CHAPTER 4.0
LOADS TRANSPORTED FROM SACRAMENTO AND SAN JOAQUIN RIVER BASINS

Estimation of transported loads of organic carbon within the Central Valley provides a preliminary understanding of the major tributary sources during different seasons and during wet and dry years. The tributary sources mix with other Delta sources, and undergo various transformation reactions that are reflected in the observed concentrations at Delta drinking water intakes. The information on tributary organic carbon concentrations and loads, combined with Delta models relating the tributary sources to the drinking water intakes, can be used to evaluate options for improving organic carbon concentrations at the Delta intakes. Information on tributary organic carbon loads at various locations in the Sacramento and San Joaquin basins can be used to evaluate options for improving organic carbon concentrations at water intakes upstream of the Delta. This chapter presents the results of calculations to estimate loads at various locations in the Central Valley, using total organic carbon or dissolved organic carbon concentration data summarized in Chapter 3, and using flow data from USGS stations near the concentration monitoring stations.

Evaluation of load at a point in a stream involves estimation of loads transported in-stream and also involves estimation of the watershed contributions. The basic approach to calculating loads at a point in a stream is simple: daily flow multiplied by concentration can provide an estimate of daily flux, which summed over a year or a season, provides an estimate of the transported load. In general, flow data are available in much greater abundance than chemical concentration data, and the commonly used approach is to estimate concentrations for the days during which there are no measured concentration values. This is commonly done by developing a correlation between flows and concentrations and sometimes including variables for time (e.g., Crawford, 1991; Cohn et al., 1992; Haggard et al., 2003; Saleh et al.,

2003). This approach could not be used for this study because, based on available data, there were no statistically significant relationships between organic carbon concentration and flow at any of the locations monitored in the watersheds. The Central Valley and Delta system is a highly managed system with flows controlled by major reservoirs on most rivers.

The method used for this study was to multiply average monthly concentration data by average monthly flows to obtain monthly loads, which were then summed to obtain either seasonal or annual loads. As described later in this chapter, the amount of concentration data varied from location to location, so the confidence in the load estimates also varies.

The watershed corresponding to any location in a stream is typically comprised of many different land uses (e.g., forested land, urban land, cropland, etc.) and a common approach to estimate the watershed load is to attribute a chemical export rate (measured in units of mass per unit area per unit time) for each type of land use (Boyer et al., 2000; Wetzel, 2001). The total load contribution from the watershed can be estimated as the contribution of the individual land uses weighted by their export rates. This general approach has been employed to develop a summary picture of organic carbon loads in the Central Valley. As discussed later in this chapter, there were limited data on the export rates from different land uses so these load estimates are considered preliminary in nature.

The following sections describe the division of the Central Valley into a set of smaller subwatersheds, a summary of water flows corresponding to this division, the estimation of transported loads in streams at key locations throughout the Central Valley, estimation of export rates from key land uses, and the comparison of watershed loads with stream transported loads.

4.1   SUBWATERSHEDS

The Central Valley was divided into 22 subwatersheds to represent the major tributaries and the major reaches of the Sacramento and San Joaquin Rivers (Figure 4-1). The subwatersheds were delineated based on the availability of flow and concentration data as well as natural watershed boundaries. The outflow points of these subwatersheds were used to compute loads. The division of the 43,300 square mile Central Valley region into these subwatersheds allows for an improved spatial resolution of the sources of loads over a scenario in which the Sacramento and San Joaquin Rivers were treated as single watersheds. Although a finer resolution is possible, i.e., by consideration of still smaller tributaries and smaller subwatersheds, the existing division shown in Figure 4-1 was considered appropriate for a conceptual model, and was the smallest scale supported by available data. The watershed delineations shown in Figure 4-1 were performed using Geographic Information System (GIS) software (ArcGiS 8, ESRI, Redlands, California).
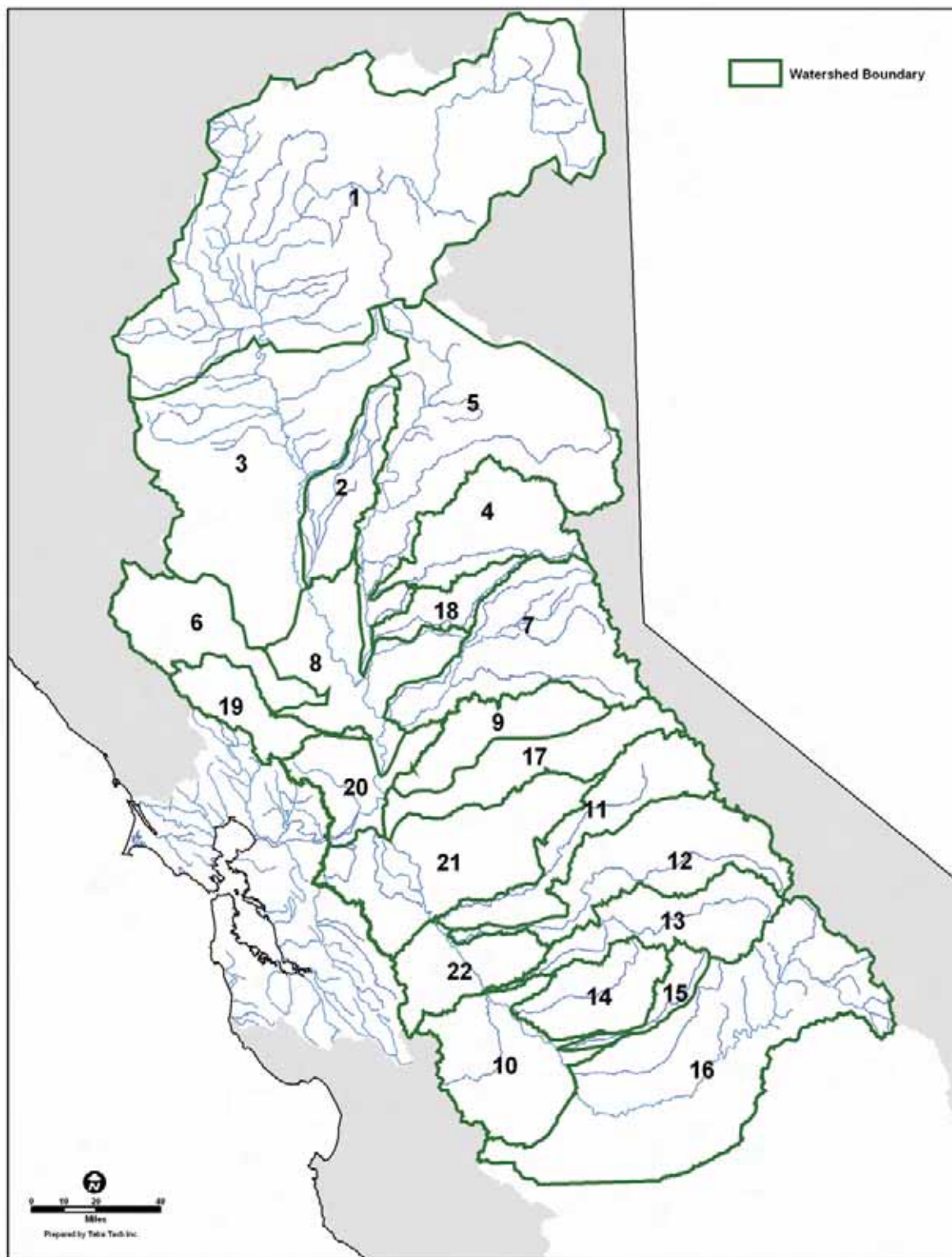
Figure 4-1. Sub-watersheds associated with principal tributaries

Another approach to the watershed delineation would be to consider only the portion of the Central Valley below the reservoirs, and consider the reservoirs as defining the boundary of the region of interest. This approach has the benefit of implicitly defining reservoir loads as a background source, with other added downstream loads being considered anthropogenic. However, because there are limited data on the concentrations of organic carbon released from the reservoirs, this approach was not used in this study. The discussion of loads that follows in this chapter is thus based on the watersheds in Figure 4-1, although future refinements of this conceptual model could consider the reservoirs to be upstream boundaries to the system.

The land use corresponding to each subwatershed was estimated using a detailed GIS-based land use map of California (obtained from http://gis.ca.gov/). The land use map was developed by the California Department of Forestry and Fire Protection (CDF-FRAP) by compiling the best available land cover data into a single data layer. Typically the most current and detailed data were collected for various regions of the state or for unique mapping efforts (farmland, wetlands, riparian vegetation). A view of the land uses in the Central Valley is shown in Figure 4-2. The percent of each subwatershed area by land use is summarized in Table 4-1.

Figure 4-3 illustrates a schematic of the Central Valley watershed showing average TOC concentrations (or DOC concentrations where TOC is not available) whose magnitude is indicated by arrow size. As discussed earlier in Chapter 3, the figure illustrates that organic carbon concentrations are higher in the San Joaquin River Basin than in the Sacramento River Basin.
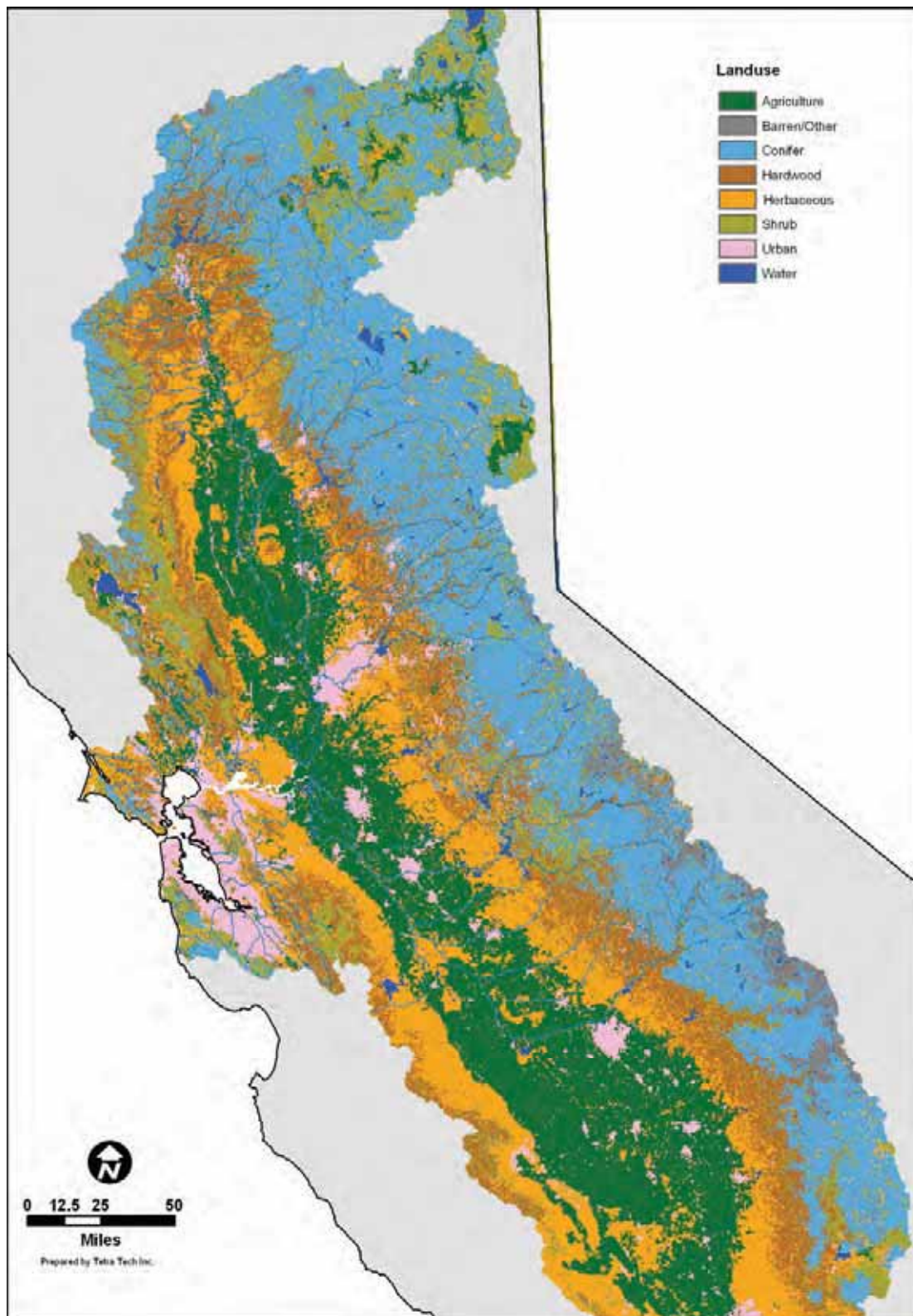
Figure 4-2.   Land use in the Central Valley. Data obtained from obtained from http://gis.ca.gov/.

Table 4-1.

Percentage of land use in different categories for each subwatershed. Land use data of California obtained from http://gis.ca.gov/.

ID[1]	Watershed Name	Shrub	Agriculture	Herbaceous	Hardwood	Barren	Conifer	Water	Urban
1	Sacramento River above Bend Bridge	22.4%	4.0%	4.8%	15.4%	1.1%	49.8%	1.5%	1.0%
2	Butte Creek	3.2%	41.1%	16.4%	12.3%	0.2%	21.7%	1.6%	3.5%
3	Sacramento River at Colusa	12.4%	23.1%	28.0%	19.2%	0.5%	14.2%	0.9%	1.7%
4	Yuba River	5.7%	1.3%	3.4%	16.1%	3.4%	67.1%	1.8%	1.2%
5	Feather River	9.8%	9.1%	6.3%	7.8%	0.6%	61.9%	2.8%	1.7%
6	Cache Creek	35.0%	11.4%	10.3%	24.1%	0.4%	10.5%	6.0%	2.3%
7	American River	8.3%	0.8%	5.7%	15.1%	3.1%	54.4%	2.0%	10.6%
8	Sacramento River at Hood/Greene's Landing	0.7%	63.7%	17.5%	8.1%	0.0%	0.2%	1.1%	8.7%
9	Cosumnes River	4.0%	12.0%	29.5%	22.0%	0.1%	28.8%	0.5%	3.0%
10	San Joaquin River at Newman	1.6%	44.1%	42.6%	7.8%	0.0%	0.0%	2.3%	1.7%
11	Stanislaus River	8.6%	11.9%	14.5%	11.1%	6.7%	41.1%	2.4%	3.5%
12	Tuolumne River	10.3%	3.8%	11.5%	13.2%	10.2%	46.7%	2.5%	1.8%
13	Merced River	14.7%	6.7%	11.6%	15.2%	5.8%	44.6%	1.1%	0.4%
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	3.9%	31.5%	43.7%	16.5%	0.0%	0.5%	0.3%	3.7%
15	Chowchilla River	6.9%	16.6%	22.9%	42.7%	0.0%	9.6%	0.3%	1.0%
16	San Joaquin River at Sack Dam	2.9%	35.1%	17.9%	10.5%	6.2%	22.0%	1.2%	4.2%
17	Mokelumne River	5.9%	16.0%	15.3%	16.3%	3.5%	38.7%	2.2%	2.1%
18	Bear River	1.8%	13.6%	18.6%	33.0%	0.6%	26.1%	1.3%	4.9%
19	Putah Creek	30.0%	9.6%	13.2%	31.9%	0.2%	7.9%	5.1%	2.0%
20	Delta North	1.0%	58.0%	28.3%	2.2%	0.1%	0.0%	2.1%	8.3%
21	Delta South	3.9%	40.0%	29.6%	10.6%	0.1%	6.5%	1.9%	7.4%
22	San Joaquin River at Vernalis	9.6%	51.9%	21.9%	11.9%	0.0%	0.0%	0.1%	4.6%

[1] Refer to Figure 4-1 for the location of subwatersheds.

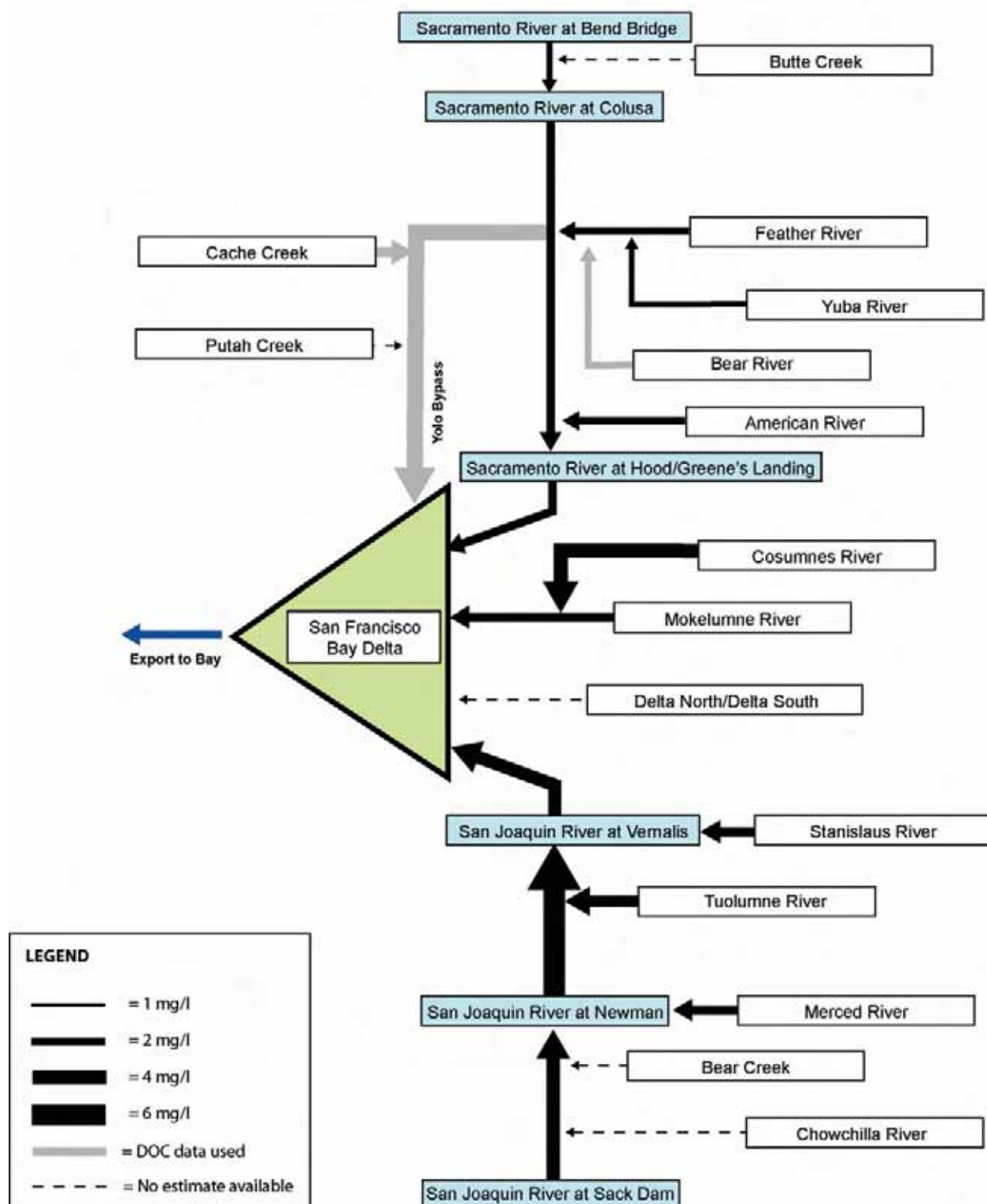# Average Organic Carbon Concentrations

Figure 4-3.   Average organic carbon concentrations in the sub-watersheds (TOC unless noted).

4.2   WATER FLOWS IN THE CENTRAL VALLEY

Because loads in streams are a product of flow and concentration, and flows can vary in a given stream by orders of magnitude during different seasons of the year, estimated loads are a strong function of flow. As a first step in the evaluation of organic carbon loads, daily flow values were obtained from nearby USGS stations at locations corresponding to the subwatersheds identified in Figure 4-1. Table 4-2 shows the USGS stations (names and IDs) that correspond with the stations in the database developed for this project. Annual and seasonal flows were calculated using these data. In several subwatersheds, there are no flow and/or concentration data. In these cases, organic carbon loads were estimated using watershed export rates described below.

Detailed descriptions of the flows at all locations that were used for this work are provided in Appendix B. This includes classification of years as wet or dry, and plots of flows in the wet and dry seasons of wet and dry years. Water years classified by the California Department of Water Resources as below normal, dry, or critical, are termed dry, and water years termed above normal or wet are termed wet. The wet season is defined as October 1 to April 30 and the dry season is defined as May 1 to September 30. Summary information on flows is provided graphically on a schematic of the Central Valley watershed. Flows in the dry and wet season of a typical dry year (2002) are shown in Figure 4-4, and flows in the dry and wet season of a wet year (2003) are shown in Figure 4-5. Both figures use the same linear scale to represent flows and can be used to compare values across seasons and years. The Sacramento River flows are substantially higher than the San Joaquin River flows, with wet season flows exceeding dry season flows.

Table 4-2.

Subdivision of watersheds in the Central Valley, nearby stations with concentration data in the Central Valley Drinking Water Policy Workgroup database, and USGS stations with continuous flow data

ID	Watershed Name	Area (km²)	Area (mi²)	Station Name in Drinking Water Database	Nearest USGS Gauge Station[1]	Name of USGS Gage Station
1	Sacramento River above Bend Bridge	23,145	8,934	Sacramento River above Bend Bridge	11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA
2	Butte Creek	2,402	927	--	11390000	BUTTE C NR CHICO CA
3	Sacramento River at Colusa	11,261	4,347	Sacramento River at Colusa	11389500	SACRAMENTO R A COLUSA CA
4	Yuba River	3,502	1,352	Yuba River at Marysville	11421000	YUBA R NR MARYSVILLE CA
5	Feather River[2]	9,995	3,858	Feather River Near Nicolaus	11425000	FEATHER RIVER NEAR NICOLAUS CA
6	Cache Creek	3,112	1,201	Cache Creek at Hwy 113	11452500	CACHE C A YOLO CA
7	American River	5,528	2,134	American River at Discovery Park	11446500	AMERICAN R A FAIR OAKS CA
8	Sacramento River at Hood/Greene's Landing[3]	4,256	1,643	Sacramento River at Hood Sacramento River at Greene's Landing	11447810	SACRAMENTO R A GREENS LANDING CA
9	Cosumnes River	2,390	922	Cosumnes River at Twin Cities Road	11335000	COSUMNES R A MICHIGAN BAR CA
10	San Joaquin River at Newman	4,170	1,610	San Joaquin River at Crows Landing	11274000	SAN JOAQUIN R A NEWMAN CA
11	Stanislaus River	3,478	1,343	Stanislaus River at Caswell Park	11303000	STANISLAUS R A RIPON CA
12	Tuolumne River	4,586	1,770	Tuolumne River at Shiloh	11290000	TUOLUMNE R A MODESTO CA
13	Merced River	3,290	1,270	Merced River at River Road	11272500	MERCED R A STEVINSON
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	2,397	925	--	--	--
15	Chowchilla River	850	328	--	--	--
16	San Joaquin River at Sack Dam	11,667	4,504	San Joaquin River at Sack Dam	11254000	SAN JOAQUIN R NR MENDOTA CA
17	Mokelumne River	3,022	1,167	Mokelumne River at New Hope Road	11325500	MOKELUMNE R A WOODBRIDGE CA
18	Bear River	1,229	475	Bear River at Forty Mile Road	11424000	BEAR R NR WHEATLAND CA
19	Putah Creek	1,795	693	--	11454210	PUTAH SOUTH CN NR WINTERS CA
20	Delta North	2,148	829	--	--	--
21	Delta South	5,730	2,212	--	--	--
22	San Joaquin River at Vernalis	2,344	905	San Joaquin River at Vernalis	11303500	SAN JOAQUIN R NR VERNALIS CA
	Total Watershed Area	**112,297**	**43,347**			

[1] Flow data USGS website (http://nwis.waterdata.usgs.gov/usa/nwis/discharge), unless otherwise noted.
[2] Flow data from Saleh et al., 2003.
[3] Flow data from DWR's DAYFLOW model.

Figure 4-4. Flows in the dry and wet season of 2002 (a dry year) on a schematic representation of the San Joaquin-Sacramento River systems.
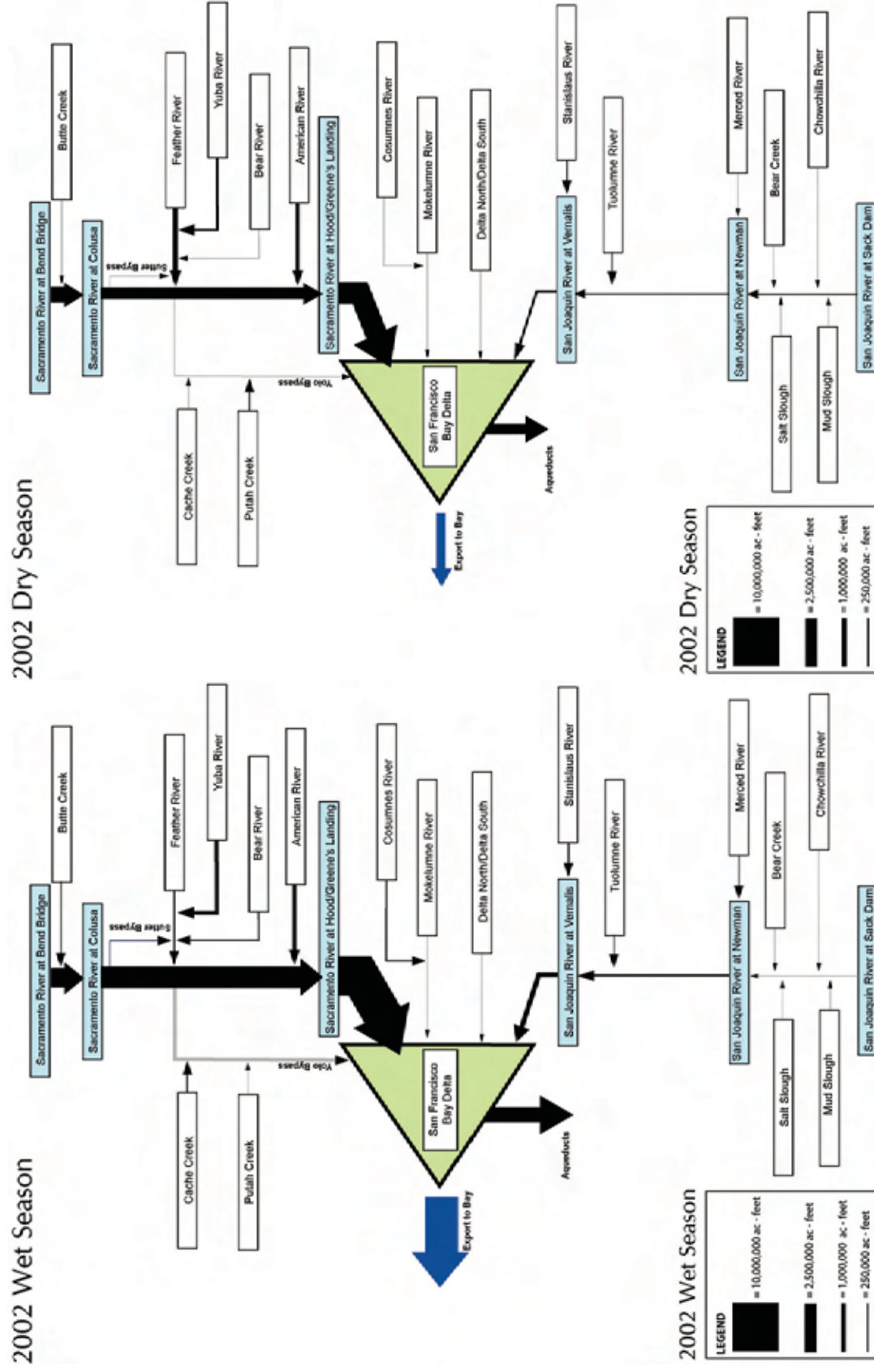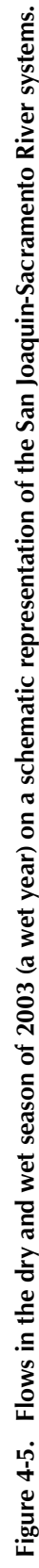
Figure 4-5. Flows in the dry and wet season of 2003 (a wet year) on a schematic representation of the San Joaquin-Sacramento River systems.

4.3   ESTIMATION OF TRANSPORTED LOADS IN STREAMS

Organic carbon concentration data were limited at most locations whereas continuous records of flow data were often, though not always, available. Organic carbon data were especially limited at many upstream locations.

For this study, the average monthly concentration and the average monthly flow are multiplied to get monthly and annual loads, as in Jassby and Cloern (2000). If one or more concentration values were available for a specific month of a given year (i.e., January 1995), the average of data for that month was used. If data were not available for a specific month and year but were available for the same month of any year, then the average of that data was used (i.e., the average of all January values). If there were no data at all for a given month, then an estimate was made using data for months before and after it (i.e., if there were no January data, then the average of December and February data was used). When no TOC data were reported, DOC was used to approximate TOC. Due to the limitations in the data, the load estimates for a number of locations are considered preliminary. The limited concentration data introduced a fair amount of uncertainty into the analysis due to the following factors:

- Grab sample data collected monthly or less frequently do not adequately characterize organic carbon concentrations, particularly during the wet season.
- The assumption that data from a month in one year could be used to estimate organic carbon concentrations for the same month in another year assumes that there is not year to year variability in the data. Based on intensive monitoring in the Sacramento River at Hood, variability is seen in the data (as presented in Chapter 5, Figures 5-7 and 5-9).
- For months for which there are no data, averages of the prior and next month were used. This assumes more consistency in the concentration data than actually exists, based on the intensive monitoring.

Monthly TOC loads were estimated using the entire record of daily flow data at selected stations, and the average monthly concentration values generated as described previously. The monthly loads were used to calculate seasonal and annual loads at the outflow points of the subwatersheds shown in Figure 4-1. Loads were estimated for all but five subwatersheds where no concentration data were available: the Bear, Owens, Mariposa Creeks (defined as one composite subwatershed in Figure 4-1), Chowchilla River, Putah Creek, and the Delta North and Delta South subwatersheds. Figures 4-6 to 4-21 present the average monthly organic carbon concentrations (including data count), the daily discharge, and the wet and dry season organic carbon loads by water year for key locations throughout the watershed. These figures illustrate the extent of available data and the time period of the record. Data from water year 1980 and beyond were used to reflect land use conditions that are reasonably representative of current conditions. For ease of comparison across stations, the time scale in all figures extends from 1980 to 2005. For the stations on the main stems of the Sacramento and San Joaquin Rivers, particularly stations near the Delta, both flow and concentration data are collected at a reasonable frequency. Stations on the tributaries have more limited concentration data. Most stations have

enough flow data to allow estimation of loads for at least 10 years between 1980 and 2005 except for the Feather River, Mokelumne River, Merced River, and San Joaquin River at Sack Dam.

Exports of organic carbon from the Yolo Bypass and from the Delta to San Francisco Bay were also computed. Flows were obtained from the DAYFLOW model discussed in greater detail in Chapter 5. Due to lack of data from any previously discussed source, concentration data for the Yolo Bypass was obtained from Schemel et al., 2002. Like the tributary stations, monthly averages of the flows and organic carbon data were calculated, and used to estimate monthly, then seasonal and annual loads (Figures 4-22 and 4-23 for the Yolo Bypass and Delta outflows, respectively).
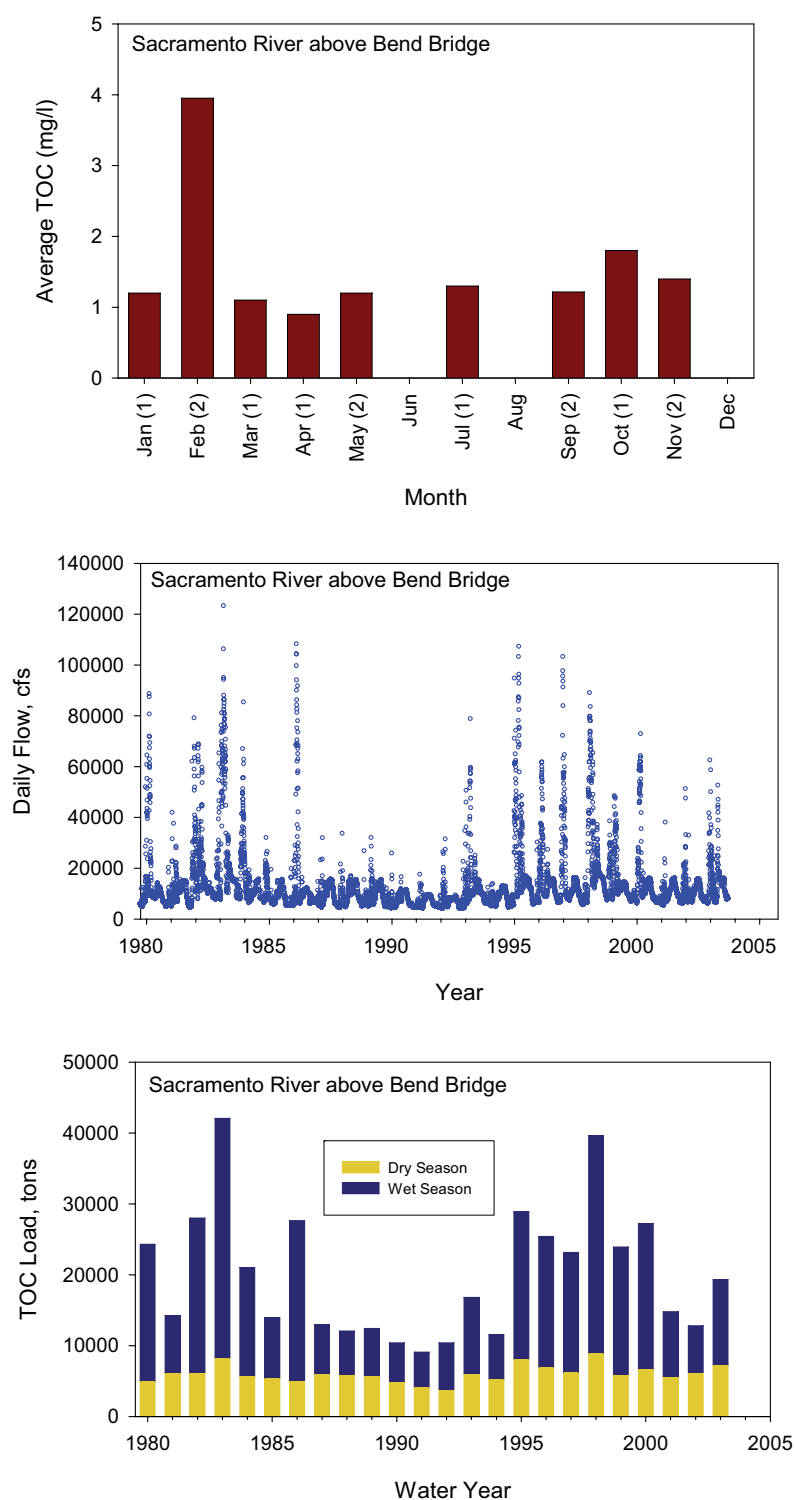
Figure 4-6.   Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River above Bend Bridge.
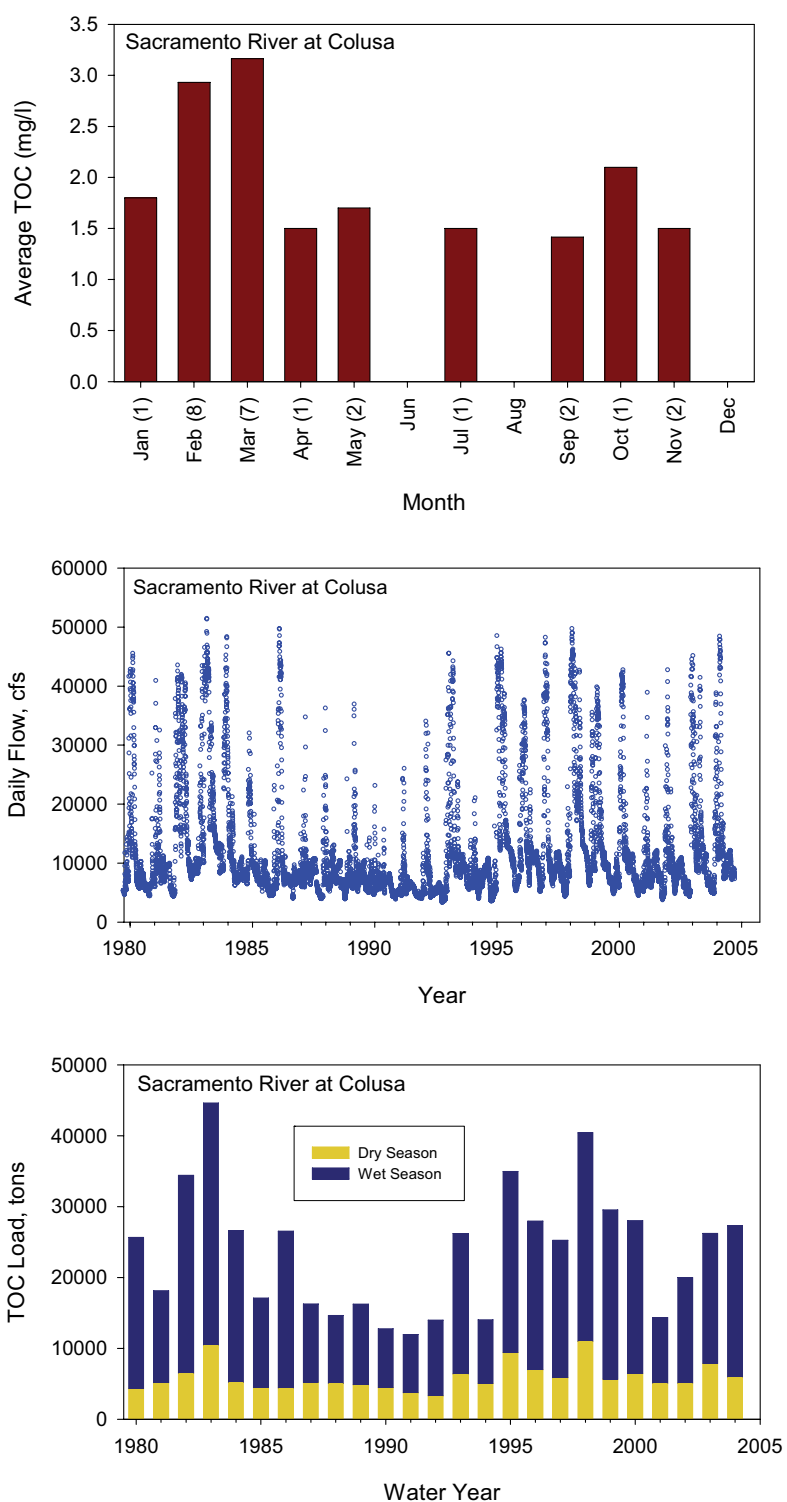
Figure 4-7. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River at Colusa.