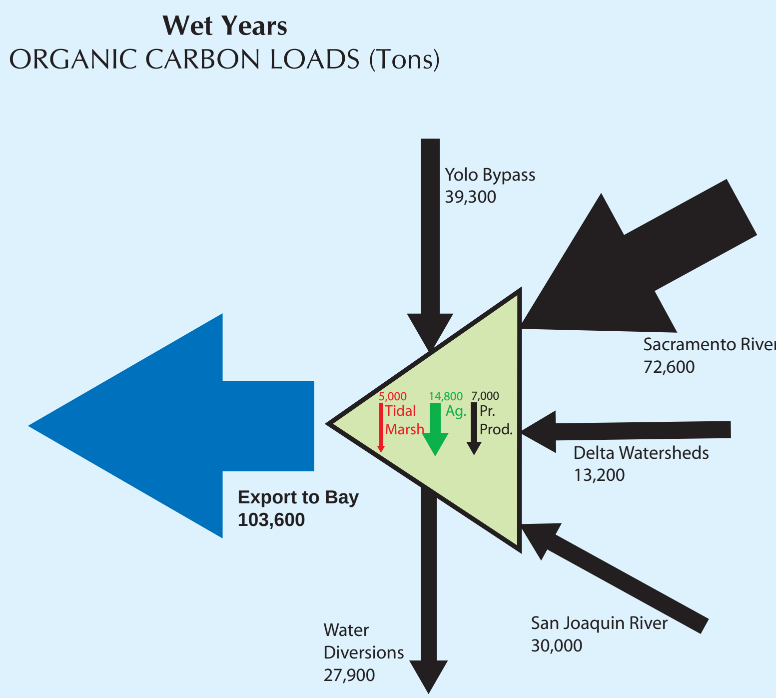
Conceptual Model for

Organic Carbon in the Central Valley and Sacramento–San Joaquin Delta

Final Report
April 14, 2006



Prepared for:

US Environmental Protection Agency, Region IX

Central Valley Drinking Water Policy Workgroup

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Prepared by

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LIST OF ACRONYMS & ABBREVIATIONS

CDF FRAP	California Department of Forestry and Fire Protection Fire and Resource Assessment Program
cfs	Cubic feet per second
CVDWPWG	Central Valley Drinking Water Policy Workgroup
DICU	Delta Island Consumptive Use
DOC	Dissolved organic carbon
DSM2	Delta Simulation Model, Version II
DFG	Department of Fish and Game
DWR	Department of Water Resources
EPA	Environmental Protection Agency
GIS	Geographic Information System
HAA	Haloacetic acid
IESWTR	Interim Enhanced Surface Water Treatment Rule
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum contaminant level
mg/l	Milligrams per liter
MGD	Million gallons per day
MWQI	Municipal Water Quality Investigations
NEMDC	Natomas East Main Drainage Canal
POC	Particulate organic carbon
THM	Trihalomethane
THMFP	Trihalomethane formation potential
TOC	Total organic carbon
USGS	United States Geological Survey
UVA254	UV absorbance at 254 nm
WY	Water year

EXECUTIVE SUMMARY

This report presents a conceptual model of organic carbon for the Central Valley and the Sacramento-San Joaquin Delta. The conceptual model was based on previously collected data from a variety of sources and can be used to direct future investigations to improve understanding of organic carbon-related sources, transformations, impacts, and management.

Organic carbon in the dissolved form (DOC) is the form considered to be more likely to react during chlorination and form disinfectant byproduct compounds. DOC is generally less bioavailable to the base of the web compared with particulate organic carbon and/or organic carbon freshly derived from primary production. Thus, early data suggest that efforts in the Central Valley and Delta to control or manage DOC levels for drinking water quality are less likely to have direct adverse effects on the food web, although this is a subject that needs to be studied further. There is general agreement in the literature that THM formation is correlated to TOC concentrations, although the relationship is more complex when specific structural characteristics of DOC are compared with THM formation potential. A commonly used measure of DOC aromaticity, specific ultraviolet absorbance (SUVA) at 254 nm, was found to be poorly correlated to THM formation in Delta waters. Characterization of organic matter through sophisticated analytical tools such as stable isotope signatures and NMR-spectroscopy is an active area of research; published information that was available at this time, however, is limited to a small number of locations near the Delta, and with limited temporal resolution. The data are indicative of a contribution due to in-Delta primary production, although the variability of this contribution as a function of time is not known. There is limited knowledge on the relative propensity of different sources to form THMs, although it appears that Delta island drainage is somewhat less reactive than tributary sources.

Organic carbon concentrations across the Central Valley were estimated by averaging time series data at many sampling locations and are represented schematically in Figure ES-1. In general, most of the organic carbon is present in the dissolved form. The data show substantially higher concentrations in the San Joaquin River basin compared with the Sacramento River basin, especially in the upper reaches of the Sacramento River basin. Across seasons, the San Joaquin and Sacramento River concentrations exhibit contrasting behavior: in the Sacramento River, the highest concentrations are observed in the wet months, whereas in the San Joaquin River, the highest concentrations are observed in the dry months. The latter is a consequence of the significant contribution of agricultural drainage to total flows in the San Joaquin River in the dry season.

Organic carbon loads at various locations were estimated using historical monthly average flow data and average monthly concentrations of organic carbon at different stations (Figure ES-2). Tributary loads were found to vary significantly between wet and dry years, with loads from the Sacramento River Basin exceeding the San Joaquin River loads by a factor of two. Current estimates for in-Delta contribution of organic carbon show that annual loads of organic carbon from the tributaries are substantially greater than the best estimates of in-Delta production. However, in dry years these may be a significant fraction of the total loads. The organic carbon export in aqueducts is relatively uniform from year to year, particularly when compared with the tributary loads. The export of organic carbon in the aqueducts is slightly larger than the average internal Delta production (Figure ES-3).

The loads transported in streams were compared to the organic carbon export rates from different land uses. Export rates of organic carbon (mass of carbon exported per unit area per year) were computed for key land uses: urban land, agricultural land, wetlands, and natural areas (including forests, shrubland, and rangeland). The calculated total watershed exports matched well with the stream loads at key locations (such as Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis) although not at all locations considered. Theses differences highlight the need for greater data collection, both to characterize stream loads and to quantify terrestrial export rates in selected watersheds. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

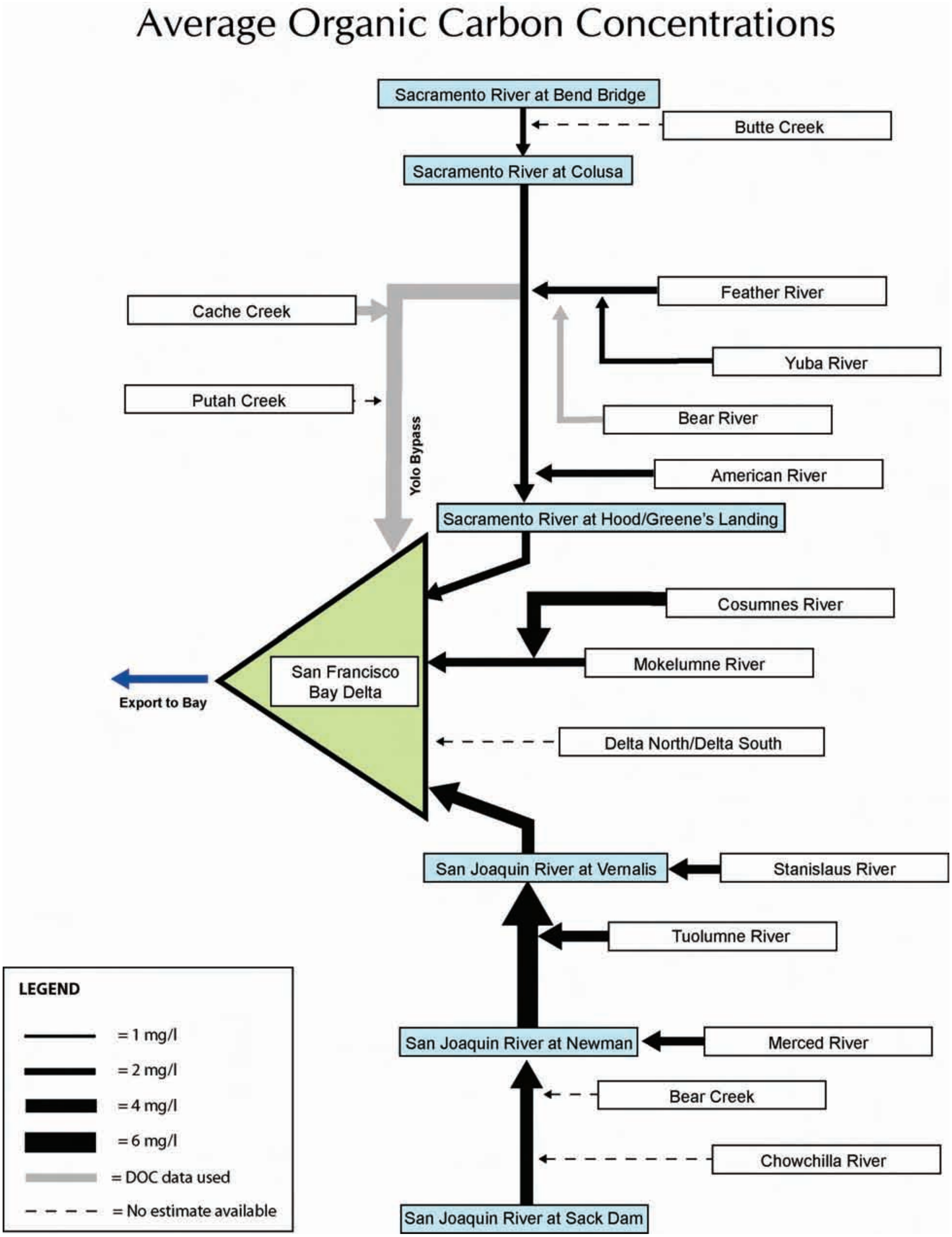


Figure ES-1. Average concentrations of organic carbon (mostly as TOC except where indicated) in the Central Valley and Delta.

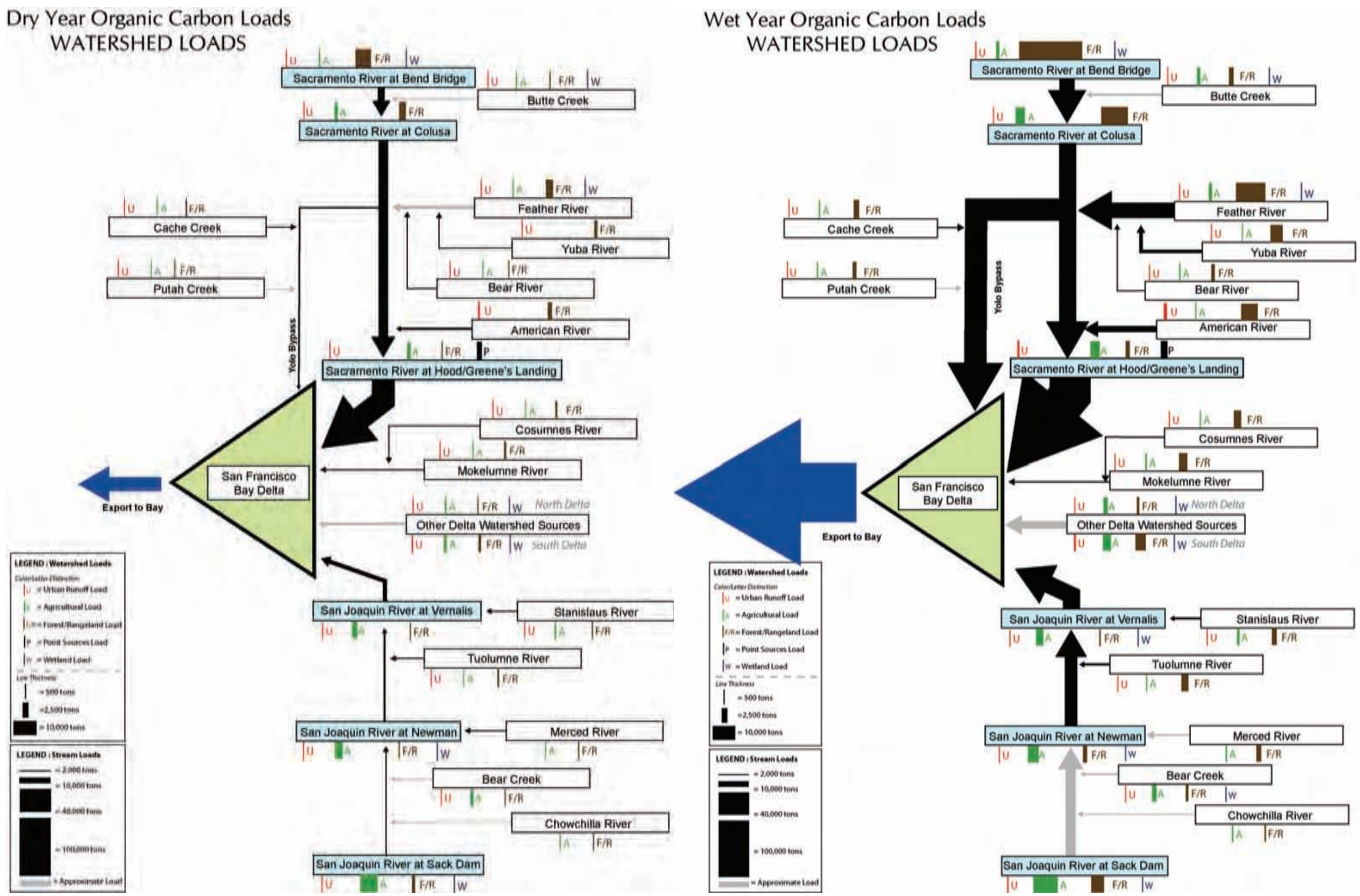


Figure ES-2. **Watershed and outflow loads for the Central Valley and Delta for average dry and wet years. Arrow thicknesses are proportional to stream loads; bars on the boxes are proportional to the loading from watershed sources.**

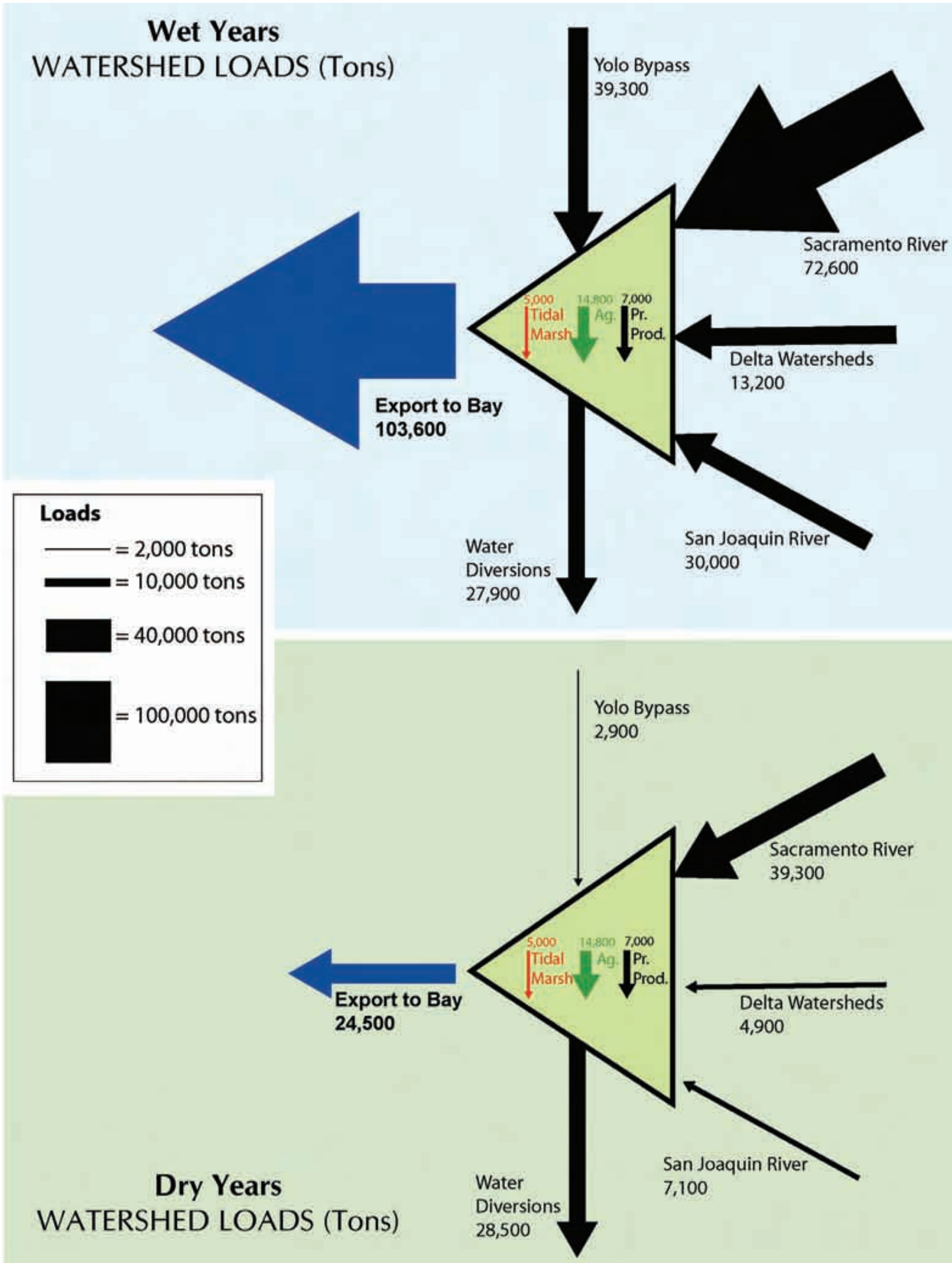


Figure ES-3. **The major tributary loads shown in Figure ES-2, along with the internal loads from in-Delta sources and exports from the Delta into San Francisco Bay and into the water diversions.**

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 contribution of various sources to organic carbon concentrations at the intakes is best estimated through modeling. California Department of Water Resources' Delta Simulation Model (DSM2) was found to be the best tool for this task. This model is well calibrated and widely used for water flow and water quality applications throughout the Delta. The model is routinely used by DWR staff to evaluate the effect of specific scenarios on concentrations at various intakes. Ongoing work, termed fingerprinting, for example, shows the contribution of different sources to water volume and DOC concentrations at key intakes over time. A similar mechanistic model of the tributaries may need to be developed if impacts at stations outside the Delta need to be studied.

The conceptual model also identified data gaps and recommended improved cataloging of data from existing monitoring and research projects and additional field data collection. The broad areas where data collection is recommended includes characterization of export rates from different land uses, improved representation of agricultural drains, the contribution of Delta Island drainage and tidal marshes, quantification of reservoir exports of organic carbon, and improved quantification of wastewater sources. Recommendations for data collection were provided here as suggestions; the actual extent of additional data to be collected will depend on available time and resources.

Looking to the future, it appears that gradual changes in potential organic carbon sources (increased urban land and/or increased wastewater sources) are unlikely to be as large as the natural year-to-year variability in loads currently exhibited in the Delta. However, the role of anthropogenic organic carbon sources and the ecological impacts of substantial water withdrawals from the Delta, can all become highly significant during dry and critically dry years. Consideration of such extreme conditions should be a focus of future modeling work. In addition to the processes during dry years, future study of organic carbon should consider other factors. These include potential changes in Delta tidal marsh area due to restoration, changes in the regulations with lower standards for existing disinfection byproducts, or the addition of new compounds to the regulations, and the likelihood of catastrophic events such as levee failures.

CHAPTER 1.0
INTRODUCTION

The Central Valley, comprising the Sacramento and San Joaquin River watersheds, is a vital source of drinking water in California. Many Central Valley communities rely on water from the Sacramento and San Joaquin rivers or their tributaries. The Sacramento-San Joaquin Delta (hereafter referred to as the Delta) provides source water to more than 23 million people in the Southern California, Central Coast, and San Francisco Bay regions (CALFED Water Quality Program Plan, 2000). The tributaries of the Sacramento and San Joaquin rivers that originate in the Cascade Range and Sierra Nevada Mountains generally have high quality water; however, as the tributaries flow into lower elevations, they are affected by flows from urban, industrial, agricultural, and natural land uses as well as a highly managed water supply system.

The Central Valley Drinking Water Policy Workgroup is working with the Central Valley Regional Water Quality Control Board (Regional Board) to conduct the technical studies needed to develop a policy that will provide greater protection to drinking water supplies in the Central Valley. The policy is initially focused on five categories of constituents: organic carbon, nutrients (nitrogen and phosphorus), salinity, bromide, and pathogens and indicator organisms. This conceptual model report is focused on organic carbon.

For more than two decades organic carbon in source waters has been identified as a constituent of concern, in the Delta and elsewhere, primarily due to the formation of carcinogenic byproducts during disinfection at water treatment facilities. Drinking water is disinfected with chlorine or other chemicals to meet regulatory requirements to inactivate pathogens that may be present in the source water. Organic carbon, like several of the other identified constituents of concern, may originate from both natural and anthropogenic (human) sources, and the levels of organic carbon may play a beneficial role in ecosystem function.

A wide variety of chemical compounds are formed during the disinfection of source waters with chlorine in the presence of organic carbon and bromide. Of the many dozen disinfection byproduct compounds that have been detected (Cohn et al., 1999), trihalomethanes (THMs) and several haloacetic acids (HAAs) are currently regulated by the US EPA as part of the Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rule (US EPA, 1998). These rules, in conjunction with the Interim Enhanced Surface Water Treatment Rule (IESWTR) and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), are intended to provide protection from microbial pathogens while minimizing the human health risk due to disinfection byproducts. Table 1-1 lists the regulated THMs, the total concentrations of which cannot exceed 0.08 mg/l, and the five regulated HAAs (also abbreviated as HAA5), the total concentrations of which cannot exceed 0.06 mg/l (US EPA, 2001). Approximately 50% of the disinfection byproduct compounds in finished drinking water are unidentified (US EPA, 2003). The list of detected disinfection byproducts and knowledge of their human health impacts continues to grow, and it is conceivable that in future years the total allowable THM and HAA5 concentrations may decrease and the number of regulated compounds may increase.

Table 1-1.
Disinfection by-products of human health concern.

Trihalomethanes (Current EPA standard*: 0.08 mg/l):	
Chloroform	$CHCl_3$
Bromodichloromethane	$CHCl_2Br$
Dibromochloromethane	$CHClBr_2$
Bromoform	$CHBr_3$
Haloacetic acids (HAA5) (Current EPA standard*: 0.060 mg/l):	
Dibromoacetic acid	$CHBr_2CO_2H$
Dichlororoacetic acid	$CHCl_2CO_2H$
Monobromoacetic acid	CH_2BrCO_2H
Monochloroacetic acid	CH_2ClCO_2H
Trichloroacetic acid	CCl_3CO_2H
Bromate (BrO_3-); MCL = 0.010 mg/l	
Chorite (ClO_2-); MCL = 1.0 mg/l	

* 1998 Stage 1 Disinfectants and Disinfection Byproducts Final Rule; 2005 Stage 2 Disinfectants and Disinfection Byproducts Final Rule

A number of water suppliers that rely on the Delta as a source of drinking water have modified their treatment processes and are using ozone as the primary disinfectant to avoid the formation of trihalomethanes and haloacetic acids. However, organic carbon in the source water still impacts facilities using ozone because increased TOC increases the required ozone dosage. Higher levels of ozone in the presence of bromide can increase bromate concentrations. Drinking water suppliers that treat

Delta water with ozone already must take steps to ensure that bromate levels do not exceed the Maximum Contaminant Level (MCL) of 0.01 mg/l.

To protect the quality of Delta source waters, CALFED has proposed a total organic carbon target of 3 mg/l or an equivalent level of public health protection using a cost-effective combination of alternative source waters, source controls, and treatment technologies. In recent years, water at the Delta pumping plants has often exceeded this concentration target, particularly during the wet season (Department of Water Resources, 2005).

Although organic carbon is referred to as a single constituent, it is well known that it is comprised of a wide variety of chemical compounds, with numerous structural forms, and a range of reactivity, solubility, and molecular weights (Thurman, 1985). Inferring these details about an aquatic organic carbon sample is not straightforward, but studies have documented the importance of organic carbon quality in influencing the quantity of THMs that are formed during chlorine disinfection. Unfortunately, there is not sufficient information about the quality or characteristics of organic carbon from many sources in the Central Valley. This report is therefore focused on total organic carbon.

This report presents a conceptual model of organic carbon that summarizes current knowledge of the sources, transformation processes, and transport of organic carbon in the waters of the Central Valley and Delta. There have been previous descriptions of conceptual models for organic carbon in this region (MWQI, 1998; Brown, 2003). The work presented in this report expands upon the earlier efforts by using more recent data and covering a larger geographical area. The conceptual model is intended to form the basis for identifying data needed to better understand the sources of organic carbon, the relationship between drinking water concerns and ecosystem concerns, and the ability to control organic carbon in the Delta and its watersheds. This is important because organic carbon concentrations are currently problematic at some water supply intakes and anticipated changes in the Central Valley and Delta system may exacerbate the problem in the future. Anticipated changes include increases in developed land, population, and concomitant increases in water withdrawals (at new and existing locations) and wastewater and urban runoff discharges. The CALFED Program includes a number of ecosystem restoration activities in the Delta, including the restoration of tidal marshes, some of which have the potential to adversely affect organic carbon concentrations at the drinking water intakes. Changes to state and federal water management system are also being contemplated.

The contents of the chapters that follow are briefly summarized as follows:

- Chapter 2 presents a summary of the key processes associated with the production, consumption, decomposition, and transport of organic carbon in watersheds and receiving waters and an overview of the chemical forms of organic carbon and what is known about its relationship to disinfection byproduct formation.

- Chapter 3 summarizes the information on organic carbon-related parameters in the database developed by the Central Valley Drinking Water Policy Workgroup. Spatial and temporal trends in concentration data are presented. This database is the primary source of information for the development of this conceptual model. Additional sources of data used for this assessment are also identified.

- Using the data summarized in Chapter 3, Chapter 4 provides an estimate of the flows and organic carbon loads transported from the tributaries to the Delta in wet and dry years. Sources of organic carbon from key non-point and point sources are estimated on a unit basis (e.g., per unit area or per unit population) to compare stream loads to watershed inputs.

- Chapter 5 presents an estimate of the organic carbon concentrations and sources within the Delta boundaries. Loads internal to the Delta are presented along with tributary sources discussed in Chapter 4. The current approach to relate tributary loads and in-Delta sources to concentrations at major pump stations is also presented.

- Chapter 6 summarizes the uncertainty in the findings from the preceding chapters and identifies additional data and studies that are needed to better understand the sources and potential impacts of organic carbon in municipal supplies. Key findings of the analysis presented in this conceptual model are highlighted. Future trends in organic carbon supplies to the Delta and vicinity are also discussed.

CHAPTER 2.0
ORGANIC CARBON IN AQUATIC ECOSYSTEMS AND PATHWAYS OF DISINFECTION BYPRODUCT FORMATION

Organic carbon, comprising living and non-living fractions, is central to the flow of energy and the trophic structure of aquatic ecosystems (Wetzel, 2001). Although high concentrations of organic carbon are generally undesirable in drinking water sources due to the formation of disinfection byproducts (Amy et al., 1990; Cohn et al., 1999), these concentrations may be beneficial and even essential for aquatic ecosystems. An understanding of the ecosystem processes of organic carbon in the Central Valley is important because any actions to manage the concentrations of organic carbon at drinking water intakes must also consider the potential ecological impacts. Likewise, restoration actions in the Delta to improve habitat quality that change organic carbon concentrations and the quality of the organic carbon must consider the impacts to drinking water. For the purpose of evaluating the role of organic carbon in ecological processes, the division into dissolved and particulate forms, and also bioavailable forms, is critical. However, the formation of THMs and other disinfection byproducts during drinking water treatment is generally not directly related to these forms, but is a function of the chemical structure and reactivity of the organic carbon. General findings from the literature on ecosystem processes and drinking water impacts are briefly reviewed in this chapter. Subsequent chapters present Central Valley and Delta specific data and quantification of the processes described in this chapter.

2.1 ORGANIC CARBON CYCLING AND TRANSPORT

The cycling of organic carbon in terrestrial environments is shown in schematic form in Figure 2-1. Organic carbon is produced from atmospheric carbon dioxide and water by plants through the many complex reactions of photosynthesis. (in forests, cropland, rangeland, and to a lesser degree on urban land). Organic carbon enters the surface soil pool following senescence and litterfall of plant matter. Microbial populations and fungi break down this organic carbon into smaller, more labile forms and ultimately to carbon dioxide. A fraction of soil organic matter is stored in the terrestrial compartment and a fraction is transported in surface runoff and into groundwater which may enter surface waters as baseflow. Not shown in this schematic are point sources such as wastewater treatment plants that may contain organic carbon originating in the watershed as well as imported organic carbon. The magnitude of organic carbon export is a function of the land use and the level of rainfall and runoff. Literature reports suggest a range of dissolved organic carbon exports from 0.38 tons/km^2/yr for cool grasslands to 9.9 tons/km^2/yr in swamp forests (Aitkenhead and McDowell, 2000). For most freshwater bodies, watershed sources of organic carbon are a much greater source than internal production (Wetzel, 2001). Other things being equal, dry regions are expected to export a lower amount of organic carbon than wet regions with greater runoff. This is relevant to the Central Valley because it exhibits a variety of precipitation characteristics, with the northern and eastern portions being wetter than the southern and western portions (NRCS, 2006).

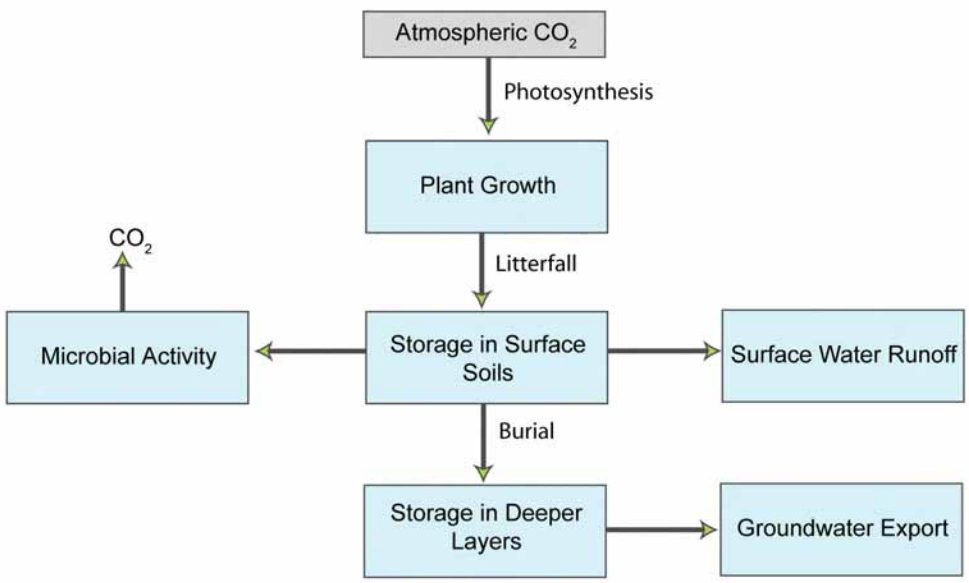


Figure 2-1. Schematic of organic carbon cycling in the terrestrial environment

The cycling of organic carbon in the aquatic environment is shown in schematic form in Figure 2-2. Organic carbon may enter a water body from terrestrial sources in the watershed as shown in Figure 2-1, and it may also be photosynthesized within the water body by benthic and planktonic algae and plants, using atmospheric carbon dioxide or dissolved inorganic carbon as a carbon source. For simplicity, the organic carbon is represented as two pools, particulate and dissolved organic carbon (POC and DOC respectively), although in reality there is a continuum of particle size and molecular weight that influences its metabolism (Wetzel, 2001). A key feature shown in Figure 2-2 is that DOC, unlike POC, cannot be directly taken up by primary consumers. Bacteria may convert DOC to bacterial biomass which then becomes available for consumption by higher organisms (Wetzel, 2001; Jassby and Cloern, 2000). POC from the watershed and POC from aquatic primary production is generally more accessible to the food web than DOC. In most ecosystems it has been observed that the detrital organic carbon (as DOC and non-living POC) is far more abundant than the organic carbon in living POC (Wetzel, 2001). Bacteria may also metabolize DOC to carbon dioxide that exits the aquatic system. The atmospheric pathway for loss of organic carbon is significant, and in some areas of the Delta, such as the islands, can be far in excess of aqueous export (Deverel and Rojstaczer, 1996). Sediments in water bodies play a key role in the cycling of organic carbon. Generally, POC can settle to the sediments, and provide a source of DOC to the overlying water column through microbial decay. Sediment POC can be stored for long periods, or may be scoured and transported downstream during high flow events. Thus, high flow events in the wet season transport large quantities of organic carbon that may have accumulated in the sediments in preceding months or years.

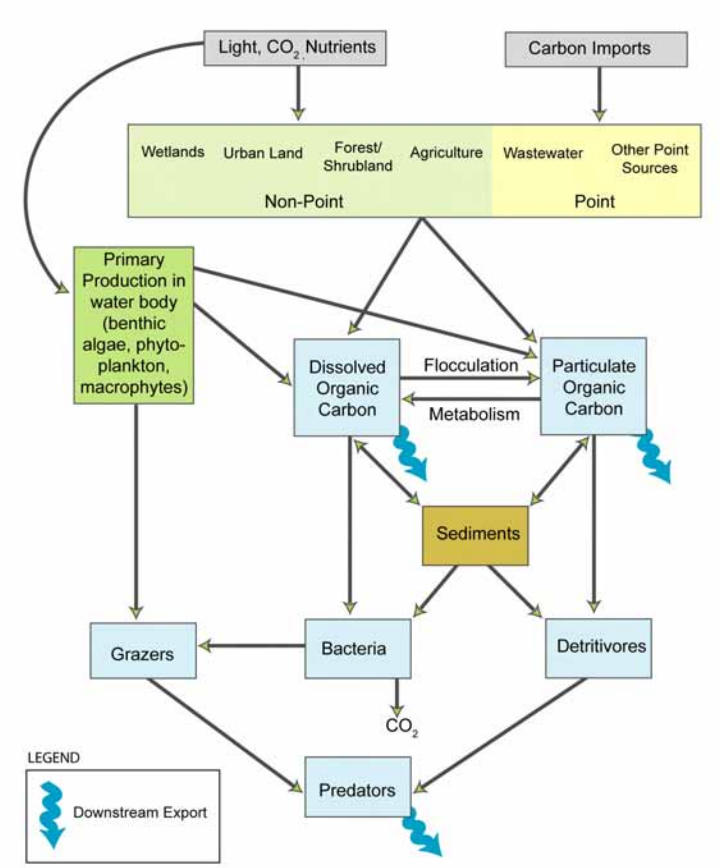


Figure 2-2. Schematic of organic carbon cycling in the aquatic environment (modified from Wetzel, 2001).

The transport processes of organic carbon are shown schematically for the Central Valley - Delta ecosystem in Figure 2-3. Organic carbon, in various stages of decay, enters water bodies through streams in drainage and runoff and through groundwater flows. Streams play a critical role in organic carbon transport. They act as conduits for organic carbon exported from land surfaces, but may also convert some of the organic carbon into carbon dioxide or store it in sediments. At other times, depending on flow rates, sediment erosion or efflux can be a contribution to the transported load. Further, streams may be an additional source of organic carbon production through algal and macrophyte growth. Organic carbon transport in streams is controlled by flow rates with the greatest loads being transported during high flow events in the wet season. In the wet season, and especially during storm flows, organic carbon stored in the surface layers of various land uses, and also in stream sediments is transported into downstream waters.

The Central Valley is unique in having reservoirs on practically all tributaries, which may play an important role in organic carbon production and export. Reservoirs, by storing water for extended residence times during the warm, dry months of the year, and by providing a large surface area, may provide an environment for algae growth in excess of what would have occurred naturally. Some of the organic carbon produced in reservoirs may be exported downstream. Conversely, reservoirs may act as large settling basins for POC, resulting in less transport of organic carbon downstream.

Tributary organic carbon loads (termed allochthonous loads), which include detrital as well as planktonic organic carbon, reach the Delta where the residence time ranges from days to weeks, depending on season and inflow volume. As shown in Figure 2-3, the Delta is itself a producer of organic carbon due to primary production by benthic and planktonic algae and plants and export from tidal marshes, agriculture, and developed lands (autochthonous loads). A fraction of the internally generated and the tributary organic carbon is exported to San Francisco Bay. Organic carbon is also lost from the Delta by the diversion of water at the drinking water intakes. Additionally, organic carbon is incorporated in sediments and metabolized to carbon dioxide. Because large drinking water intakes are located in the Delta, the quality and quantity of the autochthonous organic carbon is of particular relevance to potential drinking water quality impacts.

Declines in fish species and related food web impacts in San Francisco Bay and the Delta have motivated studies of organic carbon sources and bioavailability independent of drinking water quality-related investigations (e.g., Jassby et al., 1993). Driven by variations in tributary inflows, allochthonous organic carbon loads vary widely from year to year (Jassby et al., 2002). There is also a substantial year-to-year variation in primary production in the Delta with a declining trend in primary production in recent years that has been attributed to various causes including the consumption of phytoplankton by an exotic invading species (the Asian clam *Potamocorbula amurensis*) and other benthic consumers (Jassby et al., 2002).

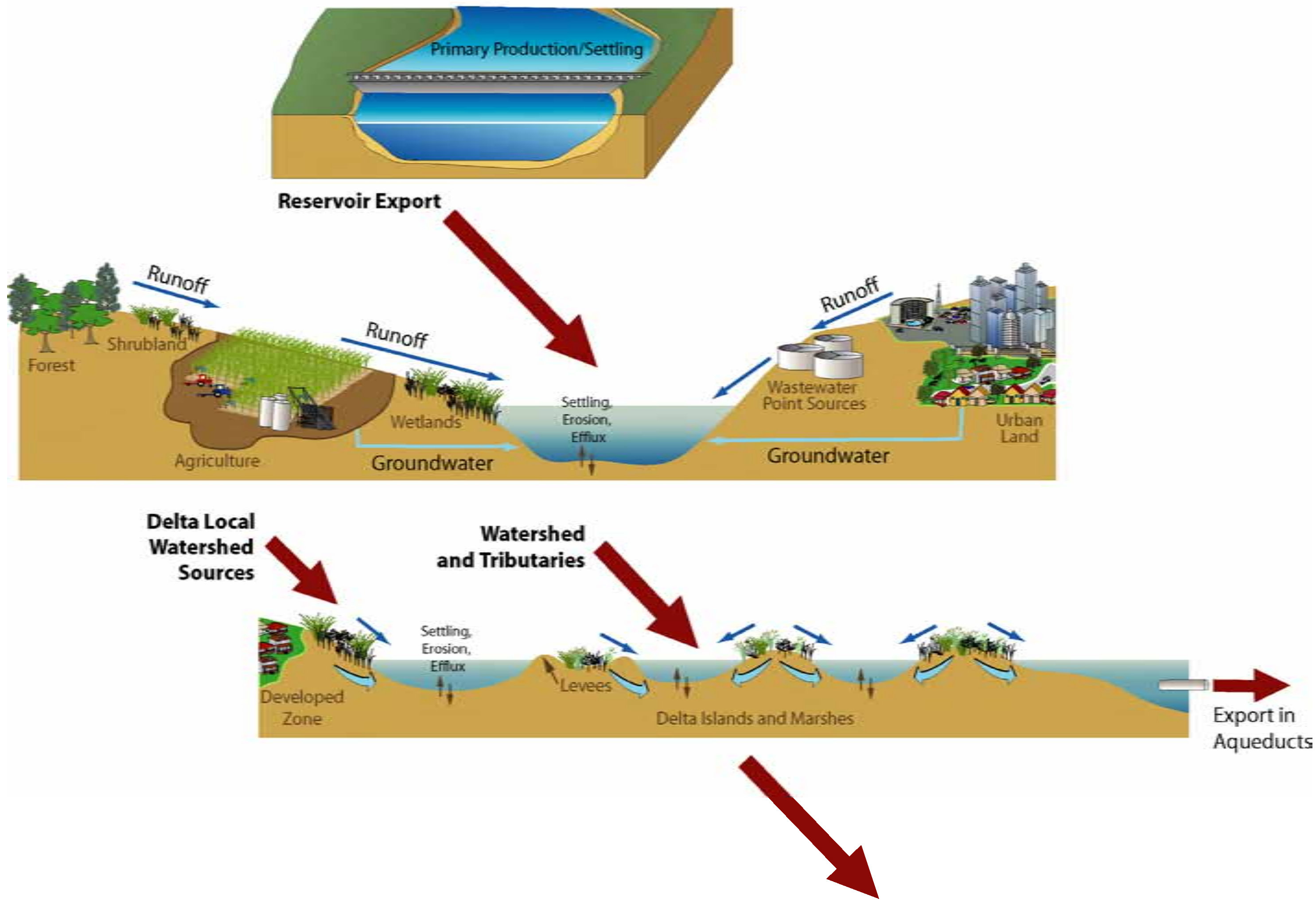


Figure 2-3. **Schematic representation of organic carbon transport in the Central Valley-Delta system. Organic carbon originates in upstream natural sources, and is released from reservoirs to the lower watershed, where there are additional contributions from point and non-point sources. The organic carbon from the tributaries enters the Delta, where there are additional point and non-point sources in its immediate watershed, as well as production within the Delta. A fraction of the organic carbon is exported in aqueducts, but in most seasons, a large fraction is exported downstream to San Francisco Bay.**

Recent studies have concluded that tributary inputs of organic carbon several times larger than in-Delta primary productivity and agricultural drainage (Jassby and Cloern, 2000). A fraction of the tributary and internal loads are exported in the water supply intakes, while the remainder flows into San Francisco Bay. Evaluation of bacterial communities in the Delta using DNA fingerprints showed seasonal, but not spatial variation, in the bacterial communities. Bacterial communities associated with local primary production-derived organic carbon were dominant in summer/fall, and communities associated with terrestrial sources were dominant in winter (Stepanauskas et al., 2003).

The bioavailability, and therefore the ecological significance, of different components of organic carbon in the Delta are variable. Although a fraction of the DOC is available for bacterial metabolism, it appears to be a less important food source at the base of the food web than organic carbon derived from primary production within the Delta (Jassby and Cloern, 2000; Sobczak et al., 2002, 2004). Further, much of the natural POC load in the tributaries is a much poorer food source than natural phytoplankton. In controlled experimental studies with a zooplankton, *Daphnia magna*, total detrital organic carbon concentrations were found to be weakly related to growth, although chlorophyll *a* concentrations were found to be a good predictor for growth (Müeller-Solger et al., 2002). This study indicates that in a system like the Delta with an abundance of detrital organic carbon, much of it from tributary sources, some consuming organisms exhibit a preference for organic carbon freshly derived from primary production. In laboratory studies on water samples from the Delta, it has been shown that a relatively small fraction of the DOC and POC is available for bacterial metabolism (operationally defined as a 21-day incubation), and the bioavailable fraction is well correlated with primary production (Sobczak et al., 2004). If these results are corroborated by further research, potential reductions in tributary loads of organic carbon are less likely to have adverse ecological impacts, and it may be found that water quality objectives for drinking water supply and ecosystem health are not necessarily in conflict.

2.2 Organic Carbon Chemistry and Drinking Water Quality

As shown schematically in Figure 2-2, organic matter in the water column of a water body consists of materials from plant, animal, and bacterial origins in various stages of decay, with fragments of variable molecular weight, functional group, and chemical reactivity. This organic carbon can exist as both POC and DOC, although DOC is generally considered the more important fraction for the production of disinfection byproducts because of its greater abundance and reactivity during chlorination (e.g., Chow and Gao, 2003; Chow et al., 2003). Organic carbon can broadly be divided into two groups, humic and non-humic substances (Thurman, 1985). Humic substances are high molecular weight compounds largely formed as a result of bacterial and fungal action on plant material and include humic acids (that precipitate at pH<2), fulvic acids (soluble at any pH), and humin (insoluble materials). Non-humic substances include proteins, carbohydrates, and other lower molecular weight substances that are more available to bacterial degradation than humic substances.

Several studies in the literature have shown the link between TOC or DOC levels and THM formation. For example, using data from 133 lakes, rivers, and reservoirs across the US, Chapra et al. (1997) showed that TOC levels were a good predictor of THM formation potential (THMFP) with a non-linear relationship (THMFP = $43.8*TOC^{1.248}$, $r^2 = 0.94$). It was also noted that higher TOC waters, possibly with a higher proportion of humic acids, produced more THMs per unit weight of carbon than lower TOC waters. In general, simple measures of organic carbon (such as DOC or TOC) work best as a predictor for THM formation if the carbon originates from one type of source. When organic carbon in a water sample originates from multiple sources, or when waters from different locations are compared, the predictive ability is likely to be weaker. Thus, for samples from a single Delta island, Fujii et al (1998) found a strong correlation between DOC and THMFP, although this relationship may be weaker when multiple locations are compared together (Weishaar et al., 2003) or when rivers with multiple sources are considered (Amy et al., 1990). A considerable amount of recent research has focused on relating organic matter compositional information to THM formation, and on identifying the origins of organic carbon near water intakes in the Delta. Much of this work has confirmed that organic carbon in water from different locations varies considerably with respect to the formation of THMs during chlorination (Bergamaschi et al., undated; Fujii et al., 1998; Fram et al., 1999; Weishaar et al., 2003). Although the relationship between organic carbon sources and concentrations at individual water supply intakes is complex, these studies suggest that management of organic carbon sources for drinking water quality should consider both quality and quantity, with greater emphasis on sources with the highest THMFP.

Organic carbon quality is characterized in a few different ways in routine monitoring and specialized research studies. The data most commonly reported in the Delta and vicinity include dissolved, particulate, and total organic carbon, ultraviolet (UV) absorbance at 254 nm, specific UV absorbance (or SUVA, which is absorbance in units of cm^{-1} divided by the DOC concentration in mg/l). To a limited extent, data are also available on the THMFP through equilibrations of water samples with gaseous chlorine in a protocol to mimic the disinfection process in water treatment plants (California Department of Water Resources, 1994). Specialized, limited-duration research studies have performed considerably more detailed analysis of the structure of natural organic matter to estimate reactivity and identify sources. These analyses have included separation into various fractions (hydrophilic and hydrophobic, humic and fulvic acids, etc.), ^{13}C-NMR spectroscopy to identify chemical structures and carbon:nitrogen ratios and stable isotope ($\delta^{13}C$, $\delta^{15}N$) signatures to identify sources. The variety of analyses of aquatic organic carbon samples and the information derived from them is summarized in Table 2-1. An important goal of these studies is to establish the link between various structural moieties of organic carbon and THMFP. When certain chemical characteristics of organic carbon associated with THM formation can be related to specific sources, the information can be used to improve management of source water quality by targeting the most reactive forms of organic carbon. Key findings from recent research on organic carbon chemistry are summarized below.

Table 2-1
DOC-related measurements.

Measurement	Information Provided
TOC and DOC	Direct measure of total quantity of organic carbon present
UV absorbance (254 nm)	Surrogate for DOC concentration
Specific UV absorbance (SUVA)	Indicative of DOC aromaticity
Fluorescence	Indicative of aromatic structures
Separation by nonionic resins	Distribution by apparent molecular weight; indicative of acidic and non-acidic fractions and of hydrophilic/hydrophobic portions; separation into humic and fulvic acids
DBP formation potential	Direct measure of drinking water quality impact
^{13}C NMR Spectra	DOM chemical structure, specific functional groups
Isotopic composition of N and C in natural organic matter	Identification of source

A significant quantity of the initial work on organic carbon characterization was focused on UV absorbance (and SUVA), because this parameter was related to the aromaticity of organic carbon, a property identified to be related to general organic matter reactivity and THM formation (Reckhow et al., 1990). More recent work in the Delta and other locations shows that the correlation between SUVA and THM formation potential is weak (Fujii et al., 1998; Fram et al., 1999; Weishaar et al., 2003). SUVA, while confirmed to be a good predictor of aromaticity by ^{13}C-NMR spectroscopy, is a weak predictor of THM formation because non-aromatic fractions of organic carbon also play an important role and all aromatic fractions are not highly reactive (Weishaar et al., 2003; Fleck et al., 2004). In Delta waters, the percentage of organic carbon was not shown to correlate with the THM formation (Fram et al., 1999). In a study with water with from a relatively homogeneous source (Twitchell Island agricultural drainage), the correlation between SUVA and specific THMFP was considerably weaker than that between DOC and THMFP (Fujii et al., 1998). SUVA has also been shown to be influenced by interferences such as pH, nitrate, and iron in water samples, although these may not be significant at the ranges of these parameters in surface waters (Weishaar et al., 2003). SUVA is used to determine the level of TOC removal required in raw water samples (US EPA, 1998) and continues to be a widely used measure of organic carbon reactivity. In fact, at most organic carbon sampling locations in the Delta and Central Valley, SUVA (or UVA) is the only other additional chemical characterization that is reported.

The most direct measure of the chemical functional groups of natural organic matter is through ^{13}C-NMR spectroscopy, a method that is complicated and expensive to apply on a routine basis. However, reports of organic matter characterization with this approach continue to grow in the literature. A major finding from the application of ^{13}C-NMR spectroscopy is that aromaticity is not a good predictor of THMFP (Weishaar et al., 2003), although the role of other functional groups has not been clearly identified (Chow and Gao, 2003).

Fractionation evaluations on organic carbon in water samples using nonionic resins, followed by tests for THMFP, have been performed by several researchers (e.g., reviewed by Chow and Gao, 2003). Fractionation of organic matter into hydrophobic and hydrophilic acids has shown that hydrophobic acids more readily form THMs than hydrophilic acids at many locations (Krasner et al., 1996), and specifically in the Central Valley and Delta (Bergamaschi et al., 2000). Fractionation into apparent molecular weight (AMW) has not shown a strong correlation between AMW and THMFP and there is no consensus in the literature on the link between the two parameters (Chow and Gao, 2003). In some instances in the Delta, lower AMW fractions were found to be more reactive than the larger AMW fractions (Amy et al., 1990). Organic carbon from different sources in the Delta was found to have different propensities to form THMs, with the limited data currently available indicating that tributary organic carbon was more reactive than that released from Delta agricultural islands (Bergamaschi et al., 2000).

Carbon:Nitrogen ratios and stable isotope chemistry in bulk organic matter (δ^{13}C, δ^{15}N) and in THMs (δ^{13}C) formed in test samples can be used to elucidate the source of organic matter, and to identify the relative reactivity of the different organic carbon fractions (e.g., Bergamaschi et al., 1999). Organic matter from tributary sources (originating in surface runoff and groundwater flow) has much lower nitrogen contents (C:N of about 50:1) compared with organic matter derived from primary production within water bodies (C:N of about 12:1) (Wetzel, 2001). Data from the Delta show relatively small differences across different sites in all of these parameters. Organic carbon at most tributary and Delta locations sampled appears to be dominated by detrital material, with C:N ratios in most cases 30 or greater. In general, the stable isotope data are consistent with a small addition of organic matter due to primary production in the Delta, with much of the organic matter originating in the tributaries (Bergamaschi et al., undated). The limited spatial and temporal detail in the data currently available precludes a more detailed assessment using these analytical approaches.

It is important to note that published research on disinfectant byproduct formation has largely focused on the potential for THM formation, and not on potential for formation of haloacetic acids and other organic halides. An exception is work by the Municipal Water Quality Investigations Program (MWQI, 2003) where a limited about of haloacetic acid formation was also studied. THMs are generally the most abundant disinfection byproduct in tests for disinfectant byproduct formation potential, and haloacetic acids are no more that 50% of the total concentration of THMs.

2.3 MAJOR FINDINGS

Organic carbon in the dissolved form (DOC) is the form considered to be more likely to react during chlorination and form disinfection byproduct compounds. DOC is generally less bioavailable to the base of the food web compared with particulate organic carbon and/or organic carbon freshly derived from primary production. Thus, efforts in the Central Valley and Delta to control or manage DOC levels for drinking water quality may not have direct adverse effects on the food web, although this is a subject that needs to be studied further.

There is general agreement in the literature that THM formation is correlated to DOC concentrations, although the relationship is more complex when a specific structural characteristic of DOC is compared with THMFP. A commonly used measure of DOC aromaticity, SUVA at 254 nm, was found to be poorly correlated to THM formation in Delta waters.

Characterization of organic matter through sophisticated analytical tools such as stable isotope signatures is an active area of research. Published information that was available at this time, however, is limited to a small number of locations near the Delta, and with limited temporal resolution. The data are indicative of a contribution due to in-Delta primary production, although the variability of this contribution as a function of time is not known. There is limited knowledge on the relative propensity of different sources to form THMs, although it appears that Delta island drainage is somewhat less reactive than tributary sources.

CHAPTER 3.0 OVERVIEW OF DATA USED FOR ANALYSIS

The conceptual model for organic carbon developed in this report is based largely on a database of organic carbon and other constituents compiled by the Drinking Water Policy Workgroup in 2004-2005. Data in the database originate from a variety of agricultural, urban, point source, and surface water monitoring programs throughout the watersheds of the Sacramento and San Joaquin rivers. Although it is possible that there are analytical differences between organic carbon measurements from these different sources, for the purpose of the large-scale evaluation that follows it is assumed that the measurements are comparable (i.e., DOC reported in different studies can be compared).

This chapter provides an overview of the organic carbon data contained in the Drinking Water Policy Database, notably the forms measured, the quantity and spatial distribution of the data, and the concentrations observed at various stations. Data from other sources were used to supplement this data where needed and are discussed below and in subsequent chapters. The plots in this chapter present an informative snapshot of the available data, and set the stage for loading analyses in the next two chapters. Figure 3-1 illustrates key locations in the Central Valley and Delta referred to in this and subsequent chapters.

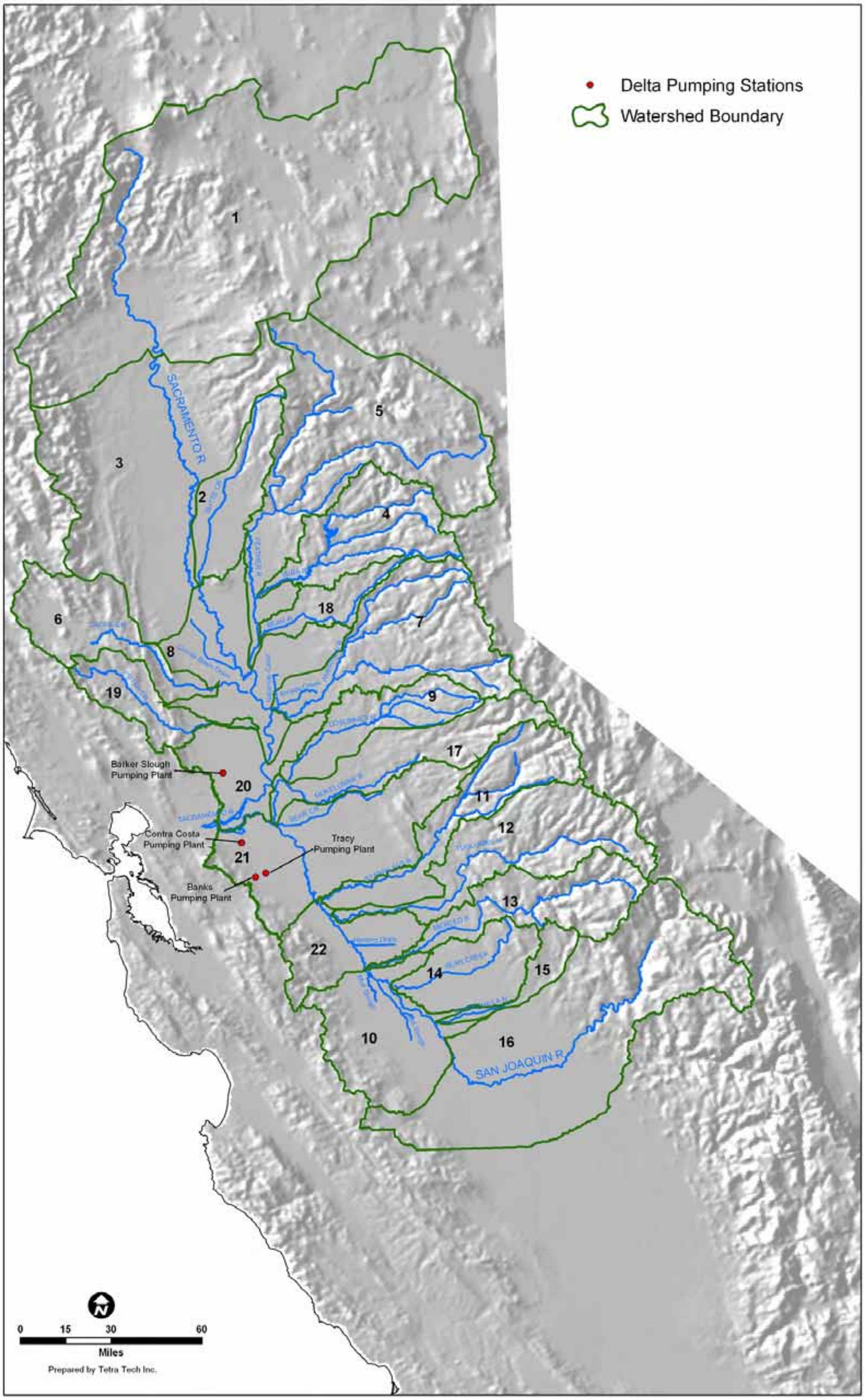


Figure 3-1. Stream reaches and other key locations in the Central Valley and Delta.

3.1 Overview of Concentration Data

Maps showing the distribution of data in the Central Valley are presented in Figures 3-2, 3-3, and 3-4 for total and dissolved organic carbon and UV absorbance at 254 nm, the only three organic carbon-related parameters in the database. Most of the data were collected along the main stems of the Sacramento and San Joaquin rivers and in the Delta. There were limited data for the tributaries to the Sacramento and San Joaquin rivers. Approximately half the stations in the database (representing about a third of the data) had no coordinate information and are not shown in these maps; and the data were not used in this analysis. Based on a spatial evaluation of the data, it appears that both DOC and TOC data are measured widely enough for watershed-wide analysis, although UVA254 is not.

A series of box plots was used to describe the range of organic carbon concentrations at various locations in the watershed. Figures 3-5 and 3-6 show the TOC and DOC concentrations by stations in alphabetic order, respectively. Data from wastewater effluent and from urban runoff were excluded from these plots. Agricultural drainage data are included in these plots, in part because it could often not be clearly distinguished from surface water flows, especially in the San Joaquin Valley. Both linear and log scales are presented because the concentrations in the Delta agricultural drains are an order of magnitude higher than at the other stations. Both plots clearly demonstrate that concentrations are substantially higher in the San Joaquin River Basin than in the Sacramento River Basin. Delta agricultural drainage contains the highest concentrations. This is notable due to the proximity of the Delta agricultural drains to major drinking water intakes.

Figures 3-7 and 3-8 show spatial views of the TOC data and DOC data, respectively. These figures also illustrate the higher concentrations in the San Joaquin River Basin, which is particularly evident for TOC (Figure 3-7).

Appendix A contains a listing of all stations with organic carbon data, including the number of data points for each parameter (DOC, TOC, and UVA254), the period over which sampling was conducted, and whether coordinate information is included. This listing can be used as a reference to identify the quantity of relevant data associated with specific stations in the database, particularly for future work to identify patterns at greater spatial detail than presented in this report. Review of Appendix A shows that stations with the largest number of data points are those on the main stem of the Sacramento and San Joaquin Rivers, especially at stations near the Delta. Many locations had measurements of either TOC or DOC, and data on all three parameters were available for a small number of stations. It was further noted that many stations appeared in the database under different, slightly varying names. In subsequent analysis, such stations were merged with a set of consistent names.

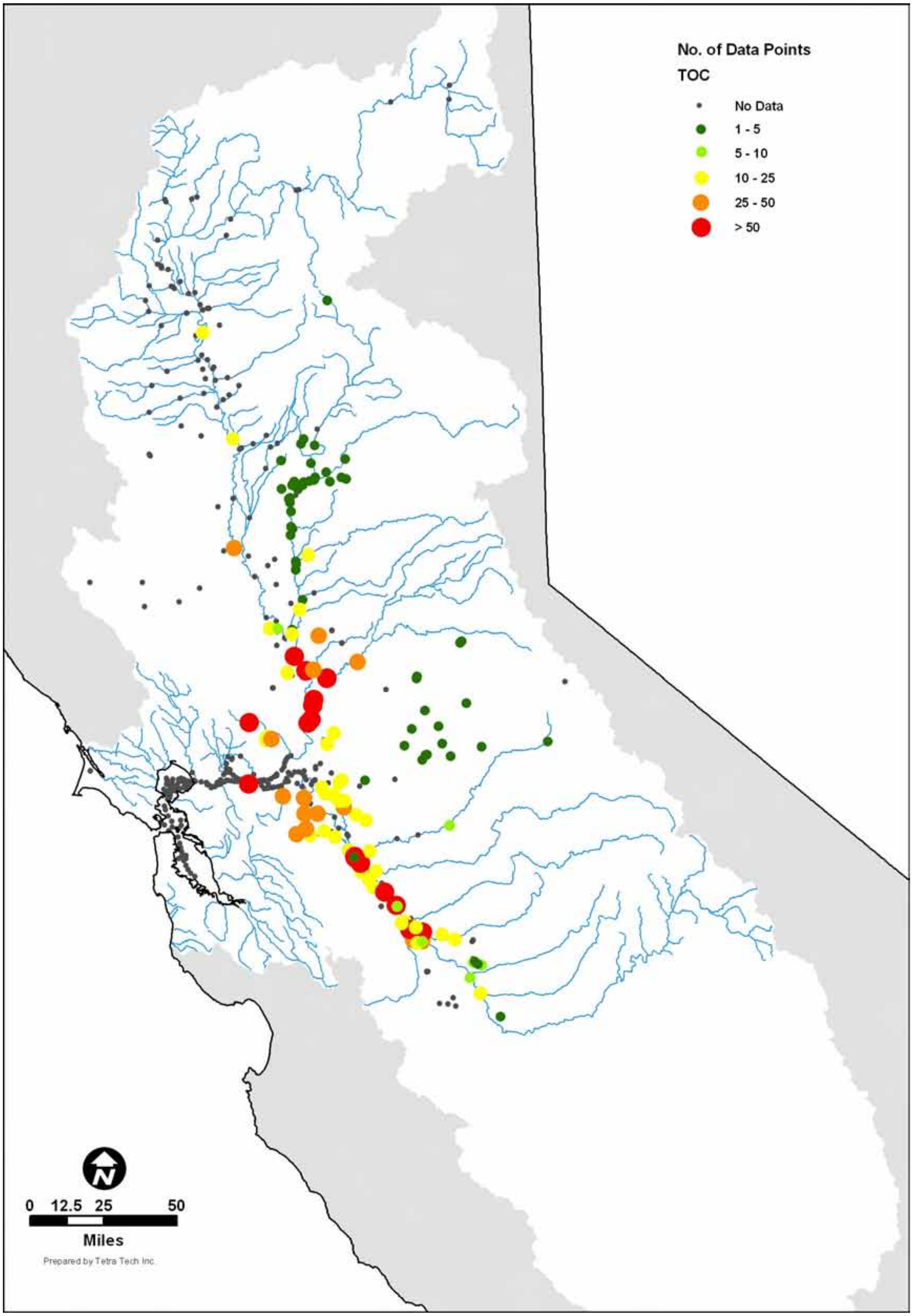


Figure 3-2. Number of TOC data points at each station in the Central Valley Drinking Water Policy Workgroup database.

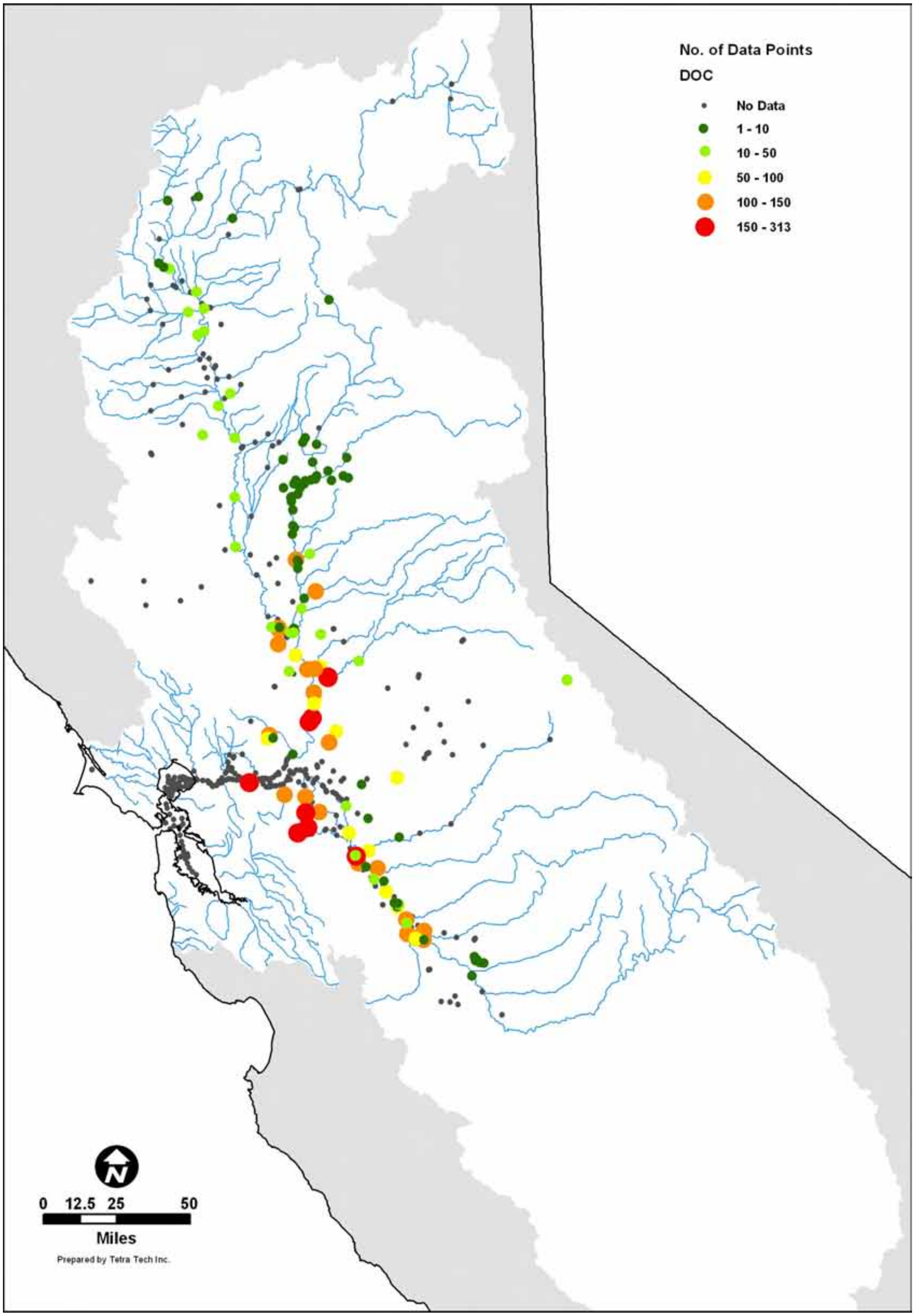


Figure 3-3. Number of DOC data points at each station in the Central Valley Drinking Water Policy Workgroup database.

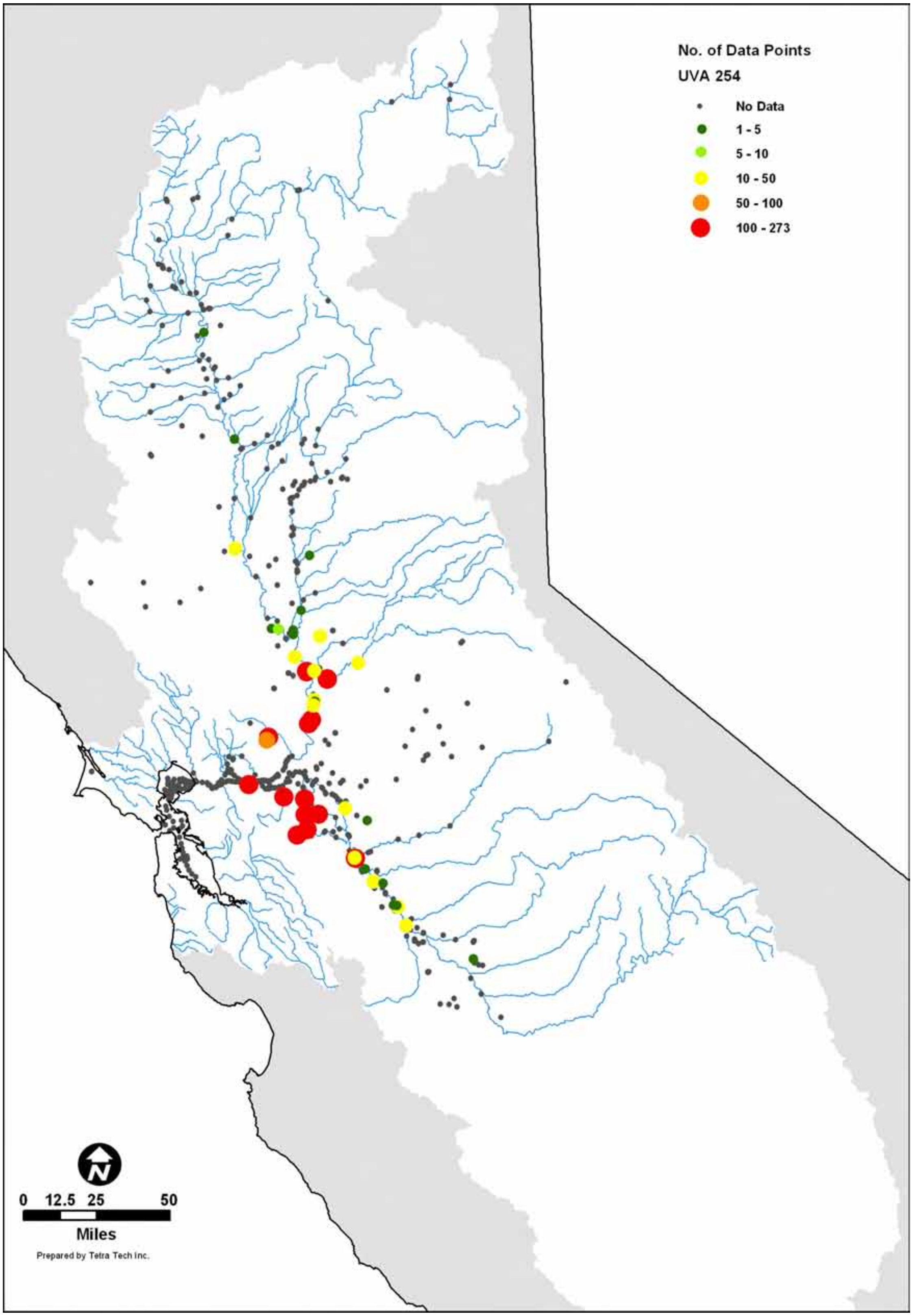


Figure 3-4. Number of UVA 254 data points at each station in the Central Valley Drinking Water Policy Workgroup database.

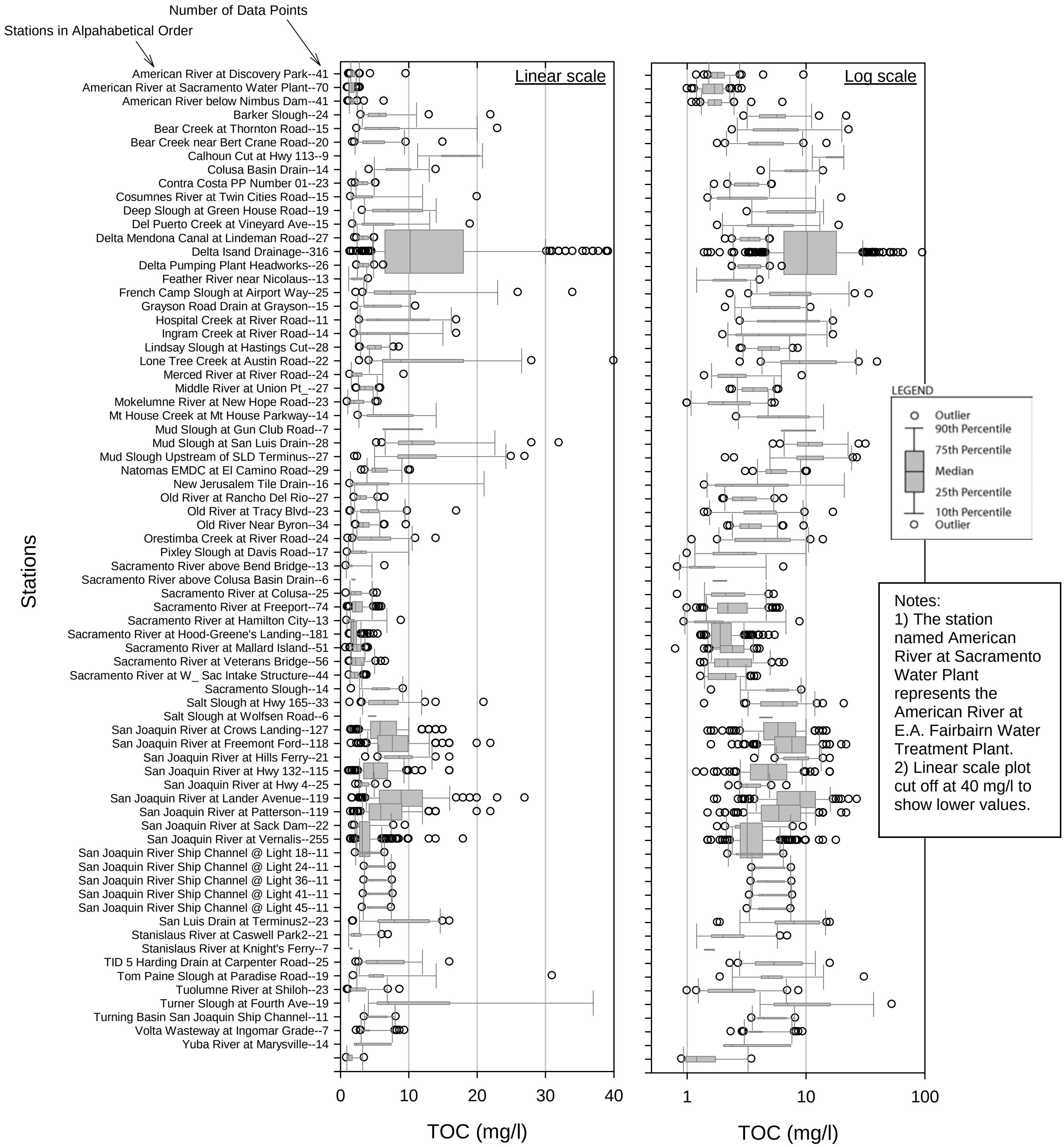


Figure 3-5. The range of TOC concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points.

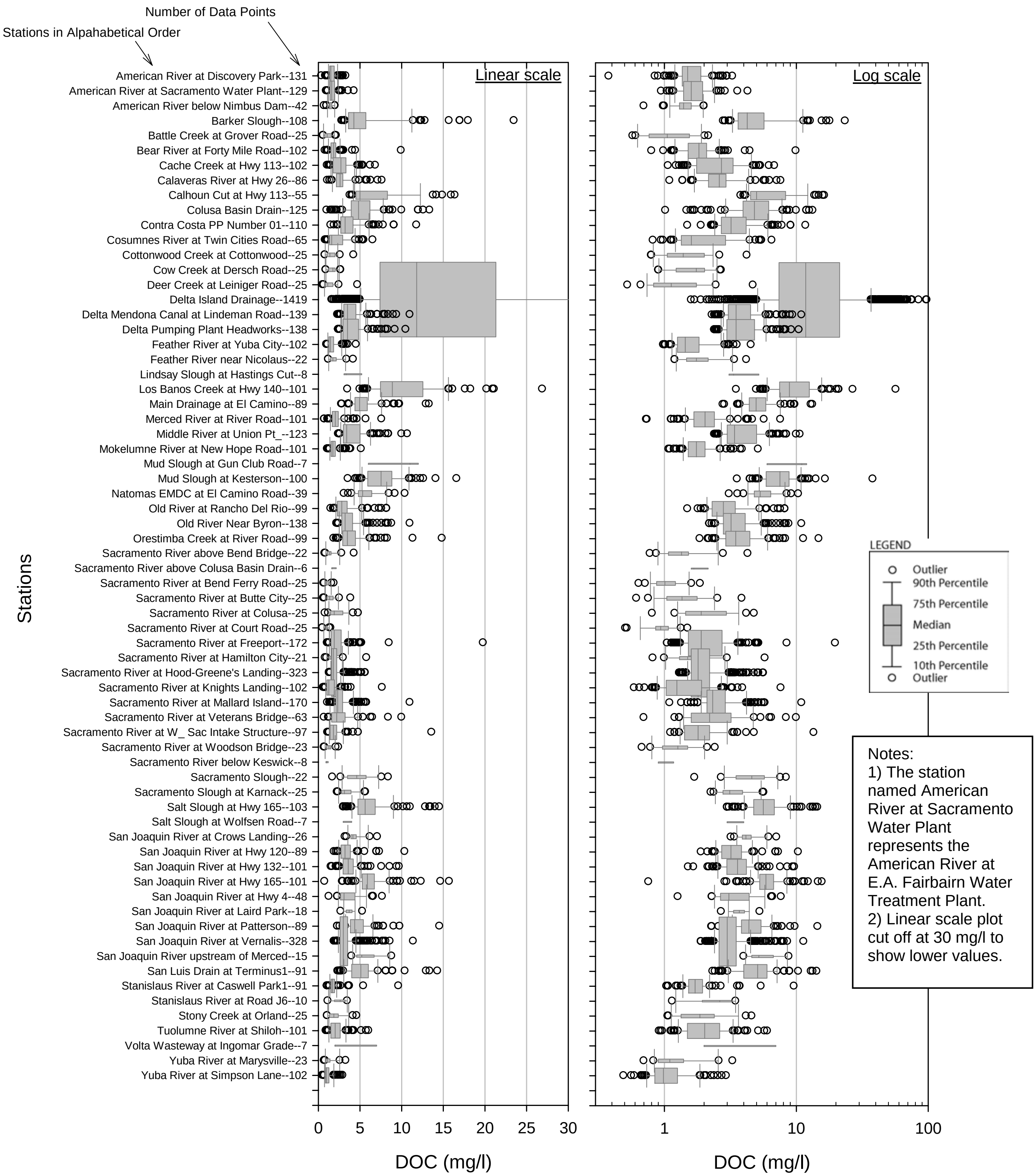


Figure 3-6. The range of DOC concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points.

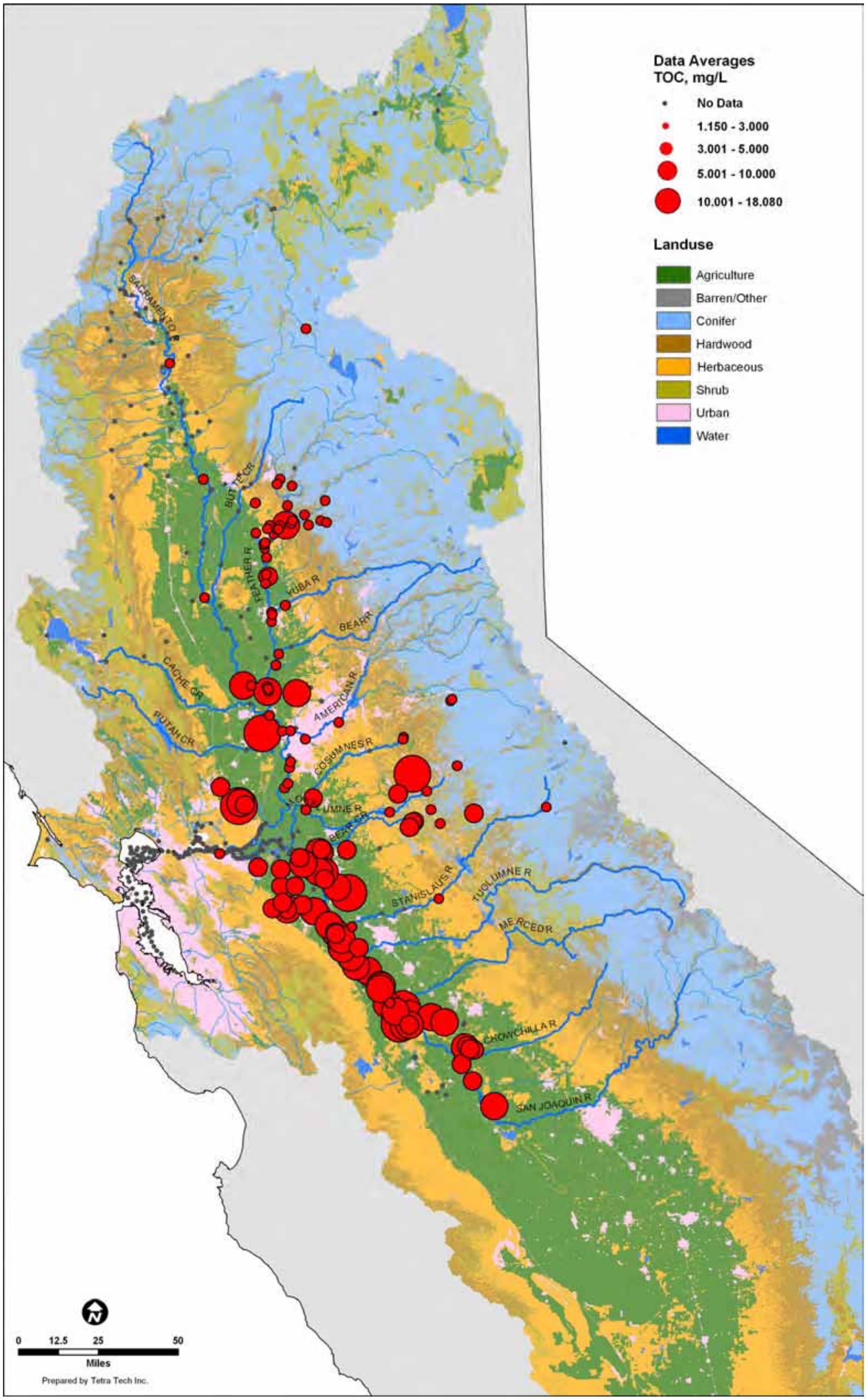


Figure 3-7. TOC concentrations in the Central Valley and Delta.

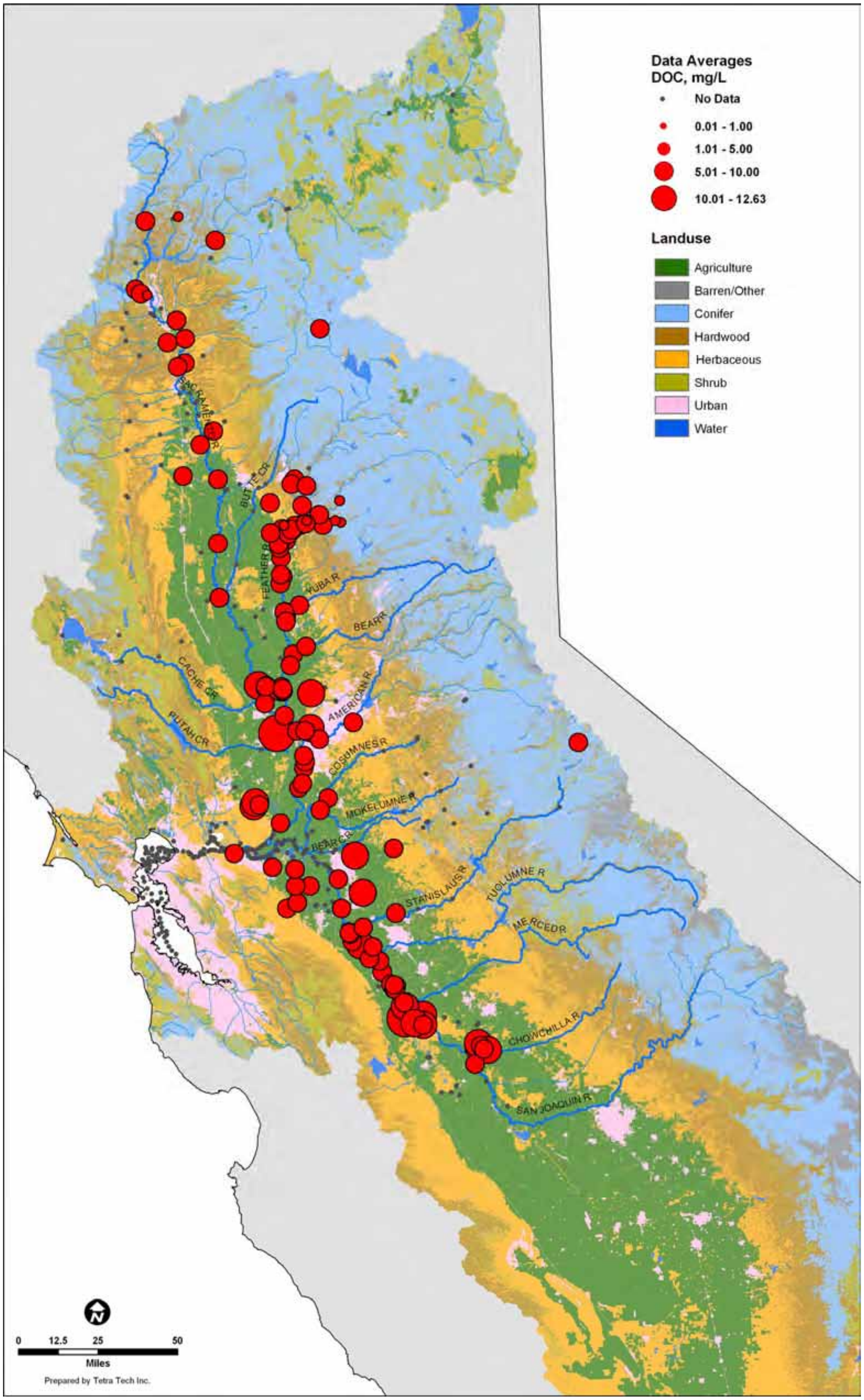


Figure 3-8. DOC concentrations in the Central Valley and Delta.

There are good correlations between DOC and TOC and between DOC and UVA254 (Figure 3-9 and 3-10) over the entire range of concentrations. However, over the range of concentrations of most interest in surface waters, i.e., less than 20 mg/l, the correlations appear weaker, particularly between DOC and UVA254. UVA254 has been has been related to aromaticity of organic carbon and THMFP (see Chapter 2). These data call for measurements of all three parameters wherever possible, and are consistent with past reports that suggest organic carbon from multiple sources is less likely to have a clear DOC-UVA254 relationship.

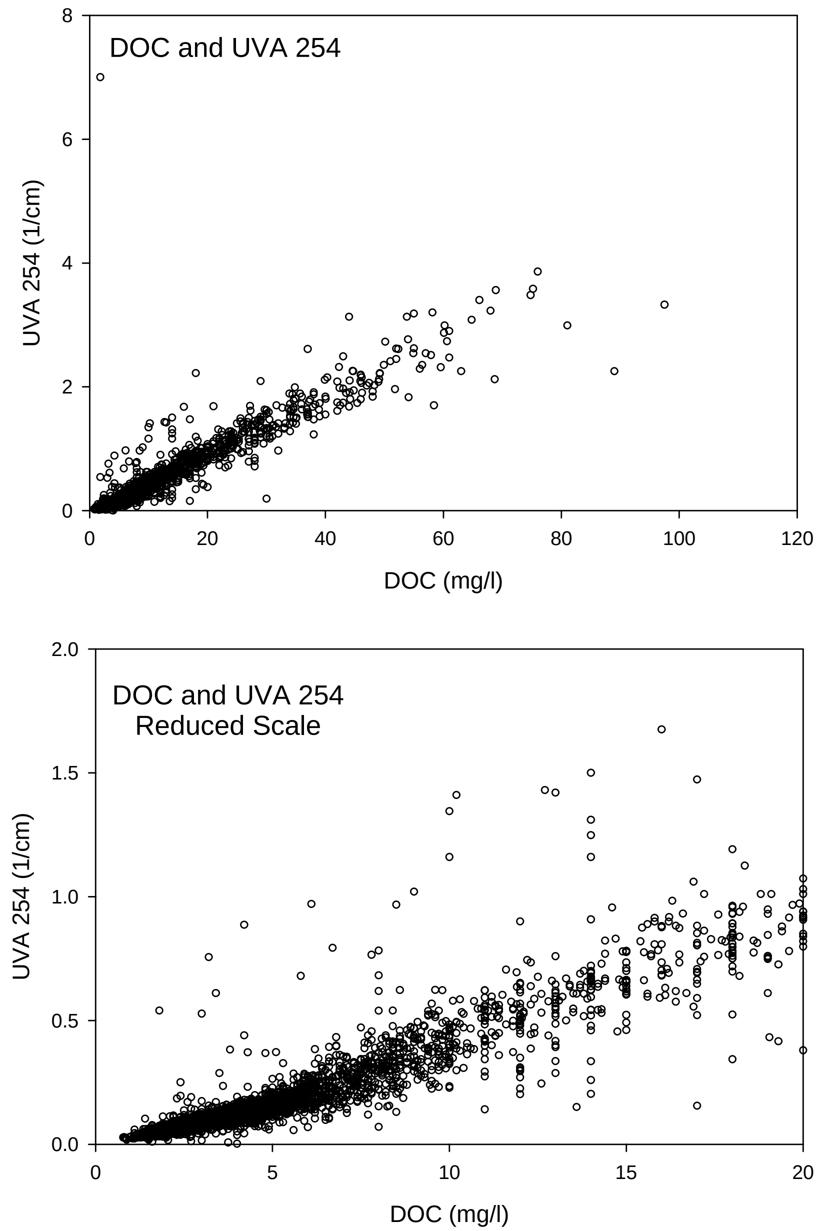
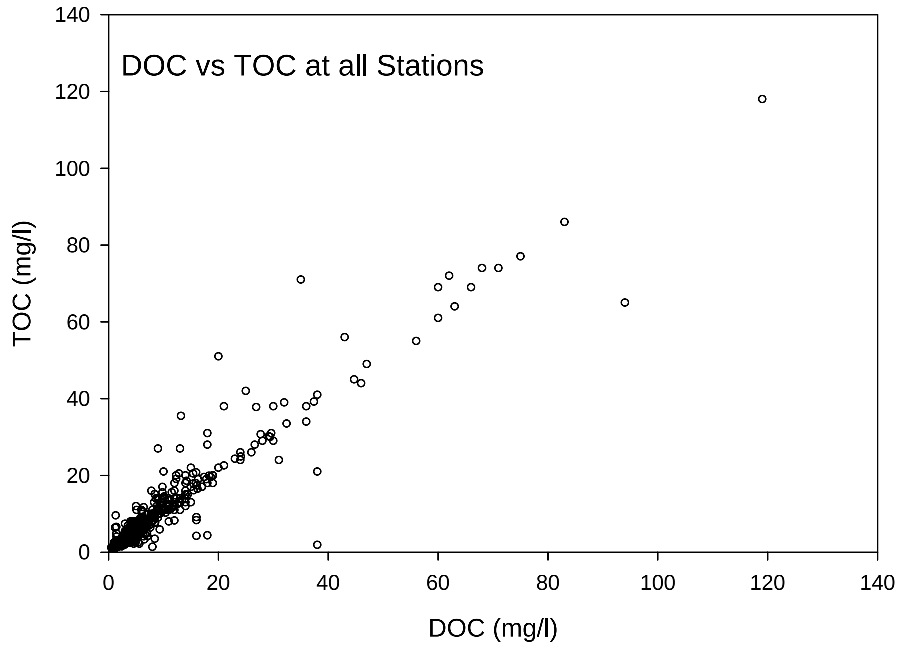


Figure 3-9. DOC and UVA254 at all stations in the database where contemporaneous measurements were available.



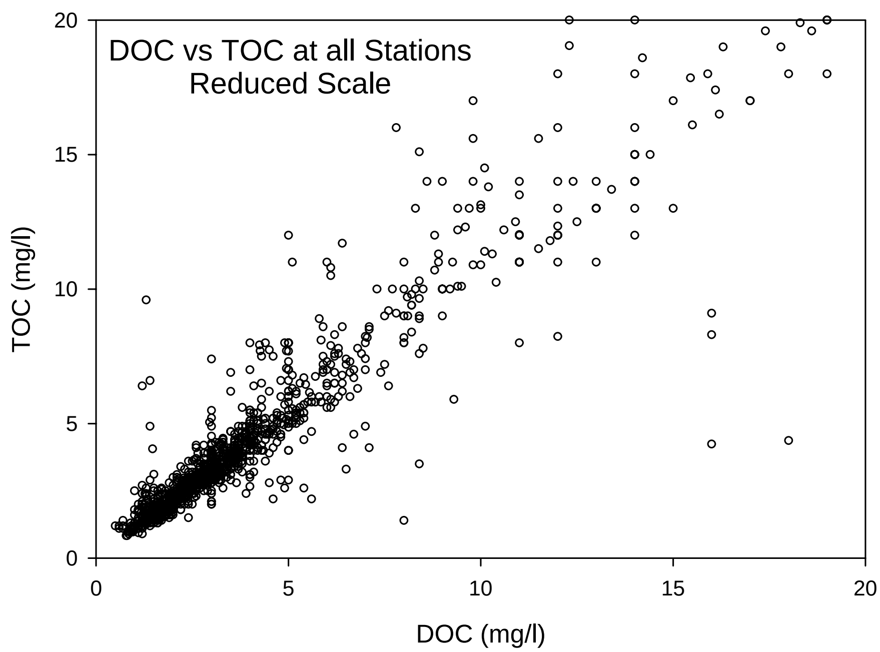


Figure 3-10. DOC and TOC at all stations in the database where contemporaneous measurements were available.

Trends along the main stem of the two major rivers were examined through box plots. Figure 3-11 and 3-12 show the TOC concentrations by station moving from upstream to downstream for the Sacramento and San Joaquin Rivers. An interesting and contrasting trend emerges. The Sacramento River concentrations increase from upstream to downstream, possibly due to the addition of organic carbon from anthropogenic (human) sources. In the San Joaquin River (downstream of Sack Dam), concentrations first increase then decrease as the river flows downstream. Immediately downstream of Sack Dam, the river is dominated by agricultural drainage which is diluted as the river flows downstream by flows from other sources with lower concentrations, principally the tributaries on the east side of the valley.

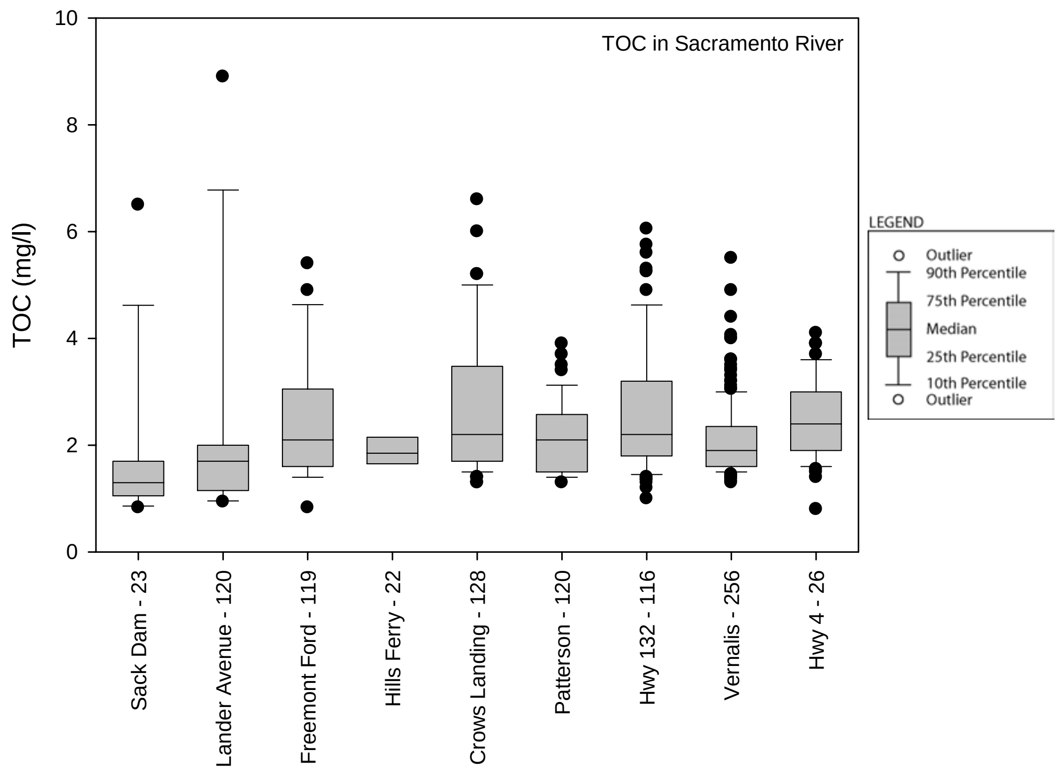


Figure 3-11. TOC at various locations in Sacramento River. The number of data points is shown after each station name.

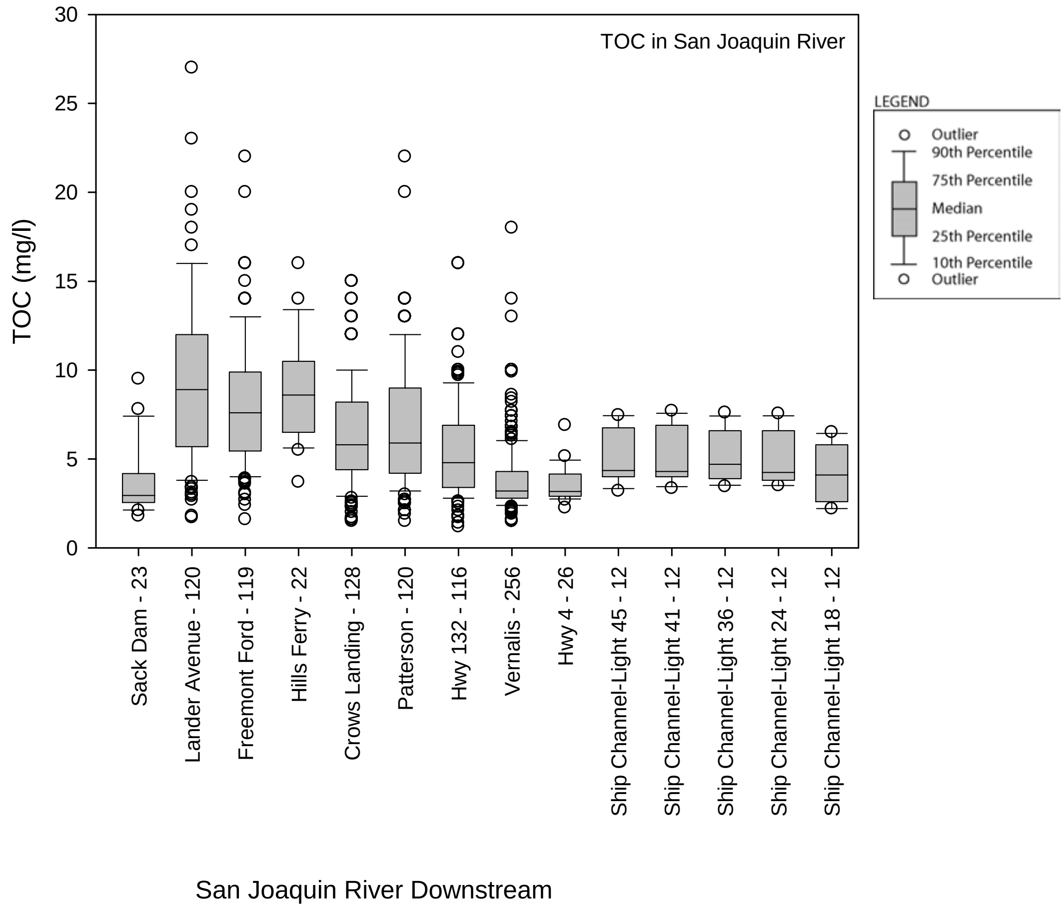


Figure 3-12. TOC at various locations in San Joaquin River. The number of data points is shown after each station name.

Seasonal patterns in concentration can also be explored through box plots as shown in Figures 3-13 and 3-14. In each of the figures, three plots display concentrations at locations moving downstream. As with the previous set of figures, there are important differences between the Sacramento and San Joaquin Basins. In the Sacramento River, the highest concentrations are associated with the wet months, with relatively lower concentrations in the dry months. Moving downstream, the seasonal variation of data decreases, as evidenced by greater uniformity of concentrations at Mallard Island than at Freeport. In the San Joaquin River, the highest concentrations are observed in the dry months when the flows are dominated by agricultural drainage. Organic carbon concentrations in the San Joaquin River are substantially higher than in the Sacramento River.

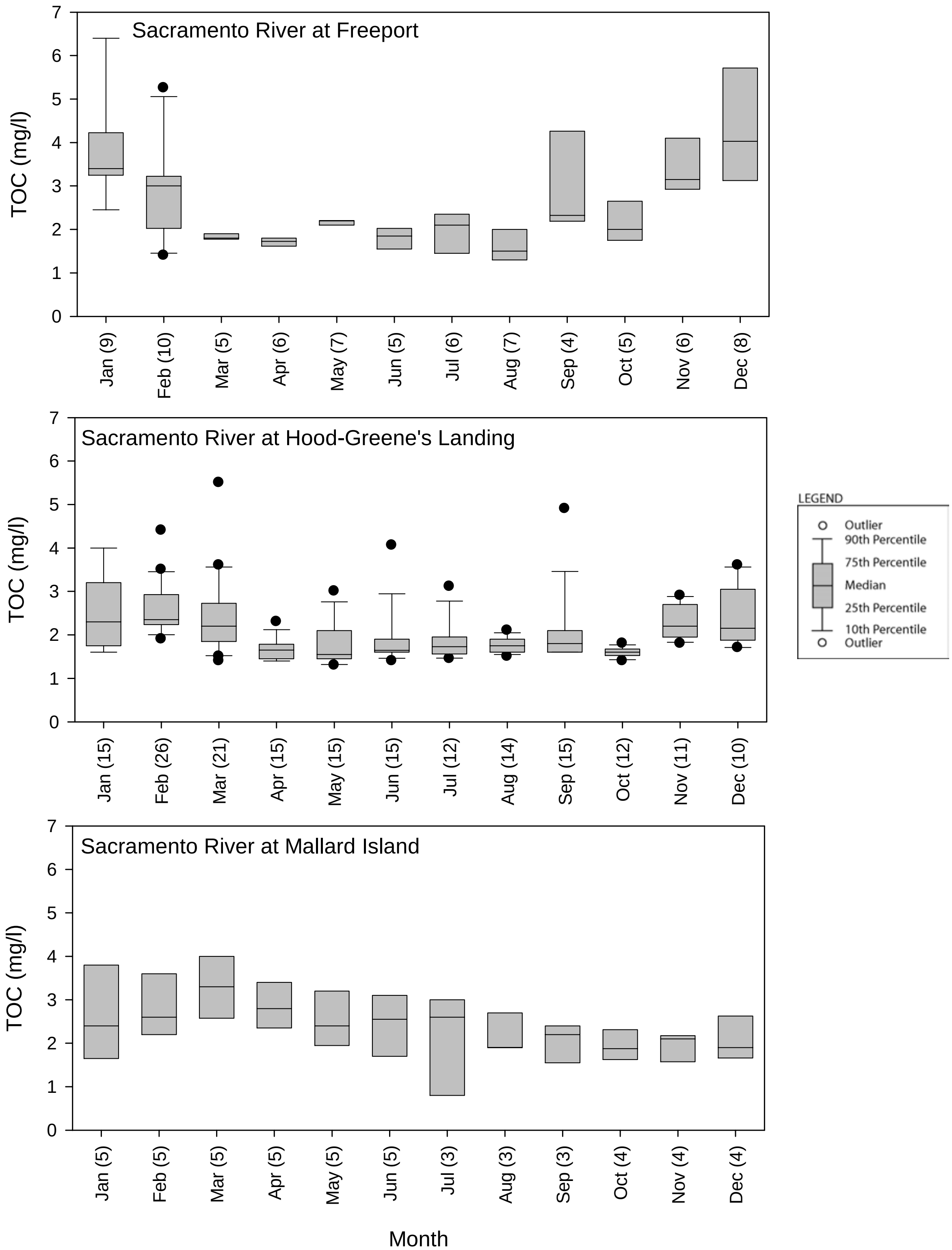


Figure 3-13. Temporal variation in concentrations at key locations in the Sacramento River. The number of data points is shown after each month.

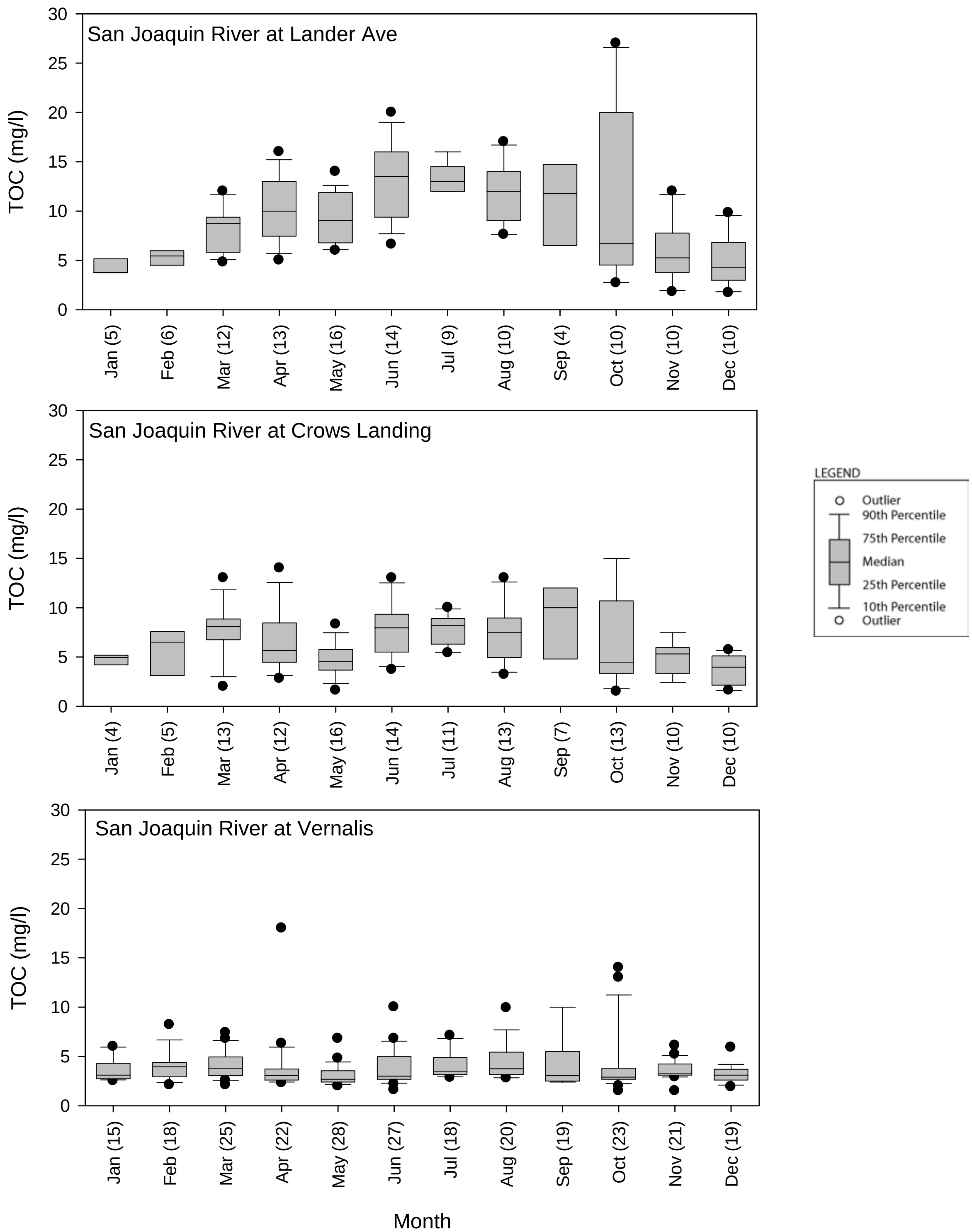


Figure 3-14. Temporal variation in TOC concentrations at key locations in San Joaquin River. The number of data points is shown after each month.

3.2 ADDITIONAL DATA USED

In addition to the values in the database discussed above, some additional sources of information were also gathered for this analysis. This includes flow data, which are used in combination with concentration data to estimate loads, and some additional chemistry data. The data described below refer specifically to data that were manipulated and/or analyzed for the purpose of this work. Analyses presented by other authors in published papers and reports are cited throughout this report.

3.2.1 FLOW DATA

The USGS has an extensive network of flow monitoring stations throughout California (Figure 3-15). Daily stream discharge data were obtained from the United States Geological Survey (USGS) from http://nwis.waterdata.usgs.gov/usa/nwis/discharge at selected locations for which loads were estimated. These locations primarily corresponded to the outflow locations of the major tributaries of the Sacramento and San Joaquin Rivers. A detailed evaluation of the flow data is presented in Appendix B. Additional flow data for the Delta region (including outflows in municipal/industrial intakes) were obtained from a computer model called DAYFLOW (supported by California Department of Water Resources, and available electronically from http://www.iep.ca.gov/dayflow/index.html). DAYFLOW uses historical pumping records where available, and this data is in the most convenient form for use and manipulation. Load estimates using the USGS and DAYFLOW values are presented in Chapters 4 and 5.

3.2.2 CHEMISTRY DATA

A major additional source of chemistry data was the Municipal Water Quality Investigations (MWQI) Program, from which data was obtained electronically for this task from http://wdl10.water.ca.gov/wq/mwqi/mwqimap.cfm. MWQI data through 2000 were included in the Drinking Water Policy Database; however, data from 2000 to the present were entered into DWR's Water Data Library. The MWQI Program obtains grab sample data on TOC, DOC, and UVA254 at 10 locations around the Delta. Limited data were also obtained from the MWQI real time monitoring program at selected locations around the Delta (http://wq.water.ca.gov/mwq/toc/tocpage.htm). Other chemistry data sources included a database of USGS and EPA data compiled for the purpose of evaluating organic carbon loads in the Central Valley (Saleh, et al., 2003). Additional data from MWQI and Saleh et al. (2003) are included in the data summary provided in Appendix A.

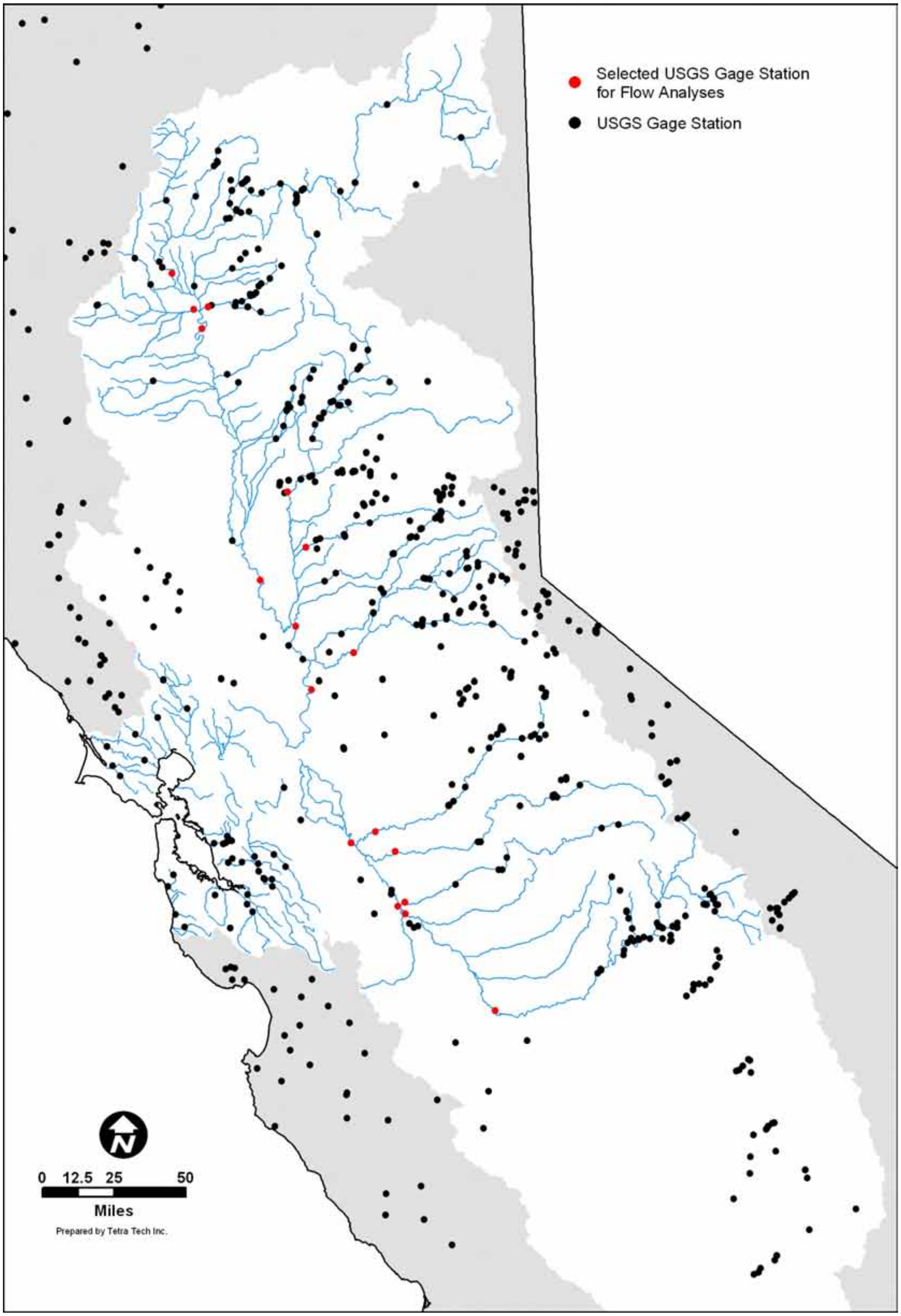


Figure 3-15. Stations with continuous flow records available through the USGS (on the internet at http://nwis.waterdata.usgs.gov/usa/nwis/discharge). Flow records for different stations exist over different time periods.

3.3 MAJOR FINDINGS

The vast majority of the organic carbon data in the database, compiled by the Central Valley Drinking Water Policy Workgroup, consisted of measurements of TOC, DOC, and UVA at 254 nm. Most stations reported one or two of these parameters, with very few reporting all three. Data on other parameters, such as THMFP, were not present in this database. Point source data on organic carbon were limited to three wastewater treatment plants. Flow data were not part of the database and were obtained from other publicly available sources.

Most of the data are collected in and near the Delta, with relatively limited sampling in the upper portions of the watershed. There was very little information on the organic carbon concentrations in reservoir releases, although reservoirs and their upstream watersheds together comprise a large portion of the overall watershed area.

Box plots provided a quick summary of the available data, and showed clearly the elevated DOC/TOC concentrations in the San Joaquin Basin and in the Delta agricultural drains. At most locations, much of the TOC is present as DOC, although the percentage varies by location and by season. The Sacramento and San Joaquin Rivers show interesting trends, with the former exhibiting the highest concentrations in wet months, and the latter the highest concentrations in dry months.

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).

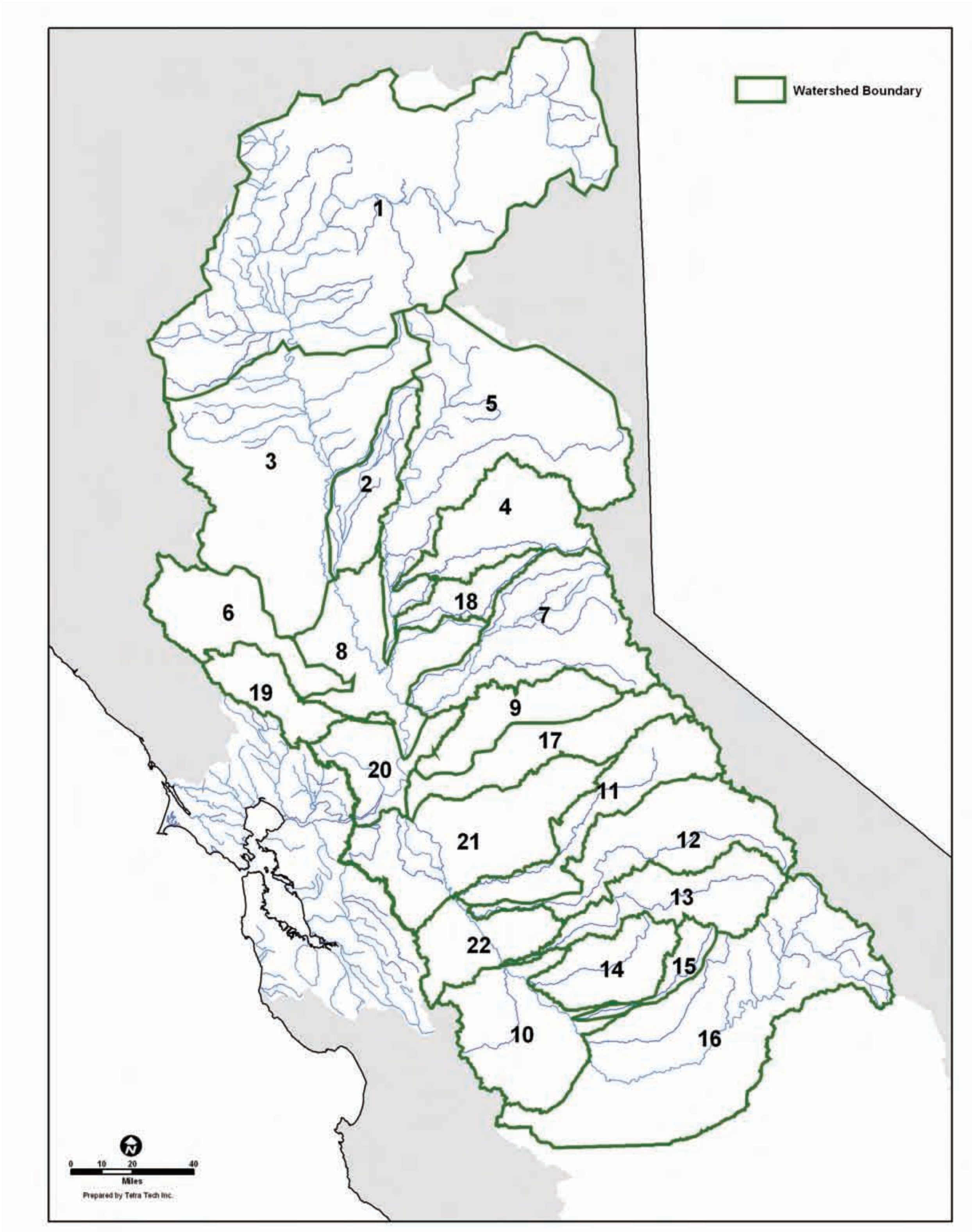


Figure 4-1. Sub-watersheds associated with principal tributaries

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.

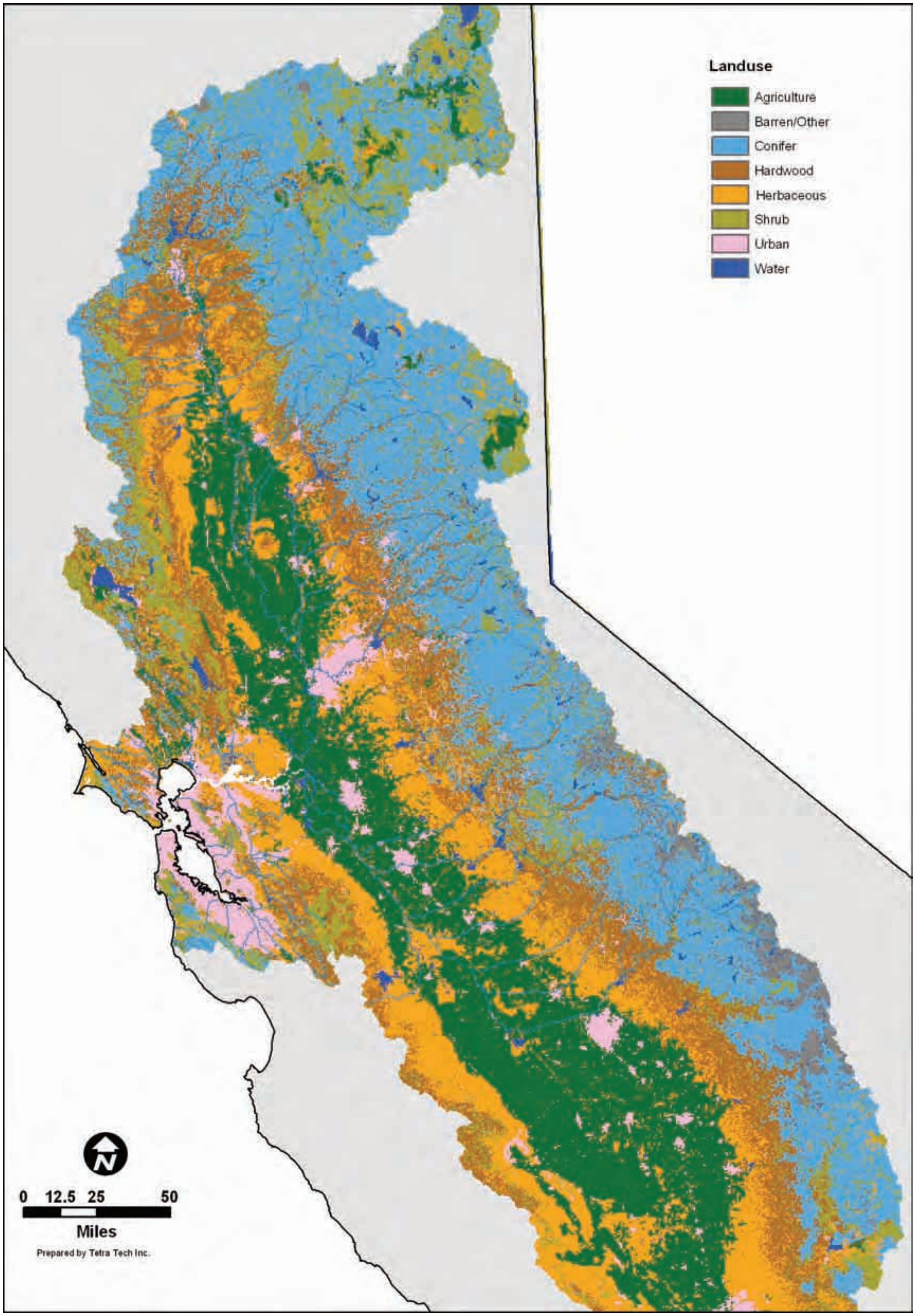


Figure 4-2. Land use in the Central Valley. Data obtained from obtained from http://gis.ca.gov/.

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.

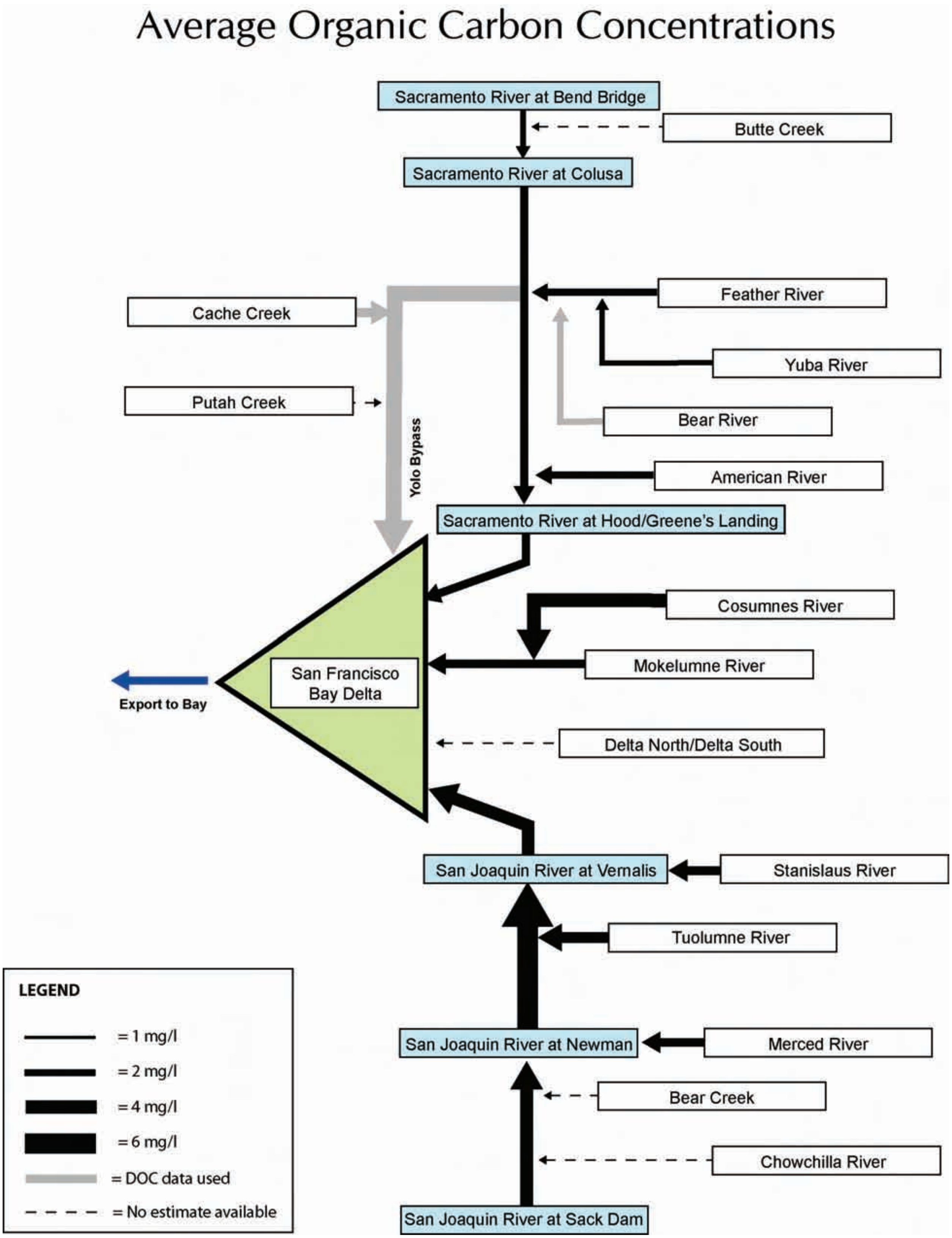


Figure 4-3. Average organic carbon concentrations in the sub-watersheds (TOC unless noted).

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 (km^2)	Area (mi^2)	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.

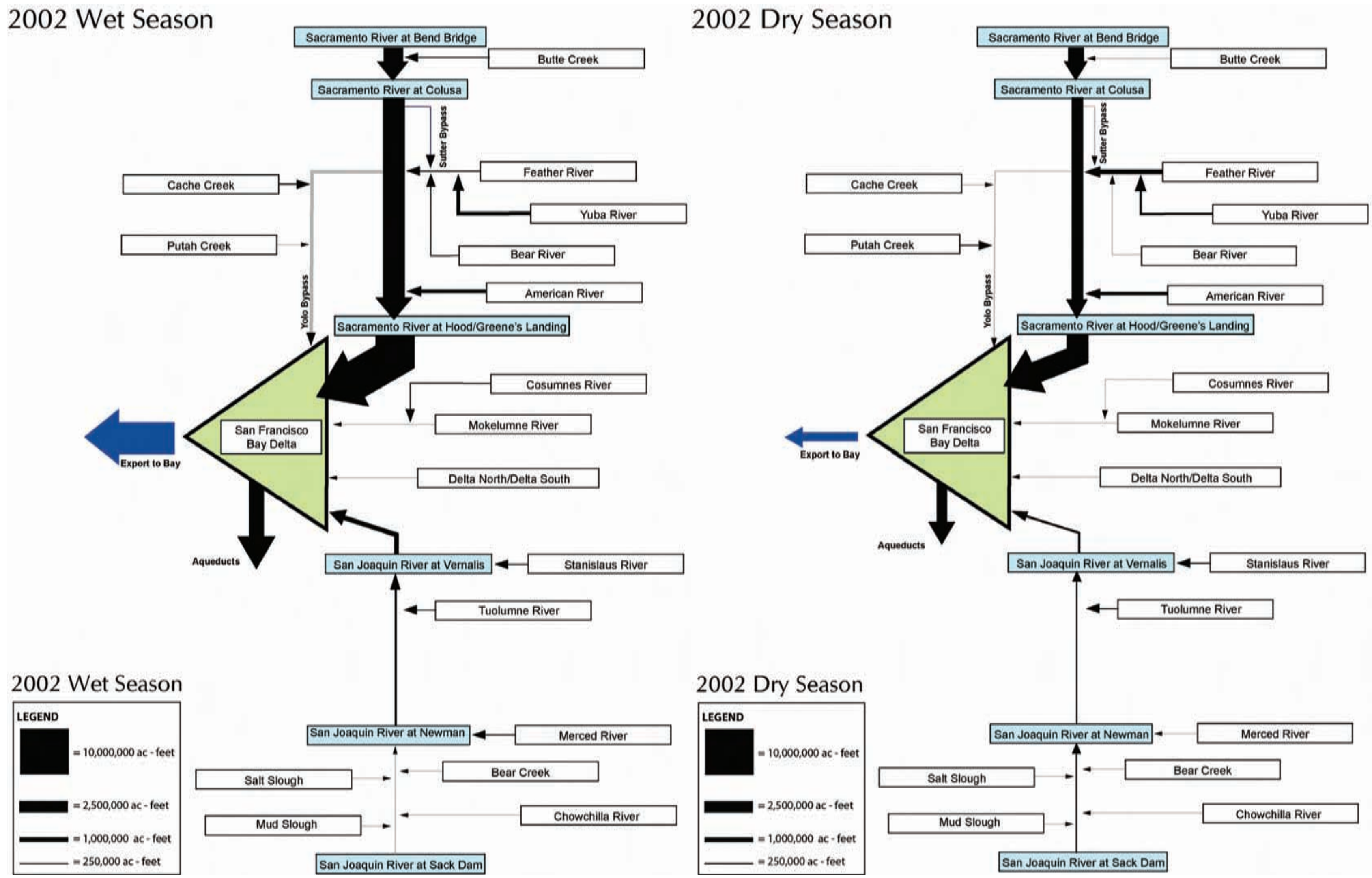


Figure 4-4. Flows in the dry and wet season of 2002 (a dry year) on a schematic representation of the San Joaquin-Sacramento River systems.

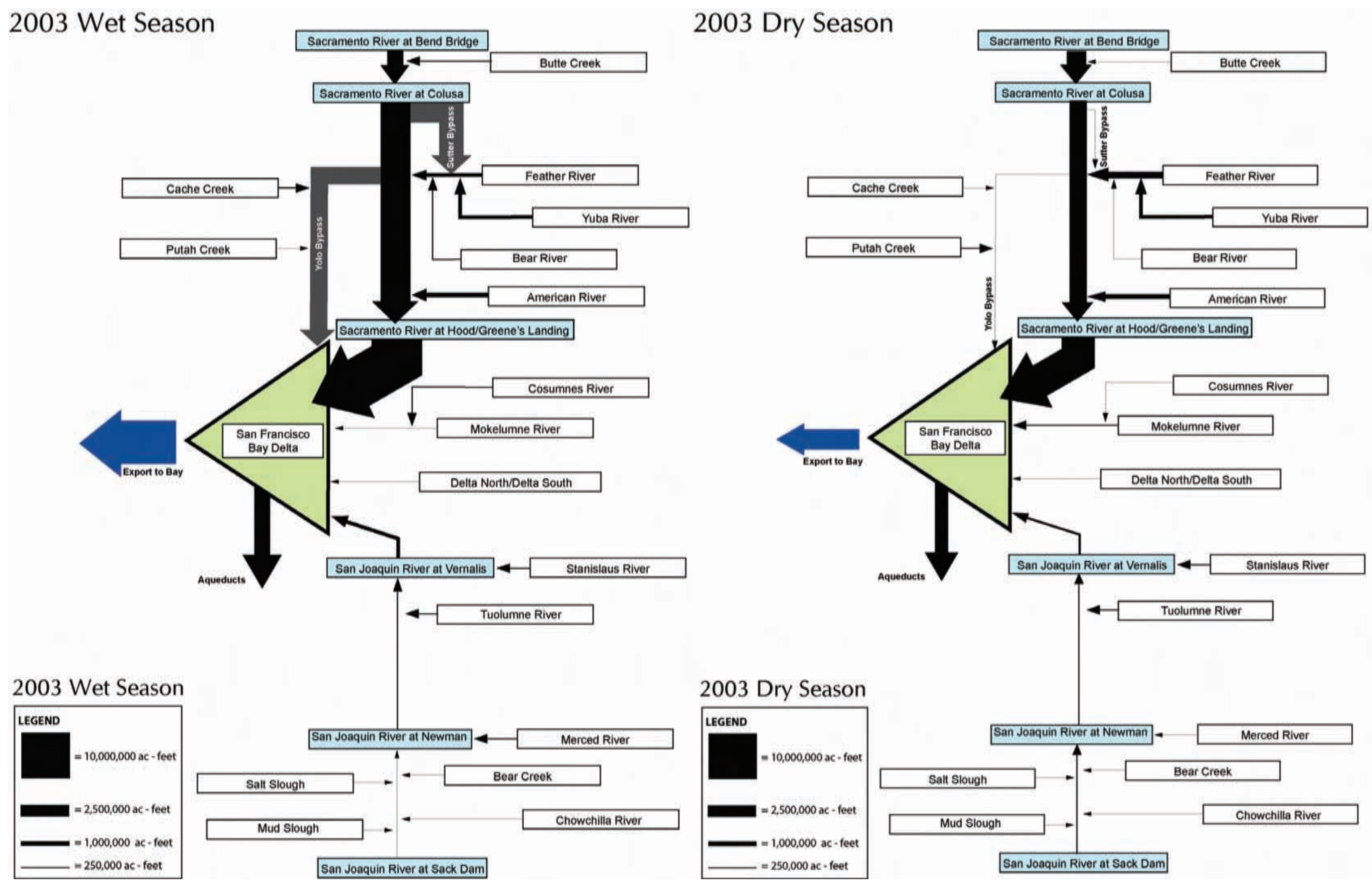


Figure 4-5. Flows in the dry and wet season of 2003 (a wet year) on a schematic representation of the San Joaquin-Sacramento River systems.

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).

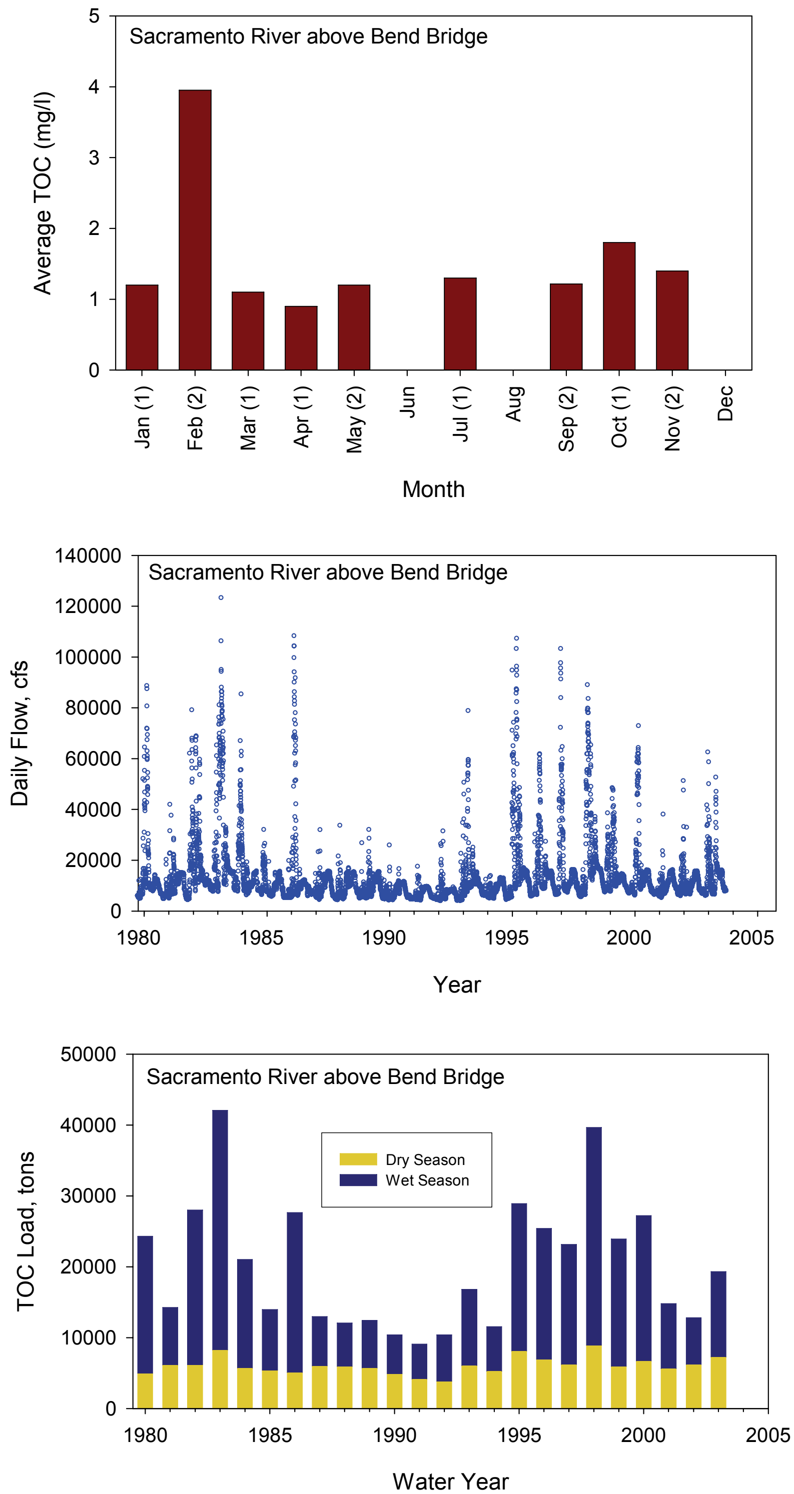


Figure 4-6. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River above Bend Bridge.

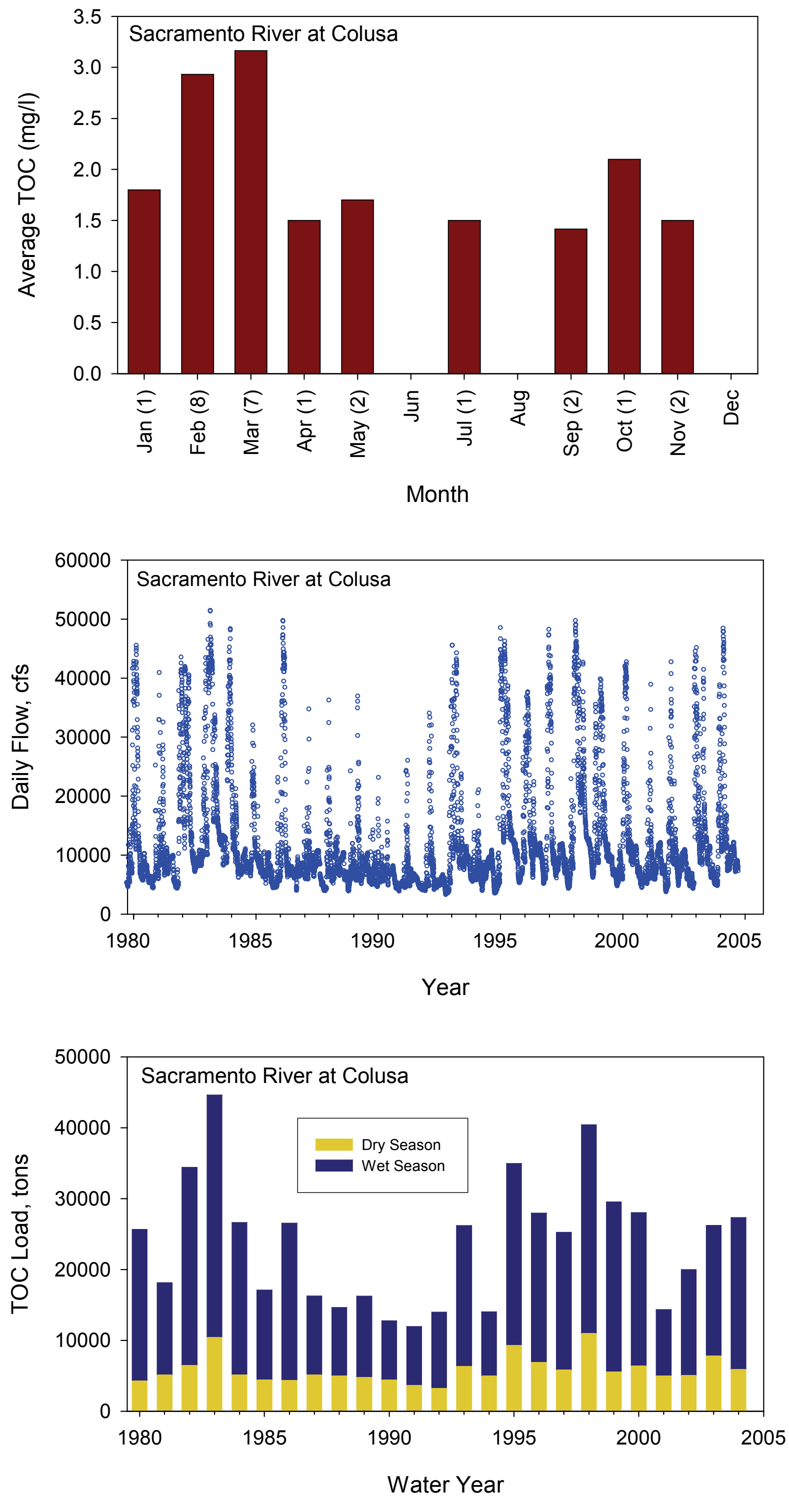


Figure 4-7. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River at Colusa.

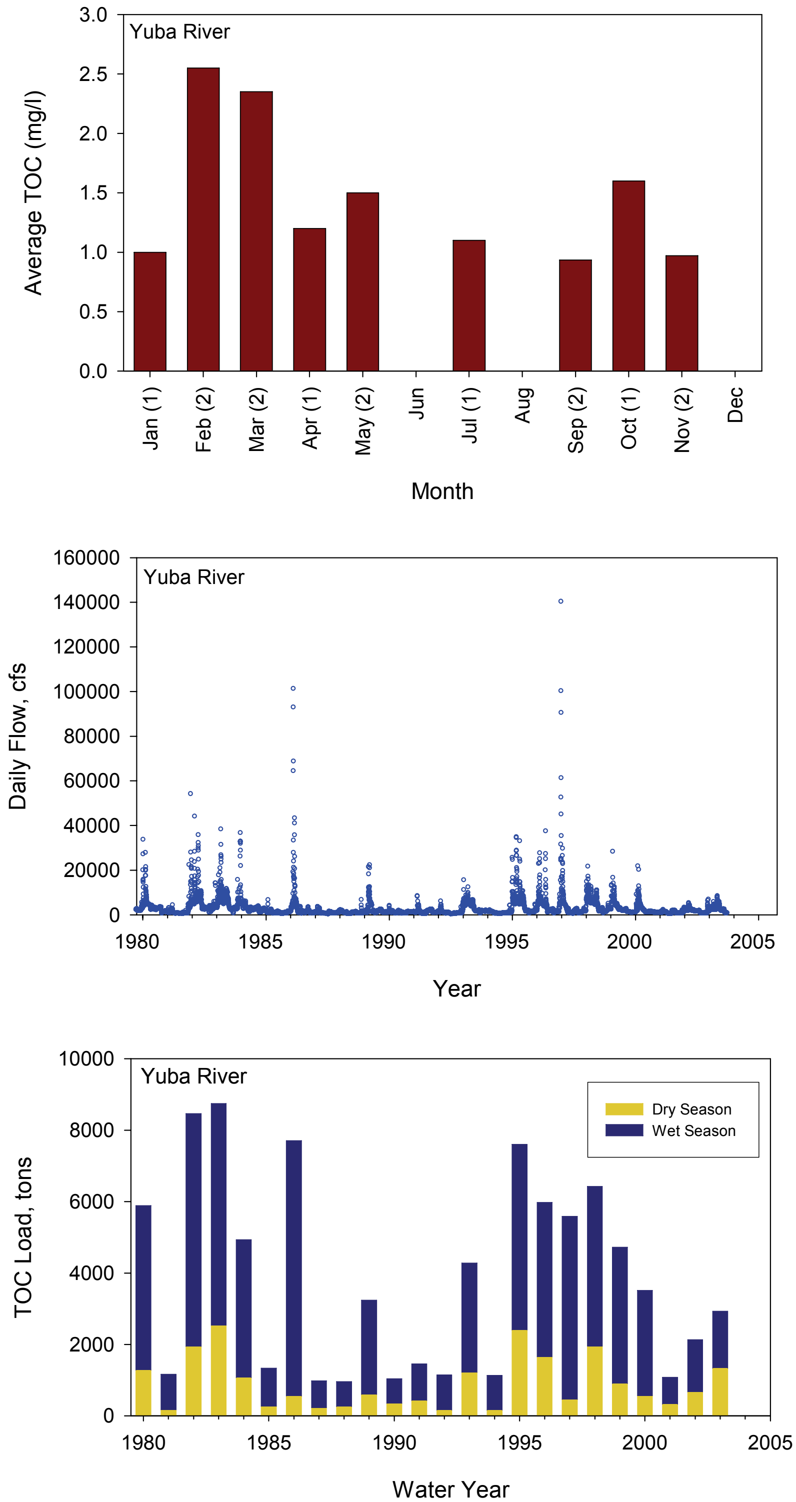


Figure 4-8. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Yuba River.

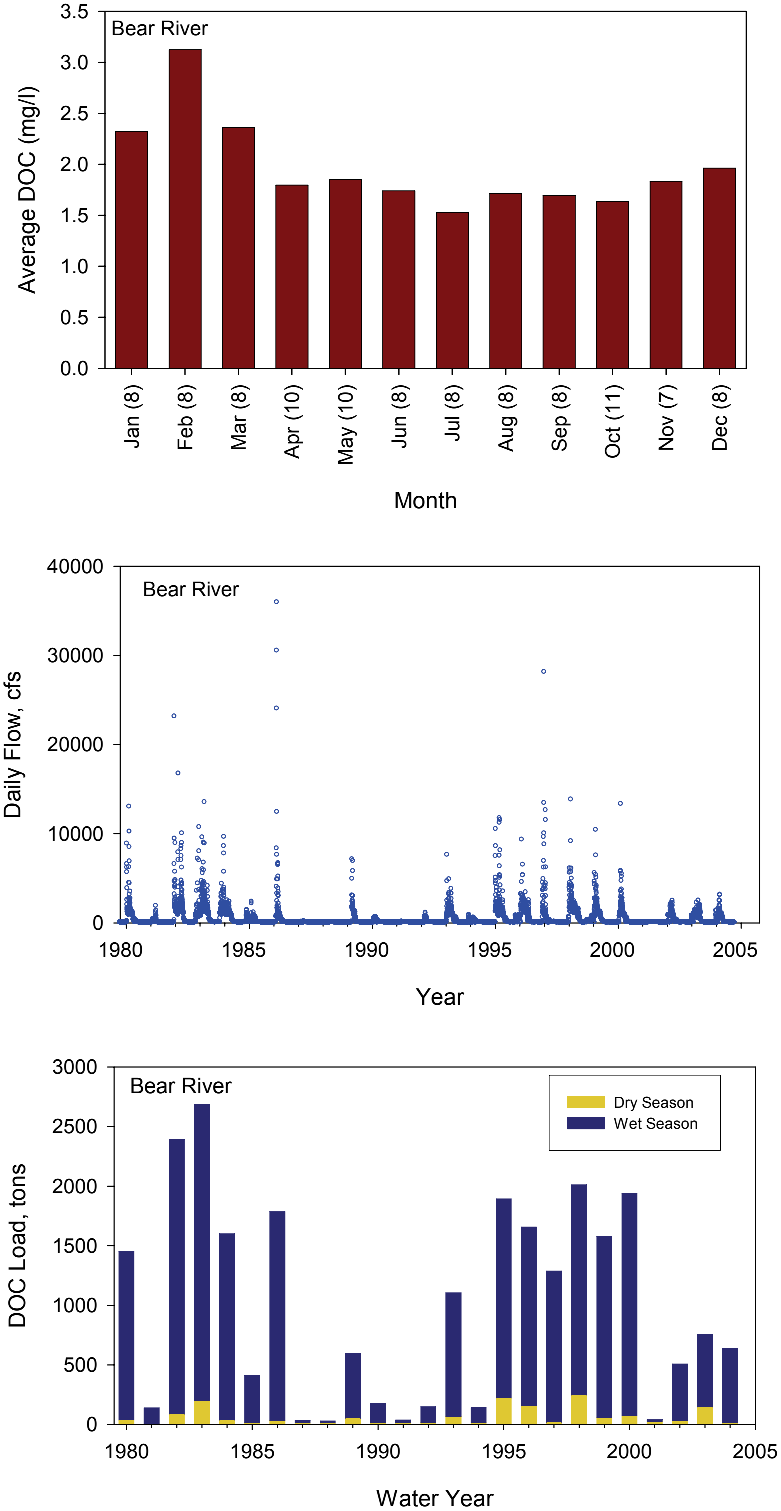


Figure 4-9. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Bear River.

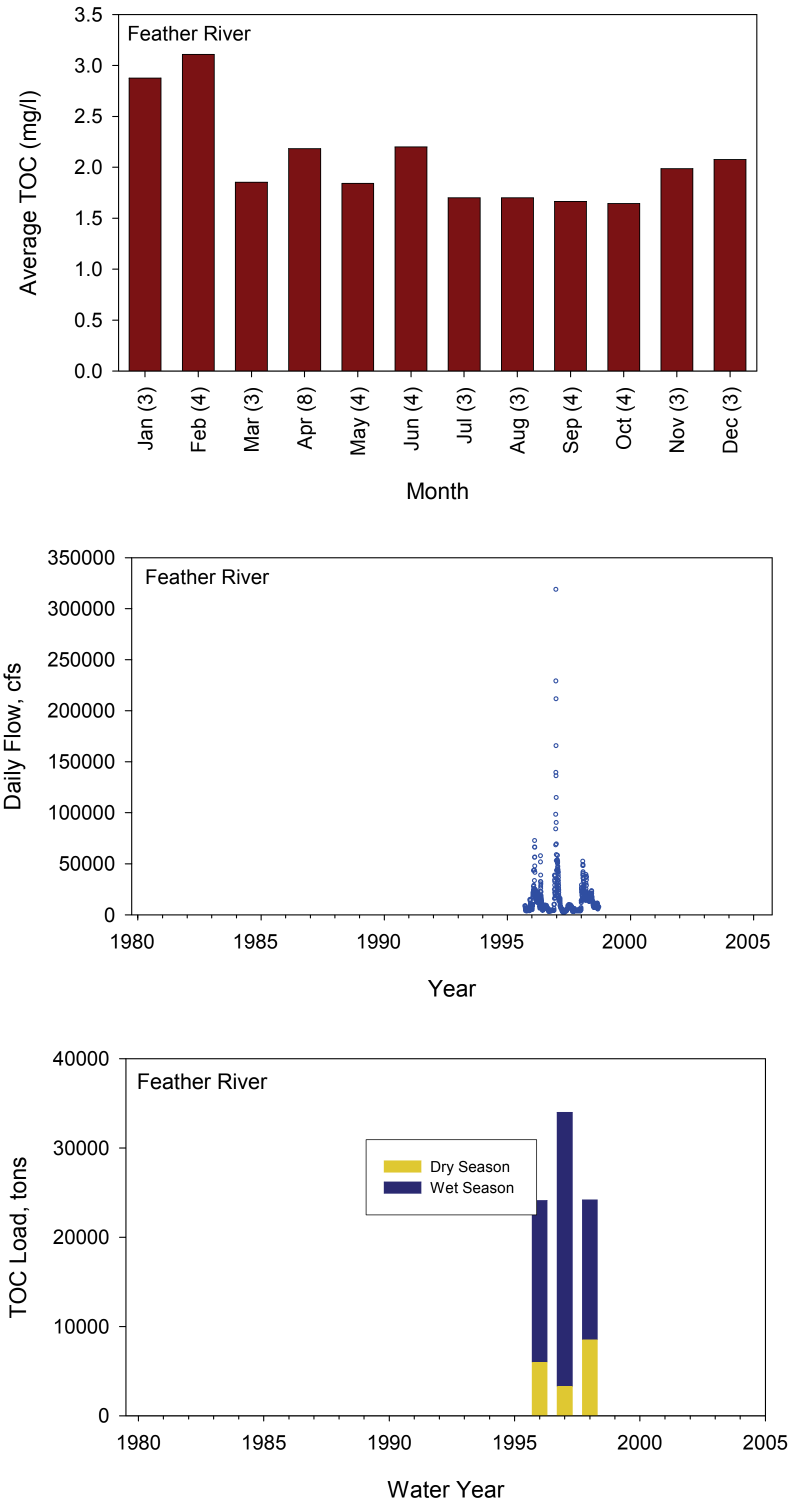


Figure 4-10. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Feather River.

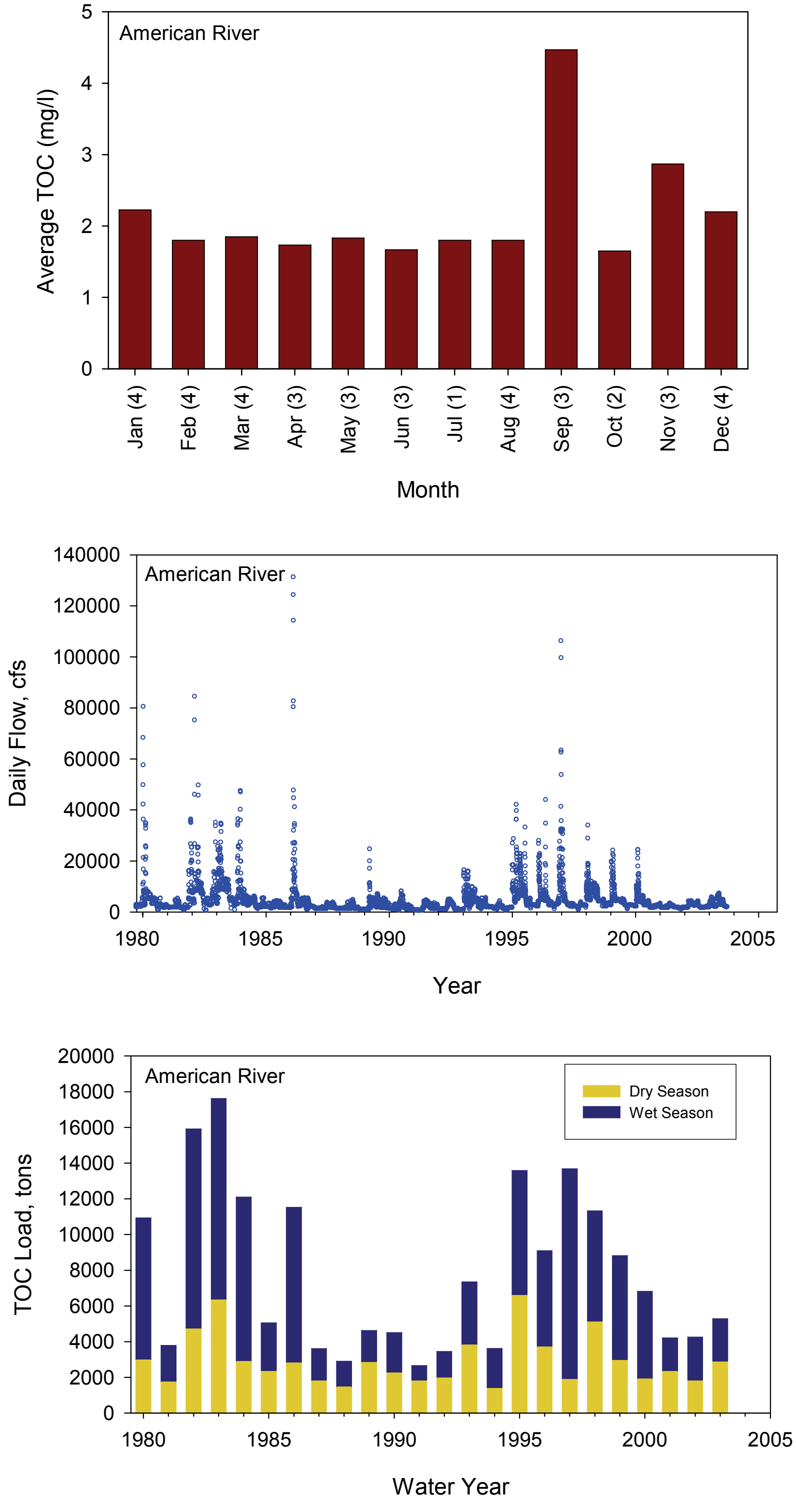
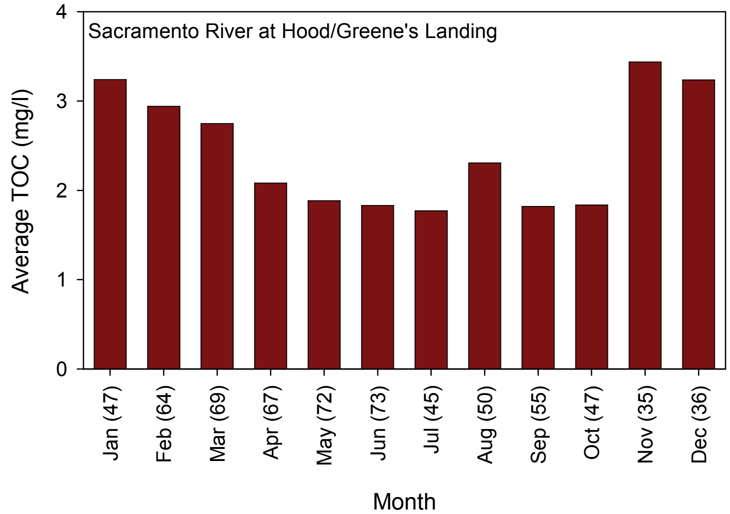
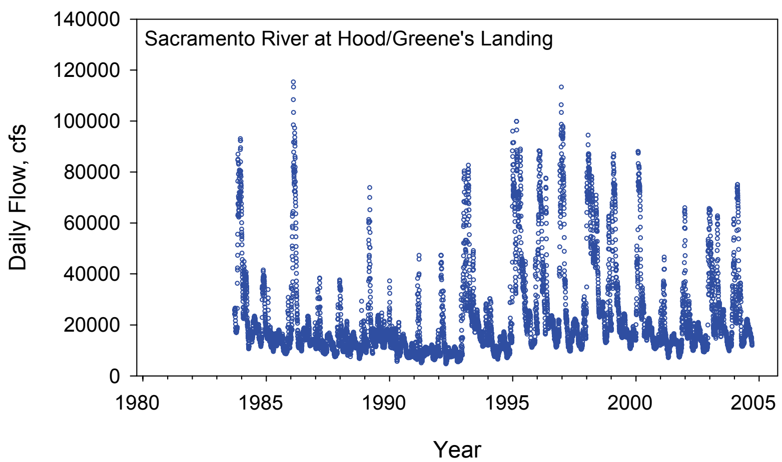


Figure 4-11. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the American River.





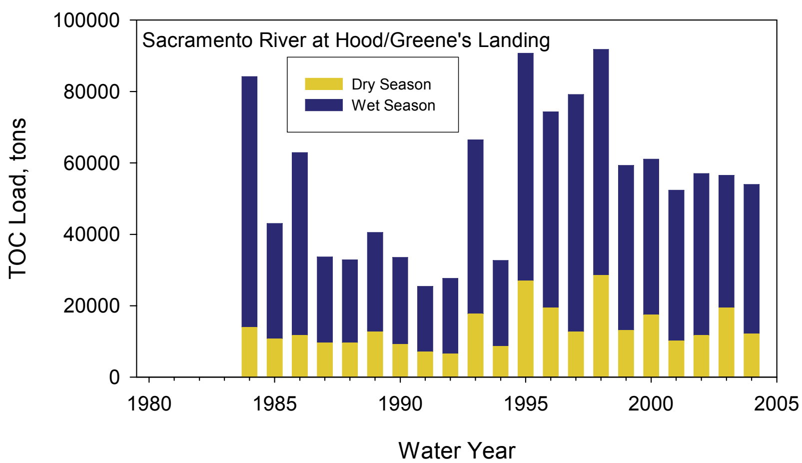


Figure 4-12. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River at Hood/Greene's Landing.

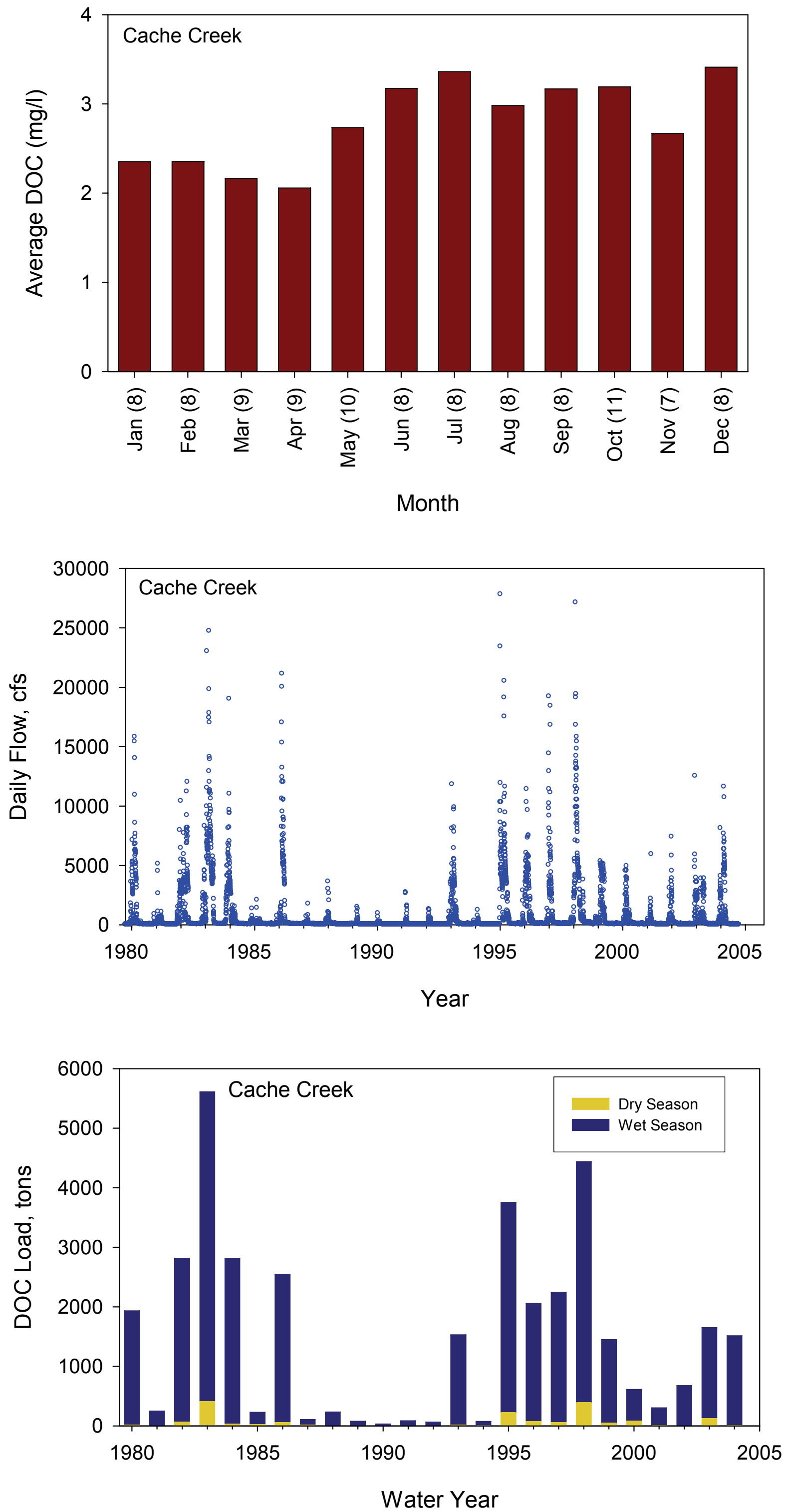


Figure 4-13. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Cache Creek.

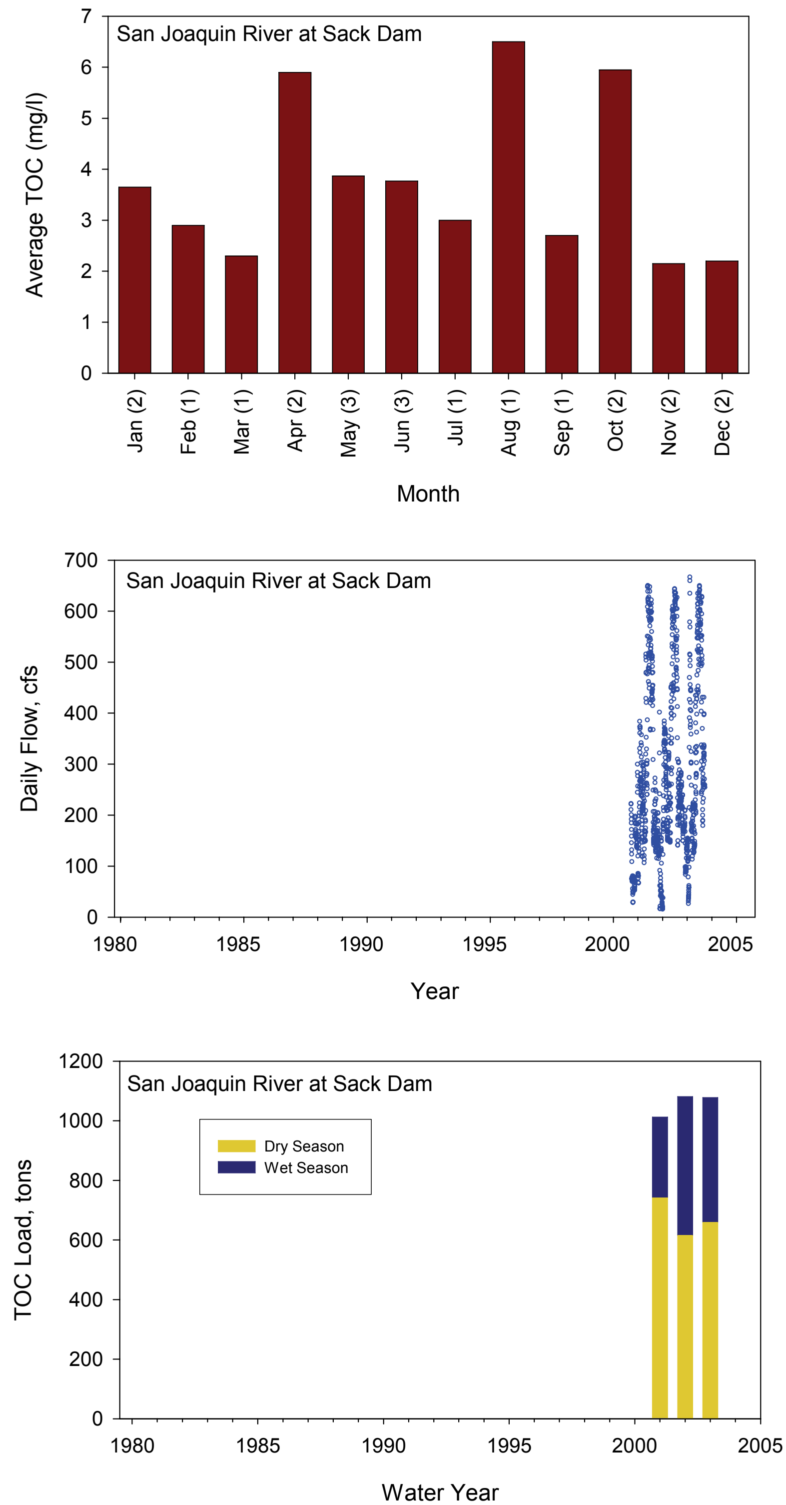


Figure 4-14. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for San Joaquin River at Sack Dam.

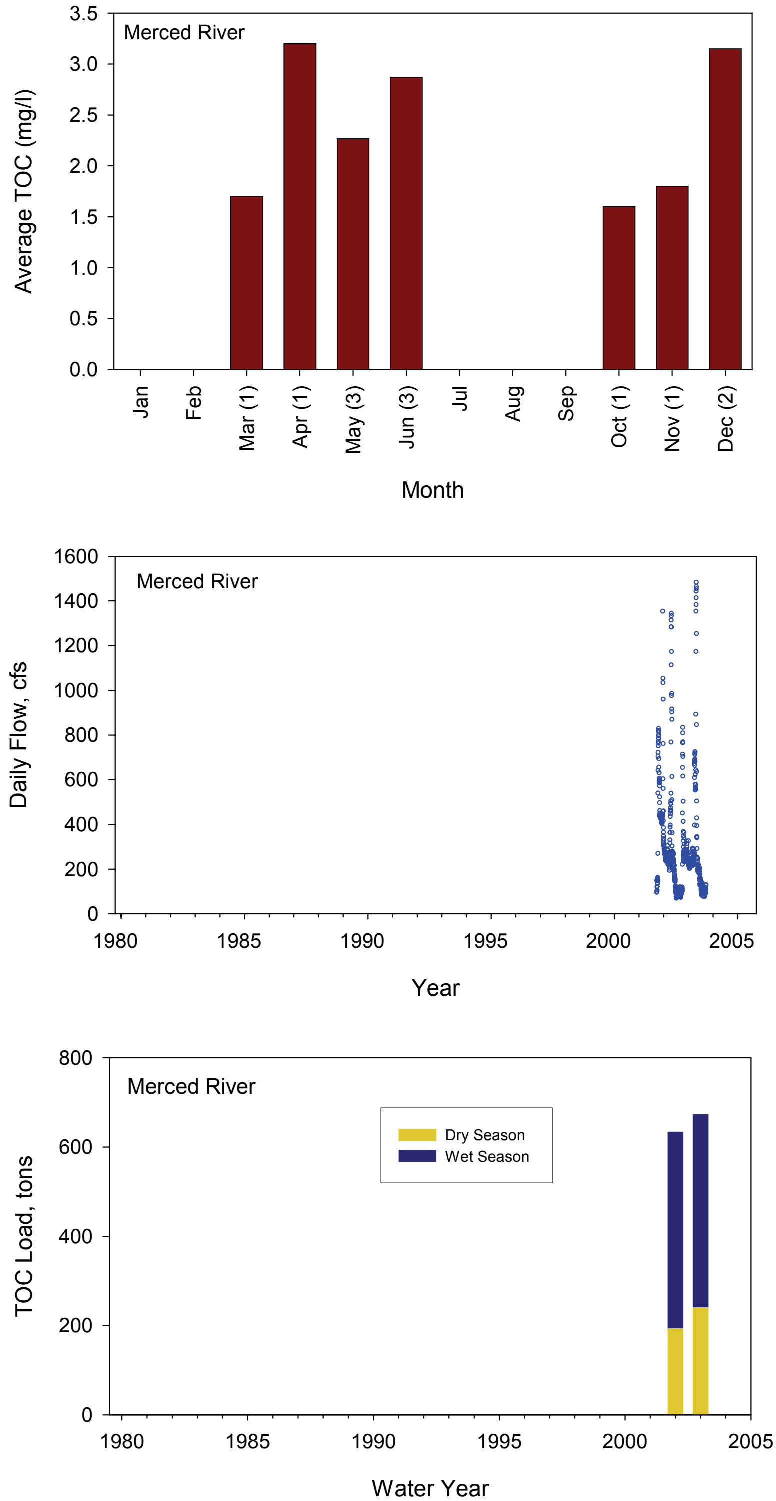


Figure 4-15. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Merced River.

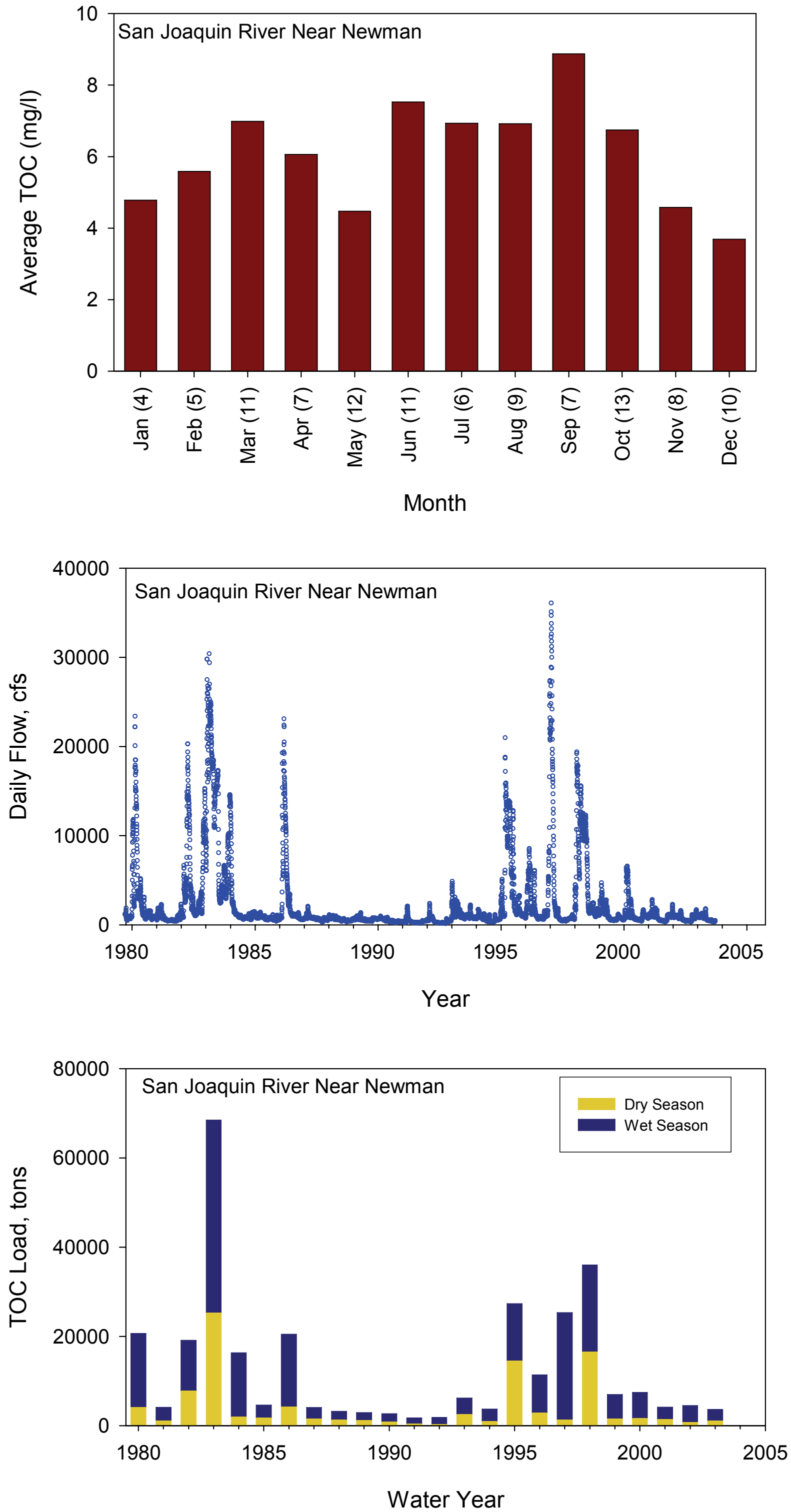


Figure 4-16. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for San Joaquin River near Newman.

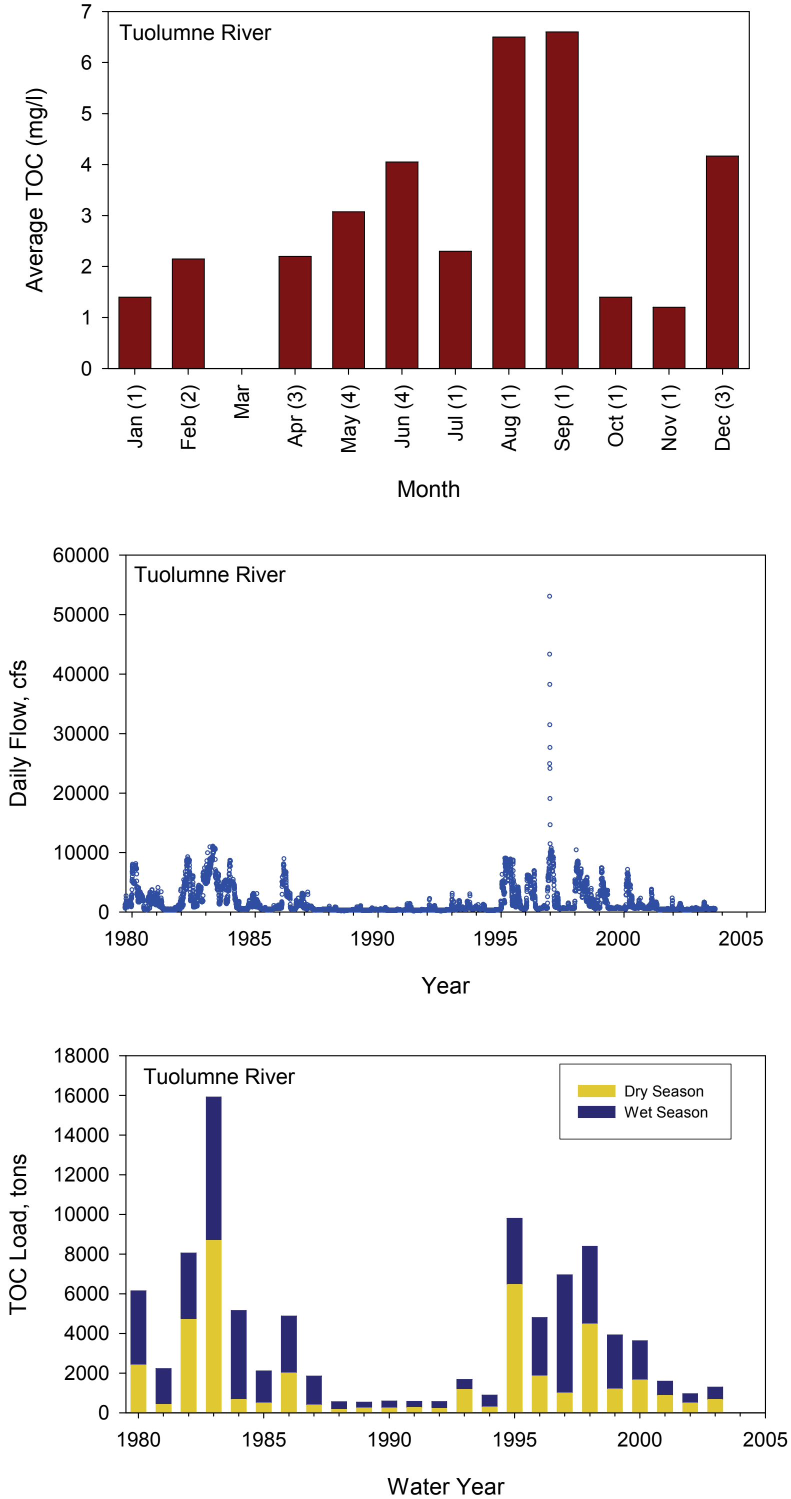


Figure 4-17. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Tuolumne River.

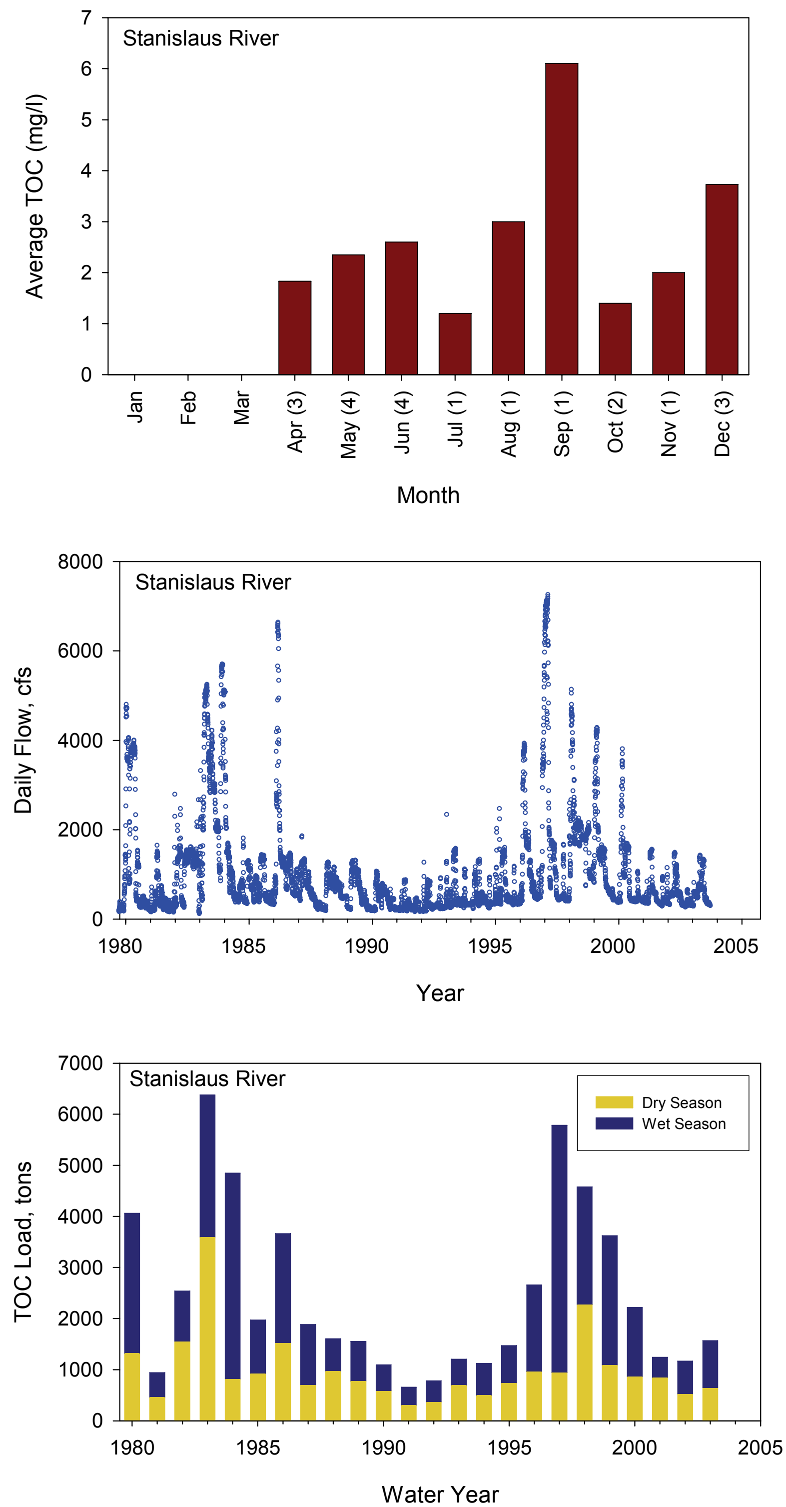


Figure 4-18. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Stanislaus River.

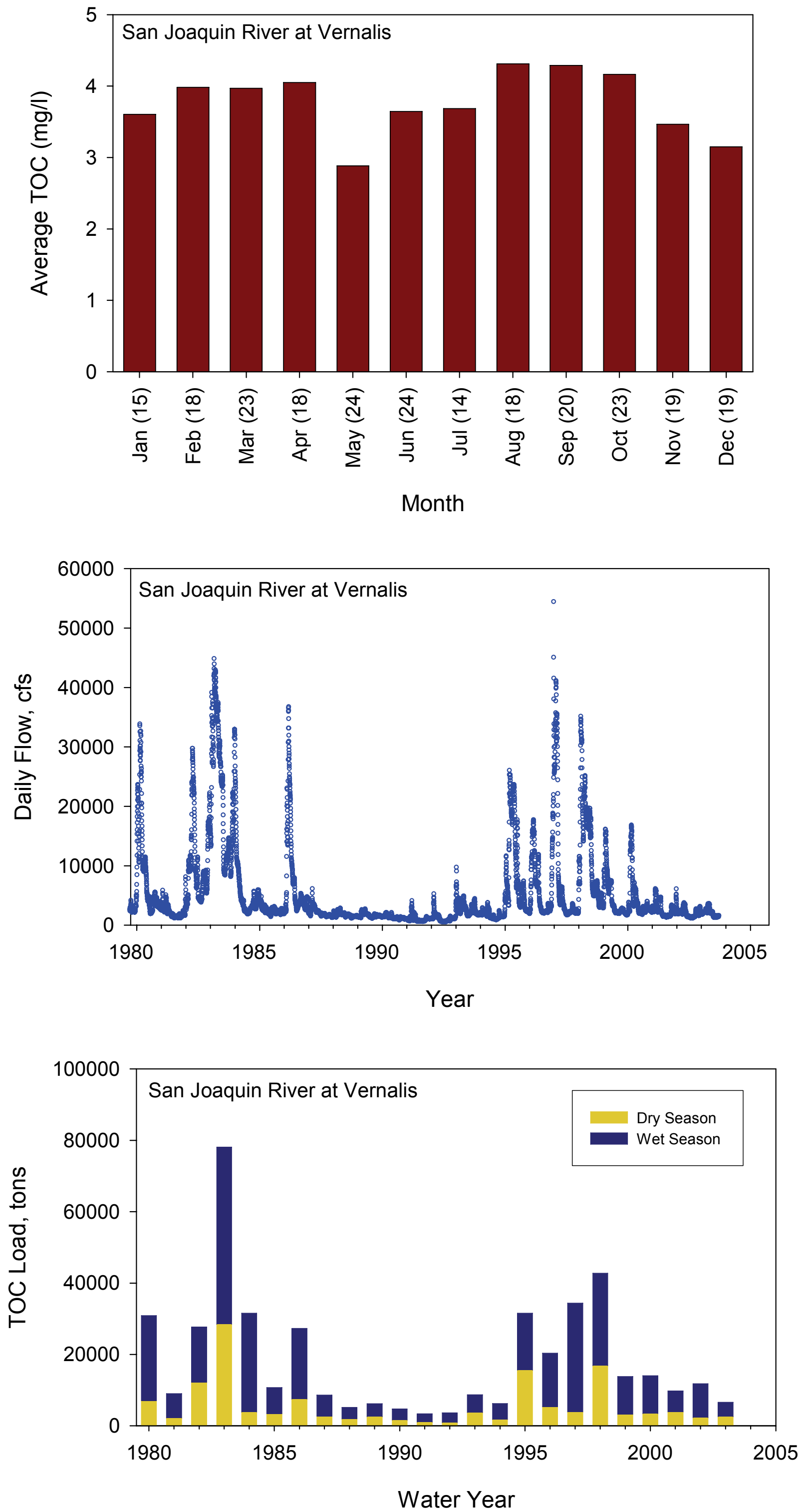


Figure 4-19. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for San Joaquin River at Vernalis.

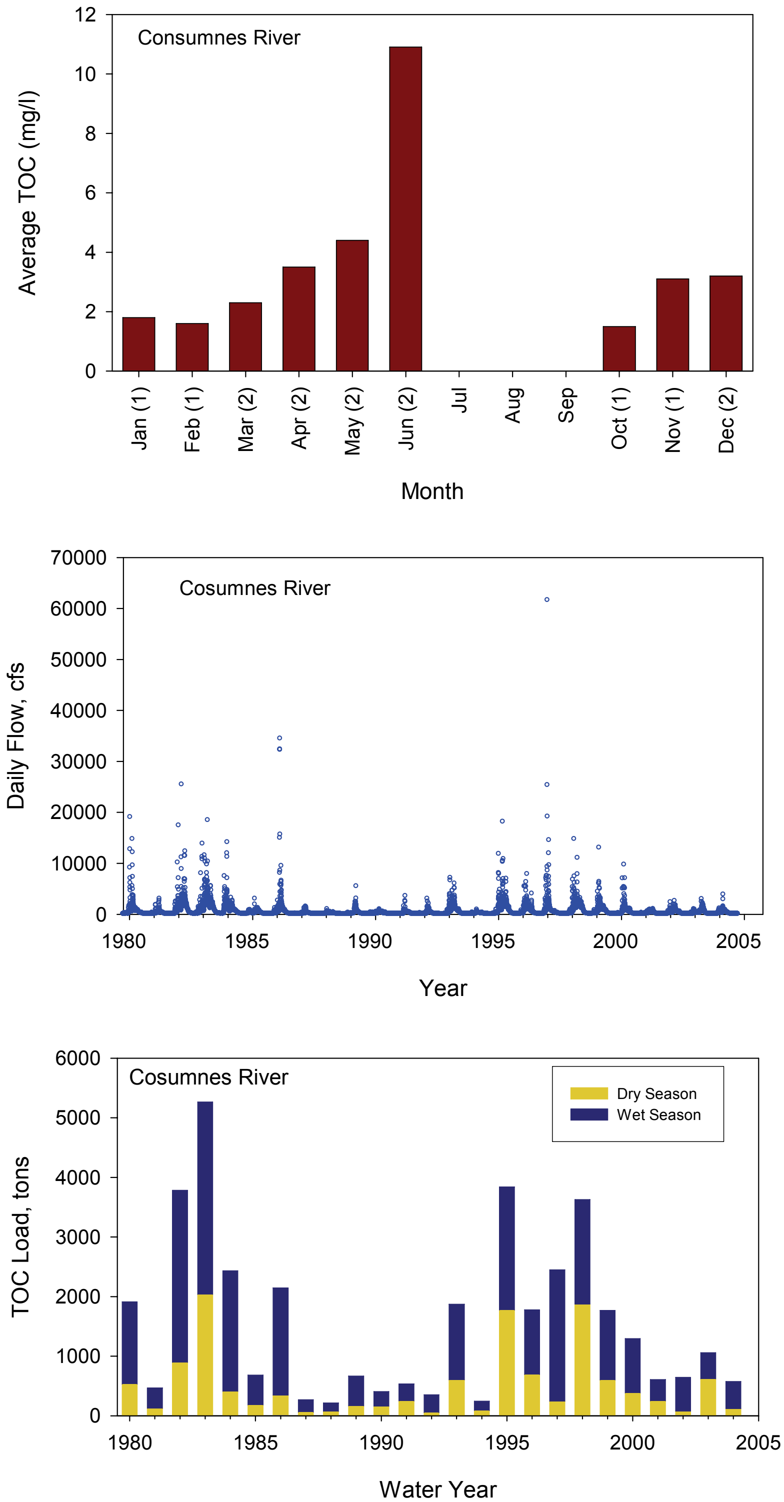


Figure 4-20. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Cosumnes River.

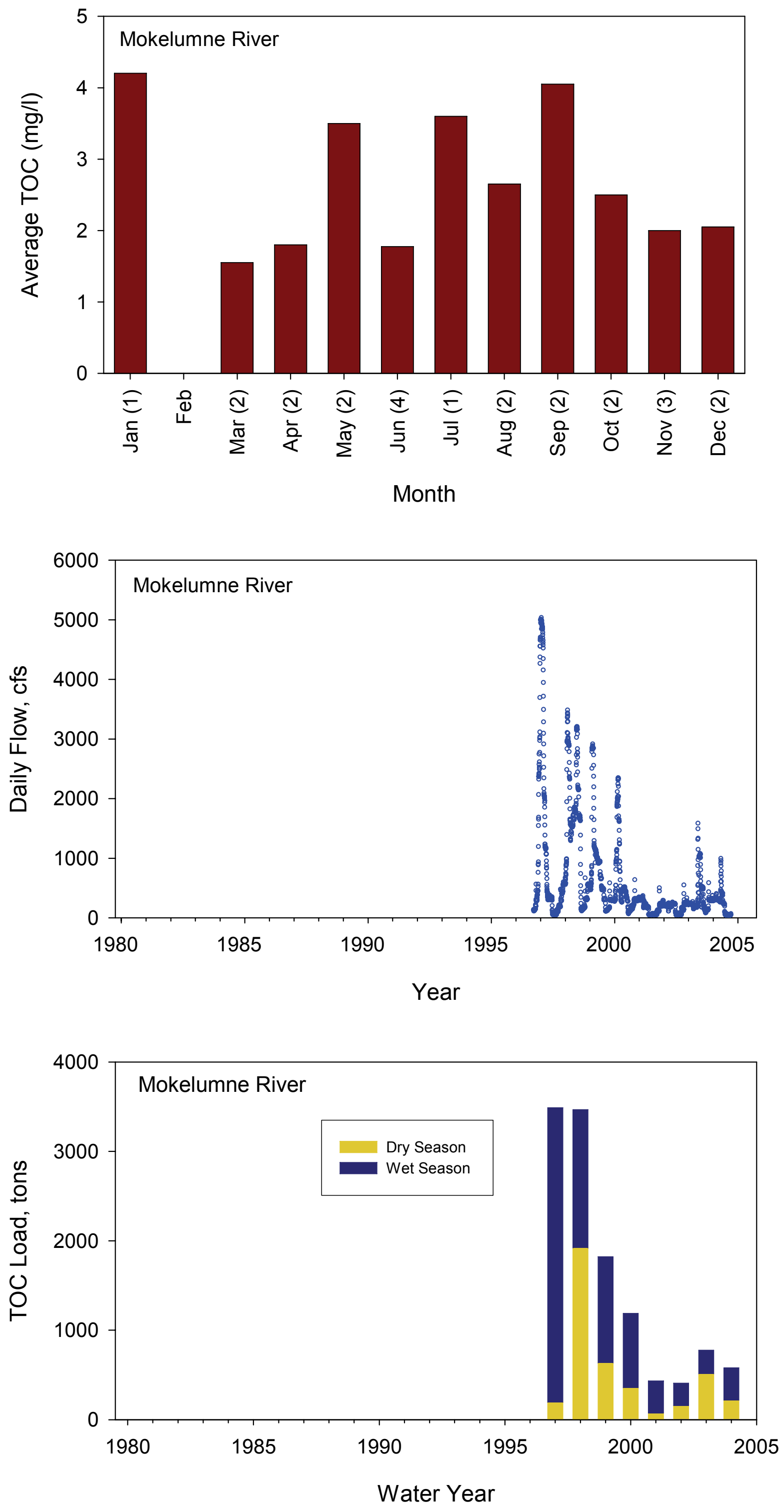


Figure 4-21. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Mokelumne River.

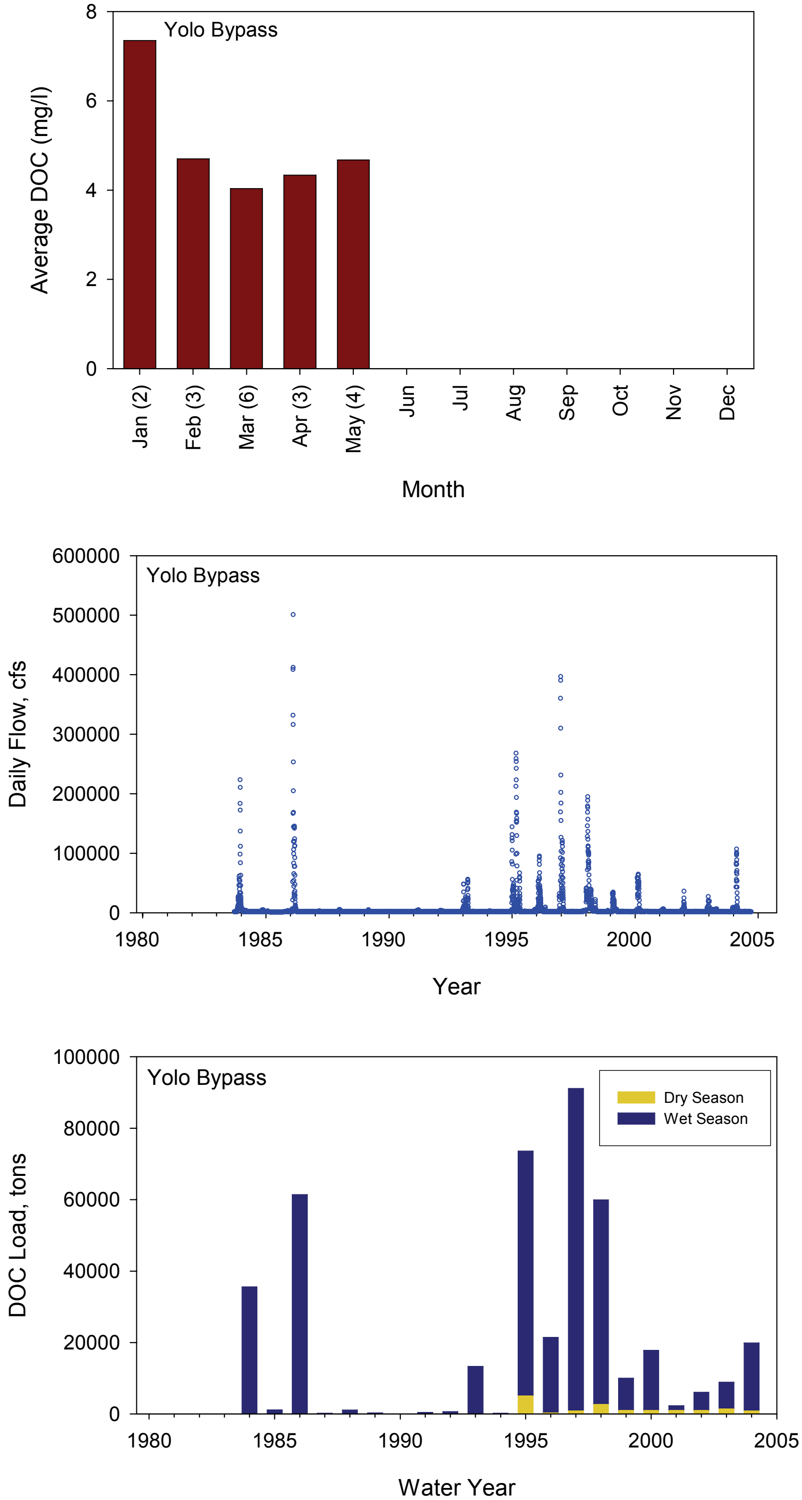


Figure 4-22. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Yolo Bypass.

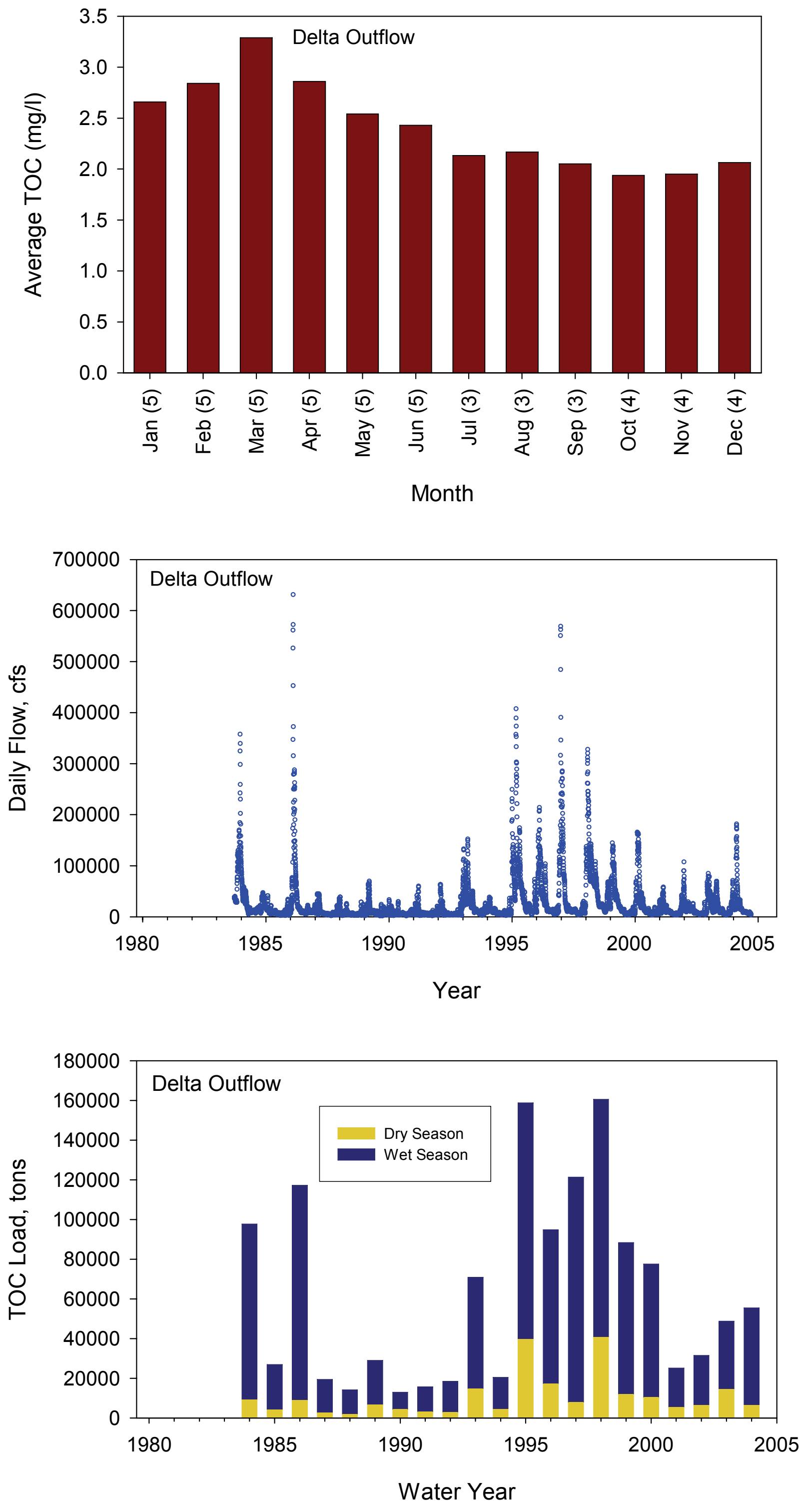


Figure 4-23. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Delta outflows.

The loads calculated for the key subwatersheds are summarized in Table 4-3 for the dry and wet season of wet and dry years. Loads of organic carbon in the dry and wet season of wet years are shown graphically in Figure 4-24. The graphical representation uses arrow thickness to scale loads, and can be used to compare across seasons and locations. The loads closely follow the pattern for flows shown in Figure 4-5, with the Sacramento River being the dominant source. This is true even though concentrations in the San Joaquin River are generally much higher than in the Sacramento River (Chapter 3). Tributary loads and Delta exports to the Bay during wet years are several times higher than during dry years.

Estimated loads from this study compare favorably with loads estimated in previous studies, as shown in Table 4-4. At the Sacramento River (either Freeport or Greene's Landing), loads from Saleh et al. (2003) for wet years and Woodard (2000) for wet and dry years are within 15% of the estimates from this study. At the San Joaquin River at Vernalis, wet and dry year loads from Woodard (2000) are within 30% of current estimates.

Table 4-3.
Loads transported at locations corresponding to the outflow points of the subwatersheds in Table 4-1.

			Dry Years (tons)			Wet Years (tons)			Export Rates (tons/km^2)	
ID	**Watershed Name**	**Upstream Area (km^2)**	Dry Season	Wet Season	Total	Dry Season	Wet Season	Total	Dry year	Wet Year
1	Sacramento River above Bend Bridge	23,144	5,384	6,858	12,242	6,648	20,069	26,717	0.53	1.15
2	Butte Creek	2,402	-	-	-	-	-	-	-	-
3	Sacramento River at Colusa	36,807	4,782	11,612	16,394	6,960	23,530	30,490	0.45	0.83
4	Yuba River	3,502	328	1,096	1,424	1,374	4,530	5,904	0.41	1.69
5	Feather River	9,994	-	-	-	5,975	21,462	27,437		2.75
6	Cache Creek	3,112	9	295	304	131	2,442	2,574	0.10	0.83
7	American River	5,528	2,002	1,876	3,878	3,761	7,320	11,081	0.70	2.00
8	Sacramento River at Hood/Greene's	61,316	9,958	29,355	39,313	18,215	54,382	72,598	0.64	1.18
9	Cosumnes River	2,390	132	339	471	845	1,710	2,555	0.20	1.07
10	San Joaquin River at Newman	19,085	1,136	2,307	3,444	7,117	15,031	22,148	0.18	1.16
11	Stanislaus River	3,478	636	664	1,301	1,367	2,220	3,587	0.37	1.03
12	Tuolumne River	4,586	428	719	1,147	3,057	3,555	6,612	0.25	1.44
13	Merced River	3,289	218	436	653				0.20	-
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	2,397	-	-	-	-	-	-	-	-
15	Chowchilla River	850	-	-	-	-	-	-	-	-
16	San Joaquin River at Sack Dam	11,667	673	384	1,057	-	-	-	0.09	-
17	Mokelumne River	3,022	238	311	550	776	1,716	2,492	0.18	0.82
18	Bear River	1,229	19	223	242	105	1,598	1,703	0.20	1.39
19	Putah Creek	1,795	-	-	-	-	-	-	-	-
20	Delta North	2,148	-	-	-	-	-	-	-	-
21	Delta South	5,730	-	-	-	-	-	-	-	-
22	San Joaquin River at Vernalis	32,782	2,222	4,908	7,130	9,237	20,821	30,059	0.22	0.92
-	Yolo Bypass	-	328	2,621	2,949	1,347	37,965	39,312	-	-
-	**Delta Outflow Loads**	**-**	**4,612**	**19,869**	**24,481**	**17,741**	**85,861**	**103,601**	-	-

Note: Loads for watersheds without data in this table are presented in Tables 4-9 and 4-10 for dry and wet years, respectively, as estimated using export rates.

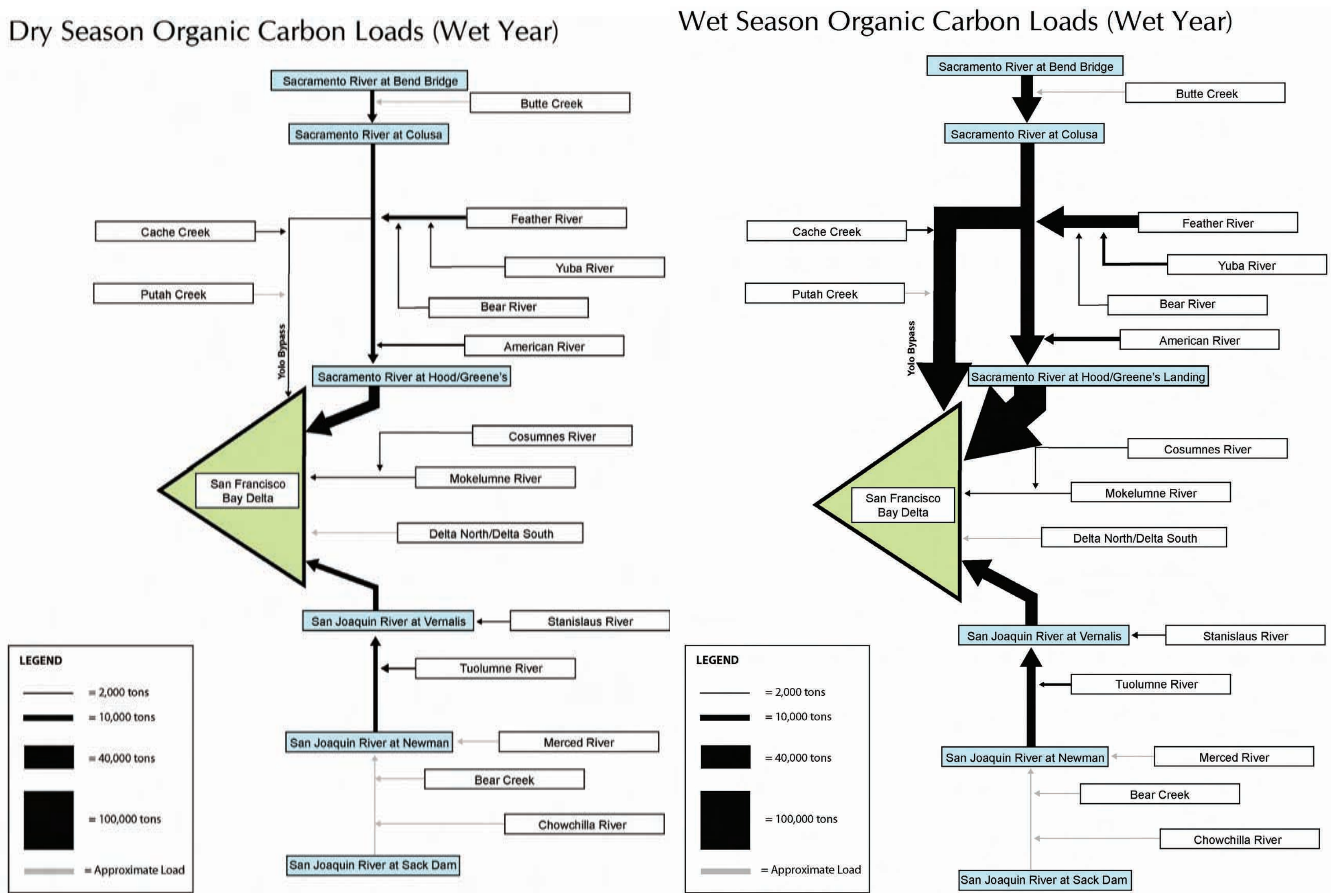


Figure 4-24. Organic carbon loads for the dry and wet season of an average wet year on a schematic representation of the San Joaquin-Sacramento River systems. In-Delta nutrient sources and sinks are presented in Chapter 5.

Table 4-4.
Estimated Loads from this study compared with other published studies (Saleh et al., 2003; Woodard, 2000)

		This Study (tons)		Saleh et al., 2003[1] (tons)	Woodard, 2000; Data from 1980-1999 (tons)	
ID	Watershed Name	Dry Years	Wet Years	Wet Years (Sac: 95-98; SJ: 86-94)	Dry Years	Wet Years
1	Sacramento River above Bend Bridge	12,242	26,717	30,564	-	-
2	Butte Creek	-	-	-	-	-
3	Sacramento River at Colusa	16,394	30,490	32,687	-	-
4	Yuba River	1,424	5,904	7,247	-	-
5	Feather River	-	27,437	40,614	-	-
6	Cache Creek	304	2,574		-	-
7	American River	3,878	11,081	9,996	-	-
8	Sacramento River at Hood/Greene's	39,313	72,598	82,658 [2]	34,697	72,966
9	Cosumnes River	471	2,555	-	-	-
10	San Joaquin River at Newman	3,444	22,148	-	-	-
11	Stanislaus River	1,301	3,587	4,180	-	-
12	Tuolumne River	1,147	6,612	3,904	-	-
13	Merced River	653	-	5,206	-	-
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	-	-	-	-	-
15	Chowchilla River	-	-		-	-
16	San Joaquin River at Sack Dam	1,057	-	-	-	-
17	Mokelumne River	550	2,492	-	-	-
18	Bear River	242	1,703	-	-	-
19	Putah Creek	-	-	-	-	-
20	Delta North	-	-	-	-	-
21	Delta South	-	-	-	-	-
22	San Joaquin River at Vernalis	7,130	30,059	17,284	4,844	23,633
	Yolo Bypass	2,949	39,312	-	-	-

[1]Actual loads in this column are based on a personal communication from C. Kratzer, 2005.

[2]Data from Sacramento River at Freeport.

4.4 ALTERNATE METHODS FOR LOAD ESTIMATION

The USGS, in the LOADEST model for computing flux in streams, provides options for alternate formulations for regression equations, nine of which are shown in Table 4-5. Because this general approach has been used in several published reports (Crawford, 1991; Cohn et al., 1992), it was applied in this work to compare results with those presented in Table 4-3. Regression models with multiple fitted coefficients are most appropriate when there are sufficient data to fit. A station with adequate data, the Hood/Greene's Landing station on the Sacramento River, was therefore employed for this comparison.

Loads were computed using the 9 models in Table 4-5 that were applicable to the Hood/Greene's Landing station data, and calculations were performed in a manner consistent with that presented in Section 4-3, i.e., loads were computed for all years and for wet and dry seasons. The results, including the upper and lower confidence intervals of the load estimates (5^{th} and 95^{th} percentile), are presented in Table 4-6. The mean loads for all years (39,000 – 53,000 tons/year) is in the middle to low end of the range of the wet and dry year loads for the Hood/Greene's Landing station on the Sacramento River computed in Section 4-3 (39,300 tons for dry years and 72,600 tons for wet years). This comparison lends credence to the relatively simple method used in the previous section of using the monthly average concentrations and flows. It is recognized, however, that for sites with enough flow and concentration data, the LOADEST approach may provide additional information that is useful, especially the upper and lower confidence limits.

Table 4-5.
Regression equations from the LOADEST program (Runkel et al., 2004).

LoadEst Model	Regression Model of Load
1	$a_0 + a_1 Ln\,Q$
2	$a_0 + a_1 Ln\,Q + a_2 Ln\,Q^2$
3	$a_0 + a_1 Ln\,Q + a_2 d_{time}$
4	$a_0 + a_1 Ln\,Q + a_2 Sin(2\pi d_{time}) + a_3 Cos(2\pi d_{time})$
5	$a_0 + a_1 Ln\,Q + a_2 Ln\,Q^2 + a_3 d_{time}$
6	$a_0 + a_1 Ln\,Q + a_2 Ln\,Q^2 + a_3 Sin(2\pi d_{time}) + a_4 Cos(2\pi d_{time})$
7	$a_0 + a_1 Ln\,Q + a_2 Sin(2\pi d_{time}) + a_3 Cos(2\pi d_{time}) + a_4 d_{time}$
8	$a_0 + a_1 Ln\,Q + a_2 Ln\,Q^2 + a_3 Sin(2\pi d_{time}) + a_4 Cos(2\pi d_{time}) + a_5 d_{time}$
9	$a_0 + a_1 Ln\,Q + a_2 Ln\,Q^2 + a_3 Sin(2\pi d_{time}) + a_4 Cos(2\pi d_{time}) + a_5 d_{time} + a_6 d_{time}^2$

$a_0, a_1, \ldots a_6$ = unknown regression coefficients
Q = streamflow
d_{time} = decimal time

Table 4-6.
Calculated loads at Sacramento River at Hood/Greene's Landing (mean and upper and lower confidence intervals - 5% and 95%), using the 9 regression equations in Table 4-5.

		All Years (tons)		
		Dry Season	**Wet Season**	**Total**
	Lower	15,878	33,818	49,906
Model 1	**Mean**	16,574	35,586	52,169
	Upper	17,295	37,422	54,505
	Lower	15,875	34,579	50,702
Model 2	**Mean**	16,568	36,604	53,181
	Upper	17,286	38,715	55,746
	Lower	13,354	28,849	42,293
Model 3	**Mean**	14,846	32,044	46,895
	Upper	16,457	35,493	51,859
	Lower	12,921	37,473	50,907
Model 4	**Mean**	13,603	39,360	52,976
	Upper	14,313	41,319	55,108
	Lower	13,117	29,356	42,599
Model 5	**Mean**	14,570	32,567	47,143
	Upper	16,140	36,029	52,038
	Lower	12,942	37,535	50,976
Model 6	**Mean**	13,635	39,510	53,159
	Upper	14,356	41,563	55,407
	Lower	10,993	32,163	43,373
Model 7	**Mean**	12,170	35,406	47,585
	Upper	13,435	38,885	52,093
	Lower	10,976	32,218	43,409
Model 8	**Mean**	12,148	35,457	47,618
	Upper	13,412	38,932	52,115
	Lower	8,170	23,456	31,715
Model 9	**Mean**	10,012	28,777	38,796
	Upper	12,144	34,942	46,986
This Study (Dry Years)		9,958	29,355	39,313
This Study (Wet Years)		18,215	54,382	72,598

4.5 ESTIMATION OF WATERSHED LOADS

Stream loads calculated above can be compared with loads originating in the watershed that include non-point sources (principally different land uses, such as agriculture, urban land, wetlands, and other natural lands), and point sources (principally wastewater treatment, although other sources may be contributors). The sections below discuss the approach used to estimate these contributions. These are preliminary estimates due to the limited data that were available on export rates from individual land uses.

4.5.1 ESTIMATION OF ORGANIC CARBON EXPORT RATES FROM NON-POINT SOURCES

Non-point source contributions of organic carbon loads to streams are expressed as mass of carbon delivered to the stream per unit area per unit time. The stream outflow represents the load contributions in surface runoff as well as baseflow (i.e., through groundwater). The export rate calculations are similar to the load estimates from streams except that for the rates to be applicable to one type of land use, the watershed in consideration must contain only that land use. Thus, an urban land organic carbon export rate is obtained from a watershed that is entirely urban land, and a background export rate is obtained from a watershed with minimal development. In practice, finding watersheds with only one type of land use is very difficult, although in some instances small indicator watersheds may be found that fit this criterion. Export rates from specific land uses, weighted by the area of that land use in a watershed, can be used to compute the non-point source contribution, as shown schematically in Figure 4-25.

Organic carbon export rates were estimated for urban land and agricultural land in the San Joaquin and Sacramento Basins, background loads from a mix of forest and shrubland (or rangeland), and from wetlands. Further stratification of land use-based export rates (e.g., by crop type for agricultural land) was not possible given the existing data. This is an area that will benefit greatly through collection of additional data in small indicator watersheds as described in Chapter 6.

The following locations were used to develop preliminary export rates:

- The Colusa Basin Drain was used for estimating agricultural loads in the Sacramento River Basin as shown in Figure 4-26. Although the Colusa Basin Drain watershed includes non-agricultural land, it was the best station based on the existing data. Harding Drain was used for agricultural loads in the San Joaquin Basin as shown in Figure 4-27.

- Mud Slough and Salt Slough were used for estimating wetland loads in the San Joaquin Basin as shown in Figures 4-28 and 4-29.

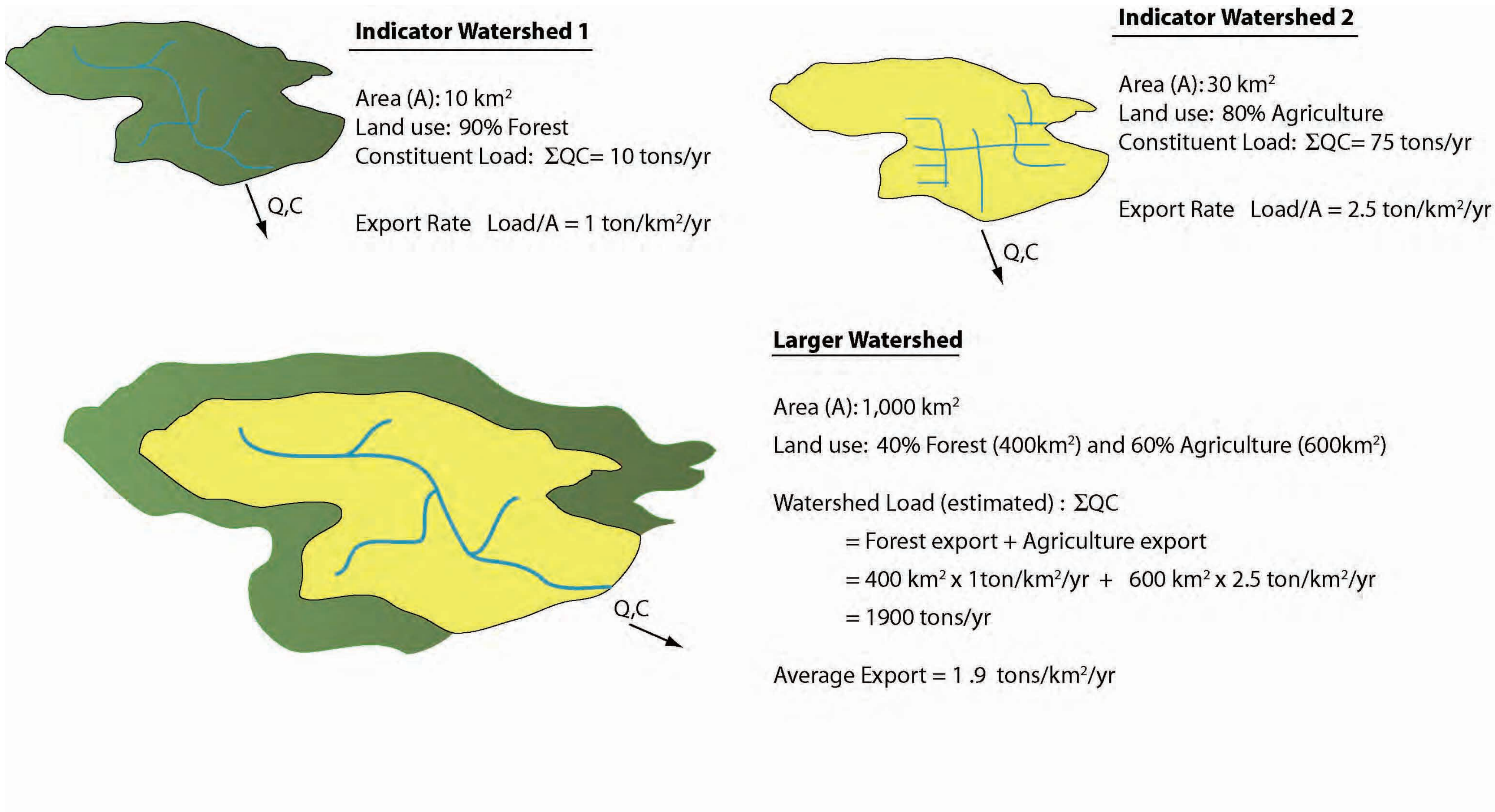


Figure 4-25. Export rates from specific land uses, weighted by the area of that land use in a watershed, can be used to compute the non-point source contribution for a mixed land use watershed.

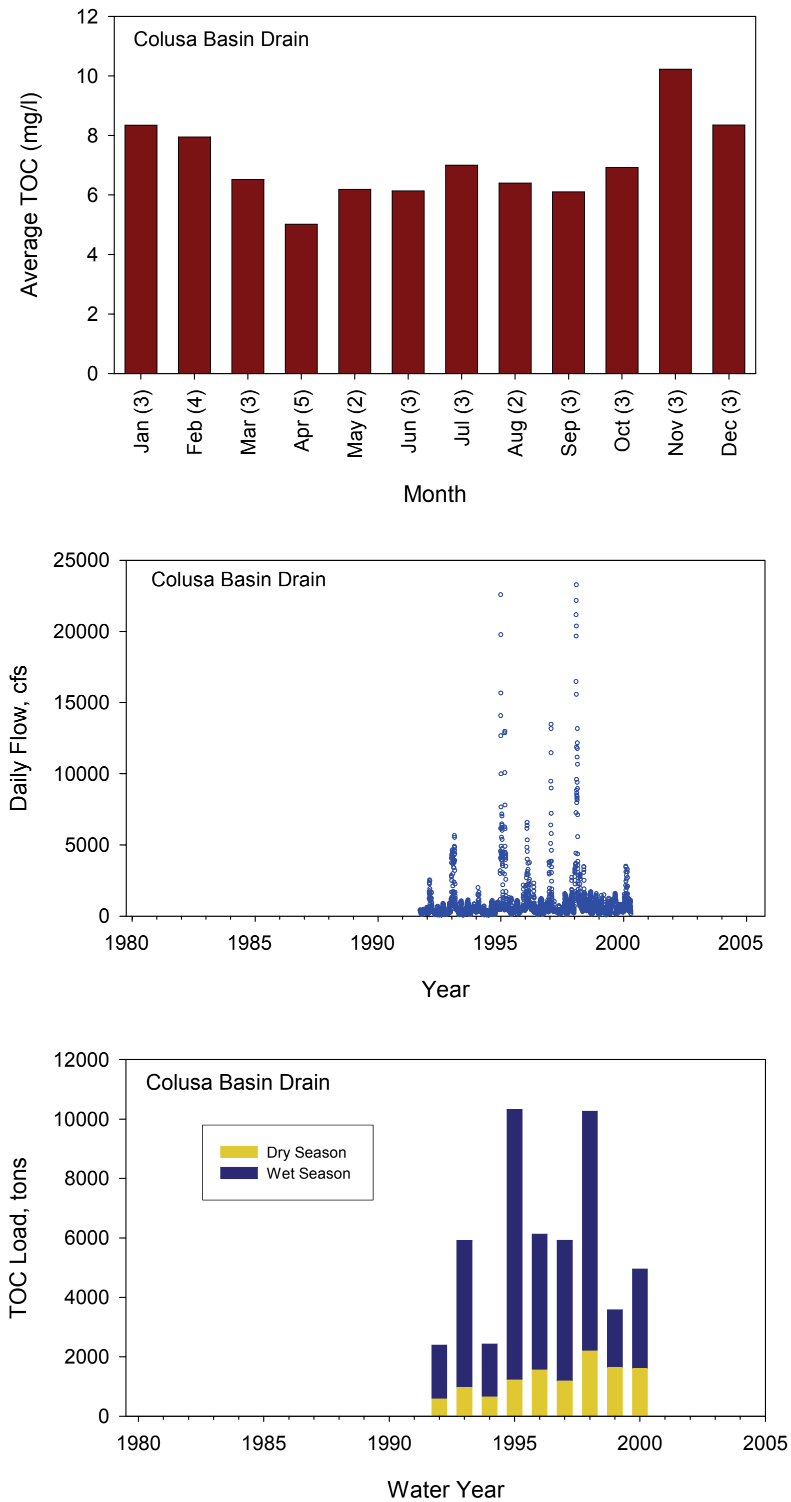


Figure 4-26. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Colusa Basin Drain. These data were used to estimate the organic carbon export rate from agriculture in the Sacramento River basin.

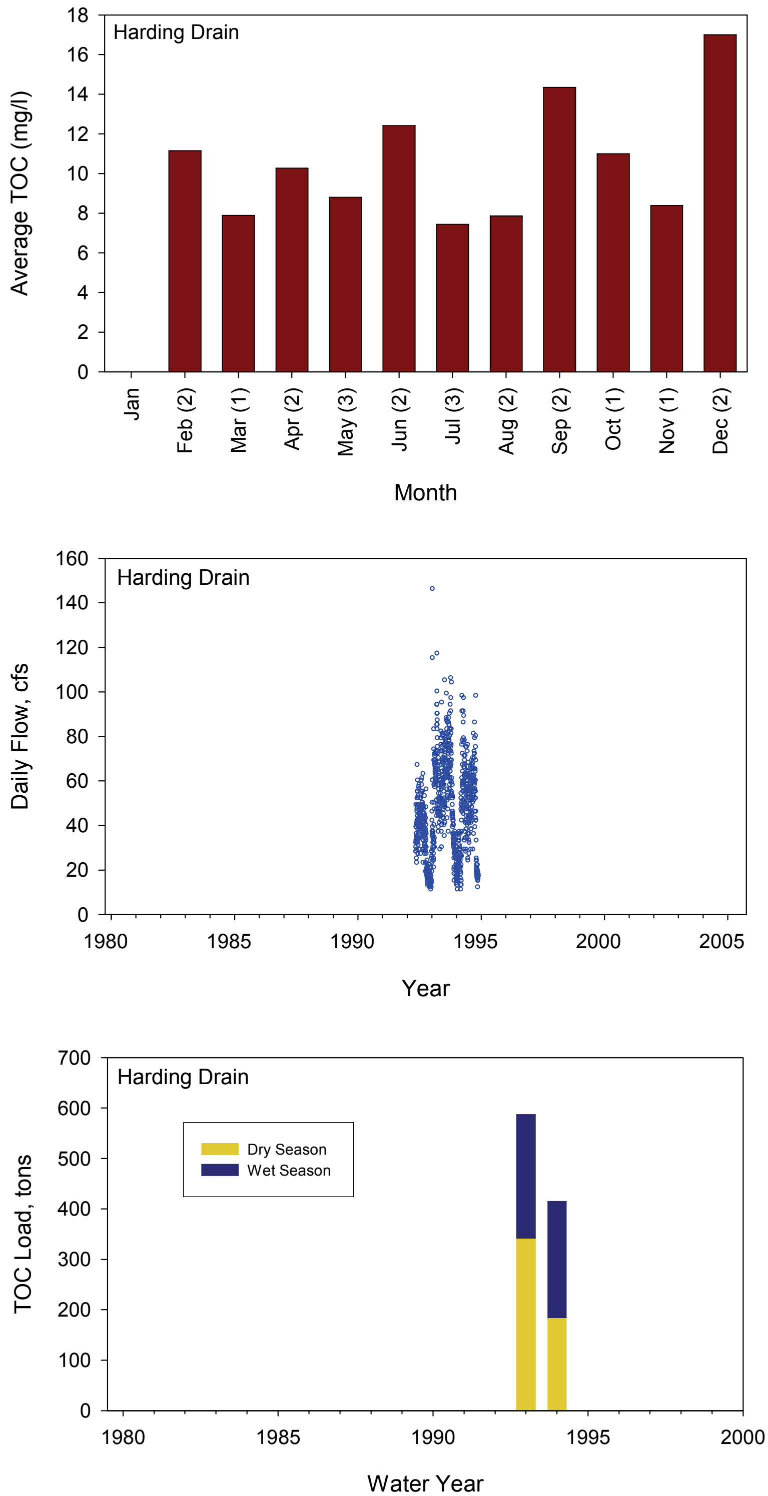


Figure 4-27. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Harding Drain. These data were used to estimate the organic carbon export rate from agriculture in the San Joaquin River basin.

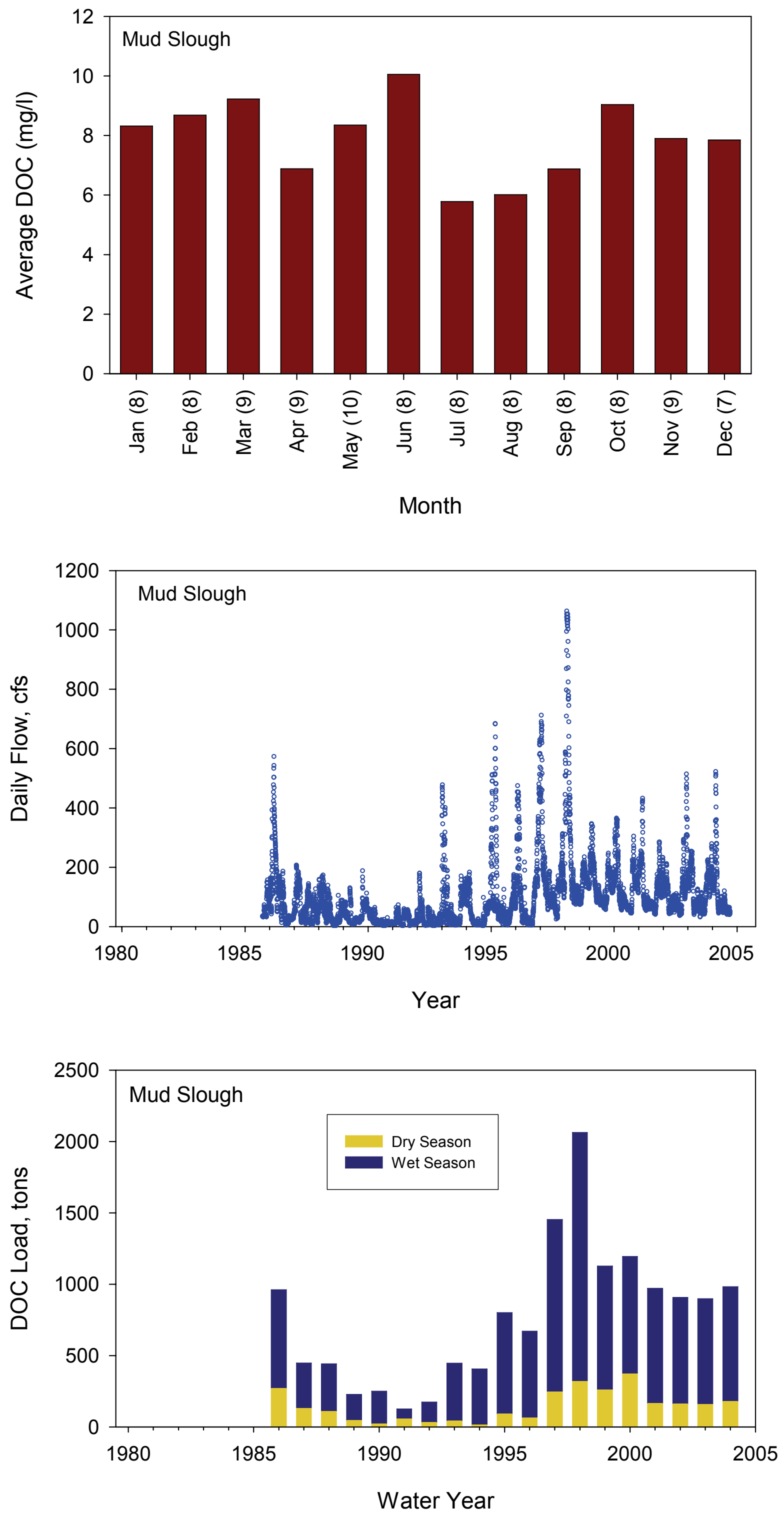


Figure 4-28. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Mud Slough. These data were used to estimate the organic carbon export rate from wetlands in the San Joaquin basin.

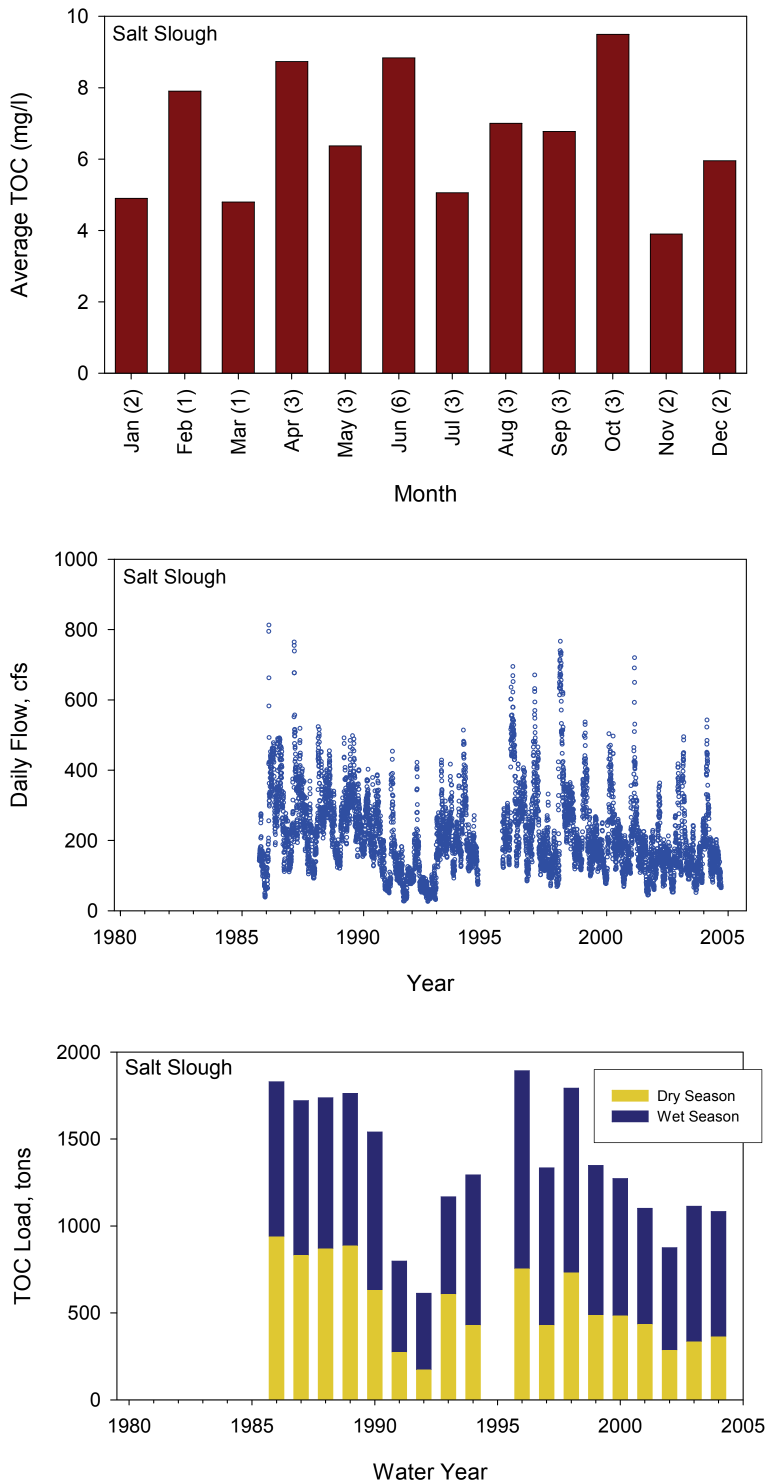


Figure 4-29. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Salt Slough. These data were used to estimate the organic carbon export rate from wetlands in the San Joaquin basin.

- The urban runoff export rate for organic carbon was estimated using USGS data collected at Arcade Creek (Saleh et al., 2003). Arcade Creek has a small, entirely urban, watershed (Figure 4-30) and is a good choice for the export rate calculation. Data collected at the Natomas East Main Drainage Canal (NEMDC) may also be used for estimating urban runoff loads. Although this watershed is rapidly urbanizing, it still contains some agricultural land. The Arcade Creek watershed was considered the best choice for this analysis since it is an entirely urbanized watershed. Other urban runoff data in the Drinking Water Policy Database from the cities of Sacramento and Stockton could not be used because these data were not accompanied by flow measurements. The urban runoff data from Sacramento, Stockton, and the NEMDC (Figure 4-31) were compared to the data collected on Arcade Creek. NEMDC data were obtained from the MWQI website for the period 1997 to 2004. The monthly average concentrations for TOC in Arcade Creek ranged from 7 to 12 mg/L. The Sacramento and Stockton stormwater TOC data show a great deal of variability with concentrations ranging from 3 to 60 mg/L and with an average concentration of 15 mg/L, somewhat higher than the Arcade Creek data. The NEMDC TOC data vary from 3 mg/l to 50 mg/l with an average concentration of approximately 8 mg/l, comparable to the Arcade Creek data. In general, dry weather concentrations are marginally higher than the wet weather concentrations, although the actual impact on delivered loads may be dominated by relative magnitudes of flow.

- No station could be clearly identified as a background station with insignificant anthropogenic activity. As a first approximation, the Yuba River watershed was used to estimate background loads for the Sacramento River Basin. Of the major tributaries, the Yuba River watershed has the least amount of urban and agricultural land. Although the TOC concentrations are low in the watershed, the occasional high flows result in an export rate virtually identical to that calculated for the Colusa Basin Drain. This may also be an expression of the inapplicability of the Yuba River Watershed for determining background export rates. The Yuba River basin wet and dry year export rates of 1.7 and 0.41 tons/km^2/yr may be compared with an estimate of 0.96 tons/km^2/yr for an relatively undeveloped watershed in the Rocky Mountains (Boyer et al., 2000).

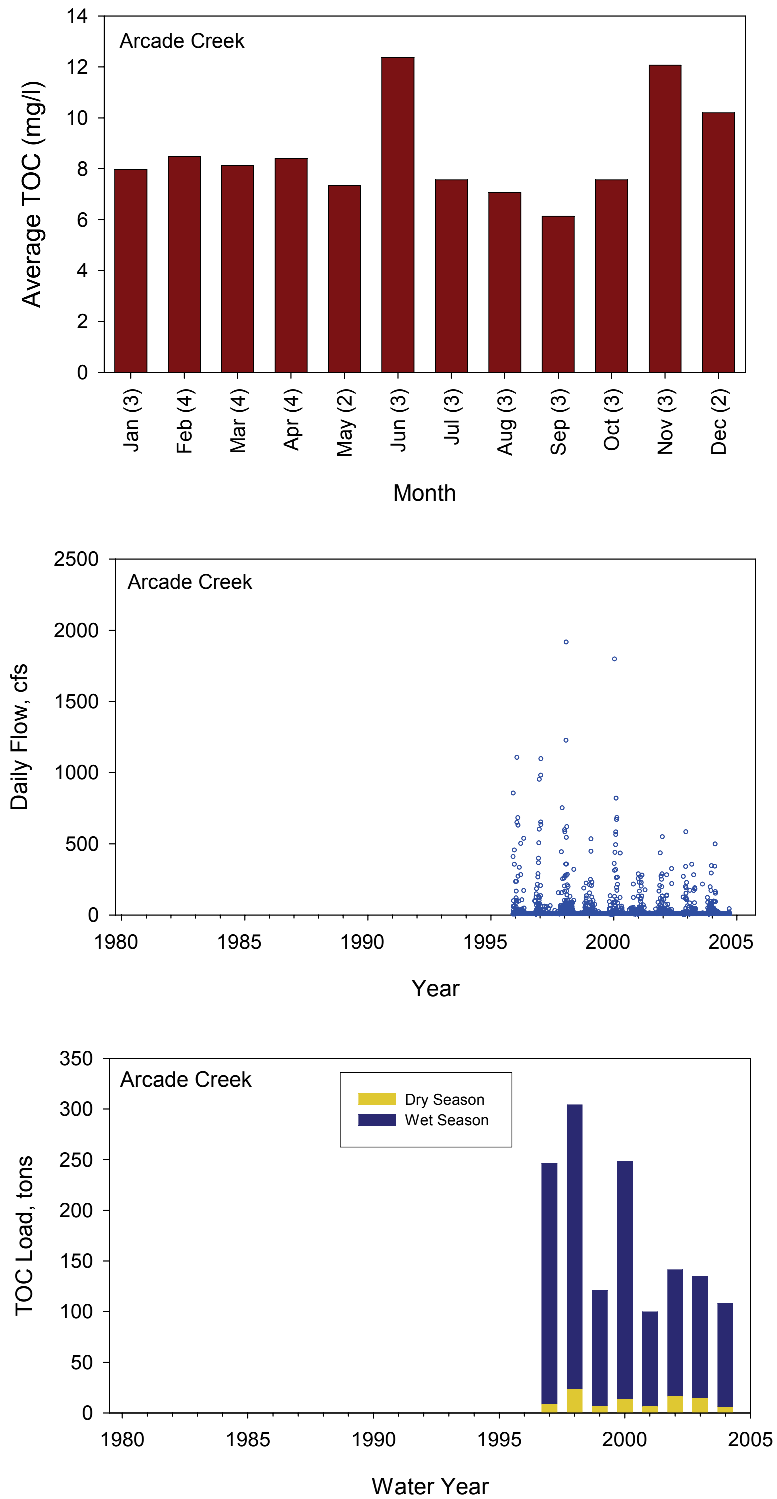


Figure 4-30. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Arcade Creek, used to estimate the urban runoff export rate for organic carbon from the Sacramento River basin.

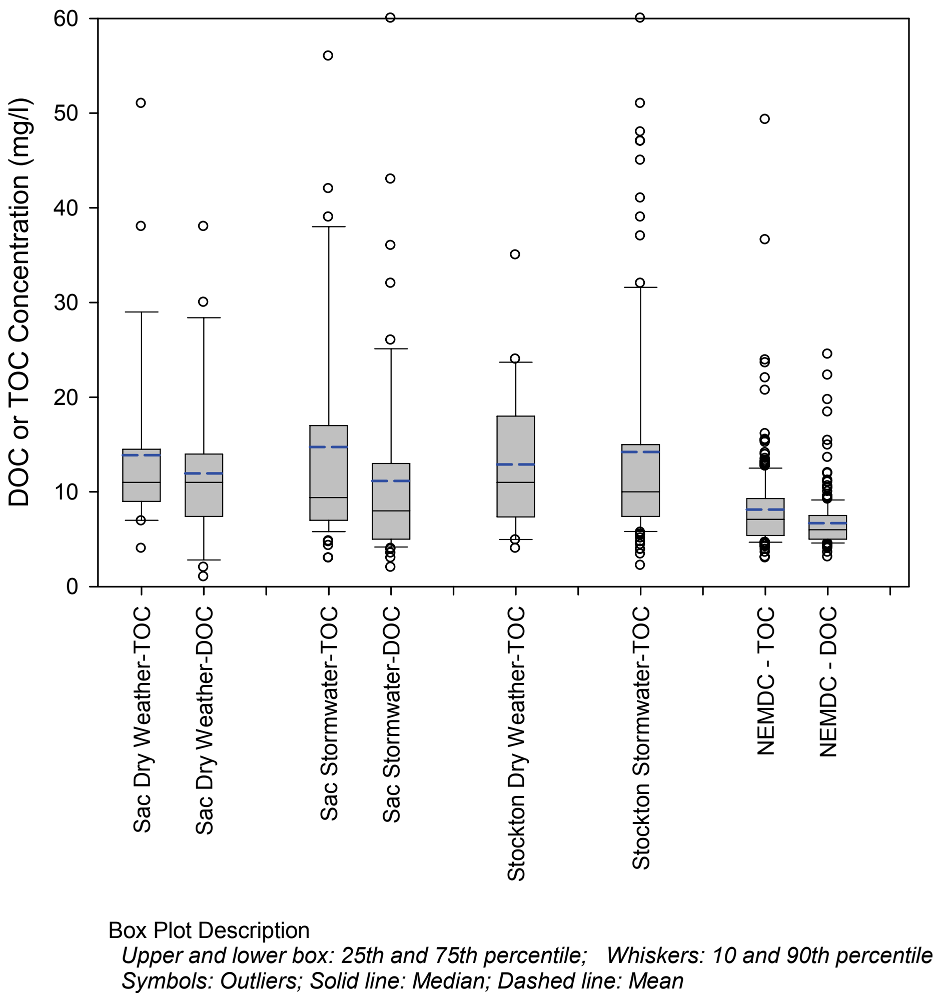


Figure 4-31. Urban runoff organic carbon concentration data from Sacramento, Stockton, and the Natomas East Main Drainage Canal (NEMDC).

The summary of export rates for various land uses in the Central Valley is presented in Table 4-7. Although it would be preferable to obtain separate export rates for the Sacramento and San Joaquin Basins because of the distinct differences in rainfall, this was not possible with existing data. Rainfall during water years 2002 and 2003 measure at three stations in the Sacramento Valley averaged 23.7 inches and measured at three stations in the San Joaquin Valley averaged 11.7 inches (MWQI, 2005), which is a factor of two difference. Therefore, when a rate from the Sacramento Basin was applied to the San Joaquin Basin (for urban runoff and for forest/shrubland), the export rate was divided by two to account for the lower rainfall in the San Joaquin Basin. When a rate from the San Joaquin Basin was applied to the Sacramento Basin (for wetlands), the rate was multiplied by two to account for the higher rainfall in the Sacramento Basin. For agricultural land, separate values were used for the Sacramento and San Joaquin Basins.

Table 4-7.
Export rates of organic carbon from major land uses in the Central Valley.

Land Use	Dry Year Loads ($tons/km^2/yr$)		Wet Year Loads ($tons/km^2/yr$)		Source	
	Sac-ramento	*San Joaquin*	*Sac-ramento*	*San Joaquin*	*Sacramento*	*San Joaquin*
Agriculture[1]	0.56	1.9	1.6	2.6	Colusa Basin Drain	Harding Drain[2]
Urban Runoff	1.3	0.67	2.4	1.2	Arcade Creek	Calculated from Sacramento value
Forest/Rangeland	0.41	0.21	1.7	0.85	Yuba River	Calculated from Sacramento value
Wetland-Dominated[3]	1.4	0.69	2.0	1.0	Calculated from San Joaquin value	Average of Salt and Mud Slough

[1]Available data do not allow separation into crop types.
[2]May include a small POTW influence.
[3]Wetland-dominated land may include a portion that is agricultural land.

4.5.2 Point Sources

Point source discharges in the Central Valley watershed include municipal wastewater treatment plants, industries, and fish hatcheries. There are no data on organic carbon concentrations in discharges from fish hatcheries or industries in the watershed. The major municipal wastewater dischargers are shown in Table 4-8 and on Figure 4-32. Municipal wastewater dischargers are not generally required to monitor organic carbon in their effluent as a condition of their National Pollutant Discharge Elimination System (NPDES) permits. Concentration and flow data were available for the cities of Davis and Vacaville, and for the Sacramento Regional Wastewater Treatment Plant, which serves all of the cities and much of the unincorporated urban area of the County of Sacramento (Figure 4-33). TOC concentrations were four times higher at Davis than Vacaville, and concentrations at Sacramento Regional were even higher.

Wastewater effluent concentrations from these three plants do not show any strong seasonal patterns (Figure 4-34) so the average annual concentration was multiplied by the average effluent flow rate to estimate the total load from each plant. The total load was divided by the population served by these wastewater treatment plants (Davis, 60,300; Vacaville, 88,200; Sacramento, 1,128,000), to obtain the TOC load per person per year (1.7, 0.6, and 3.77 kg/year for Davis, Vacaville, and Sacramento, respectively). To obtain the load from urban areas for which no data are available, the urban population in the specified watershed was determined from Census Bureau data, and the population multiplied by an average per person TOC loading of 2 kg/person/year (average of 1.7, 0.6, and 3.77 kg/person/year from the plants above).

Table 4-8.
Wastewater treatment plants in the Central Valley and Delta.

Wastewater Treatment Plant	Treatment	Design Flow (MGD)
Sacramento Basin		
Sacramento Regional	Secondary	181
Roseville-Dry Creek	Tertiary	18
Roseville-Pleasant Grove Creek	Tertiary	12
Vacaville	Secondary	10
Chico	Secondary	9
Redding Clear Creek	Secondary	9
Woodland	Secondary	8
West Sacramento	Secondary	8
Davis	Secondary	8
Yuba City	Secondary	7
Redding Stillwater	Advanced Secondary	4
Total Flow to Sacramento		*273*
San Joaquin Basin		
Modesto	Secondary	70
Stockton (Nov-Jun)	Secondary	55
Stockton (July-Oct)	Advanced Secondary	55
Turlock	Secondary	20
Merced	Secondary	10
Manteca	Secondary	10
Total Flow to San Joaquin		*165*
Delta		
Tracy	Secondary	9
Lodi	Advanced Secondary	7
Brentwood	Advanced Secondary	5
Discovery Bay	Secondary	2
Total Flow to Delta		*23*
Total Watershed Flow		**461**

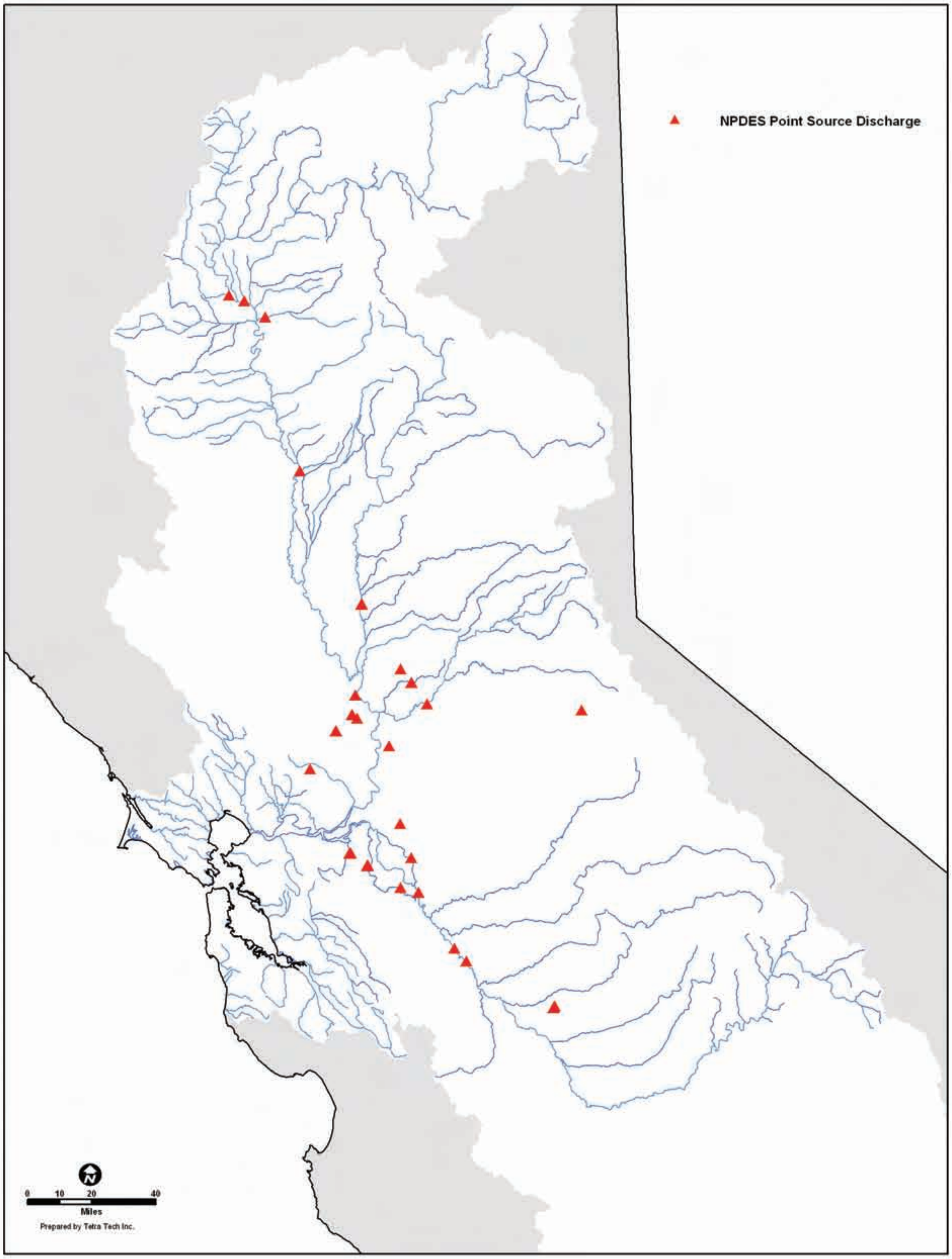


Figure 4-32. Point source discharge locations in the database developed by Central Valley Drinking Water Policy Workgroup.

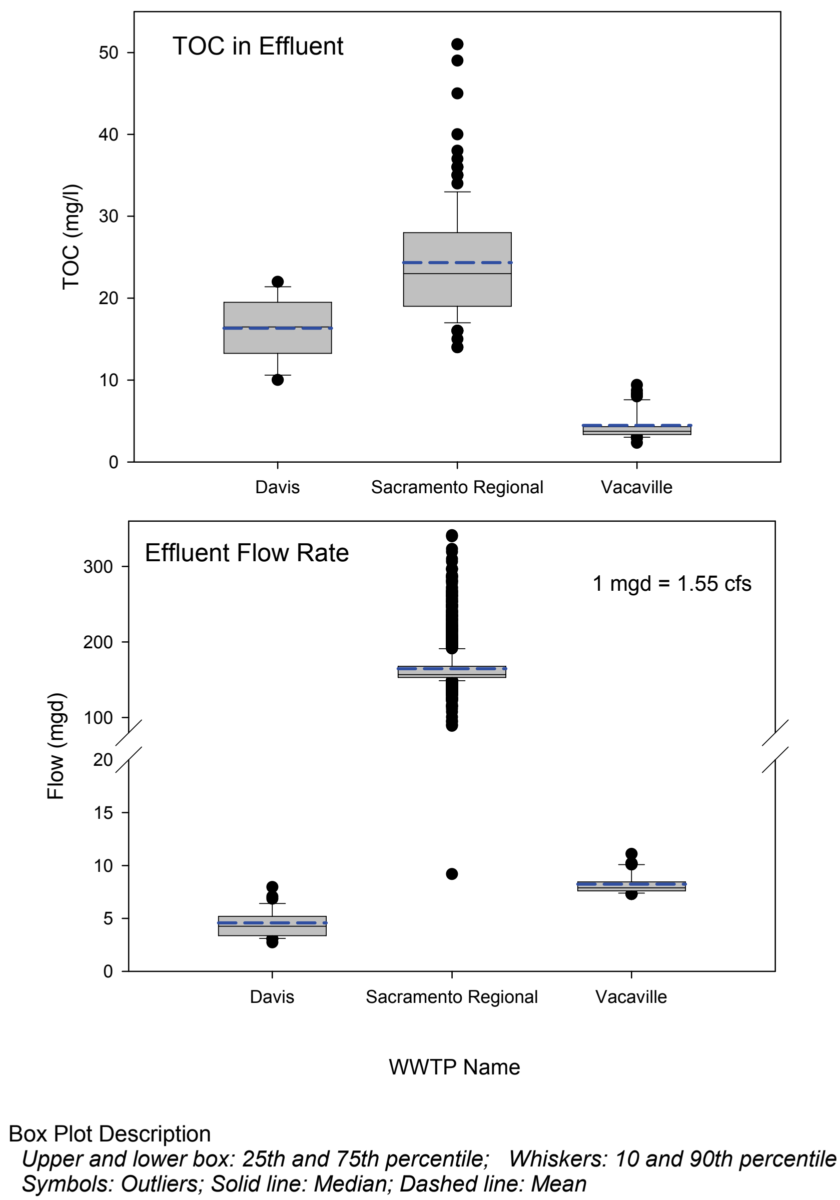


Figure 4-33. Organic carbon concentration and flow data for Davis, Sacramento, and Vacaville. These are the only point sources that monitor organic carbon in their outflows.

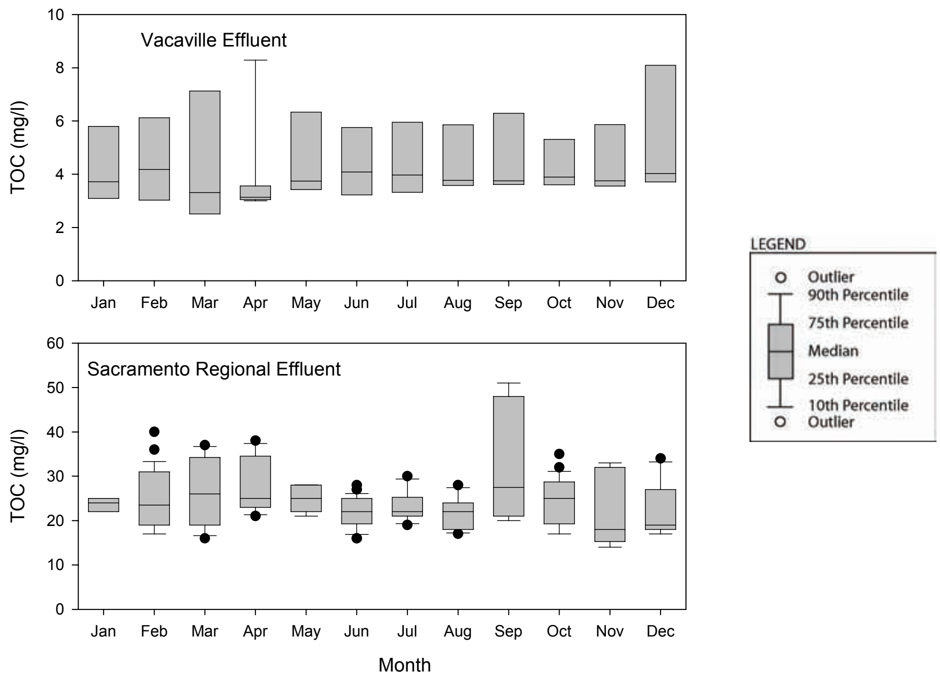


Figure 4-34. Seasonal patterns in wastewater effluent concentrations at Vacaville and Sacramento Regional Wastewater Treatment Plant. Data at Davis were insufficient for a comparison across months.

4.5.3 COMPARISON OF WATERSHED AND OUTFLOW LOADS

The relationship between upstream loads, watershed loads corresponding to a stream reach, and downstream exported loads is shown schematically in Figure 4-35. If instream transformation processes are not dominant, the sum of the upstream loads and the watershed loads should be approximately equal to the downstream exported loads. Because instream loads and export rate based watershed loads were computed independently in the previous sections, the comparison of these loads provides a useful check on the calculations so far, and discrepancies are one indication of uncertainties or inaccuracies in the load calculations.

In Figures 4-36 and 4-37, organic carbon load estimates based on in-stream measurements of flow and concentration are compared with the export rate estimate of loads for each subwatershed. The upper portion of each figure illustrates the loads estimated using export rates for each of the landuse categories for each subwatershed. The lower portion of each figure compares the sum of the watershed loads as presented in the upper portion (watershed loads), these watershed loads added to the upstream instream component (watershed loads + upstream inputs), and the outflow loads as computed using instream data, previously presented in Table 4-3 (outflows). Tables 4-9 and 4-10 tabulate this information. In several cases, including tributary stations near the Delta, the loads estimated by two very different approaches are comparable. In other cases, such as the San Joaquin River at Sack Dam (during dry years), the estimates are off by a factor of 9. In general, the greatest discrepancies occur at the locations that have the least amount of organic carbon concentration data.

Total watershed loads entering the Delta at the major tributary input locations, Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis, are presented in Figure 4-38. These load components are based solely on export rates as applied to the entire watersheds upstream of each location, and thus will be different from loads presented on the top portion of Figures 4-36 and 4-37 for Hood/Greene's Landing and Vernalis, which present loads from the individual subwatersheds for these locations (i.e., subwatersheds 8 and 22). The watershed and outflow loads are shown in a graphical schematic in Figures 4-39 and 4-40 for average wet and dry years.

A key observation from these calculations is that the background loads, primarily from land uses such as forests and shrubland, dominate in the overall annual loads in the Sacramento Basin. This occurs because the annual loads are dominated by the high wet weather flows, which originate in large part from the less-developed watersheds in the Sacramento River basin. Agricultural loads dominate in the San Joaquin Basin, particularly in dry years. A key data gap in these calculations is the limited quantity of directly measured organic carbon from background areas. The importance of this source in the overall load calculation highlights the need for this export rate to be better quantified. Additionally, better characterization of agricultural export rates, particularly in the San Joaquin Basin, would help reduce the uncertainty of this loading source.

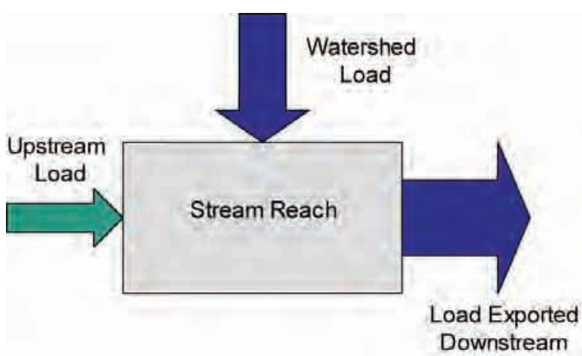


Figure 4-35. The relationship between upstream loads, watershed loads corresponding to a stream reach, and downstream exported loads. These three load values are compared in Figures 4-36 and 4-37.

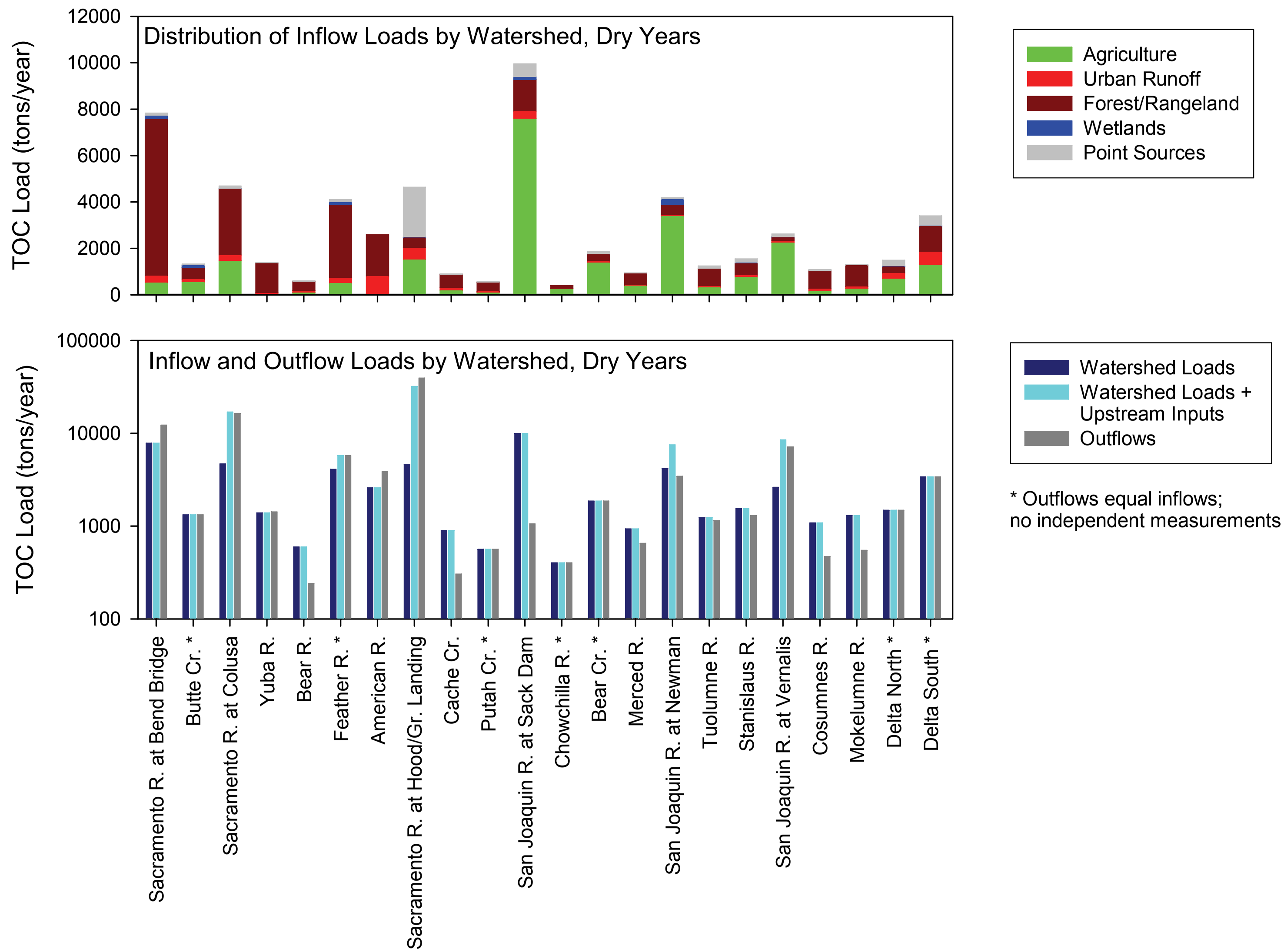


Figure 4-36. Distribution of organic carbon watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for dry years.

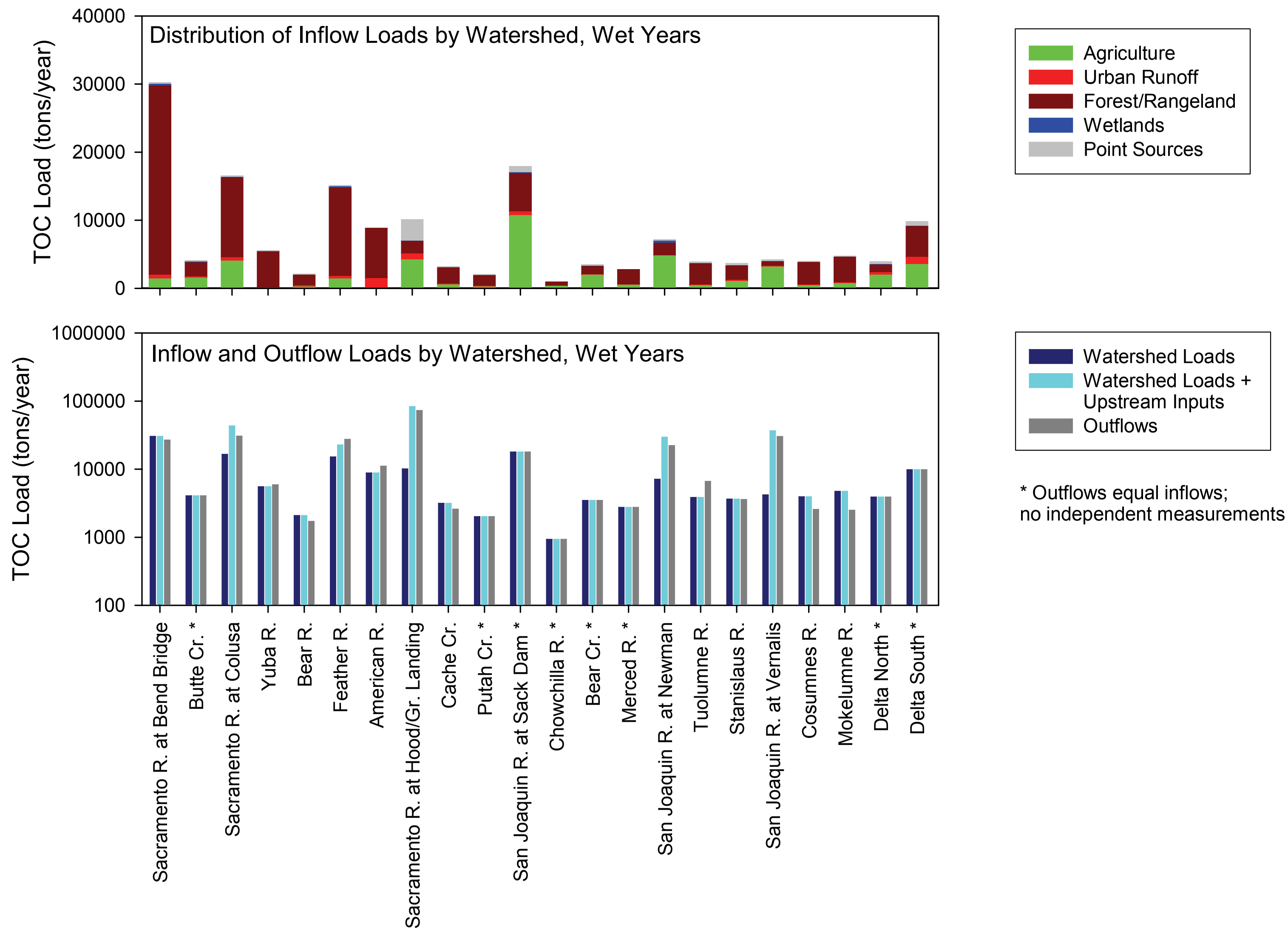


Figure 4-37. Distribution of organic carbon watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for wet years.

Table 4-9.
Comparison of upstream load, watershed loads, and downstream exports for dry years.

Watershed ID	Watershed Name	Load (tons/year)							
		Agriculture	Urban Runoff	Forest / Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	528	299	6,747	156	99	7,829	7,829	12,242
2	Butte Creek	556	113	499	106	54	1,327	1,327	*
3	Sacramento River at Colusa	1,469	250	2,858	13	100	4,689	16,932	16,394
4	Yuba River	25	55	1,292	0	17	1,389	1,389	1,424
5	Feather River	514	224	3,138	132	88	4,097	5,762	*
6	Cache Creek	199	95	578	0	27	899	899	304
7	American River	25	786	1,775	0		2,585	2,585	3,878
8	Sacramento River at Hood/Greene's Landing	1,528	495	450	14	2,147	4,634	31,994	39,313
9	Cosumnes River	161	98	788	0	38	1,085	1,085	471
10	San Joaquin River at Newman	3,400	47	431	246	59	4,183	7,501	3,444
11	Stanislaus River	769	82	524	7	164	1,546	1,546	1,301
12	Tuolumne River	319	57	767	0	94	1,237	1,237	1,147
13	Merced River	407	9	520	0	1	937	937	653
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	1,397	59	298	20	83	1,857	1,857	*
15	Chowchilla River	261	6	131	0	5	403	403	*
16	San Joaquin River at Sack Dam	7,586	325	1,354	124	561	9,950	9,950	1,057
17	Mokelumne River	273	83	914	0	33	1,303	1,303	550
18	Bear River	94	81	395	0	26	596	596	242
19	Putah Creek	97	48	392	0	27	564	564	*
20	Delta North	702	239	269	37	237	1,485	1,485	*
21	Delta South	1,293	565	1,100	27	415	3,399	3,399	*
22	San Joaquin River at Vernalis	2,250	72	163	21	114	2,620	8,511	7,130

* Flow and concentration data are not available to calculate an outflow load.

Table 4-10.
Comparison of upstream load, watershed loads, and downstream exports for wet years.

Watershed ID	Watershed Name	Load (tons/year)							
		Agriculture	Urban Runoff	Forest / Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	1,474	542	27,812	230	138	30,196	30,196	26,717
2	Butte Creek	1,553	204	2,055	156	75	4,044	4,044	*
3	Sacramento River at Colusa	4,100	453	11,779	19	140	16,492	43,209	30,490
4	Yuba River	70	100	5,327	0	23	5,520	5,520	5,904
5	Feather River	1,434	406	12,935	195	124	15,095	22,702	27,437
6	Cache Creek	556	172	2,382	0	38	3,148	3,148	2,574
7	American River	69	1,424	7,315	0		8,808	8,808	11,081
8	Sacramento River at Hood/Greene's Landing	4,265	897	1,855	20	3,034	10,072	83,124	72,598
9	Cosumnes River	450	177	3,248	0	53	3,929	3,929	2,555
10	San Joaquin River at Newman	4,816	86	1,776	363	83	7,123	29,395	22,148
11	Stanislaus River	1,090	149	2,159	10	230	3,637	3,637	3,587
12	Tuolumne River	452	102	3,163	0	132	3,849	3,849	6,612
13	Merced River	577	16	2,144	0	1	2,738	2,738	*
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	1,979	106	1,229	30	116	3,461	3,461	*
15	Chowchilla River	370	11	541	0	7	928	928	*
16	San Joaquin River at Sack Dam	10,744	589	5,581	182	787	17,883	17,883	*
17	Mokelumne River	761	150	3,769	0	47	4,727	4,727	2,492
18	Bear River	263	147	1,626	0	37	2,074	2,074	1,703
19	Putah Creek	271	87	1,614	0	38	2,010	2,010	*
20	Delta North	1,961	433	1,110	55	332	3,891	3,891	*
21	Delta South	3,608	1,023	4,533	40	581	9,785	9,785	*
22	San Joaquin River at Vernalis	3,187	130	671	30	160	4,179	36,526	30,059

* Flow and concentration data are not available to calculate an outflow load.

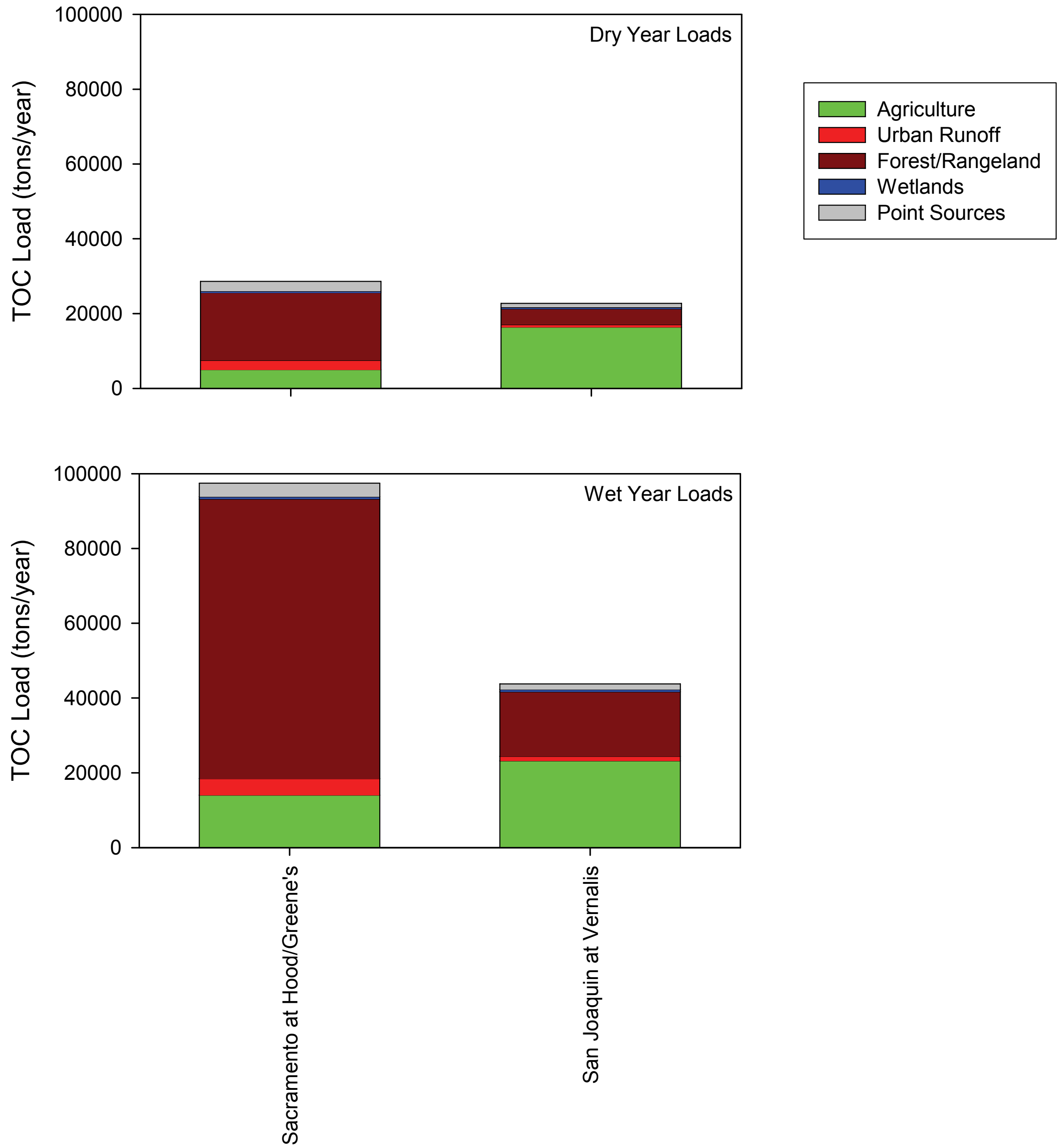


Figure 4-38. Distribution of organic carbon watershed loads by source for the Sacramento and San Joaquin Rivers.

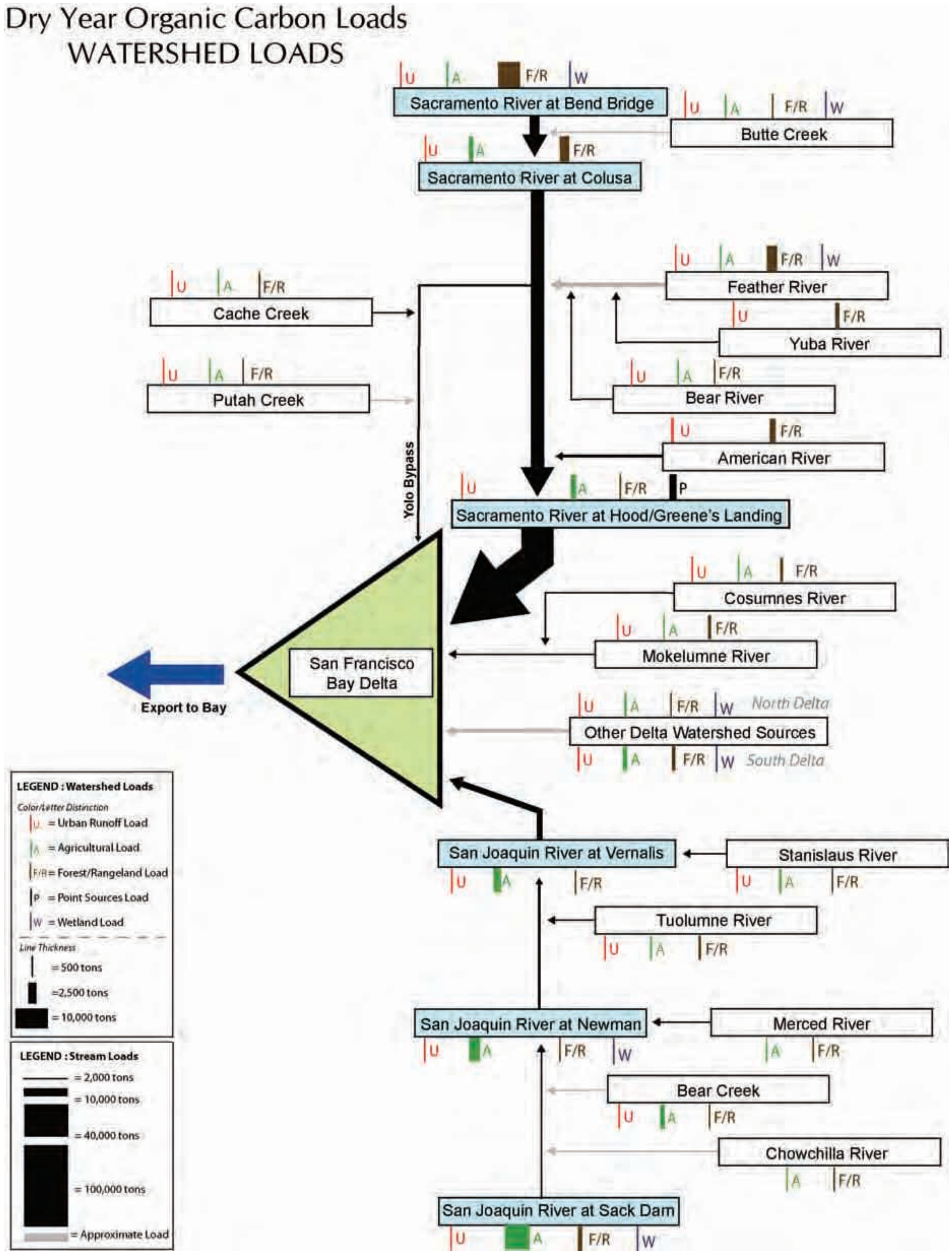


Figure 4-39. Watershed and outflow loads for the Central Valley and Delta for average dry years. This figure and the next use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

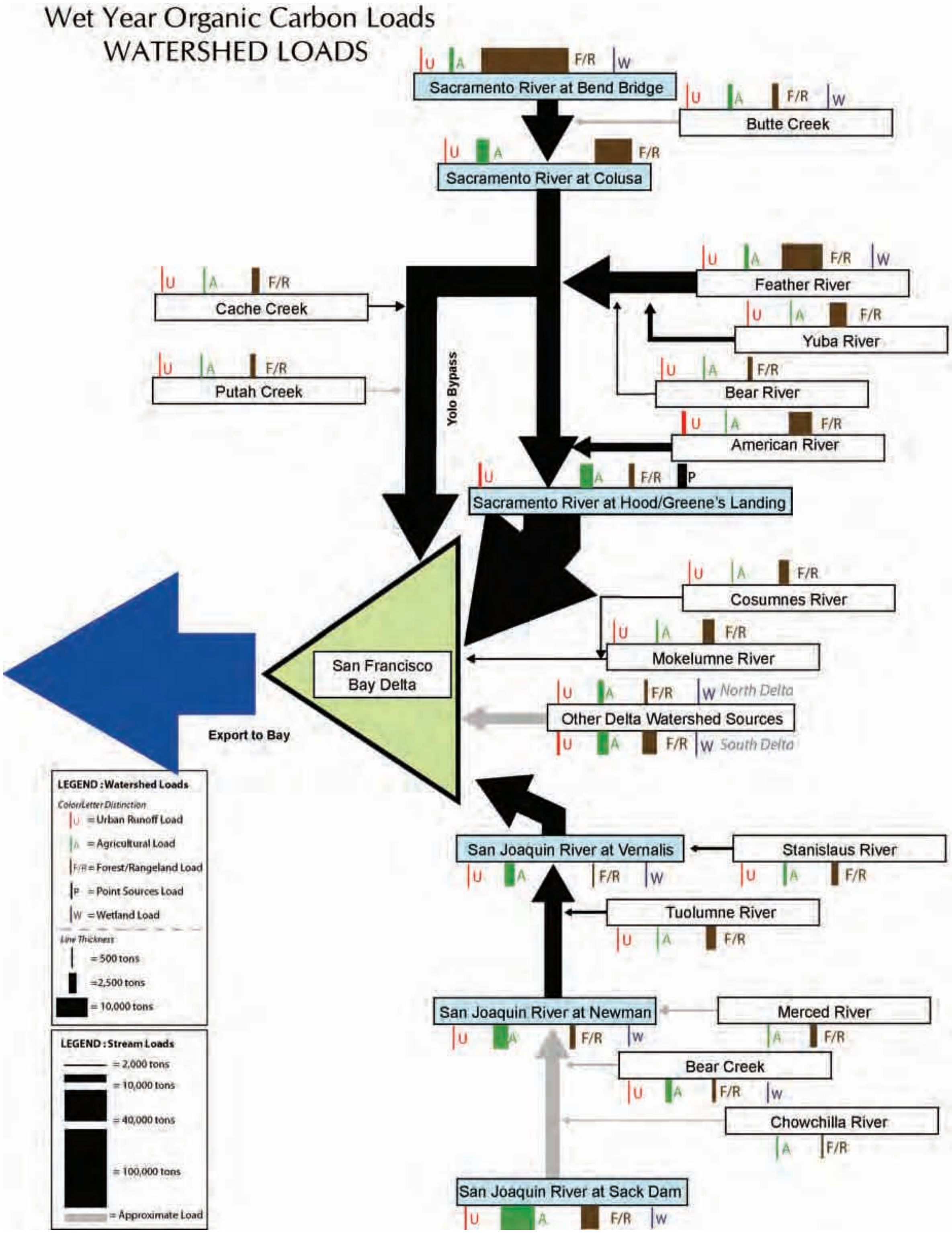


Figure 4-40. Watershed and outflow loads for the Central Valley and Delta for average wet years. This figure and the preceding one use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

4.6 MAJOR FINDINGS

Flows in Central Valley rivers are highly variable, especially in winter months, even though they are controlled by a large number of reservoirs At most stream sampling locations there are limited concentration data, whereas there are daily flow data, Loads are therefore estimated using monthly average concentration and flow values. At the Sacramento River at Hood/Greene's Landing, where daily flow and concentration data were available, the load estimated by this approach was comparable to loads estimated in previous studies.

Tributary organic carbon loads are substantially greater in the wet season than in the dry season. Tributary loads were found to vary significantly between wet and dry years. Although the organic carbon concentrations in the Sacramento River are lower than the concentrations in the San Joaquin River, the Sacramento River load to the Delta exceeds the San Joaquin River load by a factor of more than two.

It was not possible to calculate export rates for each type of land use present in the Central Valley and Delta. A limited amount of organic carbon data have been collected from watersheds with one particular type of land use. Most of the data available for this analysis were collected at locations that have mixed land uses. Export rates of organic carbon (mass of carbon exported per unit area per year) were estimated for several land uses: urban land, agricultural land, wetlands, and natural areas (including forests, shrubland, and rangeland) based on the limited data. The calculated total watershed exports are comparable to the stream loads at key locations (such as Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis). There were considerable differences in the estimated loads derived from the two methods at locations where there were limited organic carbon concentration data. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

CHAPTER 5.0 ORGANIC CARBON CONCENTRATIONS AND LOADS IN THE DELTA

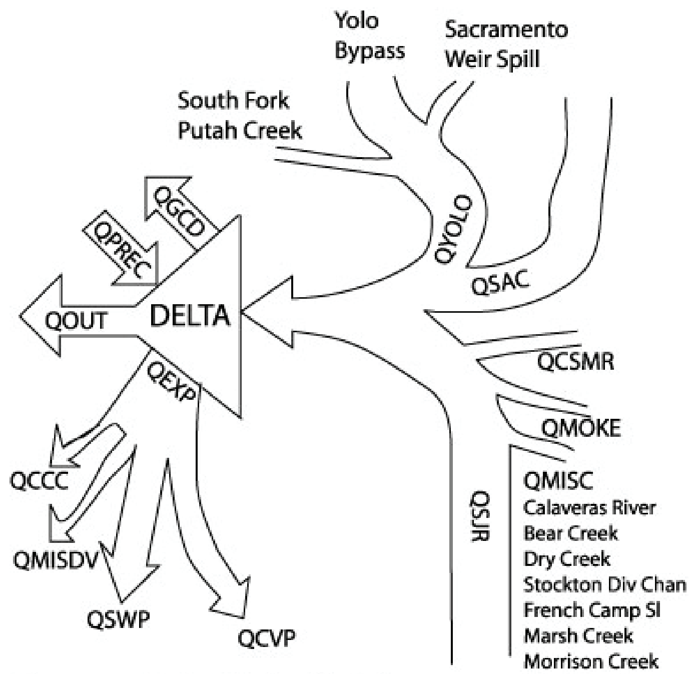
Over the past three decades, the Sacramento-San Joaquin Delta has been the focus of monitoring and computer modeling studies of organic carbon. Organic carbon data have been collected at numerous locations in the Delta and its tributary watersheds. Assessment studies, including computer modeling, have 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.



LEGEND

QSJR	San Joaquin River flow
QMISC	Miscellaneous streamflow
QMOKE	Mokelumne River flow
QCSMR	Cosumnes River flow
QSAC	Sacramento River flow
QYOLO	Yolo Bypass flow
GGCD	Gross channel depletion
QPREC	Precipitation runoff
QOUT	Delta outflow
QEXP	Exports
QCCC	Contra Costa Water District Diversions at Rock Slough and Old River
QMISDV	Flooded island and island storage diversion
QSWP	State Water Project exports at Banks Pumping Plant
QCVP	Central Valley Project pumping at Tracy
QNBAQ	North Bay Aqueduct export

Note: In DAYFLOW equations, QMISDV replaced with QNBAQ. Updated figure not available.

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

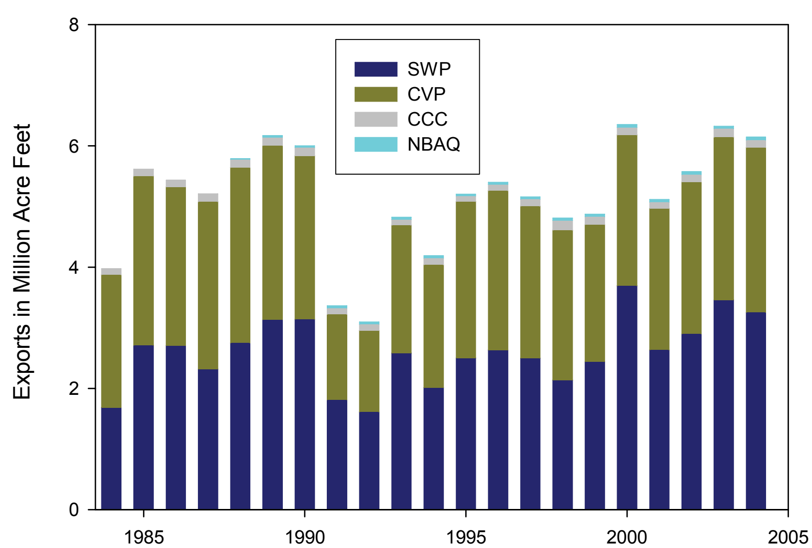


Figure 5-2. Annual water supply diversions (Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Contra Costa Water District's Rock Slough and Old River pumping plants (CCC), and the North Bay Aqueduct's Barker Slough Pumping Plant (NBAQ) as reported in the DAYFLOW model.

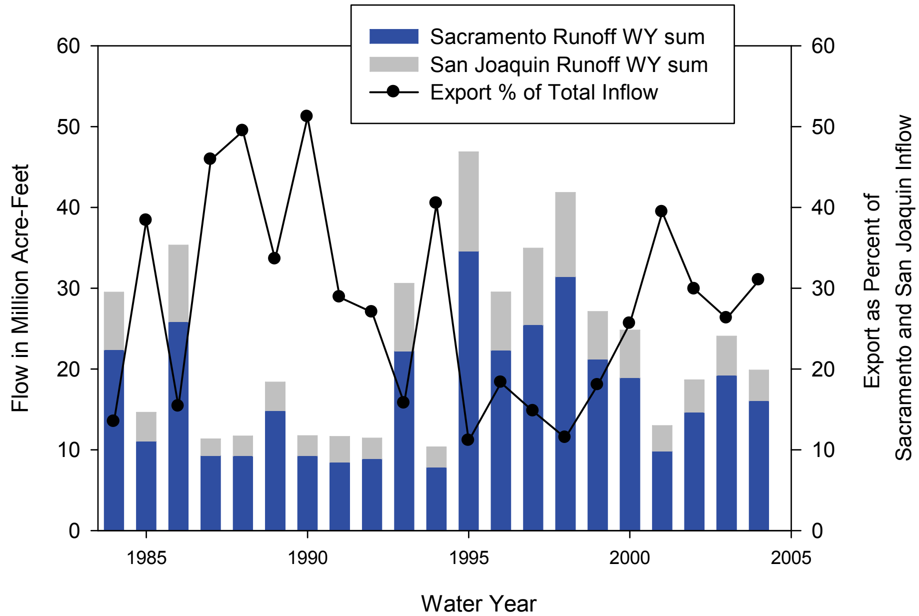


Figure 5-3. The sum of project diversions as a percentage of annual flows from the major tributaries (Sacramento and San Joaquin Rivers) to the Delta.

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.

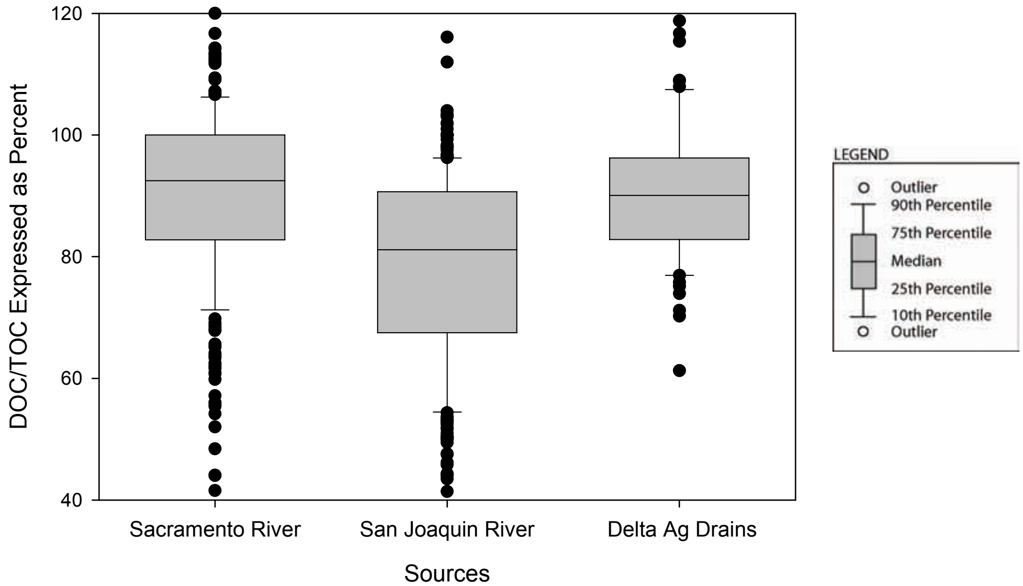


Figure 5-4. Relationship between dissolved and total organic carbon concentrations at key Delta locations.

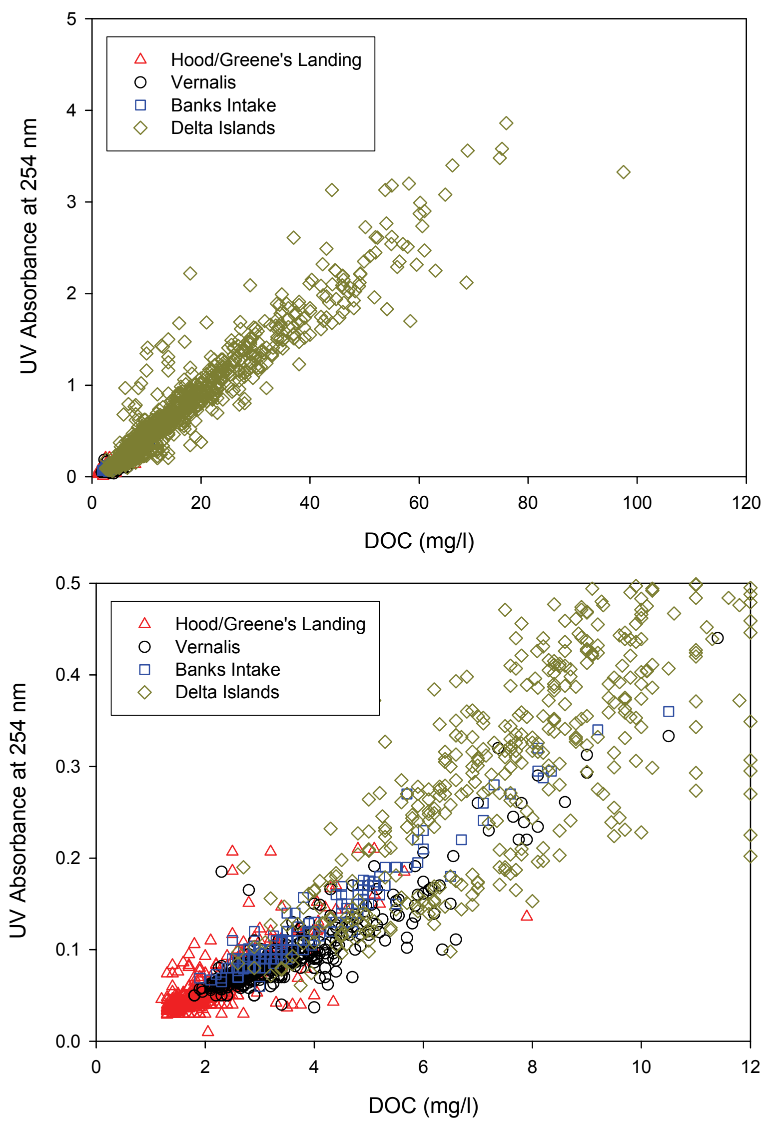


Figure 5-5. Dissolved organic carbon concentrations and UVA at 254 nm at key Delta locations.

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.

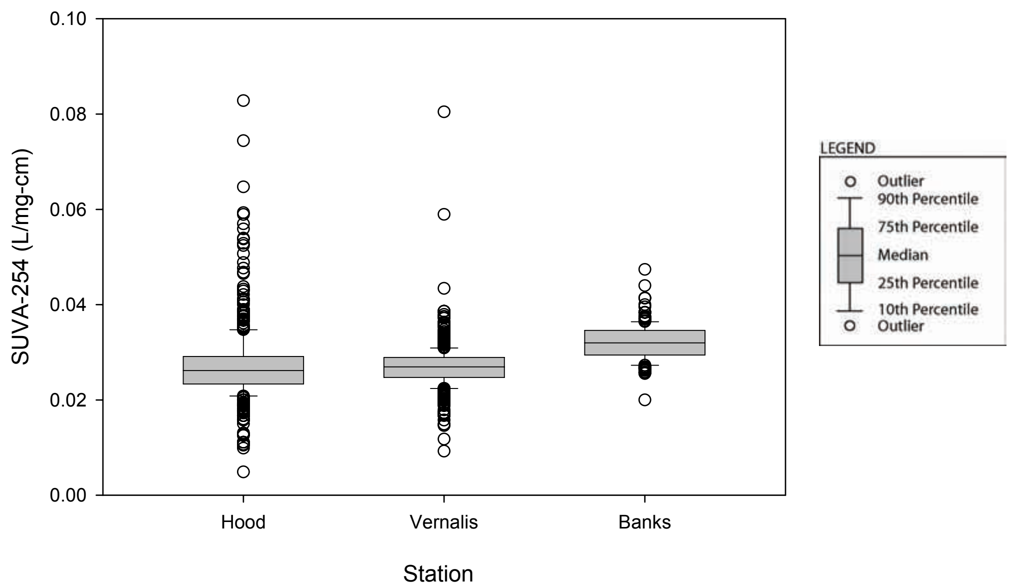


Figure 5-6. SUVA254 values (UVA normalized by the concentration of organic carbon) at Sacramento River (Hood), San Joaquin River (Vernalis) and Banks Pumping Plant.

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.

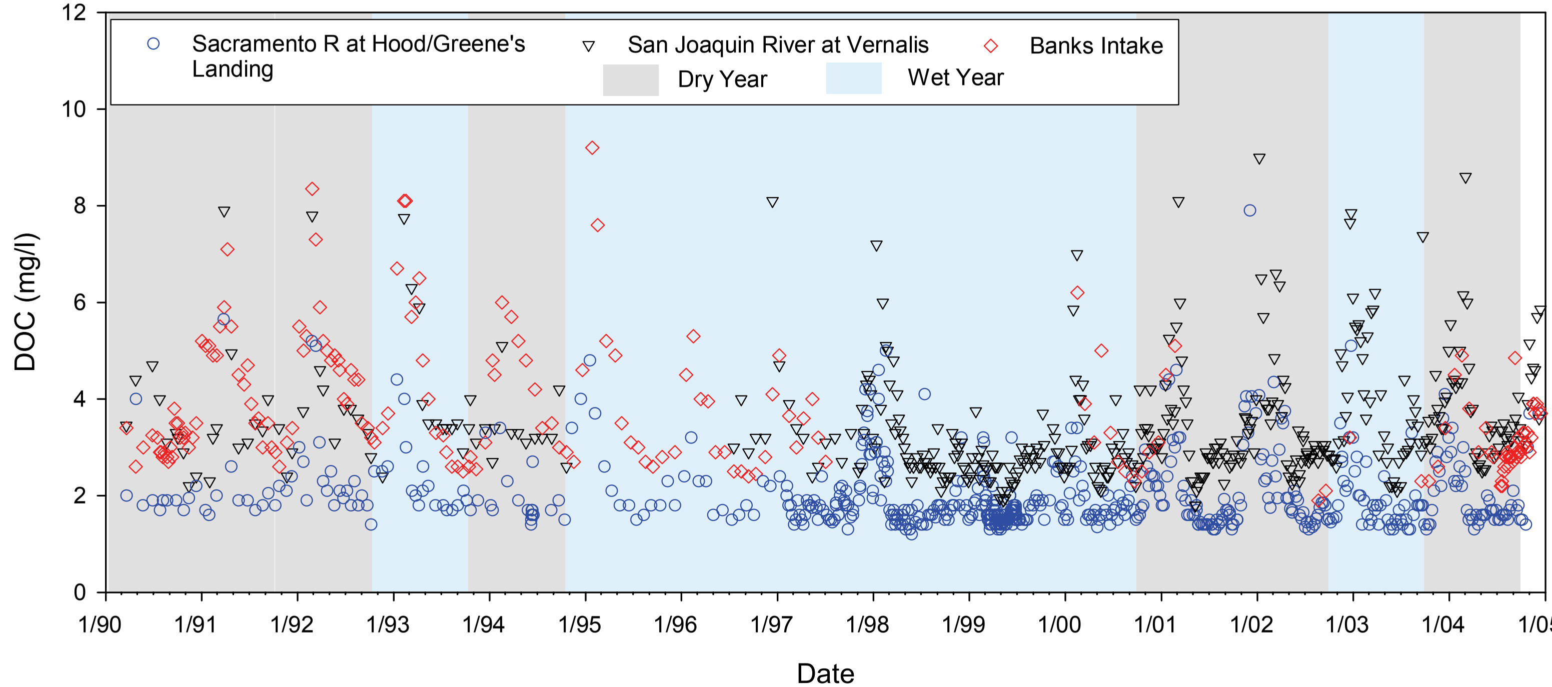


Figure 5-7. DOC concentrations at Sacramento River (Hood), San Joaquin River (Vernalis) and Banks Pumping Plant.

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.

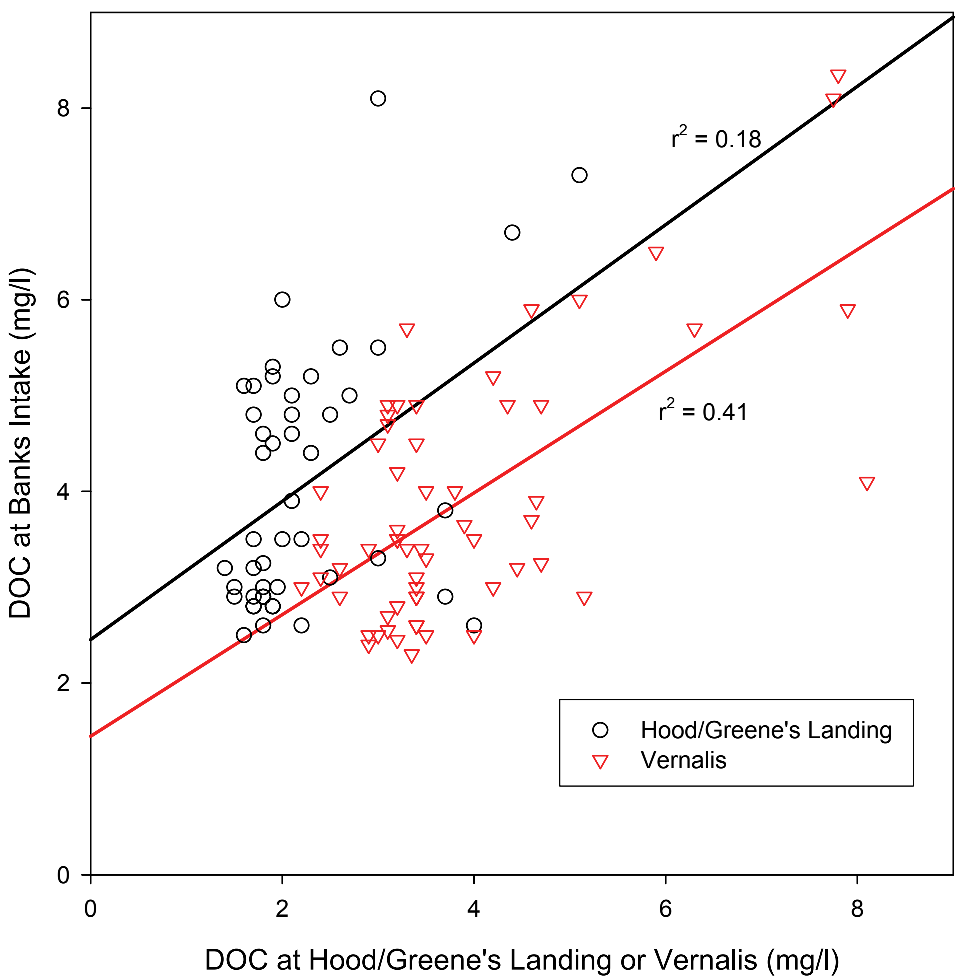


Figure 5-8. Correlation between DOC at the tributaries and DOC at Banks Pumping Plant.

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.

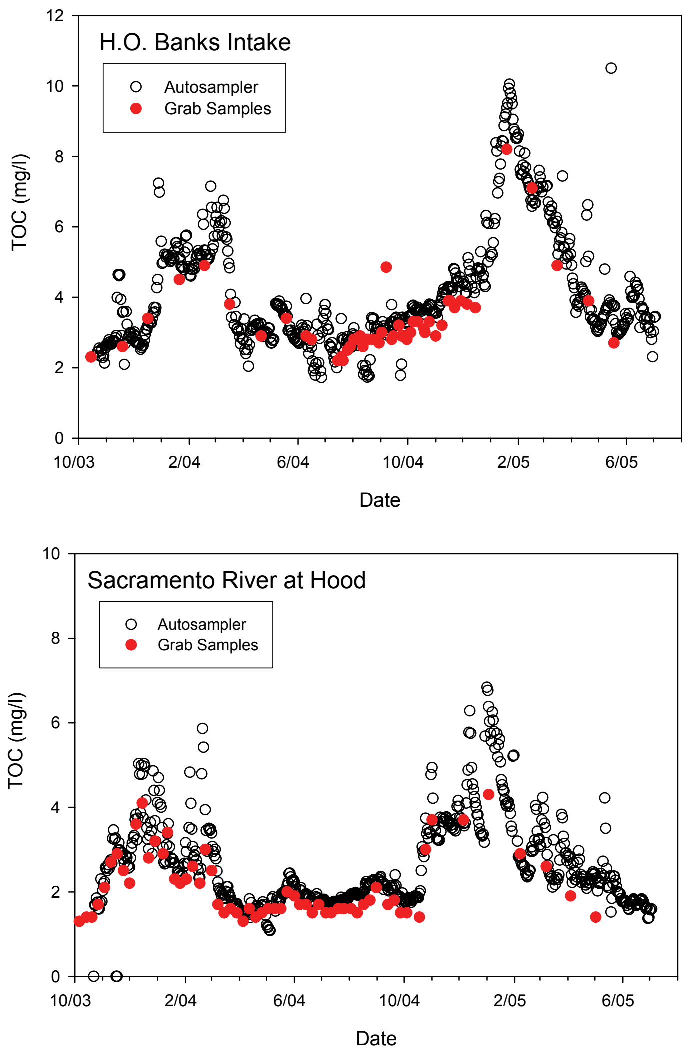


Figure 5-9. Real-time TOC data compared with grab sample data at Sacramento River (Hood) and Banks Pumping Plant.

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.

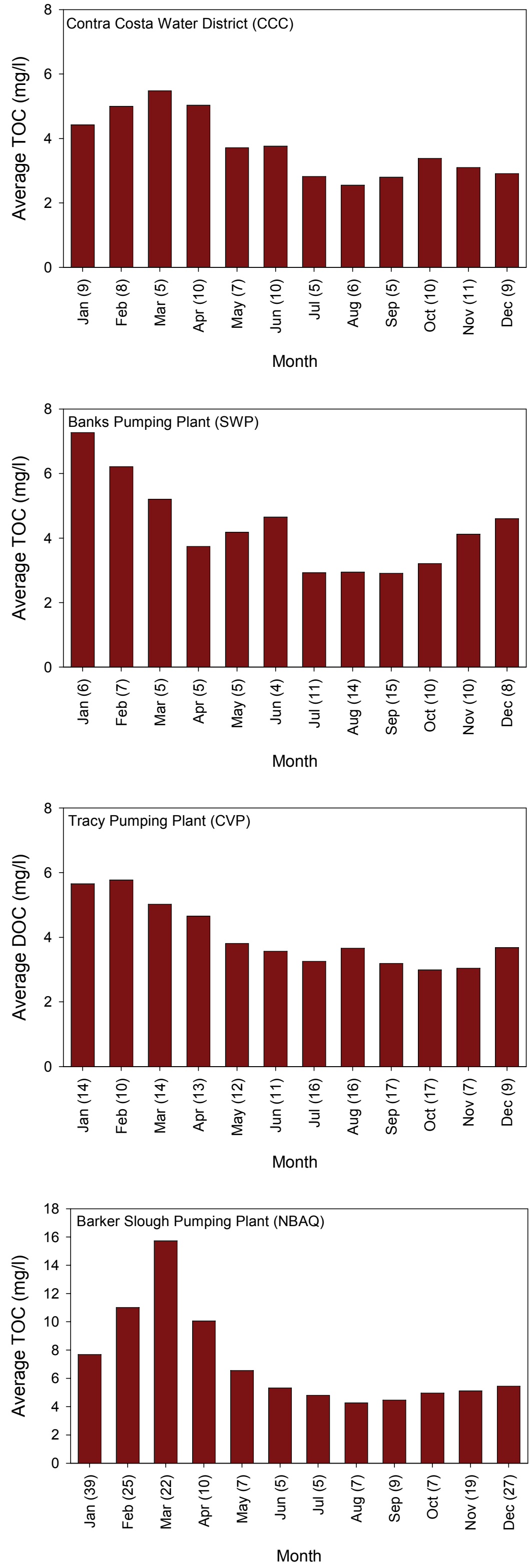


Figure 5-10. Organic carbon concentrations at water supply diversions. The number of data points is shown after each month.

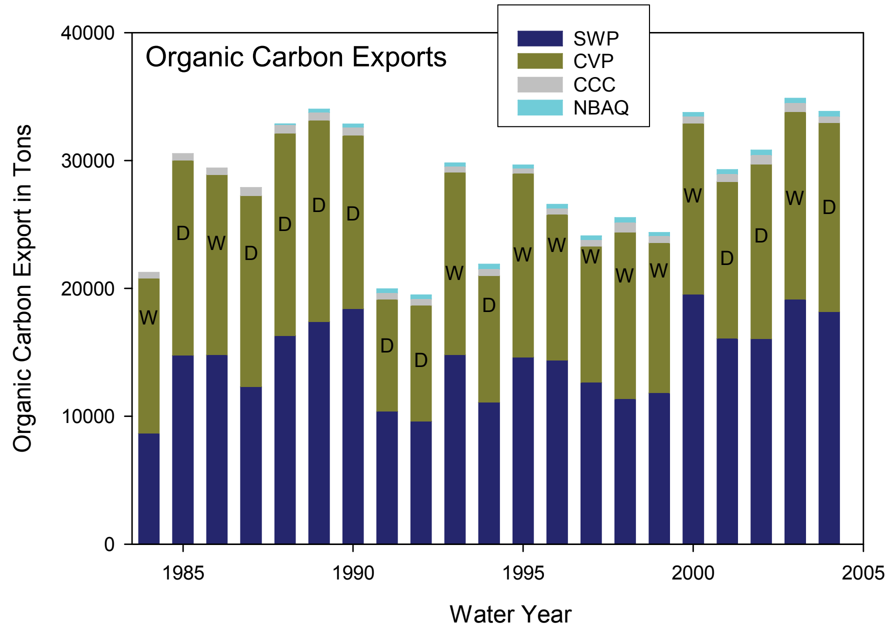


Figure 5-11. Annual organic carbon exports over the water years 1984-2004.

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/m^2/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/m^2/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).

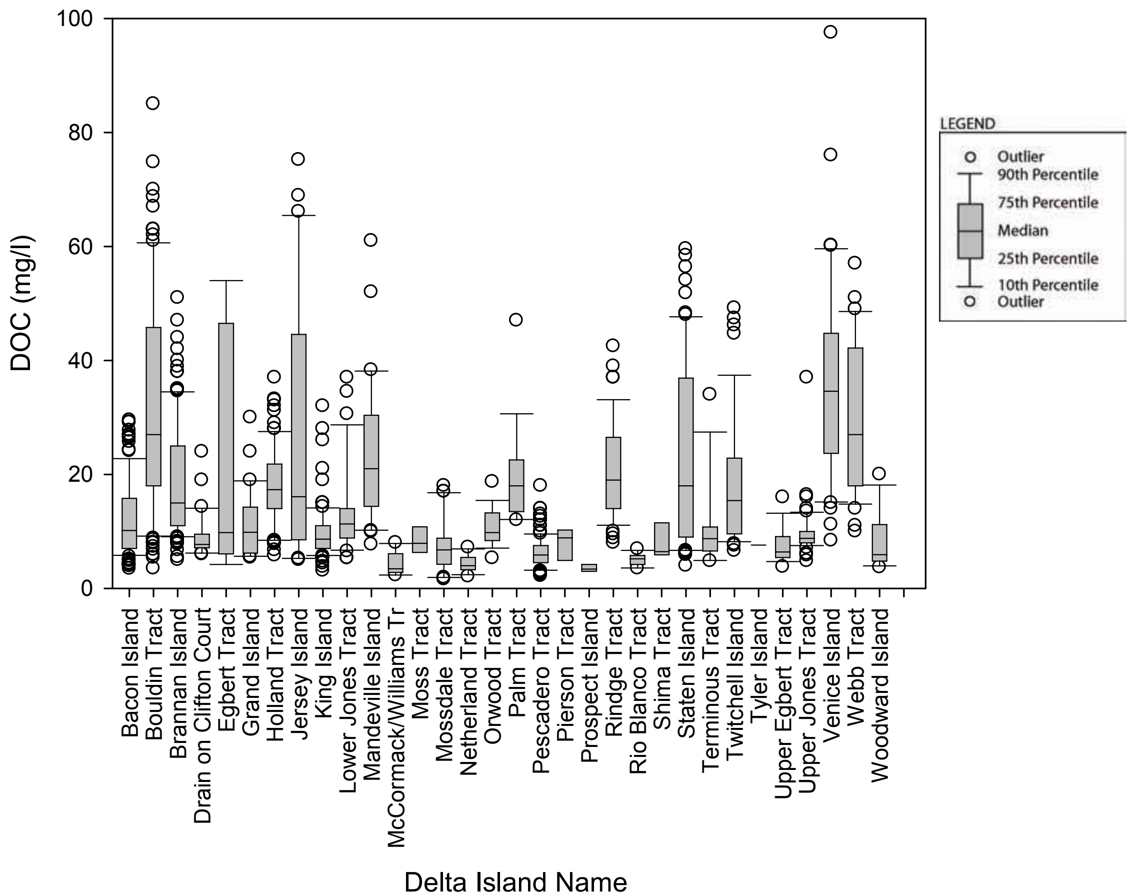


Figure 5-12. DOC concentrations in Delta agricultural drainage.

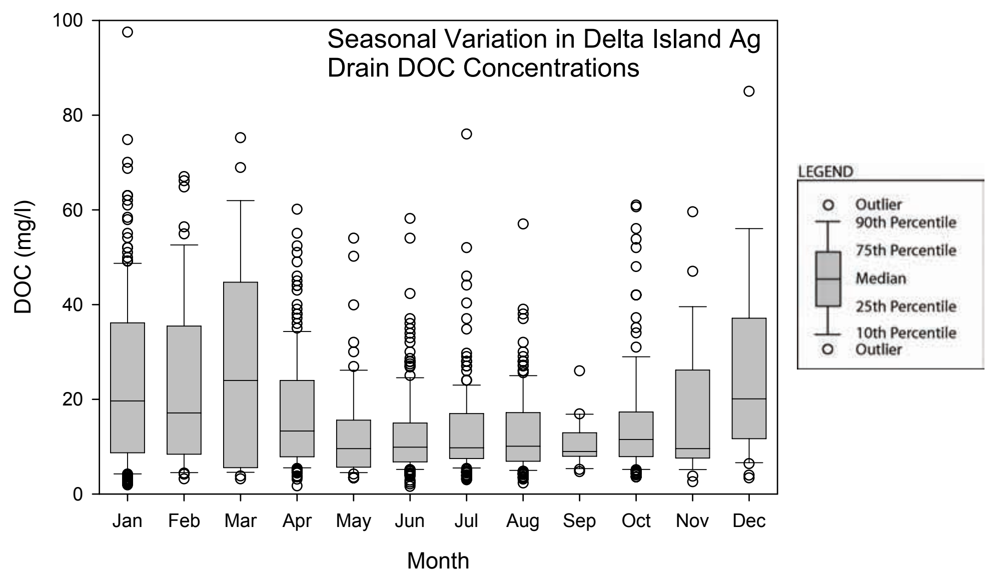


Figure 5-13. Seasonal variation in Delta agricultural drainage DOC concentrations.

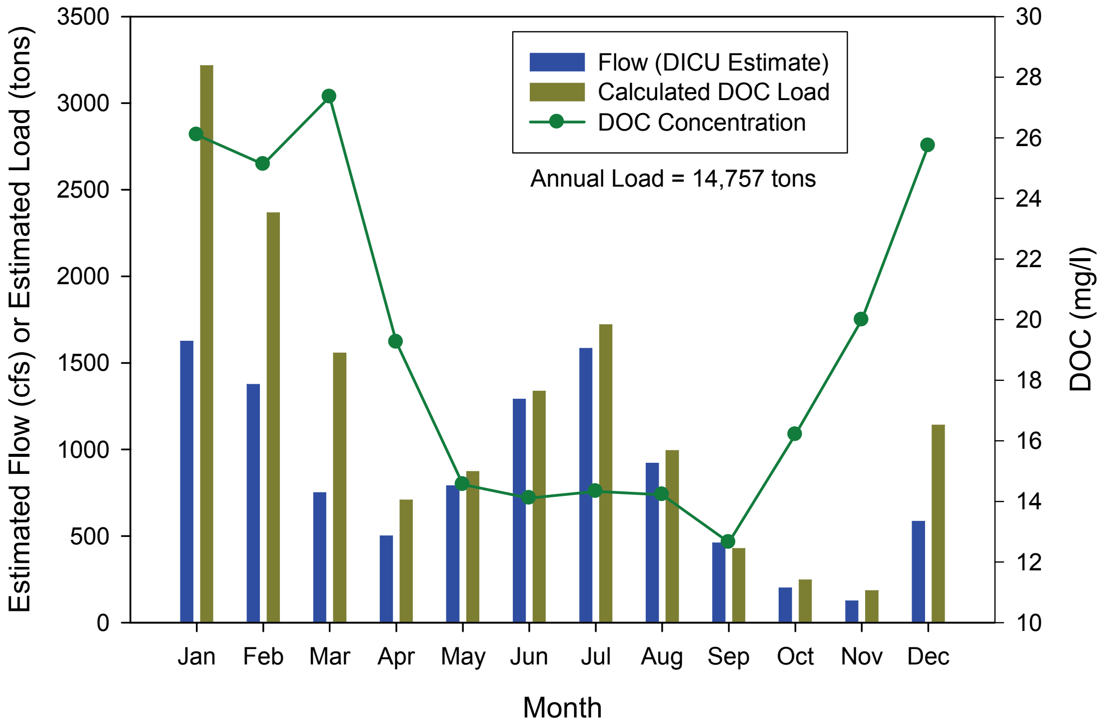


Figure 5-14. DICU estimates of flow for each month coupled with mean monthly concentration data observed at all island drains from Figure 5-13, used to estimate the contribution of DOC from agriculture on Delta islands.

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.

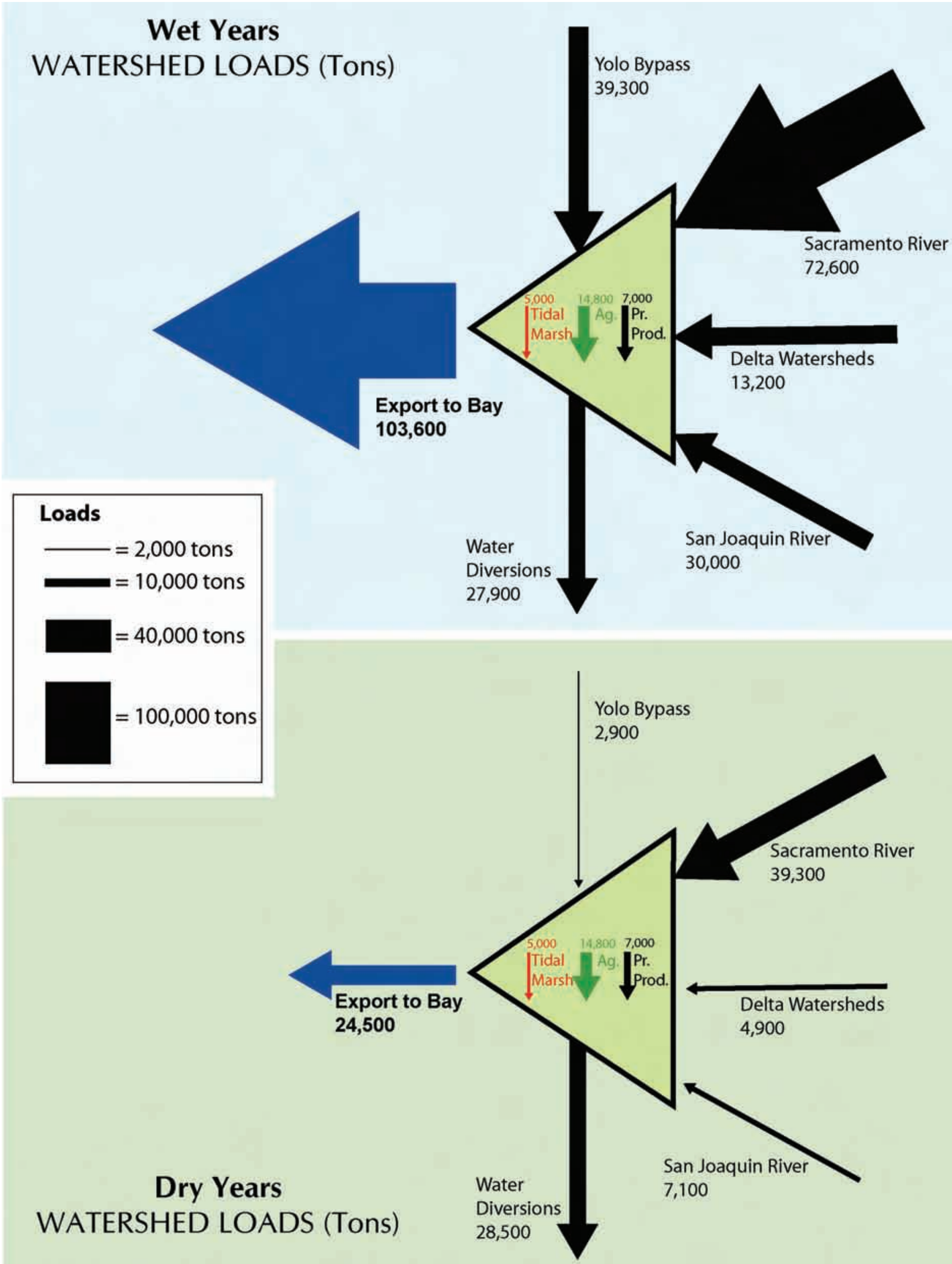


Figure 5-15. The tributary loads calculated in Chapter 4, along with the internal loads estimated in Chapter 5.

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.

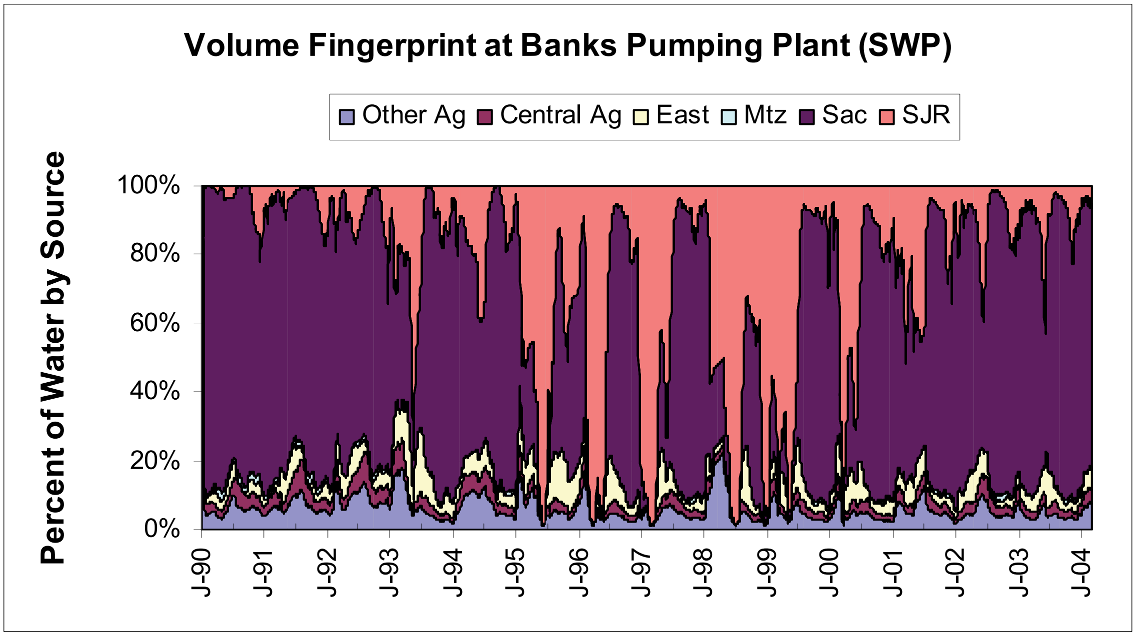


Figure 5-16. Long-term percentage contribution of flows at the Banks Pumping Plant (data provided by DWR).

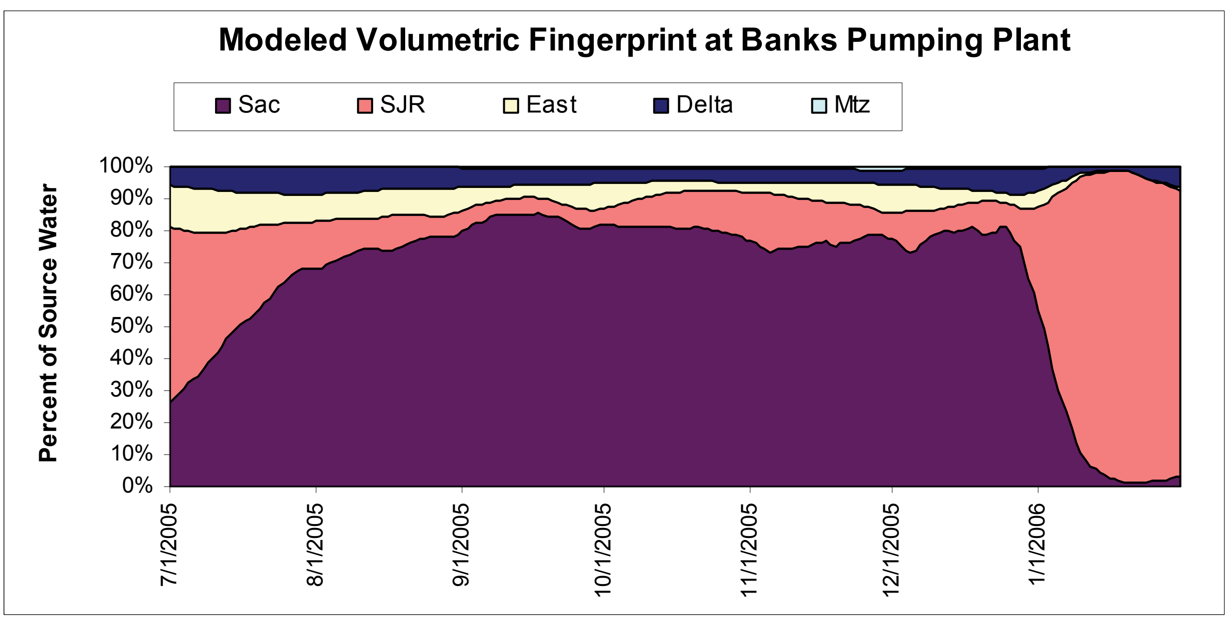


Figure 5-17. Percentage contribution of flows at the Banks Pumping Plant (data provided by DWR).

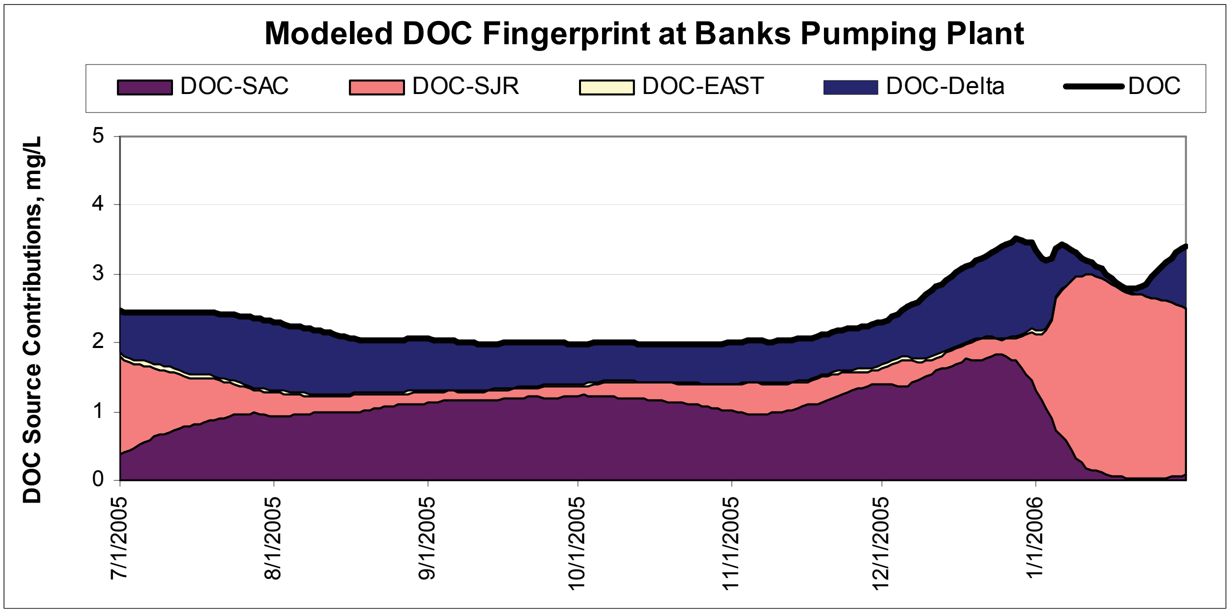


Figure 5-18. Contribution of DOC by source at the Banks Pumping Plant (data provided by DWR).

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.

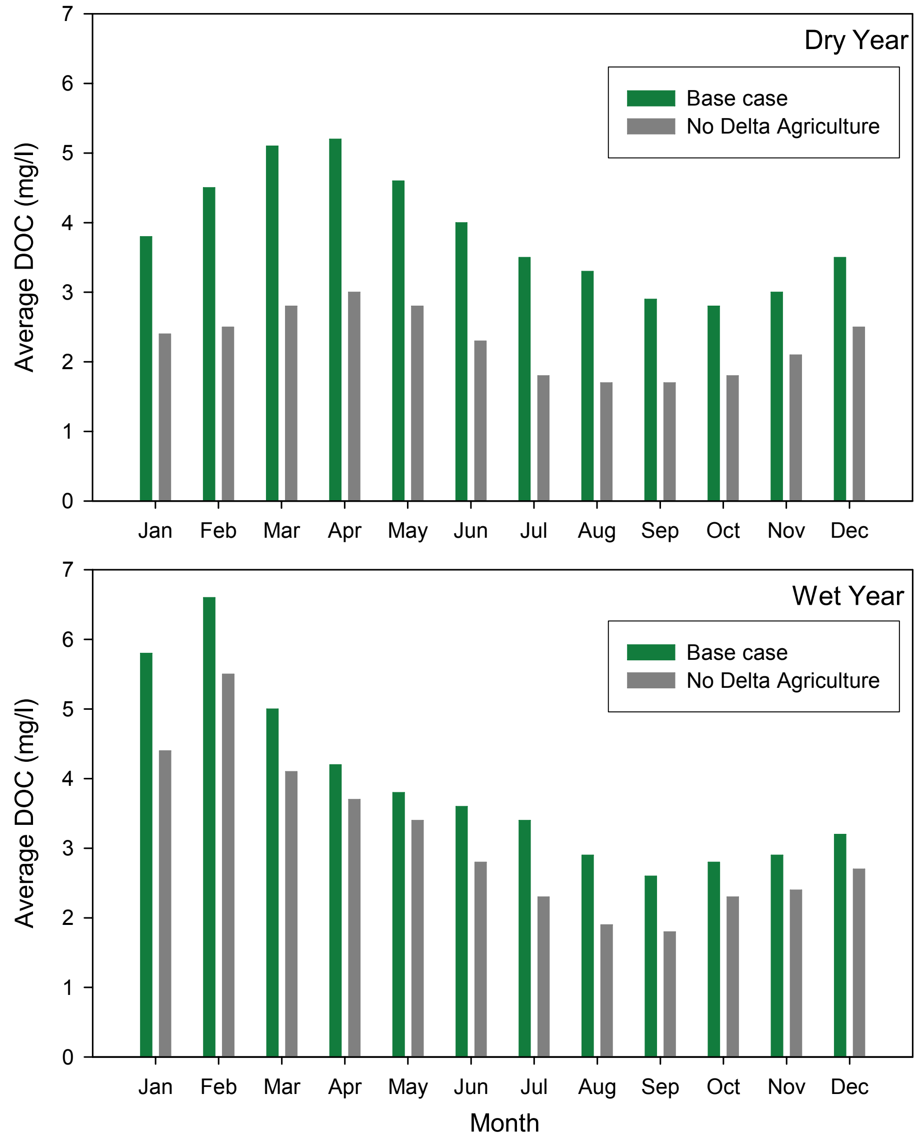


Figure 5-19. Banks intake DOC concentrations for wet and dry years for base case conditions and for a hypothetical case of no Delta Island drain contribution. Based on data from DiGiorgio (2003).

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.

CHAPTER 6.0 MAJOR FINDINGS AND RECOMMENDATIONS FOR FUTURE WORK

The development of the conceptual model in this report involved the synthesis of a large amount of data and information from published reports. The model provides a succinct summary of a tremendous amount of work that has been conducted in the Central Valley-Delta region in the last 25 years. The conceptual model can be used to direct future investigations to improve understanding of organic carbon-related sources, transformations, impacts, and management. This chapter summarizes key findings and highlights future concerns.

6.1 MAJOR FINDINGS

Organic carbon in the dissolved form (DOC) is the form considered to be more likely to react during chlorination and form disinfectant byproduct compounds. DOC is generally less bioavailable to the base of the web compared with particulate organic carbon and/or organic carbon freshly derived from primary production. Thus, efforts in the Central Valley and Delta to control or manage DOC levels for drinking water quality may not have direct adverse effects on the food web, although this is a subject that needs to be studied further. There is general agreement in the literature that THM formation is correlated to TOC concentrations, although the relationship is more complex when a specific structural characteristics of DOC is compared with THM formation potential. A commonly used measure of DOC aromaticity, SUVA at 254 nm, was found to be poorly correlated to THM formation in Delta waters. Characterization of organic matter through sophisticated analytical tools such as stable isotope signatures is an active area of research; published information that was available at this time, however, is limited to a small number of locations near the Delta, and with limited temporal resolution. The data are indicative of a contribution due to in-Delta primary production, although the variability of this contribution as a function of time is not known. There is limited knowledge on the relative propensity of different sources to form THMs, although it appears that Delta island drainage, is somewhat less reactive than tributary sources.

Flows in the Central Valley, albeit modulated by the existence of a large number of reservoirs, are nonetheless highly variable, especially in the winter months. In a pattern that is widely seen, at most stream sampling locations concentration data were obtained for a small number of dates, whereas the flow data were obtained daily. In such a situation, loads are estimated using a relationship between flow and concentration to interpolate for the dates on which no concentration data are available. Flows and organic carbon concentrations are weakly correlated, if at all. Best fit regression lines between log of concentration and log of flow were used to estimate flows. When the data are poorly correlated and these lines effectively have zero slope, they essentially reflect the mean of concentration observations. At a station where daily flow and concentration data were available, the load calculation approach presented here was found to estimate loads reasonably well.

Loads of organic carbon delivered by the tributaries are substantially greater in the winter months. Tributary loads were found to vary significantly between wet and dry years, with loads from the Sacramento River Basin exceeding the San Joaquin River loads by a factor of two. There are few sources of data for in-Delta contribution of organic carbon, and these sources are more approximate than the tributary loads. Current estimates show that annual loads of organic carbon from the tributaries are substantially greater than the best estimates of in-Delta production. However, in dry years these may be a significant fraction of the total loads. The organic carbon export in aqueducts is relatively uniform from year to year, particularly when compared with the tributary loads. In dry years, the export of organic carbon in aqueduct is nearly as large as the average internal Delta production.

The loads transported in streams were compared to the organic carbon export rates from different land uses. A small number of stations in the existing database could be used for the purpose of characterizing export from a particular land use; however, very few of the stations were sited specifically for this purpose, the export rates may be confounded by more than one land use. Export rates of organic carbon (mass of carbon exported per unit area per year) were computed key land uses: urban land, agricultural land, wetlands, and natural areas (including forests, shrubland, and rangeland). The calculated total watershed exports matched well with the stream loads at key locations (such as Sacramento River at Freeport and San Joaquin River at Vernalis) although not at all locations considered. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

The contribution of various sources to organic carbon concentrations at the intakes is best estimated through modeling. California Department of Water Resources' DSM2 model was found to be the best tool for this task. This model is well calibrated and widely used for water flow and water quality applications throughout the Delta. The model is routinely used by DWR staff to evaluate the effect of specific scenarios on concentrations at various intakes. A similar mechanistic model of the tributaries may need to be developed if impacts at stations outside the Delta need to be studied.

6.2 Uncertainties in Existing Data and Recommendations for Future Work

This section focuses on the uncertainties associated with the quantitative information presented in preceding chapters, and identifies key data gaps that should be addressed in future work, primarily through targeted monitoring and detailed mechanistic modeling. A summary of the uncertainty associated with quantitative information presented in Chapters 2, 4, and 5 is shown in Table 6-1. The uncertainty associated with the sources and the importance of obtaining more data to decrease uncertainty are discussed in this section. Recommendations are made for additional data collection, analysis of existing data, and modeling studies.

6.2.1 Organic Carbon Chemistry and Disinfection Byproduct Formation

Uncertainty and Importance

The chemistry of organic carbon, and particularly the propensity of organic carbon from different sources to form THMs and other disinfection byproducts, continues to be investigated actively. However, because of the dynamics in the system (in the flows and production of organic carbon), available data are insufficient to draw conclusions about the quality or the THMFP of organic carbon from different sources. The data are especially lacking in much of the watershed upstream of the Delta. There is significant uncertainty associated with this information even though it is important for assessing drinking water impacts. A better understanding of the potential for disinfection byproduct formation of different sources of organic carbon could lead to more informed decisions on how to best manage organic carbon in the system. For the immediate future, total organic carbon will be the primary focus of the Central Valley Drinking Water Policy Workgroup because drinking water suppliers are regulated on the concentrations of total organic carbon in the source water, and the research to characterize the quality of carbon from the various sources in the Central Valley will be costly and time consuming.

Table 6-1.
Relative levels of uncertainty and importance of organic carbon sources identified in the Conceptual Model.

Source	Level of Uncertainty	Importance
Tributary Loads		
Sacramento Basin		
Sacramento R. at Bend Bridge	High	Medium
Butte Cr.	High	Low
Sacramento R. at Colusa	High	Medium
Yuba R.	High	Medium
Bear R.	Medium	Low
Feather R.	High	Medium
American R.	Medium	Medium
Sacramento R. at Hood/Greene's Landing	Low	High
Cache Cr.	High	Low
Putah Cr.	High	Low
San Joaquin Basin		
San Joaquin R. at Sack Dam	High	Low
Chowchilla R.	High	Low
Bear Cr.	High	Low
Merced R.	High	Medium
San Joaquin R. at Newman	Medium	Medium
Tuolumne R.	Medium	Medium
Stanislaus R.	Medium	Medium
San Joaquin R. at Vernalis	Low	High
Delta		
Cosumnes R.	Medium	Low
Mokelumne R.	Medium	Low
Delta North	High	Medium
Delta South	High	Medium
In-Delta Sources		
Delta Island Agricultural Drainage	High	High
Export Rates		
Agricultural Land	High	High
Urban Runoff	Low	High
Background Areas	High	High
Wetlands	High	High
Other		
Point Source Discharges	Medium	High
Reservoirs	High	Medium

Recommendations

The Workgroup should stay apprised of research that is being conducted by USGS and MWQI on carbon quality.

6.2.2 TRIBUTARY LOADS

Uncertainty and Importance

The number of water quality samples and the length of the flow data record were used to assign the rankings of low, medium, and high uncertainty associated with each of the subwatersheds listed in Table 6-1. The loads in the Sacramento River at Hood/Greenes Landing and the San Joaquin River at Vernalis are well characterized due to many years of data collection and more recent real time monitoring. In general, the loads of organic carbon in the other subwatersheds that discharge to the Sacramento and San Joaquin rivers are not adequately characterized. Currently, the DWR modelers treat the Sacramento River at Hood/Greenes Landing and the San Joaquin River at Vernalis as boundary conditions to the Delta model. Although the models are able to predict how much of the load at a Delta pumping plant is due to each of the rivers, the models do not predict the sources of organic carbon within the Sacramento and San Joaquin watersheds. Additional data collection in the upper watersheds will allow the models to be extended upstream of the current boundary conditions.

Recommendations

The real time data collected in the Sacramento River at Hood, the San Joaquin River at Vernalis, and the Banks Pumping Plant should be reviewed to better define the relationships between concentration and watershed processes such as precipitation and reservoir releases. A more detailed review of these data can provide guidance on the importance of monitoring during certain times of the year, during specific events (such as storms), and on the frequency of monitoring needed to fully characterize organic carbon at an individual site. In addition, there are substantial data that were not used in this study because the concentration data were collected at locations for which there are no flow data or because the database did not contain latitude and longitude information. The Workgroup should review all of the data that have been collected for each of the subwatersheds and determine the key locations that require additional monitoring. The information gained from the review of the real time data should be used to determine the timing and frequency of monitoring.

6.2.3 IN-DELTA SOURCES

Delta Agricultural Drainage

Uncertainty and Importance

There are extensive data on organic carbon concentrations in Delta island agricultural drainage; however drainage volumes are currently estimated with the DICU model. Fingerprinting studies have shown that Delta agricultural drainage contributes a substantial amount of organic carbon to the Banks Pumping Plant under some conditions. It is important to have an accurate estimate of the drainage volumes before management options can be considered.

Recommendations

USGS is currently monitoring drainage volumes on Twitchell Island and MWQI is conducting a study of drainage volumes on Staten Island. These measured drainage volumes should be compared to estimates from the DICU model to assess how accurately the model predicts drainage volumes. Then decisions can be made on the importance of obtaining additional drainage volume data.

Delta Primary Production

Uncertainty and Importance

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.

Recommendations

The Workgroup should track the investigations being conducted on the Pelagic Organism Decline (POD) and request that additional work be conducted on Delta primary productivity, if it is not included in the POD work plan.

Tidal Marshes

Uncertainty and Importance

Tidal marshes, although a small area compared to the watershed of the Sacramento and San Joaquin rivers, have the largest export rate of any land use evaluated in Chapters 4 and 5 (150 tons of carbon/km^2/year). This export rate was based on a literature review because studies on Delta tidal marshes have not been completed. Because of the potential magnitude of this source, its proximity to Delta intakes, and the likelihood that these areas will grow in future years because of planned restoration efforts, the importance of this source should be evaluated.

Recommendations

The USGS study results on Twitchell Island should be reviewed when the study is completed to determine if Delta research confirms the findings in the literature. In addition, fingerprinting analyses should be conducted to determine the sensitivity of organic carbon concentrations at the major Delta pumping plants to varying estimates of tidal marsh export rates and acreage. This information can then be used to determine if additional research is needed on Delta tidal marshes.

6.2.4 Export Rates

There is an extensive amount of organic carbon concentration data collected in the major streams in the Central Valley. These data can be used to compute export rates from mixed land uses. However, for distinguishing sources, it is important to estimate the contribution of specific land uses. To meet this objective, focus should be placed on studying small indicator watersheds or specific sources.

Reservoirs

Uncertainty and Importance

There are reservoirs on most of the rivers in the Central Valley watershed but there are currently limited data on the concentrations of organic carbon released from the reservoirs. Based on the data that are available in the Sacramento Basin, the watersheds upstream of the reservoirs contribute substantial volumes of water that contains low concentrations of organic carbon (1-2 mg/L).

Recommendations

The Workgroup should gather any additional data that are available on reservoir releases, particularly in the San Joaquin watershed. If sufficient data are not available to confirm that organic carbon concentrations are low in reservoir releases, additional data should be collected on the major rivers immediately downstream from reservoirs in the San Joaquin Basin.

Agricultural Land

Uncertainty and Importance

Over 5,460,000 acres (20%) of the Central Valley watershed is used for agricultural production. There are currently limited data on the loads of organic carbon discharged from agricultural land in the tributary watersheds. The data from the Colusa Basin Drain in the Sacramento Basin is representative of loads from rice fields. Information is needed on other types of agricultural in the Sacramento Basin, such as orchards and row crops. Due to different sources of water and different methods for management of drainage in the San Joaquin Basin, the loads of organic carbon from agricultural operations on the west side of the San Joaquin Basin may differ from those on the east side of the Basin.

Recommendations

The Workgroup should obtain data collected by the agricultural waiver monitoring programs and from the Regional Board agricultural monitoring to determine if organic carbon loads from agricultural lands can be adequately estimated or if more focused monitoring is needed. In addition, USGS recently started a project to estimate contaminant loads from a small agricultural watershed, Willow Slough. This study should be tracked, and, when the results are available, they should be used to refine the estimate of agricultural loads.

Wetlands

Uncertainty and Importance

Data from Mud and Salt Sloughs were used for estimating the wetland export rate for both the Sacramento and San Joaquin watersheds because no other wetland data were available. Wetlands only represent 234,000 acres (less than one percent) of the Central Valley watershed.

Recommendations

Due to the limited extent of wetlands in the watershed no additional data collection is recommended at this time.

6.2.5 WASTEWATER TREATMENT PLANTS

Uncertainty and Importance

Organic carbon and flow data were available for three wastewater treatment plants (Sacramento Regional Wastewater Treatment Plant, Davis and Vacaville for this study. There was considerable variability in the concentrations of organic carbon in wastewater effluent from these three plants. Due to the volume of wastewater discharged in the Central Valley and the fact that population growth will lead to even greater volumes in the future, this source needs to be better characterized.

Recommendations

Organic carbon data should be collected from a number of wastewater treatment plants representing different treatment processes. These data can be analyzed to determine if organic carbon loads are related to treatment processes and to improve the estimates of organic carbon loads from wastewater treatment plants. Regional Board staff is reviewing permit files to determine if additional data are available on organic carbon concentrations from wastewater treatment plants. The Workgroup should review the additional data and determine if any additional monitoring is needed.

6.2.6 Fish Hatcheries

Uncertainty and Importance

Fish hatcheries are permitted to discharge up to 352 MGD (average dry weather flow of 256 MGD) into Central Valley waters and there are currently no data on organic carbon concentrations in fish hatchery waste. The importance of this source is currently unknown and should be investigated.

Recommendations

The Workgroup should collect organic carbon data from several fish hatcheries during the next year or two. These data will be useful in determining if fish hatcheries are a source of organic carbon that should be included in refined conceptual models.

6.2.7 Urban Runoff

Uncertainty and Importance

The export rate for urban runoff was estimated from a three year study of a single developed watershed, Arcade Creek. Additional data on urban runoff loads are needed to refine the load estimates presented in this report.

Recommendations

MWQI is completing a seven year study on organic carbon loads from a rapidly urbanizing watershed in Sacramento and Placer counties. The Workgroup should review the MWQI study results and compare the export rate with the one calculated from Arcade Creek. In addition, the Workgroup should work with the City and County of Sacramento and the City of Stockton to determine if loads can be calculated from the data collected as part of their NPDES storm water permit programs.

6.3 Future Concerns

From a review of the temporal variability of the loads, where available, it is clear that the year-to-year variations are so large that, on average, gradual changes in typical sources, such as increasing population or gradual increase in area of urban land, are unlikely to be discernible. In other words, over a two-decade time frame, given similar hydrology, the variability of loads is unlikely to be much different than what it is has been in the recent past. There are four areas of additional concern, however. The first pertains to dry and critically dry years. In these years, the relative contribution of organic carbon from anthropogenic sources is much larger, and the volumes of water withdrawals are a large fraction of total tributary inflows. Under these conditions, there is a stronger likelihood in future years of excessive DOC concentrations in source waters, and a stronger possibility of adverse ecological impacts to the Delta due to large withdrawals. The second concern pertains to the occurrence of catastrophic events such as levee failure. As the data have shown, organic carbon concentrations in the Delta agricultural drains are far in excess of any other concentrations measured in the system. Levee failure has the potential to effectively raise Delta-wide organic carbon concentrations substantially, with significant impacts on water suppliers. The third concern relates to the increase in area of tidal wetlands as part of Delta-wide restoration. Based on current knowledge, the contribution of organic carbon from this source, on a unit area basis, far exceeds any other non-point source. Because of the proximity of these wetlands to drinking water intakes, the potential significance of an increase in their area on drinking water quality must be closely investigated. The final concerns relate to the changing regulatory landscape. If the allowable THM and HAA5 limits in drinking water supply are lowered, or if additional compounds are added to the list of regulated chemicals, water suppliers may well face significant challenges in meeting such standards.

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