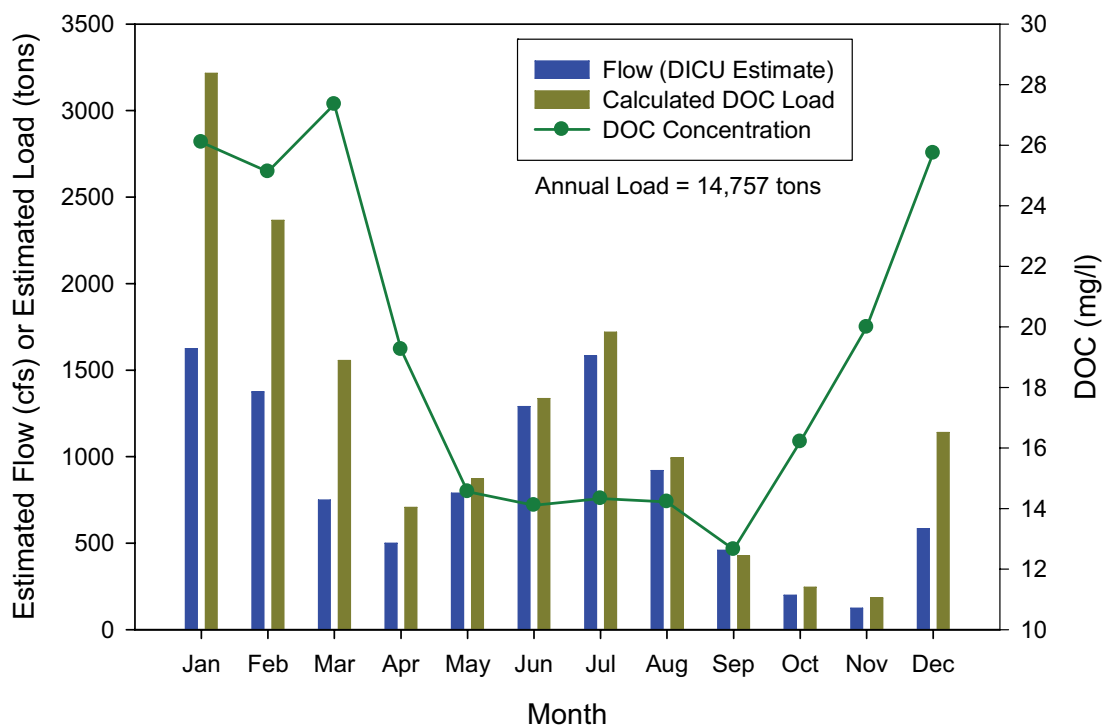


Figure 5-14. DICU estimates of flow for each month coupled with mean monthly concentration data observed at all island drains from Figure 5-13, used to estimate the contribution of DOC from agriculture on Delta islands.

5.3.3 SUMMARY OF ORGANIC CARBON LOADS IN THE DELTA

Figure 5-15 presents annual averages of the tributary loads estimated in Chapter 4 and the in-Delta loads estimated in this chapter, illustrating that the tributary loads are substantially greater than the in-Delta loads during wet years. In wet years the in-Delta sources contribute approximately 15% of the total load. Year to year variations may be significant, and in dry years when the tributary loads are smaller, the in-Delta loads are approximately 33% of the total load. The in-Delta loads are based on far less data than the tributary loads and additional monitoring is needed to provide a better estimate of in-Delta loads, particularly the loads due to primary productivity and tidal marshes.

Figure 5-15 shows that during wet years the load of organic carbon to the Delta (tributaries and in-Delta sources) exceeds the exports from the Delta (to the Bay and the water diversions) by 50,000 tons. During dry years this drops to 28,000 tons. These are not precise numbers due to the uncertainty in the load estimates, particularly for the in-Delta sources; however, some of this carbon is available as a food source for Delta organisms. Current work on ecosystem processes shows that although the tributary loads of organic carbon are much greater than the in-Delta primary production, it is the latter that is more bioavailable and a more important food source to the biota in the Delta.

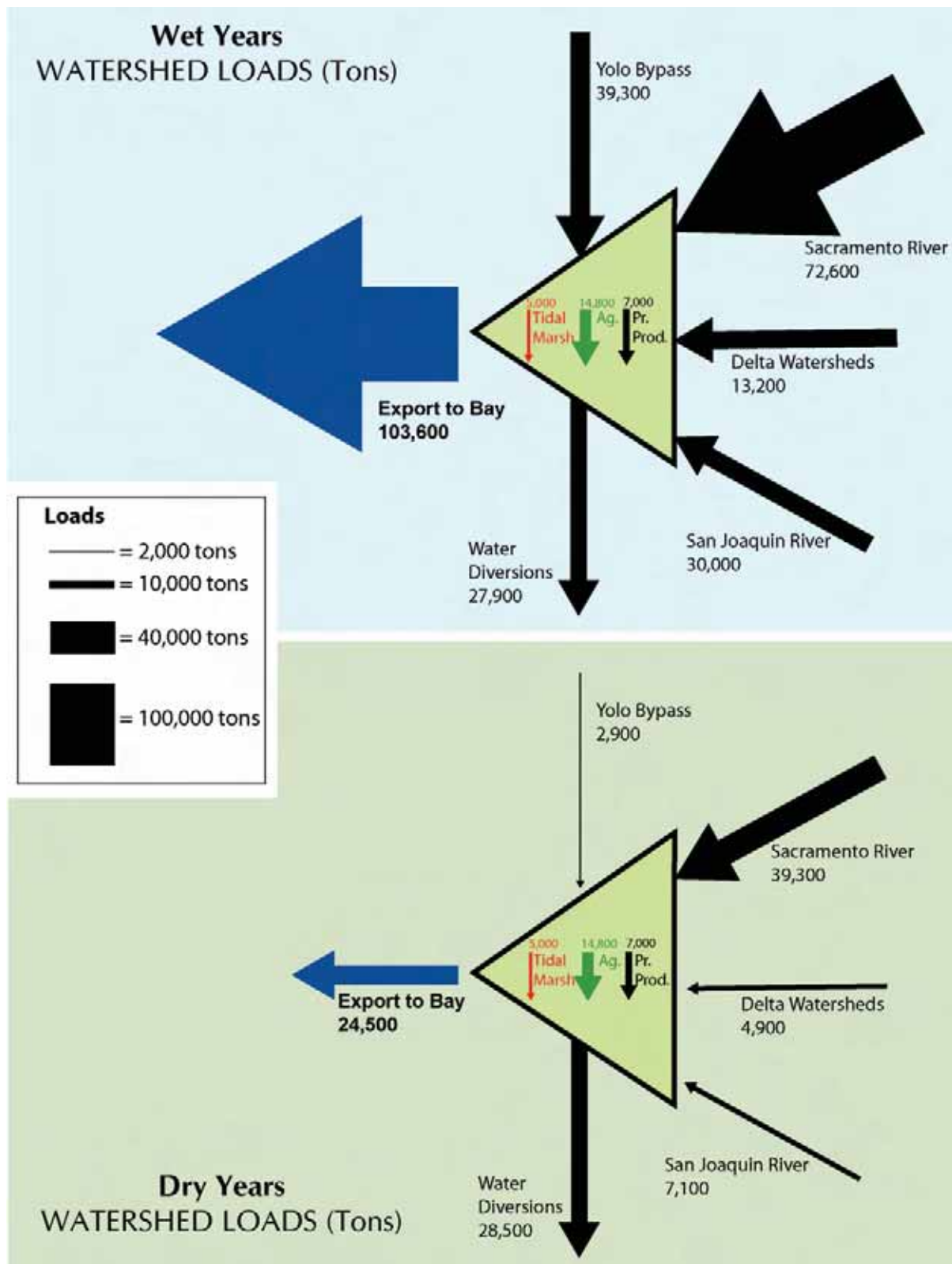


Figure 5-15. The tributary loads calculated in Chapter 4, along with the internal loads estimated in Chapter 5.

5.4 RELATING ORGANIC CARBON SOURCES AND CONCENTRATIONS AT INTAKES

Estimates of organic carbon loads provide information on the major sources of organic carbon in the watersheds. The concentration of organic carbon in the source waters and the quality of the organic carbon are also of interest. This interest is driven by both regulatory requirements that base drinking water treatment on the concentration of organic carbon in the source water and on the goal of water suppliers to protect source water quality. To evaluate source water improvement strategies in a system as complicated as the Delta, the sources that are contributing to elevated organic carbon concentrations at the intakes must be identified.

Detailed studies of organic carbon chemistry at various locations (reviewed in Chapter 2) and monitoring of various potential sources assist in identifying and characterizing the quantity and quality of organic carbon sources. Some studies “fingerprint” sources based on organic carbon chemistry and use this fingerprint to trace them to drinking water intakes. Another method of fingerprinting is the use of numerical hydrodynamic models. The two parallel lines of investigation provide an independent verification of key findings, and over time, may lead to a comprehensive understanding of organic carbon processes in the Delta.

The Delta Simulation Model, Version II, or DSM2, is a river, estuary, and land modeling framework that represents hydrodynamics and water quality processes throughout the Delta. DSM2 consists of two separate modules for hydrodynamics and water quality, DSM2-Hydro and DSM2-Qual. Calculations are performed using hydrology for a base period from 1976 to 1991, which contains a mix of wet and dry years. Using flow results from DSM2-Hydro, DOC concentrations at the Delta boundaries, and DOC concentrations in agricultural drainage, DSM2 computes DOC at various locations throughout the Delta.

DSM2 has also been used to investigate the contribution of flow and DOC by source at the Banks intake. Figure 5-16 presents the percent contribution of water at the Banks Pumping Plant from the Sacramento and San Joaquin rivers and other sources from 1990 to 2004. This figure illustrates that in dry years the majority of water at the Banks Pumping Plant comes from the Sacramento River. During wet years, the San Joaquin River contributes the majority of water for many months of the year. Long term fingerprints of organic carbon have not yet been completed.

Figures 5-17 and 5-18 illustrate the percentage contribution of flow and the contribution of DOC concentration by source at the Banks Pumping Plant, respectively, for the period July 2005 to January 2006. Beginning in August, Sacramento River flows dominate all other flows, while by January, San Joaquin River flows begin to dominate at the intake (Figure 5-17). Similarly for concentration, by August the Sacramento River contribution to DOC concentration has become larger than the San Joaquin River contribution. In January, the San Joaquin River contribution to DOC concentration dominates all other contributions to the concentration at Banks (Figure 5-18). This type of analysis can be used to identify the major sources of organic carbon at the Delta pumping plants. This

information, combined with information on the periods of time when organic carbon concentrations at the pumping plants are problematic for drinking water suppliers, can be used to identify management actions that could potentially improve water quality.

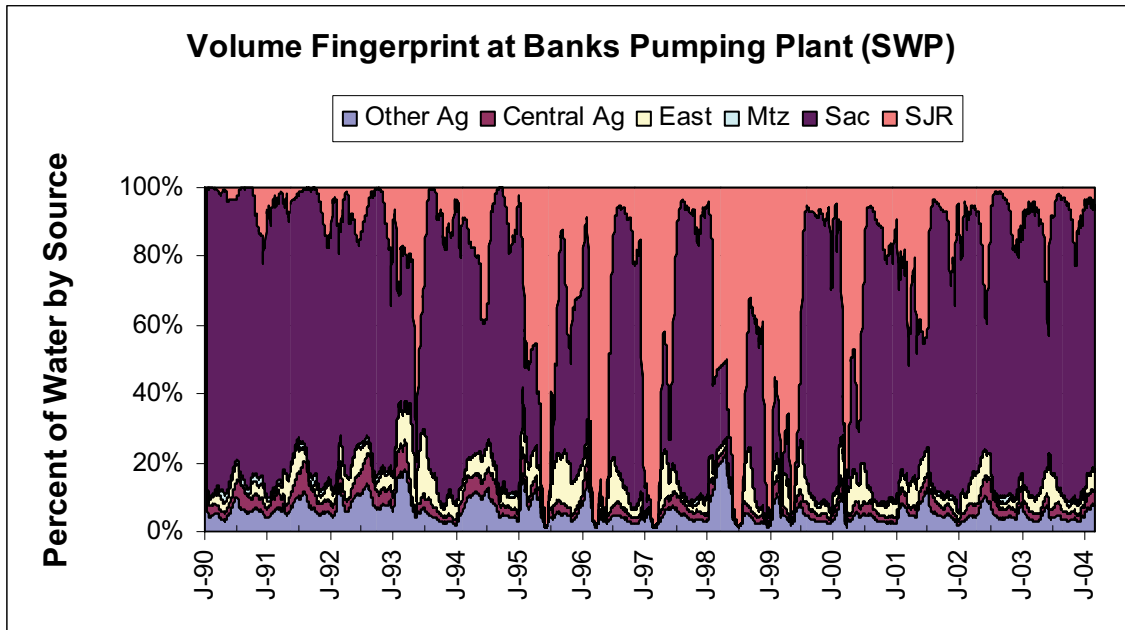


Figure 5-16. Long-term percentage contribution of flows at the Banks Pumping Plant (data provided by DWR).

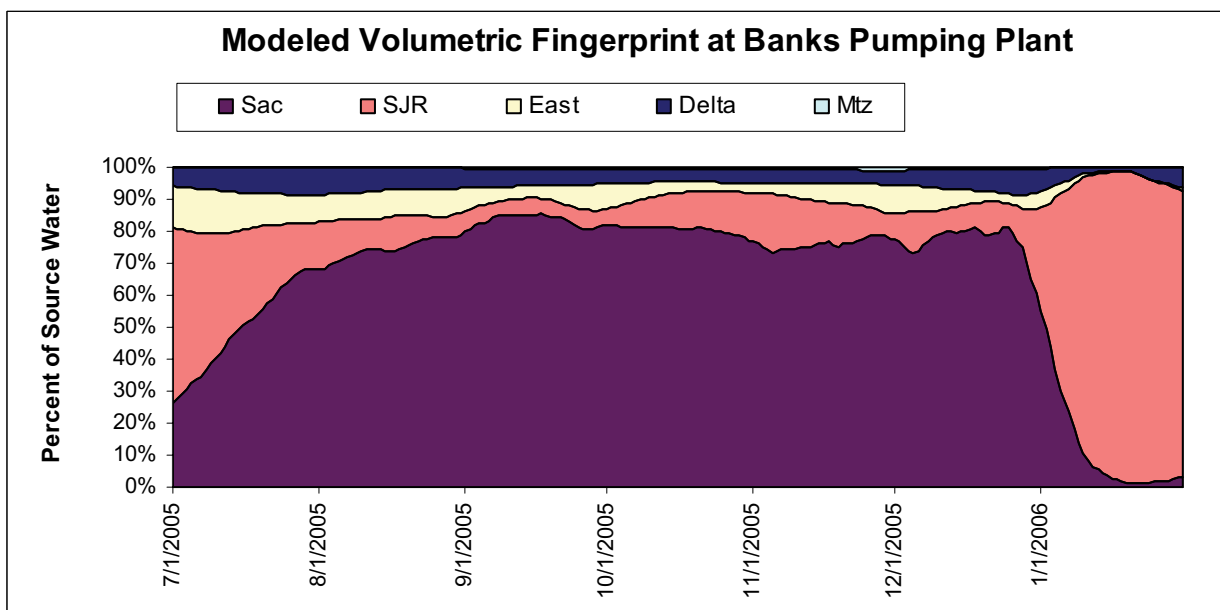


Figure 5-17. Percentage contribution of flows at the Banks Pumping Plant (data provided by DWR).

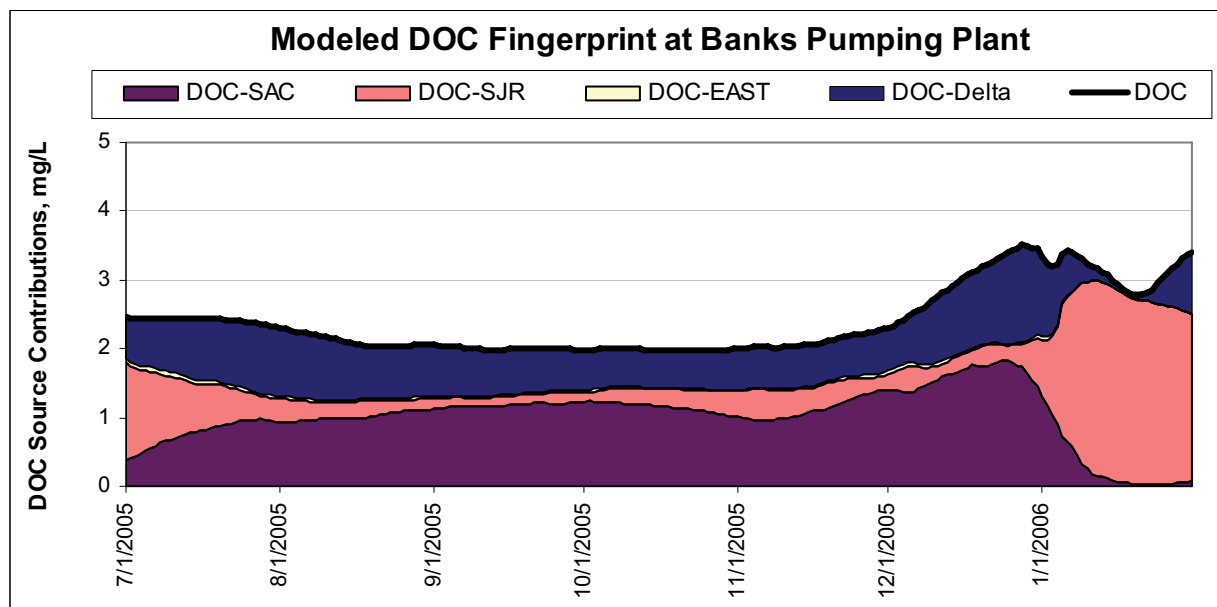


Figure 5-18. Contribution of DOC by source at the Banks Pumping Plant (data provided by DWR).

The contribution of Delta islands to the DOC concentrations at various locations in the Delta has been explored through DSM2 (DiGiorgio, 2003). Calculations were performed for the base case, i.e., the islands exported organic carbon at their current rates, and a hypothetical case where the islands contributed no organic carbon to the Delta. It was found that setting Delta islands' loads to zero led to a significant decrease in concentrations especially in summer and fall months. At the Banks intake for example (Figure 5-19), decreases of nearly 50% from the base case average concentration were calculated in dry years, resulting in DOC concentrations of 3 mg/L or less in all months. Wet year concentration decreases were also significant, albeit smaller (maximum of 35%). During wet years DOC concentrations were reduced by 1 to 1.5 mg/L.

The role of in-Delta sources, including Delta islands, has been identified as a significant source in past work using organic carbon chemistry (Bergamaschi et al., 1999). These modeling and analytical findings, and their general agreement, are significant and provide information on the major sources of organic carbon at times when concentrations are problematic for water suppliers.

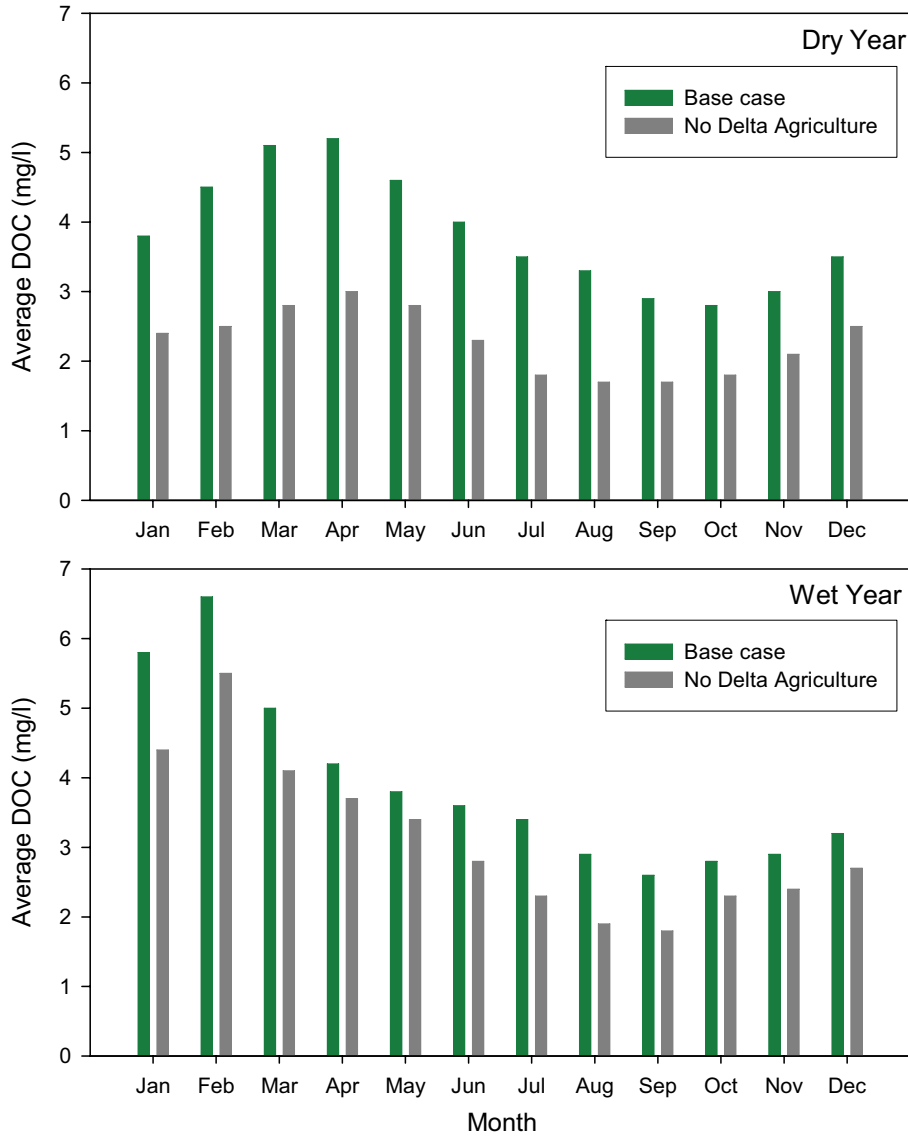


Figure 5-19. Banks intake DOC concentrations for wet and dry years for base case conditions and for a hypothetical case of no Delta Island drain contribution. Based on data from DiGiorgio (2003).

5.5 MAJOR FINDINGS

The estimates of in-Delta loads of organic carbon are based on limited data and are fairly uncertain. In-Delta primary productivity estimates are based on one study whose results were extrapolated both spatially and temporally to calculate organic carbon loads from this source. Estimates of organic carbon loads from tidal marshes were based on data from the literature because studies in the Delta have not been completed. The concentrations of organic carbon in Delta agricultural drains has been well characterized by the MWQI Program but there have been no recent direct measurements of flow for most of the Delta islands. Flow is currently estimated by

the DICU model. Additional monitoring and focused studies are needed to improve the in-Delta load estimates.

The tributary loads of organic carbon are substantially greater than the in-Delta loads during wet years. In wet years the in-Delta sources contribute approximately 15% of the total load. Year to year variations may be significant, and in dry years when the tributary loads are smaller, the in-Delta loads are approximately 33% of the total load.

The contribution of various sources to organic carbon concentrations at the intakes is best estimated through a numerical hydrodynamic model developed by DWR (DSM2). A fingerprinting study for 1990 to 2004 shows that the Sacramento River is the predominant source of water at the Banks Pumping Plant during dry years and that during wet years the San Joaquin River contributes a substantial amount of water. Fingerprinting studies on organic carbon have been completed for recent periods. These studies, combined with information on the periods of time when organic carbon concentrations at the pumping plants are problematic for drinking water suppliers, can be used to identify management actions that could potentially improve water quality.

One study examined the impact of removing all Delta agricultural drainage from the Delta. Although this is a hypothetical scenario because it would be impossible to remove all of the drainage, it points out the important contribution agricultural drainage makes to DOC concentrations at the Banks Pumping Plant. In addition, it demonstrates the ability of the models to assist in analyzing actions that could potentially improve water quality at the Delta pumping plants.