State of California
The Resources Agency
Department of Water Resources

WATER QUALITY CONDITIONS IN THE SACRAMENTO-SAN JOAQUIN DELTA DURING 1994

Report to the State Water Resources Control Board
In Accordance With Water Right Decision 1485, Order 4(f)

DEPARTMENT OF WATER RESOURCES
Environmental Services Office

September 1997

Pete Wilson
Governor
State of California

Douglas P. Wheeler
Secretary for Resources
The Resources Agency

David N. Kennedy
Director
Department of Water Resources

FOREWORD

The California State Water Project is a multipurpose project. In addition to its primary role of providing a statewide water supply, it provides flood control, power, and recreation. Operating this extensive system must include consideration of water quality needs and an understanding of the relationships between project operations and potential impacts on the aquatic environment.

The Department of Water Resources has operated the State Water Project in accordance with State Water Resources Control Board Decision 1485 (August 1978) and its predecessor, Decision 1379 (July 1971). These decisions establish water quality standards to protect beneficial uses of water supplies in the Delta and Suisun Marsh. Monitoring required by the decision is conducted by the Department of Water Resources and U.S. Bureau of Reclamation to ensure compliance with these standards, identify changes potentially related to State Water Project and Central Valley Project operations, and assess the effectiveness of the Delta Water Quality Control Plan in preserving Delta and Suisun Marsh water quality.

This program and associated special studies have helped water project operators gain a better understanding of the effects of State Water Project operation on the Delta's ecology. It has also provided information that will be used to help determine future operating criteria to protect waters of the Delta and San Francisco Bay.

Decision 1485 requires that a detailed report on monitoring results be prepared annually and submitted to the State Water Resources Control Board. Water quality data are being stored electronically so they can be accessed by interested parties. The database also serves as an important information source for agencies, organizations, and individuals involved in Delta study programs.

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SUMMARY

Water year 1994[1] was a critically dry year following an above average year and was characterized by low stream inflow, salinity intrusion into the Sacramento-San Joaquin Delta, and resumption of statewide drought conditions experienced from 1987 through 1992. Statewide, precipitation was 65 percent of average, seasonal runoff was 40 percent of average, and unimpaired runoff into the Sacramento Basin was 7.8 million acre-feet, the fourth lowest on record. During February, the only month with near average precipitation statewide, average streamflow peaked at 20,275 cubic feet per second in the Sacramento River and 2,012 cubic feet per second in the San Joaquin River. Reservoir storage was high, at 90-100 percent of average throughout much of the year, because of extensive carryover storage resulting from the generous runoff of water year 1993.

Adequate reservoir releases throughout the water year and scheduled curtailment of pumping at the State Water Project resulted in all Water Right Decision 1485 standards being met in 1994. As a result of these activities, Delta outflows exceeded 4,000 cubic feet per second throughout the summer, when outflow is usually at a minimum, and no record high or low water quality values were measured for nutrient concentrations, specific conductance, pH, water transparency, or water temperature. However, dissolved oxygen levels in the eastern Stockton Ship Channel near Rough and Ready Island were less than the 5.0 mg/L standard in September and early October. Diversion of more water into the San Joaquin River by placement of a rock barrier across the mouth of Old River contributed to the return of concentrations to greater than 5.0 mg/L by October 18, 1994.

The reduced dilution produced by the relatively low streamflows in 1994 apparently did not increase the potential toxicity of Delta water to humans and aquatic biota. Of the nine trace metals measured, six were above minimum reporting limits, were within the range of previous drought year values, and did not exceed the Primary Drinking Water standards established for human health concerns. A Secondary Drinking Water standard for dissolved manganese established for taste and odor concerns was exceeded on one occasion. Dissolved chromium and copper levels occasionally exceeded the aquatic biota toxicity levels established by the Environmental Protection Agency. Finally, the herbicide simazine, widely used in the spring to control emergent broadleaf weeds and grasses in

1 This report covers the calendar year. However, hydrologic conditions are based on a water year, which begins October 1 and ends September 30. A water year is numbered using the year in which it ends.

fields, orchards, and vineyards, was above the Primary Drinking Water Standard at all stations in May 1994. Fall levels of simazine were below detection limits.

Chlorophyll *a* maxima throughout the upper estuary in 1994 were low when compared with the early 1970s, 1980s, and 1993. Upstream, chlorophyll *a* concentrations were generally higher in May and September; downstream they were higher in June and September. As in previous years, the highest chlorophyll *a* levels in 1994 (maximum of 70 μg/L in June) were in the south Delta. However, regional highs were less than those detected there in the critically dry years of 1991 and 1992. The phytoplankton assemblage dominant during the maxima at most regions was a mixture of flagellates and diatoms, with no single dominant species. *Potamocorbula amurensis* probably contributed to the low chlorophyll *a* and high phaeophytin concentrations in Suisun and San Pablo bays.

The low inflow and salinity intrusion associated with the critically dry water year resulted in maintenance of high levels of fine substrates at most benthic sampling stations, increased levels of fine substrate at some stations, and increased summer and fall specific conductance at the western benthic sampling stations. These conditions enabled the introduced and salt-tolerant Asian clam *Potamocorbula amurensis* to continue to dominate in Suisun and San Pablo bays. Dominant species at the less saline benthic sampling stations in 1994 included the introduced freshwater clam *Corbicula fluminea* and the native arthropod *Corophium stimpsoni*.

Chapter 1
INTRODUCTION

The State Water Resources Control Board sets water quality objectives to protect beneficial uses of water in the Sacramento-San Joaquin Delta and Suisun Bay. These objectives are met by establishing standards mandated in water right permits issued by the Board. The applicable 1994 standards are included in Water Right Decision 1485, issued in August 1978. State Water Project operations can be affected by these standards because the operations modify flow and water quality variables. During drought years, operations are further modified to comply with these standards and are, therefore, particularly affected. The State Water Project is operated to comply with these standards and meet contractual water quality objectives at all points of delivery.

Decision 1485 requires the Department of Water Resources and U.S. Bureau of Reclamation to conduct a comprehensive monitoring program to determine compliance with the water quality standards and to report results annually to the State Water Resources Control Board. This report summarizes water quality monitoring results for calendar year 1994, presents water quality patterns, and meets the reporting requirement of Term 4(f) of Decision 1485.

Monitoring and Data Storage

The Bay/Delta Compliance Monitoring Program provides regular surveillance of the estuary and enables rapid detection of short-term water quality changes. Discrete sampling is done at 26 sites (Figure 1), with field help and financial assistance from the U.S. Bureau of Reclamation. Discrete monitoring sites are sampled once or twice each month for a variety of physical, chemical, and biological variables, including specific conductance, nutrient concentrations, air and water temperature, wind velocity, pH, dissolved oxygen concentration, chlorophyll concentration, phytoplankton and benthic community composition and density, and substrate composition. Onboard continuous monitoring is conducted between sites to supplement the discrete sampling. In addition, six multiparameter shoreline installations continuously monitor specific conductance, dissolved oxygen concentration, pH, air and water temperature, chlorophyll concentration, solar radiation, and wind velocity and direction at strategic locations.

Changes in water quality and in the phytoplankton, benthic, and higher aquatic plant communities of the upper estuary are detected by discrete sampling and continuous monitoring in the main channels using DWR and USBR monitoring vessels. The multiparameter continuous monitoring instrumentation onboard Department of Water Resources and U.S. Bureau of Reclamation monitoring vessels measures specific conductance, water temperature, dissolved oxygen, pH, turbidity, and chlorophyll fluorescence. A mobile laboratory van is used to sample sites inaccessible to the monitoring vessels. Both the vessels and the van are equipped for onsite analyses of selected variables. Remaining samples are processed and stored for later, extensive laboratory analyses.

Compliance monitoring data collected during 1994 are stored electronically at the National Computer Center in Raleigh, North Carolina. Physical and chemical data are stored on the Environmental Protection Agency's STORET system, and the biological data are stored as Statistical Analysis System datasets. These data are available to the public. In addition, selected data are stored on the DWR Water Data Information System.

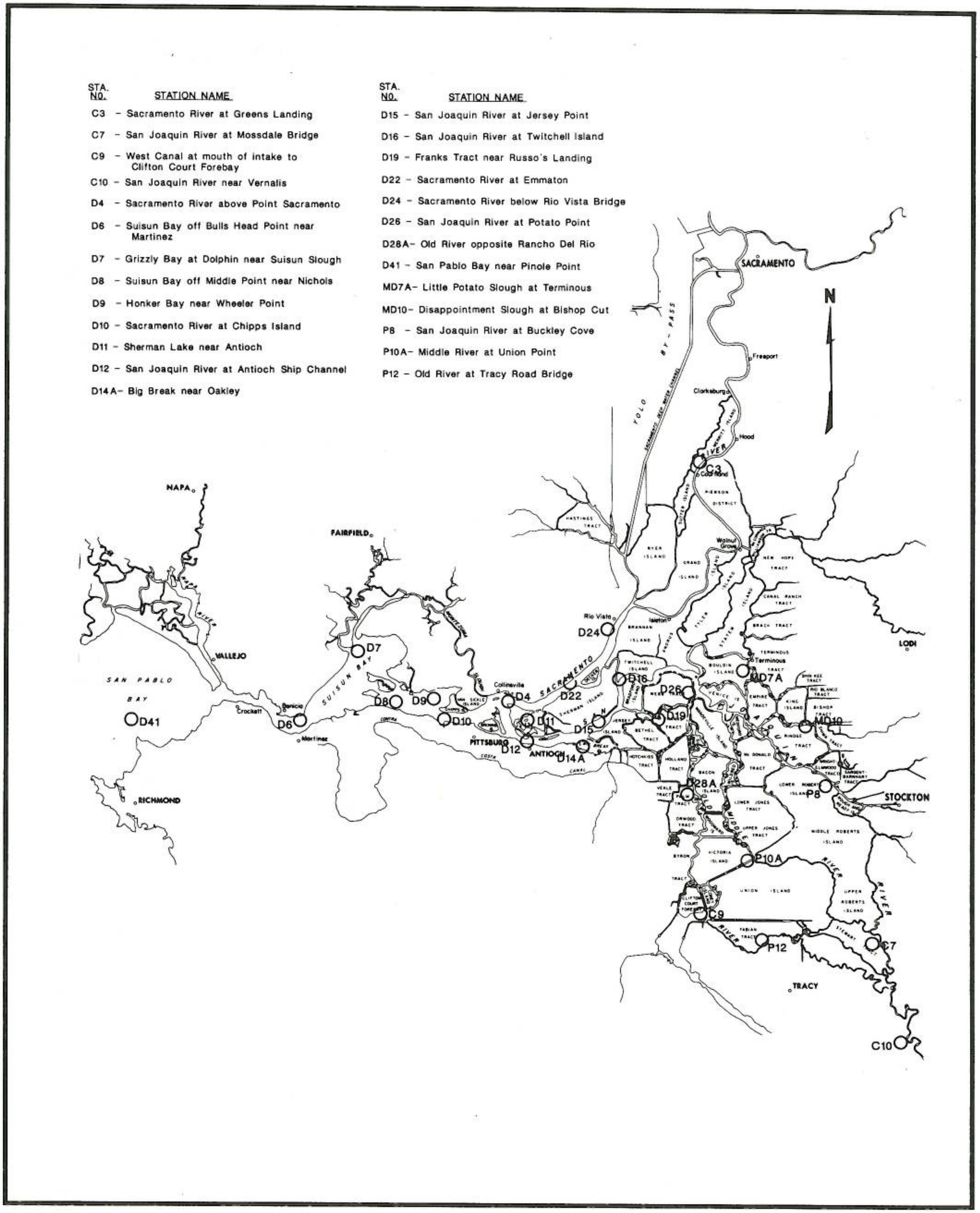

Figure 1
1994 MONITORING SITES

Hydrologic Conditions

Unless otherwise noted, hydrologic information in this section is based on data contained in the Department of Water Resources Bulletin 120 series titled *Water Conditions in California Reports 1-4 for 1994* and the *California Water Supply Outlook for 1993 and 1994* (various dates).

Water year 1994 (October 1, 1993, to September 30, 1994) had the fourth lowest runoff on record, with a Sacramento River Index[1] of only 7.8 million acre-feet, and was classified as critically dry for the Sacramento-San Joaquin Delta according to criteria contained in Water Right Decision 1485.[2] In this report, a critically dry year will be referred to as critical. A water year is classified as critical when the Sacramento Valley unimpaired runoff is equal to or less than 10.2 million acre-feet. As such, water year 1994 was a critical year following 5 critical years (1987, 1988, 1990, 1991, 1992), 1 dry year (1989), and 1 above-normal year (1993). Figure 2 shows the Sacramento River Indices for this 8-year period. In spite of above-average precipitation in 1993, 1994 was characterized by resumption of drought conditions experienced statewide from 1987 through 1992, with low summer outflow and extensive salinity intrusion into the Delta. Unlike the previous drought years, however, reservoir storage during much of 1994 was close to 100 percent of average because of carryover storage resulting from the generous spring and early summer runoff of 1993.

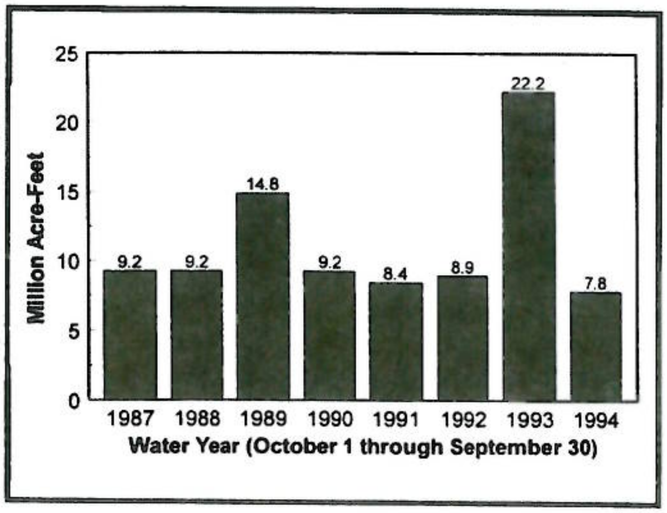

Figure 2
SACRAMENTO RIVER UNIMPAIRED RUNOFF, 1987-1994

Precipitation was below normal during water year 1994. Of the 7 months (October-April) responsible for most of the precipitation during a typical water year, only February had near average precipitation, with 105 percent of average statewide. As a result, the April 1, 1994, snowpack was only 50 percent of average. Snowpack is the chief component of the spring runoff that fills the water supply reservoirs along the lower Sierra slopes and was one of the major characteristics that differentiated 1994 from 1993. In 1993, April 1 snowpack was 150 percent of average, or three times the 1994 level.

By May 1, statewide seasonal precipitation was 65 percent of average, snowpack water content was only 30 percent of average, seasonal runoff was at 40 percent of average, and the 1994 water year was officially classified as critical.

The Delta Outflow Index[3] was less than 10,000 cubic feet per second throughout most of the 1994 water year (Figure 3). The low index reflected the low rainfall, snowpack, and

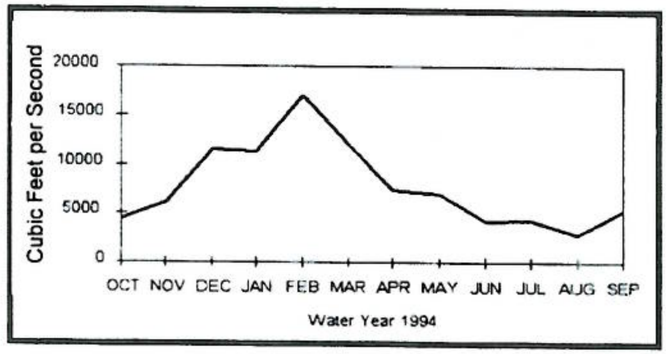

Figure 3
DELTA OUTFLOW, WATER YEAR 1994

1 The Sacramento River Index is the sum of measured runoff at four locations: Sacramento River above Bend Bridge near Red Bluff, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.
2 State Water Resources Control Board. *Water Right Decision 1485 for the Sacramento-San Joaquin Delta and Suisun Marsh*. 1978.
3 The Delta Outflow Index is a calculation of freshwater outflow from the Delta past Chipps Island.

runoff characteristic of 1994 and the 1987-1992 drought years. The index is closely tied to the volume of flow from the Sacramento and San Joaquin rivers, the major sources of inflow to the Delta. The average monthly Delta Outflow Index exceeded 10,000 cubic feet per second from December through March and was less than 5,000 cfs in October 1993 and in June through August 1994. High February rainfall increased the average monthly index to a maximum of 17,042 cfs. Figure 4 shows average monthly streamflow in the Sacramento and San Joaquin rivers for calendar year 1994. These outflows resulted from daily streamflow approaching 30,000 cfs in the Sacramento River at Freeport and 3,000 cfs in the San Joaquin River at Vernalis. Streamflow for the rest of the year was similar to flow during the 1987-1992 drought.

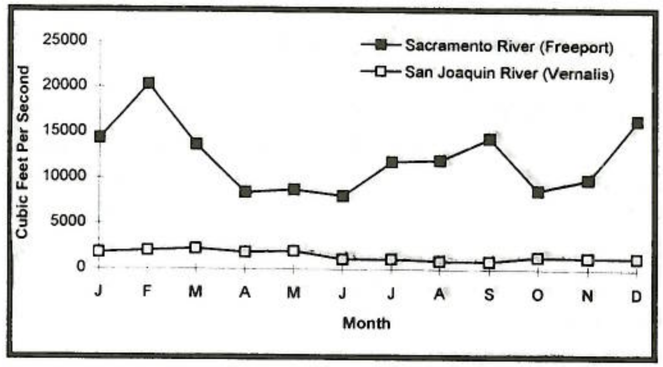

Figure 4
AVERAGE MONTHLY FLOW IN THE SACRAMENTO AND SAN JOAQUIN RIVERS, CALENDAR YEAR 1994

Compliance with Delta Water Quality Standards

During calendar year 1994, no Decision 1485 water quality standards were exceeded in the Delta or Suisun Marsh. Carryover reservoir storage provided Delta outflows in excess of 4,000 cfs throughout the summer and contributed to meeting the standards.

Chapter 2

WATER QUALITY

As a requirement of Decision 1485, water quality samples are taken semimonthly to monthly from 26 locations throughout the Delta, Suisun Bay, and San Pablo Bay (Figure 1). Changes in water quality are used to help assess the impact of State Water Project and Central Valley Project operations on estuarine biota, and to determine compliance with water quality standards. The regions of the estuary and their representative sampling sites are:

Region	Representative Stations
Northern Delta	C03
Lower Sacramento River	D04, D22, D24
Lower San Joaquin River	D16, D19, D26
Western Delta	D11, D12, D14, D15
Central Delta	C09, D28A, P10A
Eastern Delta	MD7, MD10
Southern Delta	C07, C10, P08, P12
Suisun Bay	D06, D07, D08, D09, D10
San Pablo Bay	D41

Regions were determined from hierarchical cluster analysis of stations using average monthly discrete water quality data. The analyses grouped stations for which 14 water quality variables demonstrated similar patterns over time. The variables were: specific conductance, water and air temperature, dissolved oxygen, nitrate, orthophosphate, silica, chlorophyll and pheophytin concentration, water transparency (Secchi disk depth), pH, wind velocity, suspended solids, and turbidity.

General Patterns Common to All Regions

Differences can occur in water temperature between regions because of differences in the geomorphology of each region and because of differing degrees of wind-induced mixing of the water column; tidal mixing; and seasonal inflows. In the eastern, central, and southern Delta, low inflow and little tidal influence produced less vertical mixing and a longer water residence time, and summer water temperature increased from winter lows of 8-10°C to highs of 23-25°C. In Suisun and San Pablo bays, summer high water temperatures were lower, at 19-21°C. Because solubility of oxygen decreases significantly with increasing water temperature (about a 2 mg/L decrease with a 10°C increase[1]), summer dissolved oxygen levels in all regions were less than winter levels. Dissolved oxygen levels ranged from 8.8-11.1 mg/L in the winter to 6.8-8.9 mg/L in the summer. Regions with high flows (northern Delta) and short water residence times and tidal mixing (lower Sacramento River, lower San Joaquin River, and western Delta) generally had higher summer dissolved oxygen levels than regions with low flows, longer water residence times, and little mixing (eastern, southern, and central Delta).

In most regions, levels of ammonia, nitrate, and silica were higher in winter and spring than in summer and fall. This pattern results from the runoff moving these nutrients from the upstream watersheds and from seasonal dormancy in biological activity. Levels of these nutrients dropped in summer and fall due to nutrient uptake by phytoplankton and

1 American Public Health Association. *Standard Methods for the Examination of Water and Wastewater*. 19th Edition. Washington, DC, 1995, 1100 pages.

reduced freshwater inflow. In Suisun and San Pablo bays, summer intrusion of marine water apparently altered this trend by elevating summer nitrate levels.

Northern Delta

Water quality in the northern Delta region is influenced by inflows in the Sacramento River. Average monthly flows in the Sacramento River were low throughout calendar year 1994 (Figure 4). Higher streamflow in winter and fall was associated with slightly higher nutrient (nitrate, ammonia, orthophosphate, and silica) levels[2], lower water transparency, and lower water temperature associated with cooler air temperature (Figure 5)[3]. Although specific conductance was also higher in the fall, it generally remained low (139-209 µS/cm) in 1994. The summer decrease in nutrient levels is probably due to utilization by phytoplankton. Chlorophyll levels were low throughout the year, however, with a May peak of <3.0 µg/L.

Streamflow also had a major influence on dissolved oxygen levels in the northern Delta. Higher streamflow and cooler water temperature in winter, spring, and fall contributed to higher dissolved oxygen concentration, 8.1-10.6 mg/L. With warmer water temperature and lower streamflow, summer dissolved oxygen concentrations were lower, with a minimum of 7.2 mg/L in July.

Lower Sacramento River

In the lower Sacramento River region, water quality is strongly affected by the tides and seasonal inflow from the Sacramento River. In 1994, changes in some of the water quality conditions were associated with peak winter (January-March) streamflow, as shown in Figure 6.

High winter flow, especially in February, coincided with low specific conductance (282 µS/cm in February), lower pH, and high ammonia and silica concentrations. Lower nutrient (nitrate, ammonia, and silica) concentrations in the summer and fall were probably due to nutrient uptake by phytoplankton during this period of higher algal productivity. The lowest summer and fall concentrations of these nutrients were one-fourth to one-half the highest winter and spring concentrations. Increased suspended material associated with high winter streamflow, peaking in February, and high March winds contributed to the progressive drop in water transparency from January through March. Low water transparency throughout the late spring and early summer was probably a function of high wind velocity (15-45 km/hr) and increased phytoplankton populations. Dissolved oxygen concentrations in this region were stable, relatively high (7.6-10.6 mg/L), and not directly associated with streamflow. Similarly, the summer water temperature maxima (23.0°C in August) followed the seasonal cycle of air temperature, not streamflow. Finally, salinity intrusion associated with low Sacramento River flow in summer and fall and agricultural discharges in fall resulted in a gradual increase in specific conductance from the spring low to late-fall levels approaching 5,000 µS/cm.

Lower San Joaquin River

In the lower San Joaquin River region, water quality is strongly affected by the tides and by seasonal inflow from the San Joaquin River, especially during the summer and fall of drought years. In 1994, peak San Joaquin River flow in winter and spring (January-

2 Nutrient concentrations in the text and in Figures 5-13 are represented as nitrate for nitrate nitrogen, ammonia for ammonia nitrogen, orthophosphate for orthophosphate phosphorus, and silica for silicon dioxide.

3 Figures 5-13 represent the average of the monthly discrete water quality data obtained at the representative stations included in each region.

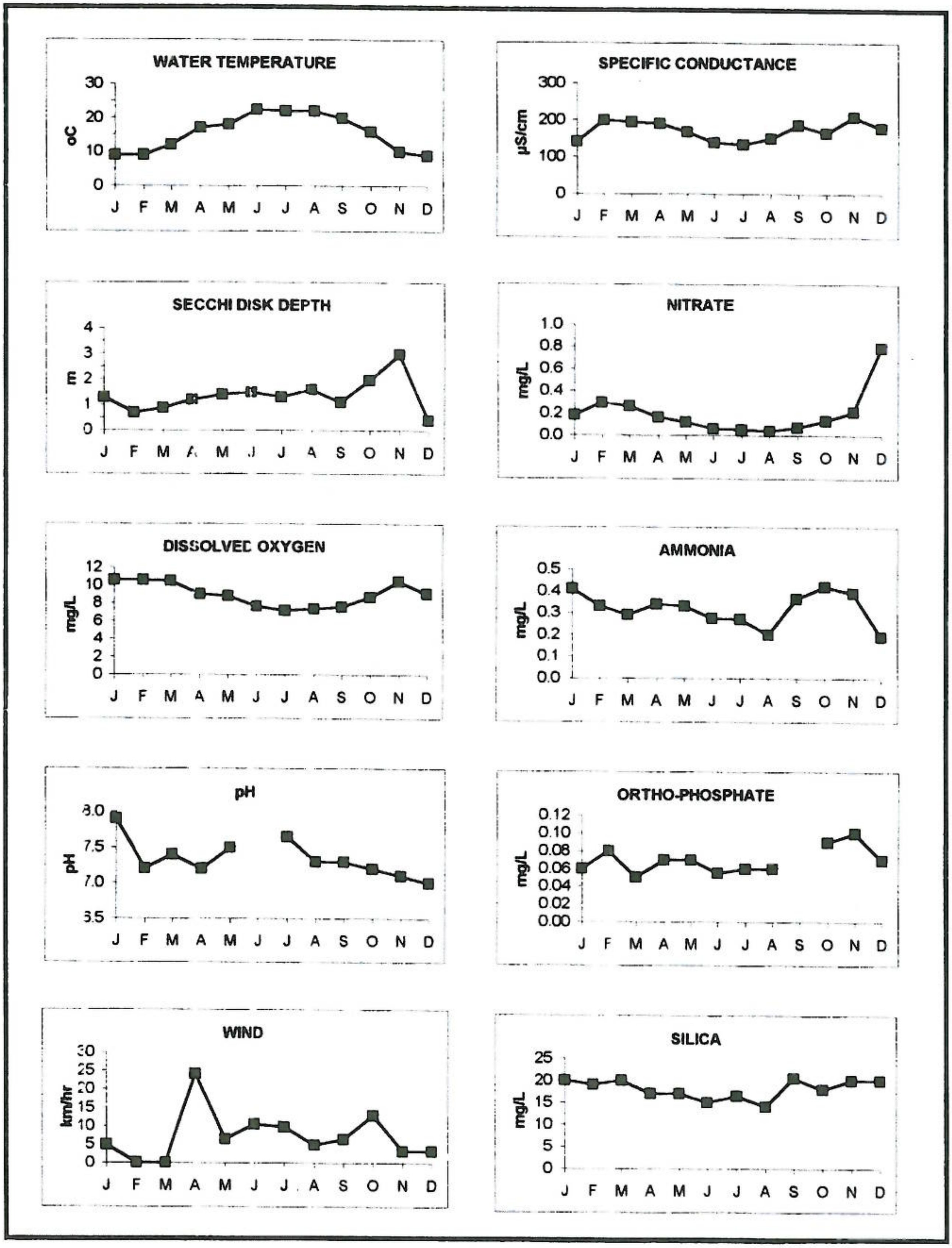

Figure 5
WATER QUALITY IN THE NORTHERN DELTA, 1994

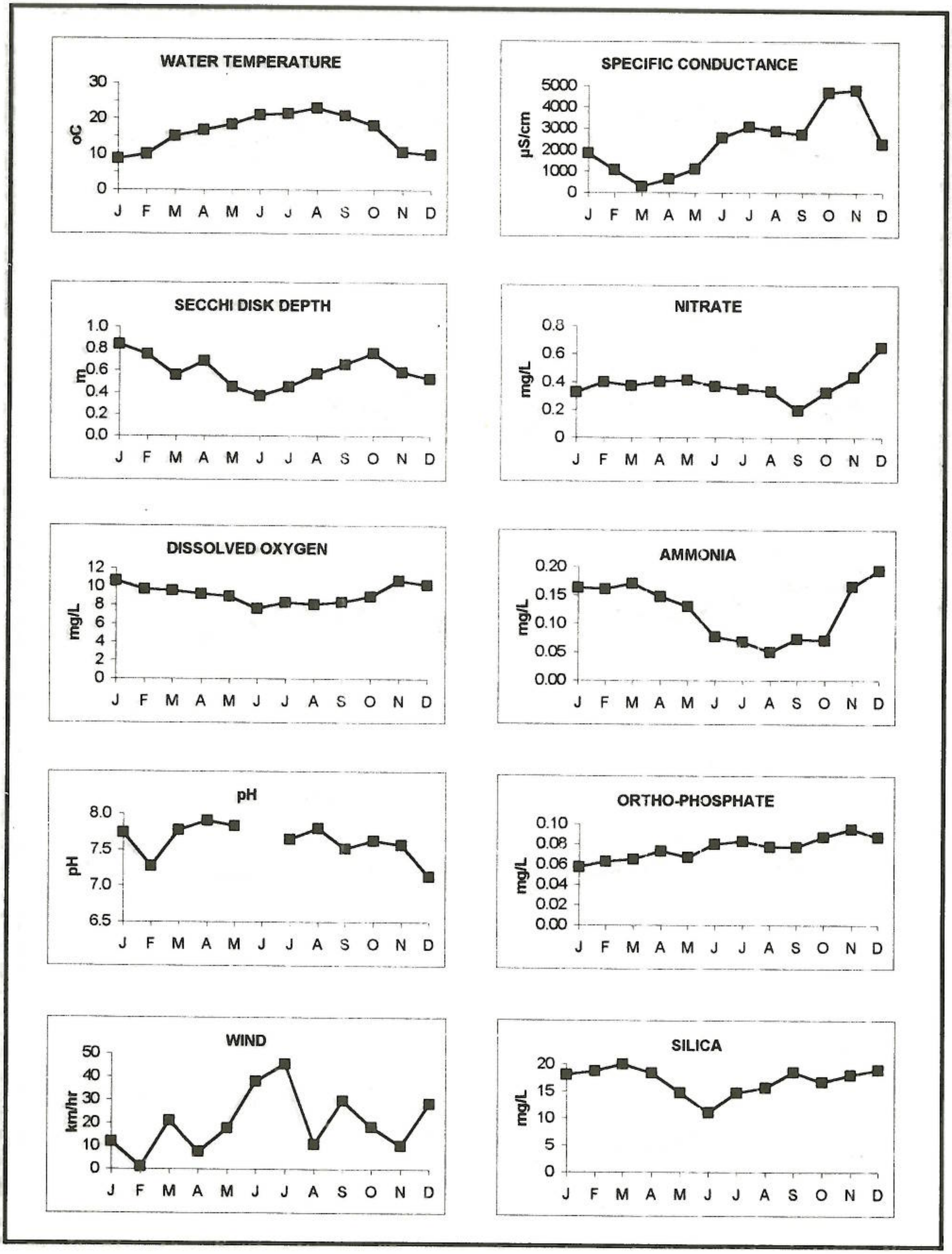

Figure 6
WATER QUALITY IN THE LOWER SACRAMENTO RIVER, 1994

May) influenced some of the water quality variables (Figure 7).

High streamflow coincided with low specific conductance (April minimum of 243 μS/cm) and high nutrient (nitrate, ammonia, orthophosphate, and silica) concentrations. The highest winter and spring levels of these nutrients were about two to four times the lowest summer and fall levels. Water transparency (Secchi disk levels ≥1.0 meter) in late spring and summer were probably a function of high wind velocity (25-35 km/hr) and slightly elevated phytoplankton populations. Chlorophyll concentrations peaked in May (<6.0 μg/L) and September (<3.0 μg/L), but remained at background levels, indicating that algal biomass was a minor factor in reducing transparency. With the exception of June (7.2 mg/L), dissolved oxygen concentrations in the lower San Joaquin River region were high (8.3-10.5 mg/L), stable, and not directly associated with streamflow. In addition, the summer water temperature maxima (25.3°C in August) followed the summer increase in summer ambient air temperature, and not streamflow. Finally, the gradual summer and fall increase in specific conductance — to a high of 1,785 μS/cm in September — was due to salinity intrusion as a result of low summer and fall San Joaquin River flow.

Western Delta

The western Delta is characterized geographically by the confluence of the Sacramento and San Joaquin rivers. Water quality in this region is strongly affected by flow in these rivers and by tidal fluctuations and summer salinity intrusion. Variation of water quality in this region is shown on Figure 8 and appears to be associated with streamflow (Figure 4).

Specific conductance was low (≤1,600 μS/cm) from January through May, when flow in both rivers was high, and rose progressively throughout summer and fall to a November high of 4,863 μS/cm, as flows progressively decreased. The high winter and spring streamflow period also coincided with elevated nutrient (nitrate, ammonia, and silica) concentrations. These nutrient levels dropped in the late spring or summer (minima achieved in June for silica, August for ammonia, and September for nitrate) as phytoplankton productivity increased. The June and July reduction in water transparency (Secchi disc depths to <0. 6 meters) could be due to resuspension of settled material as a result of increased wind velocity. Peak wind velocity in the western Delta from June through August was 35-45 km/hr. Although chlorophyll levels peaked from April through June, they were low (<3.0 μg/L) throughout the year. Therefore, algal biomass in the water column was not a factor in the reduced late spring and summer water transparency. Except for a June value of 7.5 mg/L, dissolved oxygen concentrations in the region were relatively high (8.3-10.6 mg/L), stable, and not directly associated with streamflow. Similarly, the summer water temperature maximum (23.5°C in August) followed the seasonal cycle of air temperature, and not streamflow.

Central Delta

The central Delta includes the Old and Middle rivers. During drought years, water quality in this region is influenced by low summer and fall streamflow, high phytoplankton biomass, flow reversals, and longer water residence times than regions on the Sacramento and San Joaquin rivers. Higher winter and spring streamflow throughout the region was associated with low specific conductance (<500 μS/cm), as shown on Figure 9. Lower summer and fall inflow resulted in a gradual increase in specific conductance, with the annual high (657 μS/cm) in September.

The high winter and spring inflow period also coincided with high nutrient (nitrate, ammonia, and silica) concentrations, high pH values, and, in January and February, Secchi disc depths >1.0 meter. Concentrations of each of the nutrients decreased in the late spring, summer, and early fall, as flows decreased and phytoplankton biomass increased. Ammonia

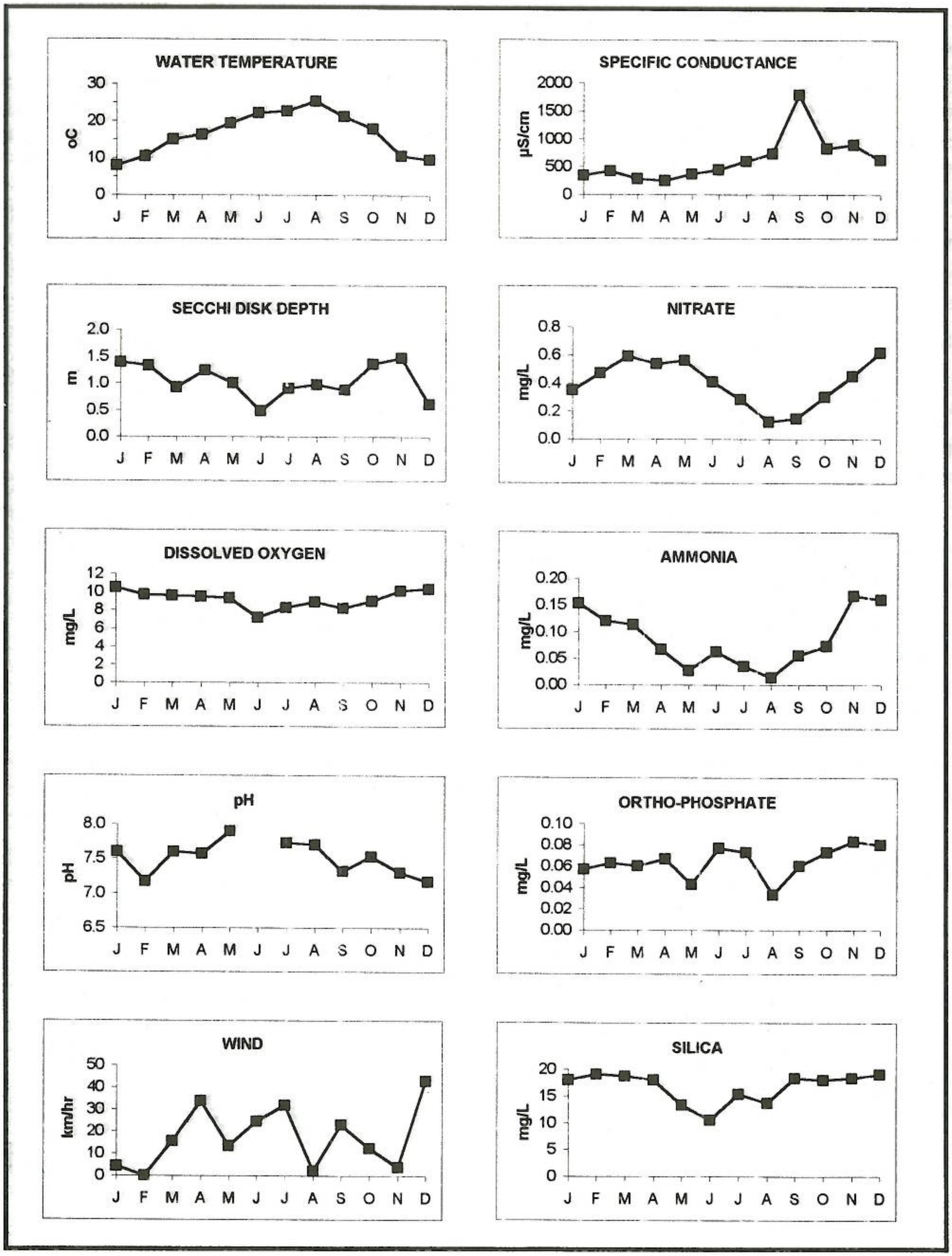

Figure 7
WATER QUALITY IN THE LOWER SAN JOAQUIN RIVER, 1994

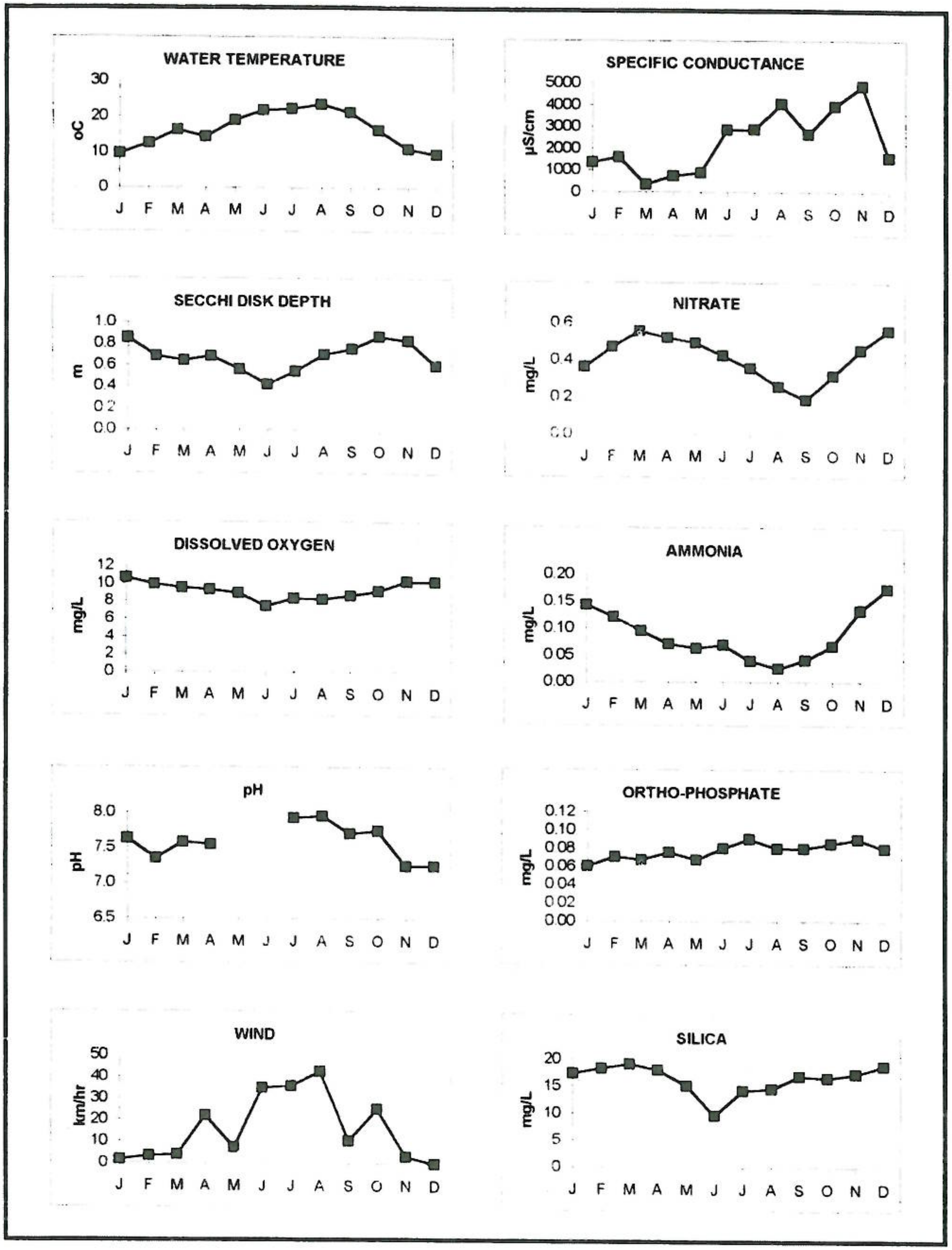

Figure 8
WATER QUALITY IN THE WESTERN DELTA, 1994

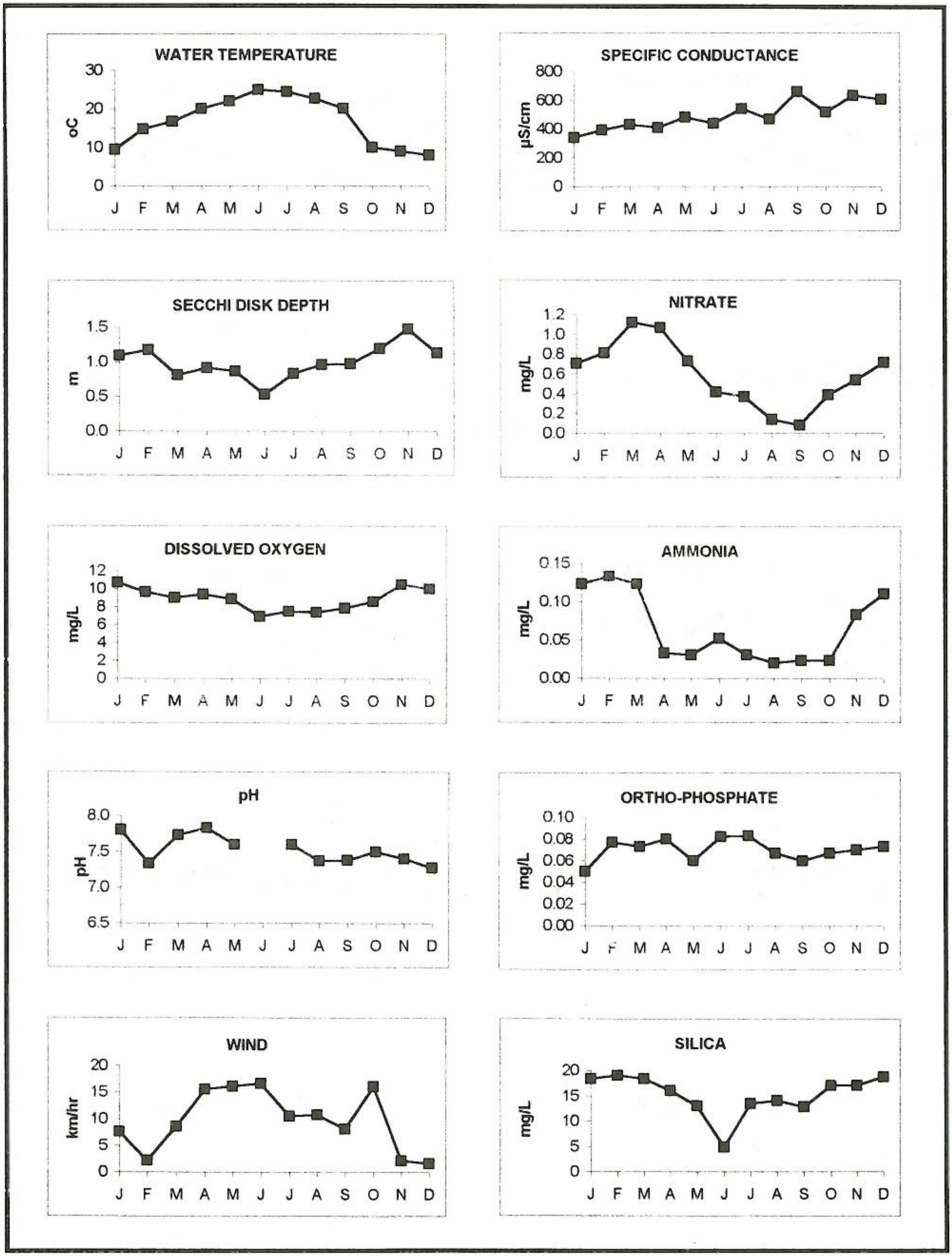

Figure 9
WATER QUALITY IN THE CENTRAL DELTA, 1994

levels were ≤0.05 mg/L in April-October, nitrate levels were ≤0.42 mg/L in June-October, and silica reached 4.9 mg/L in June. Most of these levels were a quarter to a third of late-fall, winter, and early-spring levels. Low late-spring and early-summer water transparency (June minimum Secchi disc depth of 0.53 meter) was probably a function of higher wind velocity (15-20 km/hr) and slight elevation of phytoplankton biomass. Chlorophyll levels were low (≤5.0 µg/L) throughout the year. Although dissolved oxygen in this region was relatively stable, concentrations fell below 8.0 mg/L from June through September, apparently due to warm water temperature, reduced tidal mixing, and longer water residence time. For the rest of the year, dissolved oxygen levels were 8.6-10.7 mg/L. Finally, summer water temperature maxima (24.5°C in June and 25.0°C in July) followed the seasonal increase in summer ambient air temperature.

Eastern Delta

The eastern Delta includes the area north of the San Joaquin River and east of the Mokelumne River. Water quality in this region is influenced by inflow from smaller rivers and creeks such as the Mokelumne River and Bear Creek in addition to the San Joaquin and Sacramento rivers. Sacramento River water enters this region when the Delta Cross Channel between the Sacramento River and the Mokelumne River is open. This region is characterized by high winter inflow, minimal tidal influence, and longer water residence time than regions directly on the Sacramento or San Joaquin rivers. Water quality data for this region are summarized in Figure 10.

Characteristics of the eastern Delta region are reflected in the specific conductance measurements, which were low (<400 µS/cm) throughout the year. The lowest values were in summer and fall, when inflow was low. During this low-flow period, the Delta Cross Channel was kept open, and Sacramento River water apparently contributed to the summer and fall reduction in specific conductance in the eastern Delta. The high winter and spring inflow period coincided with high nutrient (nitrate, ammonia, orthophosphate, and silica) concentrations, and high pH values. Concentrations of each of the nutrients dropped dramatically in the late spring, summer, and early fall period as flows decreased and phytoplankton biomass increased. Annual minima for ammonia (0.01 mg/L), orthophosphate (0.045 mg/L), and silica (9.0 mg/L) occurred in May, when the chlorophyll *a* level was 20 µg/L. Nitrate levels gradually decreased throughout late spring and summer to a minimum of 0.09 mg/L in September. Orthophosphate and silica levels were half of the winter and early-spring levels, and late-spring ammonia and summer nitrate levels approached one-tenth of the highest winter and early spring levels of these nutrients. Low spring and summer water transparency (Secchi disc depth ≤0.88 meter) were probably a function of wind velocity, which increased from winter levels of 7 km/hr to 10-20 km/hr during much of this period and increases in the phytoplankton biomass. Dissolved oxygen concentrations in the eastern Delta region followed a pattern similar to that of the central Delta region with summer (June-September) levels <8.0 mg/L, apparently due to warm water temperature, minimal tidal mixing, and longer water residence time. The dissolved oxygen levels for the rest of the year were 8.4-11.1 mg/L, indicating the relative stability of this variable in the region. The summer water temperature followed the seasonal increase in summer ambient air temperature, with a maximum of 24.3°C in June.

Southern Delta

The southern Delta region includes the San Joaquin River from the Stockton area southward and upper Old River, which branches off the San Joaquin River and flows westward toward Clifton Court Forebay. Water quality in this region is influenced by low summer and fall inflow (especially during drought

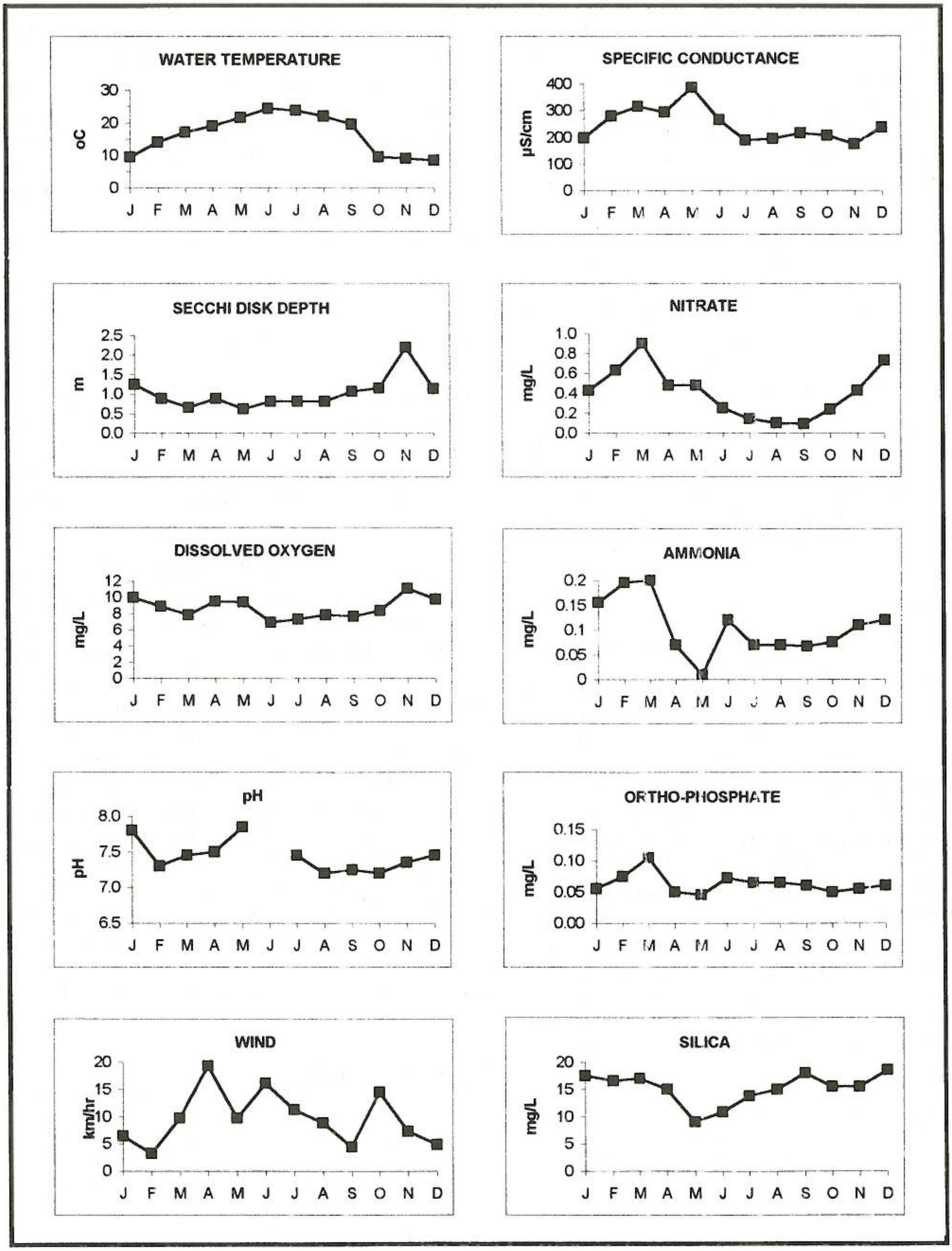

Figure 10
WATER QUALITY IN THE EASTERN DELTA, 1994

years), minimal tidal influence, high summer phytoplankton chlorophyll concentrations, and long water residence time. Water quality data for this region are summarized in Figure 11.

In 1994, winter and spring flow in the San Joaquin River was slightly higher than summer and fall flow and was sufficient to produce minor changes in specific conductance, which was 715-1060 µS/cm throughout winter, spring, and summer. In September, however, specific conductance increased to 2096 µS/m, primarily due to increasing amounts of irrigation water returned into the San Joaquin River. The higher winter and spring inflow period did, however, coincide with higher nutrient (nitrate, ammonia, orthophosphate, and silica) concentrations, and water transparency. The highest levels of these variables occurred in the January-March period. Concentrations of nitrate, ammonia, and orthophosphate dropped dramatically as flows decreased in late spring and summer. The low streamflow enabled phytoplankton populations to reach "bloom" proportions, resulting in high uptake of the nutrients in the water column. As described in Chapter 3, phytoplankton concentrations approached 30 µg/L in April, peaked at 70 µg/L in June, and exceeded 25 µg/L in June-September[4] in the southern Delta region. The spring and summer reduction in water transparency (Secchi disc depth ≤0.5 meter) was probably due to a combination of factors. The early spring reduction was probably due to the increase in wind velocity from ≤5 km/hr in the winter to 10-20 km/hr in the spring; the summer reduction was probably due to the high biomass of phytoplankton in the water column. Dissolved oxygen levels were 7.3-10.5 mg/L throughout the year, with spring and summer levels only slightly less than fall and winter levels. In all other regions, the high summer water temperature (the July maximum of 24.9°C in the southern Delta is a typical summer high) contributed to lower summer dissolved oxygen levels. In the southern Delta region, however, photosynthesis associated with high phytoplankton biomass in the spring and summer (April and June-September) apparently compensated for the temperature-related drop in dissolved oxygen levels normally found in the summer and maintained relatively constant dissolved oxygen levels throughout the spring and summer.[5] The net result is that spring and summer dissolved oxygen levels occasionally dropped below 8.0 mg/L (in March, May, and July), but the decreases were not consistent.

A localized dissolved oxygen depression occurs annually in the eastern portion of the deep water ship channel below Stockton. This problem is addressed in Chapter 6.

Suisun Bay

The Suisun Bay region includes Suisun Bay and the combined channels west of the confluence of the Sacramento and San Joaquin rivers. Water quality in this region is influenced by high winter and spring inflow during non-drought years, significant summer and fall salinity intrusion during drought years, and strong tidal mixing. In addition, the Suisun Bay region maintains high abundance of the Asian clam, *Potamocorbula amurensis*, a bottom filter feeder that can influence water quality by reducing suspended material in the water column.

Water quality varied with streamflow during 1994 in the Suisun Bay region (Figure 12). Higher streamflow in January-March for the Sacramento River and January-May for the San Joaquin River was associated with winter and early-spring decreases in specific conductance (March minimum of 5,898 µS/cm).

Elevated concentrations of silica (13.4-16.8 mg/L) and ammonia (0.13-0.18 mg/L) in winter and spring also followed the high inflow pattern. Although concentrations of these

4 Chlorophyll data are not available for August.

5 All discrete samples were taken during daytime hours.

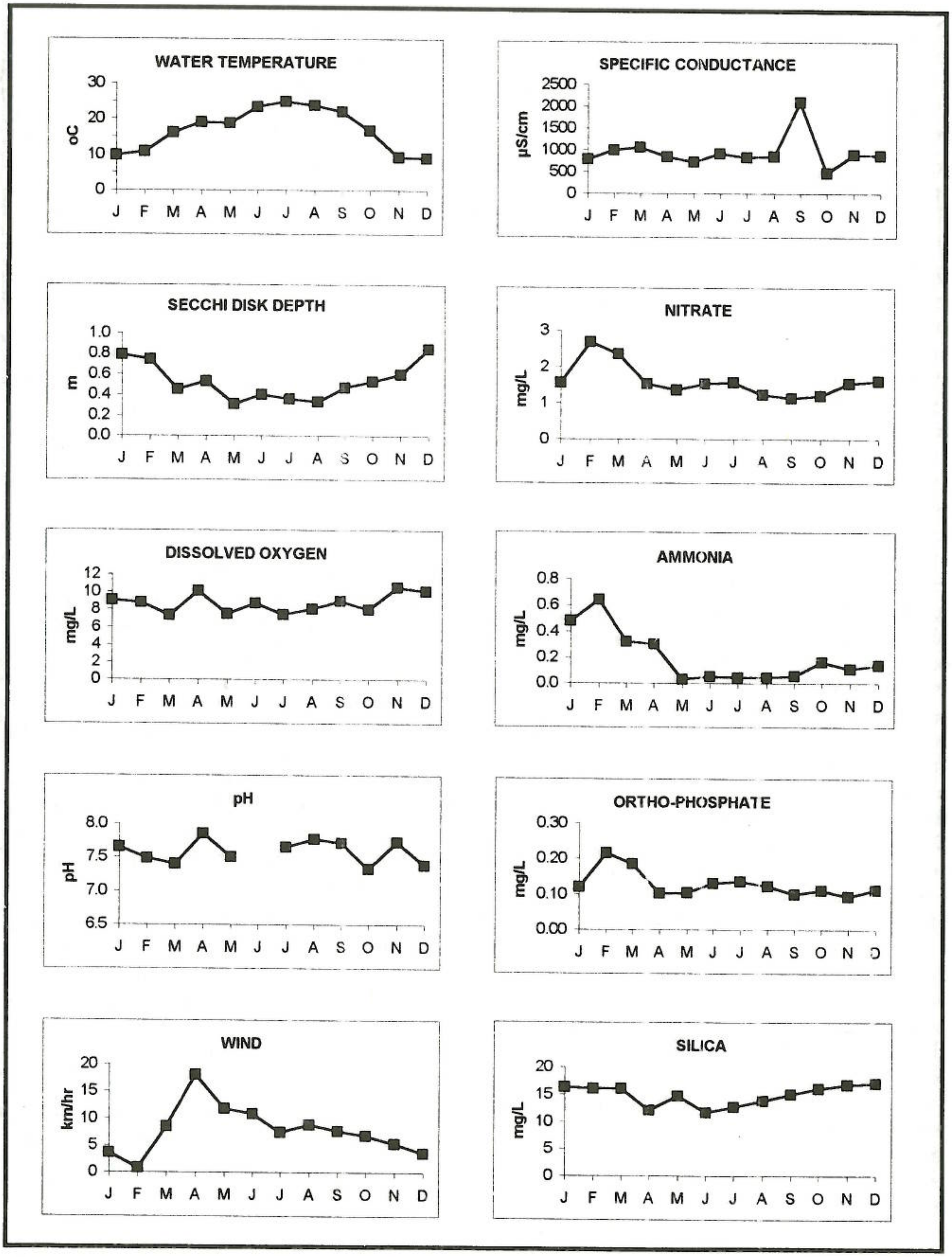

Figure 11
WATER QUALITY IN THE SOUTHERN DELTA, 1994

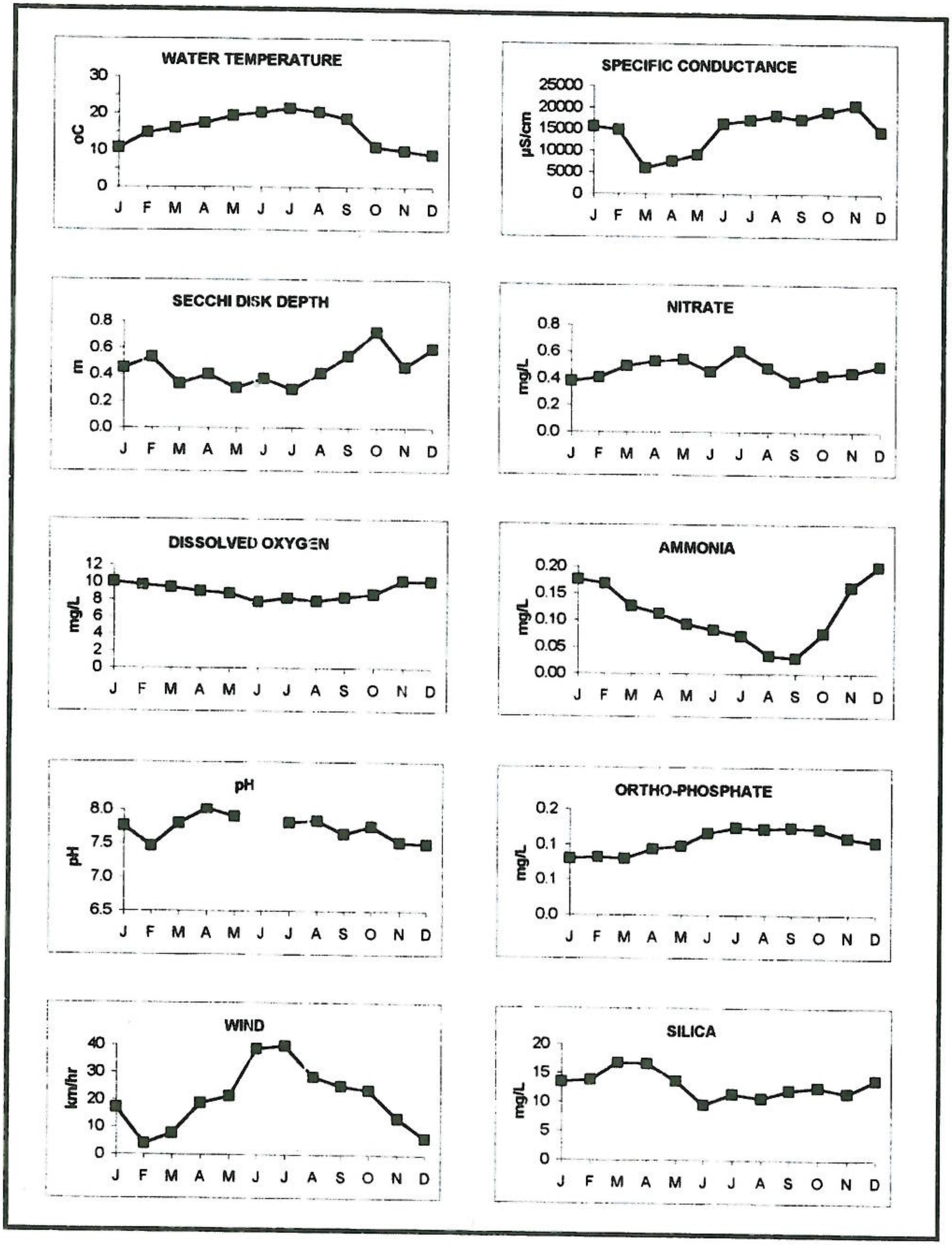

Figure 12
WATER QUALITY IN SUISUN BAY, 1994

silica and ammonia apparently increased with streamflow due to downstream movement from watershed runoff, orthophosphate appears to have decreased to low levels (0.80-0.82 mg/L) with streamflow because of dilution of upstream sources. In summer and fall, marine water, with higher orthophosphate concentrations, can intrude to produce the higher levels of orthophosphate. As a result of this intrusion in 1994, orthophosphate levels gradually increased throughout the late spring and early summer to levels ≥0.122 mg/L from July through October. The spring and early summer reduction in water transparency (Secchi disc depths to ≤0.41 meter) was due in part to higher streamflow, which increased sediment load from upstream regions and increased resuspension of sediment. The reduction was also probably due to high wind velocity (20-40 km/hr) during much of this period, which also increased vertical mixing of suspended sediment. A zone of maximum turbidity can occur at the freshwater/saltwater interface in this region.

The minor fall increase in water transparency (Secchi disc depth peaked at 0.72 meter) in October could be partly due to increased filtration of the water column by *P. amurensis*, whose abundance peaked during this period. Algal productivity contributed to the slight drop in silica levels in the Suisun Bay region from June through August. Specific conductance gradually increased from the early spring low in March to a fall high of 20,500 µS/cm in November, as inflows decreased and salinity intrusion increased. Because of the tidal influence, summer wind mixing, and lower air temperature, summer water temperature (July maximum of 21.4°C) was much lower than in other regions. These factors appear to have contributed to stable dissolved oxygen, which was relatively high (7.7-10.2 mg/L) throughout the year.

San Pablo Bay

The San Pablo Bay region is the westernmost region and is subject to the strongest tidal influence and salinity intrusion of all of the regions described. In addition, the region is characterized by extensive shoal areas in both the northern and southern portions of the Bay. The benthic filter feeder P. amurensis is also abundant in the San Pablo Bay region. During drought years, the San Pablo Bay region is subject to reduced seasonal freshwater influence from upstream drainages. Even though 1994 was a critically dry year, the influence of streamflow on water quality was detected during the winter and spring, as shown in Figure 13.

Specific conductance was relatively stable at 37300-43100 µS/cm throughout much of the year, with slightly lower values in the high outflow months of March (34900 µS/cm) and December(36000 µS/cm).

Higher winter and spring inflow appears to have also contributed to changes in some of the nutrient levels in the region. Winter and spring nitrate and orthophosphate levels were slightly lower than summer and fall levels, apparently due to summer salinity intrusion. Wind velocity peaked in June-August, with a range of 46.7-56.3 km/hr. Water transparency dropped, with Secchi disc depths of >1.0 meter in late winter, 0.44 meter in spring, and 0.39 meter in fall. This decrease was probably due in large part to mixing and resuspension of sediments brought about by the high summer wind velocity. The minor fall increase in water transparency to an October peak Secchi disc depth of 1.28 meter could be partly due to the influence of P. amurensis, whose abundance also peaked during this period. Because of marine intrusion, lower average air temperature and wind-induced mixing of the water column, summer maximum water temperature did not exceed 20.0°C and was the lowest of all regions. Dissolved oxygen concentrations were stable, <8.0 mg/L for an extended period (May-October), and ranged from a June low of 6.8 mg/L to a December high of 9.4 mg/L.

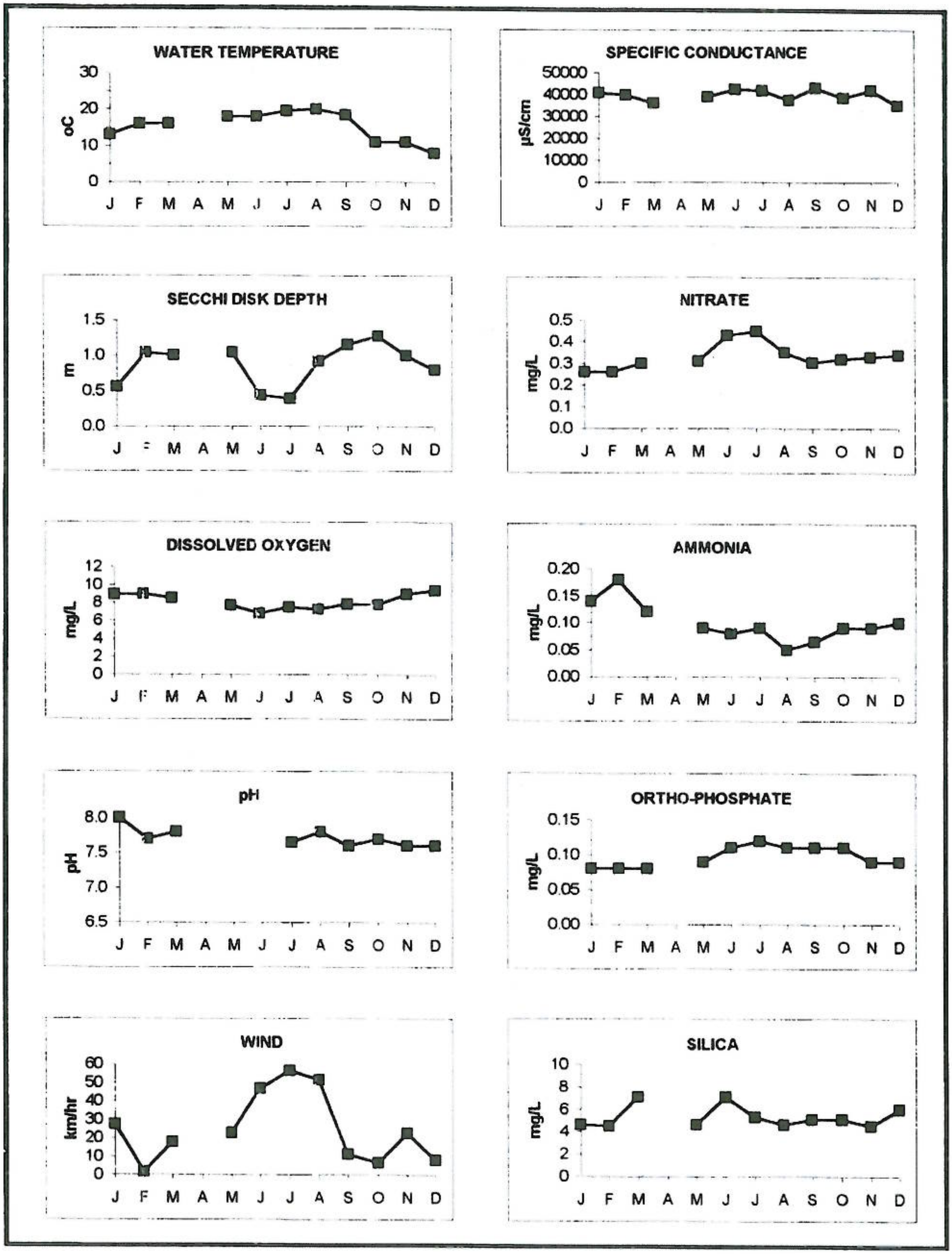

Figure 13
WATER QUALITY IN SAN PABLO BAY, 1994
Sampling at this site was not conducted in April.

Chapter 3

PHYTOPLANKTON BIOMASS AND COMMUNITY COMPOSITION

This chapter describes changes in chlorophyll *a* concentration (an estimate of phytoplankton biomass) and community composition for 1994 at various locations in the Delta and Suisun and San Pablo bays. As required by Decision 1485, the Department of Water Resources and U.S. Bureau of Reclamation collect phytoplankton samples at stations throughout the upper estuary. Samples are collected semimonthly or monthly for measurement of chlorophyll *a* concentration at 26 stations and for identification and enumeration of phytoplankton at 16 stations (Figure 1). For this summary, selected stations were grouped into regions based on hierarchical cluster analysis (Chapter 2).

Percent chlorophyll *a* concentration is used as an indicator of actively growing phytoplankton cells. Percent chlorophyll *a* concentration is computed as the ratio of chlorophyll *a* concentration to chlorophyll *a* plus pheophytin concentration times 100. Percent chlorophyll *a* concentration increases during the initial phase of a phytoplankton bloom, when cell division is exponential, and decreases during the decline phase of a bloom, when pigment breakdown products like pheophytin increase. Figure 14 shows average chlorophyll *a* and pheophytin concentrations and percent chlorophyll throughout the upper estuary in 1994.

Northern Delta

Chlorophyll *a* concentrations were less than 3 µg/L in 1994 in the northern Delta (Figure 14). Chlorophyll *a* concentrations were slightly higher in May when a mixed assemblage of diatoms dominated the phytoplankton community. High percent chlorophyll *a* concentrations suggest these cells were growing more rapidly than in other months. Chlorophyll *a* concentrations also increased in December, when the phytoplankton community was a mixed assemblage of diatoms, greens, and flagellates. However, high pheophytin concentrations and low percent chlorophyll *a* concentrations suggest these populations were growing less rapidly than in spring.

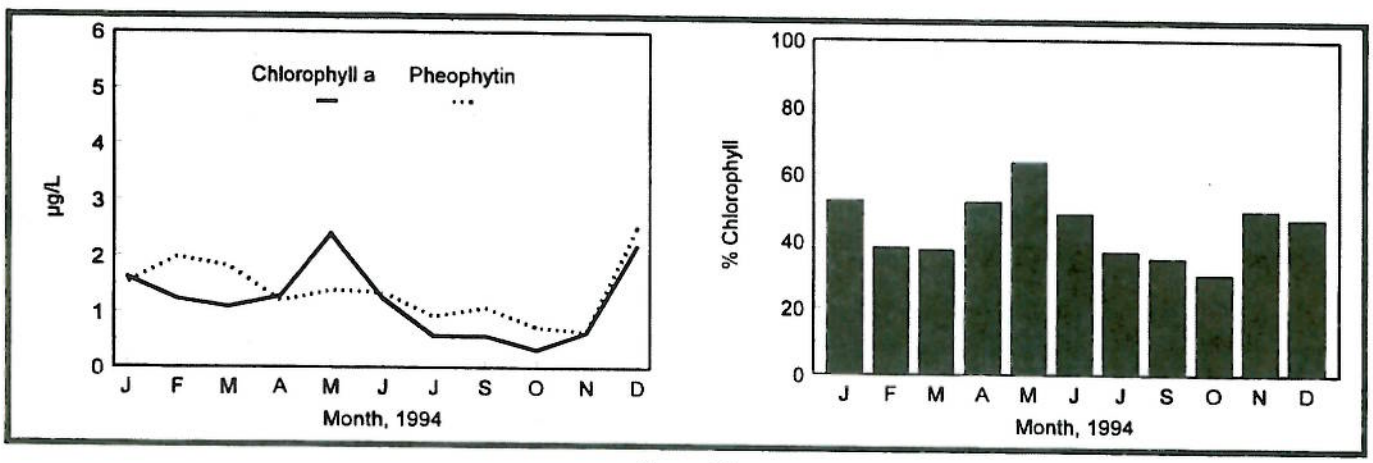

Figure 14
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE NORTHERN DELTA, 1994

The low chlorophyll *a* concentrations in 1994 were characteristic of the northern region, where concentrations rarely exceed 8 µg/L[1]. Although 1994 was a critical year, chlorophyll *a* concentrations did not increase as they did during the 1977 drought. Instead, 1994 was similar to 1987 and 1988, when critically dry conditions were accompanied by low chlorophyll *a* concentrations and low percent chlorophyll.

Lower Sacramento River

Chlorophyll *a* concentrations in the lower Sacramento River were at least 1-2 µg/L throughout the spring and fall and reached maxima of 2.5 µg/L in May and 1.5 µg/L in September (Figure 15). Maxima were associated with a mixed assemblage of flagellates and diatoms in May and with miscellaneous flagellates in September. Percent chlorophyll near 60% suggests the phytoplankton were growing well but not exponentially during these maxima. Higher pheophytin concentrations in June were probably produced by the decline of the phytoplankton maximum in May and benthic grazing.

The low average chlorophyll *a* concentrations in 1994 were similar to those measured during the 1987-1992 drought, which were lower than in wet years of the early 1970s and 1980s.

Lower San Joaquin River

Average chlorophyll *a* concentrations in the lower San Joaquin River did not exceed 6 µg/L (Figure 16). Maximum concentrations were measured in May and September when the phytoplankton community was comprised of the filamentous diatoms *Skeletonema potamos*, *Thalassiosira eccentrica*, and *Aulacoseira* (formerly *Melosira*) *granulata*. Percent chlorophyll of about 70% suggests these phytoplankton were growing well but not exponentially. Maximum pheophytin concentrations in June were probably caused by the decline of the May bloom and in December by the onset of winter.

Compared with the period of record, chlorophyll *a* concentrations in the lower San Joaquin River region were low in 1994, where average chlorophyll *a* concentrations higher than 15 µg/L were common in the early 1970s

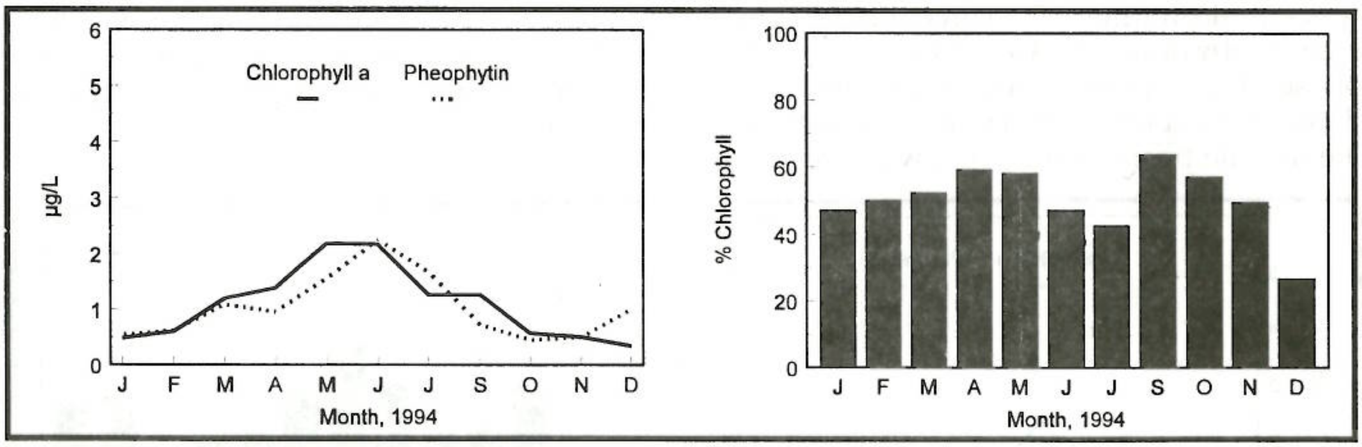

Figure 15
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE LOWER SACRAMENTO RIVER, 1994

1 Department of Water Resources, Water Quality Conditions in the Upper San Francisco Estuary Between 1970 and 1973. 1996.

and 1980s. The low chlorophyll *a* concentrations in 1994 were characteristic of the 1977 and 1990-1991 critical years, and the low percent chlorophyll was within the range of values measured since the 1980s.

The absence of an *A. granulata* bloom in this region in 1994 was unusual and was probably due to the critically dry conditions. *A. granulata* often blooms at Potato Slough (D26) and, in wet years, spreads throughout the lower San Joaquin River and downstream.

Western Delta

Chlorophyll *a* concentrations in the western Delta did not exceed 3 µg/L and rose only slightly in May, when the phytoplankton community consisted of mixed diatoms and flagellates (Figure 17). Low chlorophyll *a* concentrations were accompanied by intermediate to low percent chlorophyll (60%), similar to the 1980s and 1990s.

The low chlorophyll *a* concentrations and percent chlorophyll in 1994 was not characteristic for this region. Before 1990, chlorophyll *a* concentrations usually exceeded 10 µg/L, and percent chlorophyll frequently exceeded 60%.

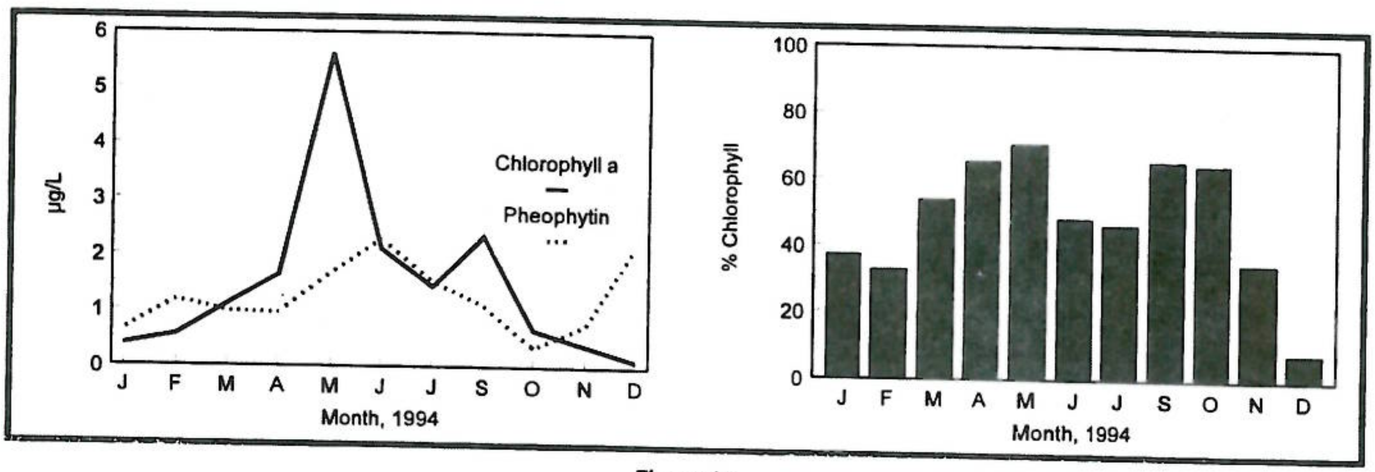

Figure 16
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE LOWER SAN JOAQUIN RIVER, 1994

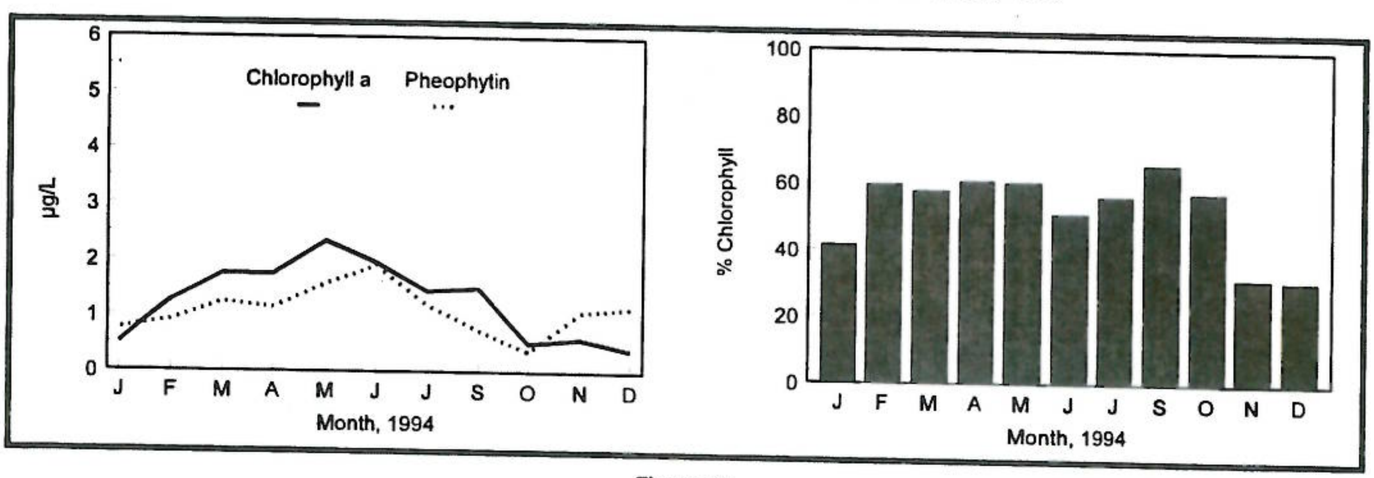

Figure 17
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE WESTERN DELTA, 1994

Central Delta

In the central Delta, chlorophyll *a* concentrations peaked in March, June, and September, with the maximum of 5 µg/L in September (Figure 18). The phytoplankton community shifted with each season: flagellates in March, flagellates and diatoms in June, and diatoms and flagellates in September. The maximum in September contained the chain-forming diatom *A. granulata*, an important species to the State Water Project contractors because it can clog water treatment facilities and cause a taste and odor problem in treated water. Percent chlorophyll at 60-70% suggests these phytoplankton were growing well but not exponentially.

Chlorophyll *a* concentrations in 1994 were lower than in many previous years. The maximum in 1994 was a factor of 8 lower than in 1993 but was similar to those in the late 1970s and early 1990s. Chlorophyll *a* concentrations were higher in the wet years of the early 1980s, when a larger portion of the more productive San Joaquin River water moved through the central Delta. In contrast, chlorophyll *a* concentrations have been lower in critical years, when the less productive Sacramento River water is diverted across the Delta.

Eastern Delta

In the eastern Delta, chlorophyll *a* maxima consisted of a 20 µg/L peak in May and a 5 µg/L peak in September (Figure 19). Both maxima were composed of miscellaneous diatoms and flagellates, but in September, filamentous forms including *Skeletonema potamos*, *Thalassiosira eccentrica*, and *A. granulata* were also present. *A. granulata* is common in this area and frequently develops into blooms. Phytoplankton neared exponential growth in May, when percent chlorophyll reached 80%, but was slower in September at 60%.

The chlorophyll *a* maximum was lower in 1994 than in 1991-1993 but was similar to maxima of the late 1970s and 1980s. Differences among years were probably a function of *A. granulata* blooms, which often develop near the mouth of the Mokelumne River.

Southern Delta

In 1994, the southern Delta had the highest chlorophyll *a* concentrations in the upper estuary. A chlorophyll *a* maximum occurred in June (70 µg/L), between two smaller maxima in April and September (Figure 20). The phytoplankton community during the three maxima were primarily composed of *Thalassiosira eccentrica* and *Cyclotella* spp., with miscellaneous greens and flagellates. High pheophytin concentrations and intermediate percent chlorophyll suggest phytoplankton were growing slightly better during April and September than in other months.

Among years, average chlorophyll *a* concentrations were higher in 1994 than in 1993 (a wet year) but lower than in 1991 and 1992 (critical years). Concentrations were similar to those in the early 1970s and were at least a factor of 3 higher than those in the 1980s. Percent chlorophyll in 1994 was similar to measurements after 1980 but slightly lower than in the 1970s, when values were frequently higher than 70%.

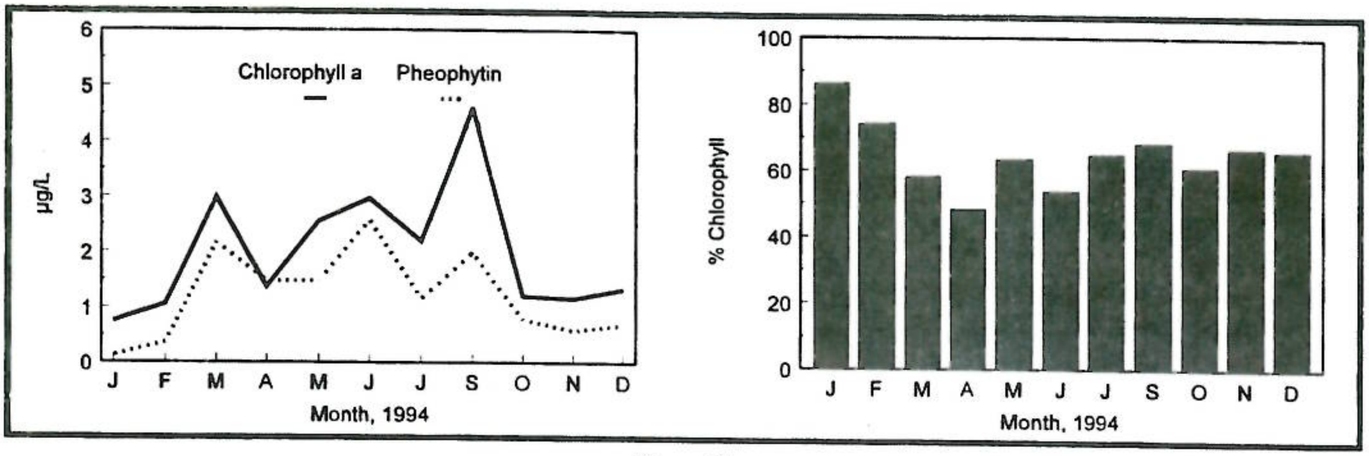

Figure 18
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE CENTRAL DELTA, 1994

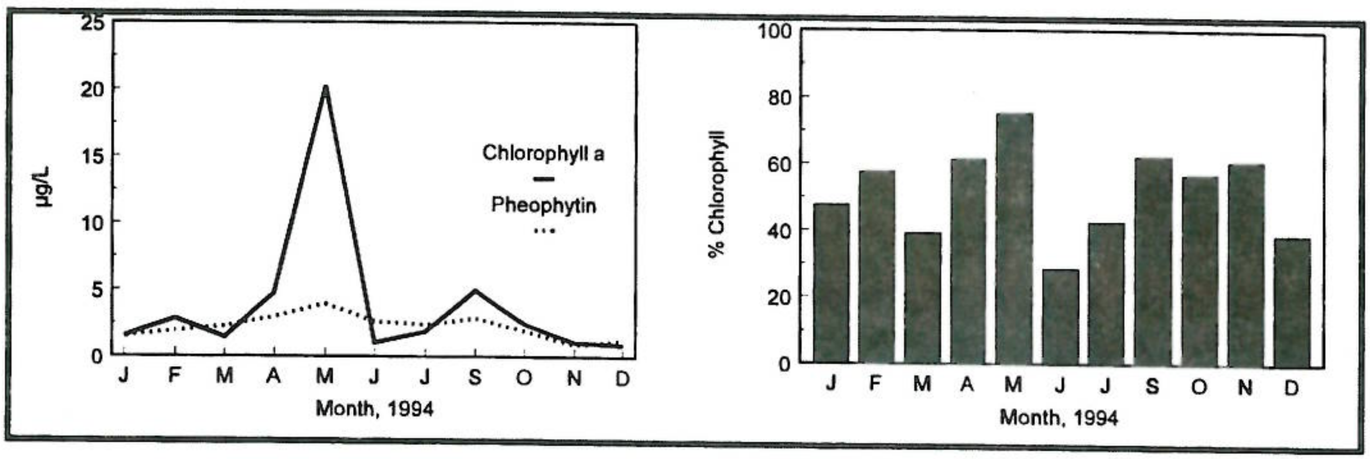

Figure 19
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE EASTERN DELTA, 1994

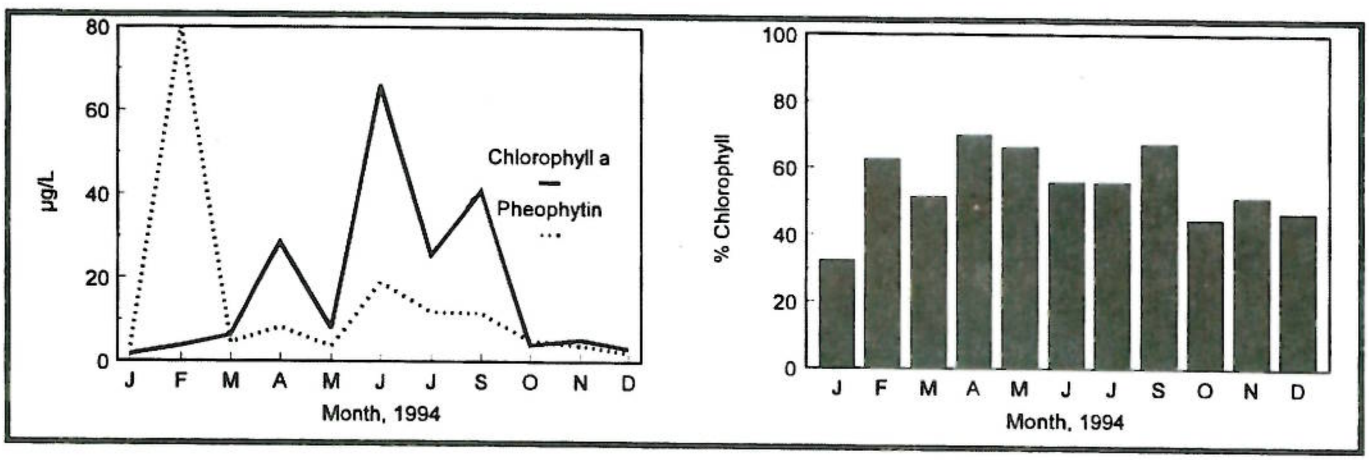

Figure 20
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN THE SOUTHERN DELTA, 1994

Suisun Bay

Chlorophyll *a* concentrations in Suisun Bay did not exceed 1.5 µg/L in 1994 (Figure 21). Concentrations remained near 1.5 µg/L between May and September and were associated with a mixed phytoplankton community of flagellates and diatoms. The low percent chlorophyll was probably produced by high pheophytin concentrations associated with benthic grazing. During critical years, the clam *P. amurensis* increases in Suisun Bay, where grazing increases the breakdown of chlorophyll *a* to pheophytin.

The low chlorophyll *a* concentrations in 1994 were similar to those measured after 1987, when the clam *P. amurensis* became established in the Suisun Bay region. It is hypothesized that the clams are responsible for the decline by a factor of 10 in chlorophyll *a* maxima since 1987[2] and may contribute to the long-term loss of diatoms[3]. Increased grazing is also suggested by the low percent chlorophyll values after 1987. Clams, however, have not permanently removed the phytoplankton maximum. High streamflow reduced clam density to 20 µg/L or less in 1993.

San Pablo Bay

Chlorophyll *a* concentrations in San Pablo Bay did not exceed 4 µg/L in 1994 (Figure 22). Unlike other regions, the chlorophyll *a* maximum was in September, and concentrations were higher in June than in May. The delayed bloom period in San Pablo Bay could be caused by reduced light availability through the summer due to fog and high turbidity associated with high spring and summer wind velocity. Throughout summer and fall, flagellates and diatoms were common. High percent chlorophyll suggests the phytoplankton were growing well, especially in September when values reached 80%.

The low chlorophyll *a* maximum in 1994 was uncommon in San Pablo Bay, where concentrations usually exceed 4 µg/L and have reached 14 µg/L. However, the low maximum was characteristic of the 1987-1992 critical years, when benthic grazing by *P. amurensis* increased. High percent chlorophyll suggests the phytoplankton grew well despite the increased grazing pressure.

2 Alpine and Cloern 1992.

3 Lehman 1996.

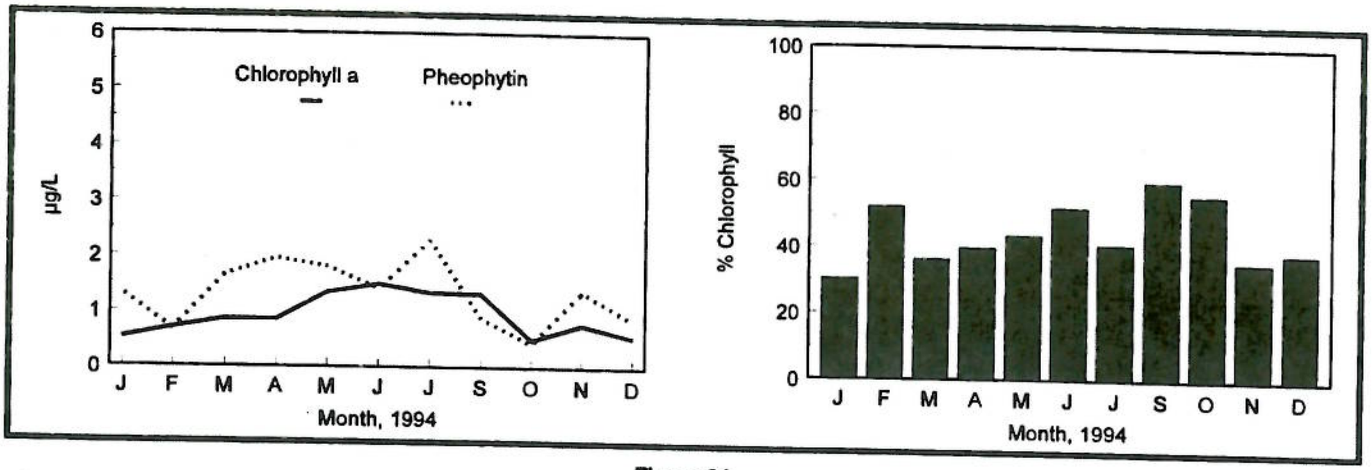

Figure 21
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN SUISUN BAY, 1994

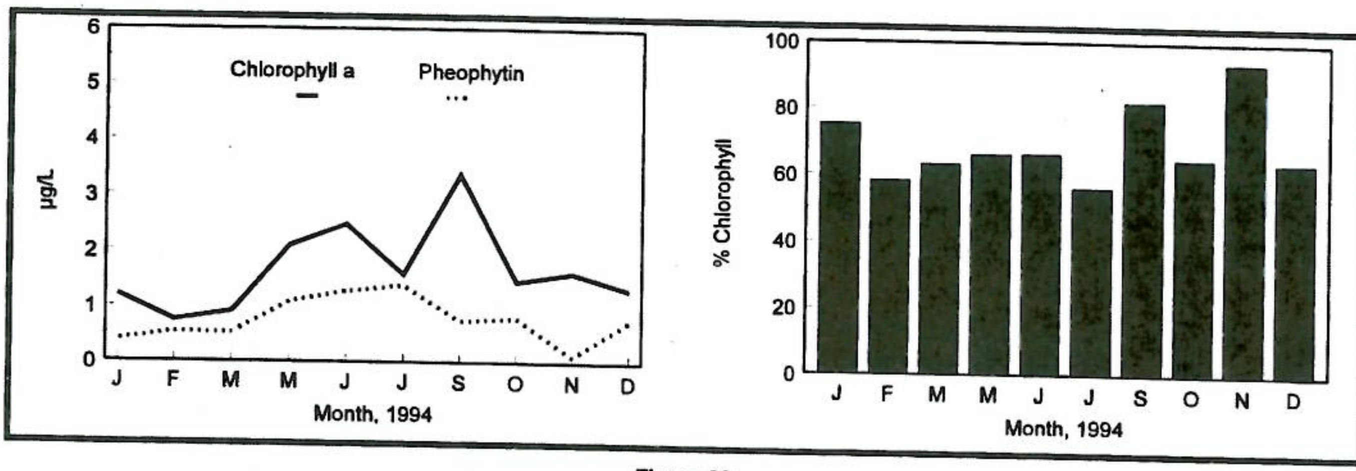

Figure 22
CONCENTRATIONS OF CHLOROPHYLL AND PHEOPHYTIN AND PERCENT CHLOROPHYLL IN SAN PABLO BAY, 1994

BENTHIC MONITORING

The benthic monitoring program is designed to document substrate composition and the distribution and abundance of benthic (bottom dwelling) organisms in the Delta and Suisun and San Pablo bays. The benthos of the Delta and westerly bays includes a diverse assemblage of organisms ranging from single-cell bacteria and ciliates to large crabs and clams. The program monitors changes in the benthic macrofauna, which includes organisms larger than 0.5 mm. Trends in substrate composition are used to establish associations between changes in the benthic fauna and the surrounding habitat.

Since 1980, the benthic monitoring program has consisted of monthly bottom grab samples collected from five environmentally diverse sites (Figure 23). The sixth site, D41A, was added in 1991. Each site is divided into a maximum of three channel sectors: right bank (R), left bank (L), and center (C). Bottom grab samples for benthic macrofauna or substrate analysis are collected at the sites and sectors as indicated in Table 1.

A private laboratory sorts, identifies, and enumerates organisms in the macrofauna samples. Inorganic and organic content plus particle size of substrate samples are determined by the DWR Soils and Concrete Laboratory. Inorganic and organic content are determined by heating the sample to 440°C for 24 hours. Any material lost as a result of heating is considered organic; any remaining material is considered inorganic. Inorganic

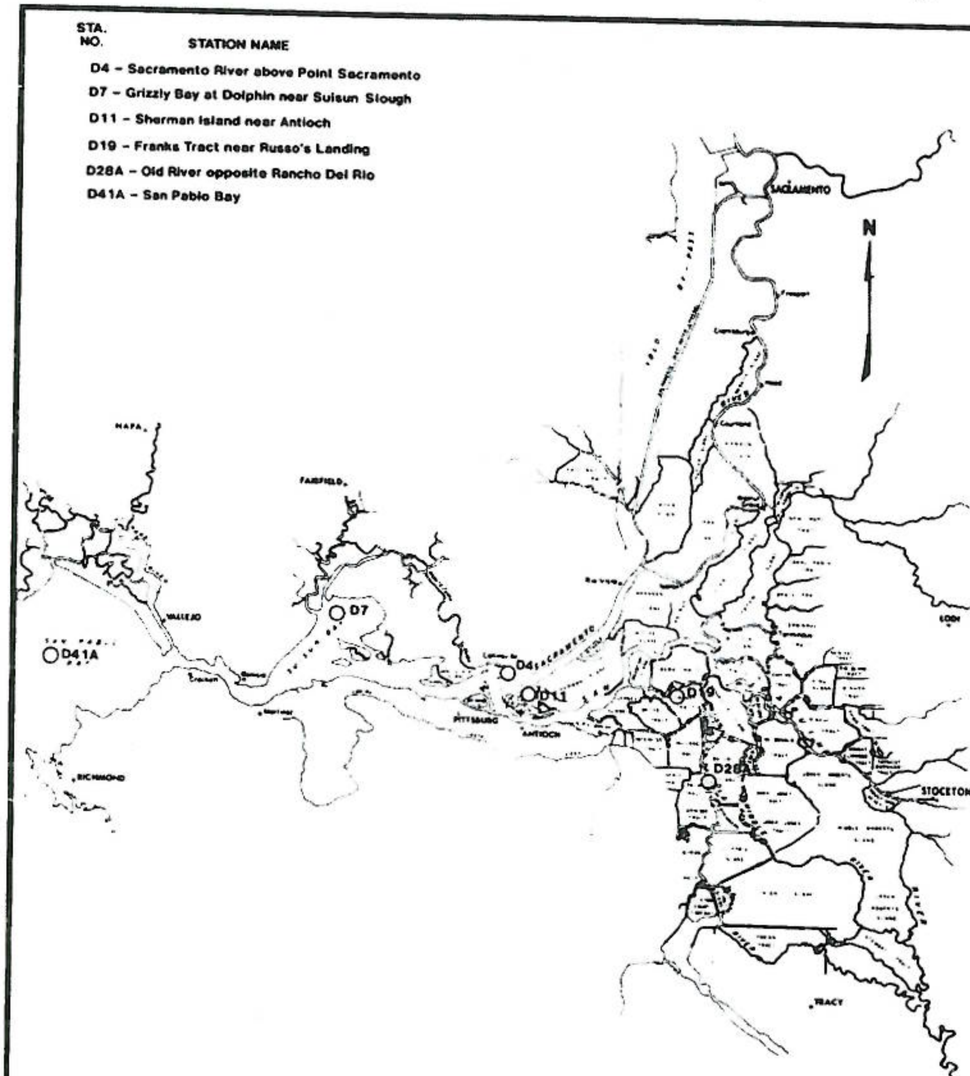

Figure 23
BENTHIC MONITORING SITES, 1994

particle size is determined by mechanical sieve analysis. Particle size categories are: fines (silt and clay, 1-5 µm), sand (6-6,000 µm), and gravel (7,000-150,000 µm).

This chapter reviews major changes in substrate composition and in benthic assemblage and abundance in water year 1994. This was a critically dry year following an above average year (1993) and a series of critically dry or dry years (1987-1992). In spite of the high reservoir carryover storage in 1994, the return of low inflows resulted in conditions characteristic of the previous drought years, including higher salinity intrusion.

Table 1
BENTHIC AND SUBSTRATE SAMPLING SITES

Site	Sector*	Type of Sample**	Habitat
D4	R	Substrate/Benthos	River Channel
	C	Substrate/Benthos	
	L	Substrate/Benthos	
D7	R	Substrate	Shallow Bay
	C	Substrate/Benthos	
D11	R	Substrate	Flooded Tract
	C	Substrate/Benthos	
	L	Substrate	
D19	R	Substrate	Flooded Tract
	C	Substrate/Benthos	
	L	Substrate	
D28A	R	Substrate/Benthos	River Channel
	C	Substrate/Benthos	
D41A	R	Substrate/Benthos	Shallow Bay

* Sectors are determined while facing downstream (Right, Center, Left).
** Substrate samples consist of one random grab.
Benthic samples consist of three grabs.

Substrate Composition

Substrate composition in 1994 was similar to that measured during previous low outflow years. Water velocity and sediment carrying capacity were reduced as a result of low streamflow associated with dry conditions. This produced high proportions of fines at all non-channel sites and reduced amounts of sand at some channel sites. Substrate trends for 1994 are illustrated in Figure 24.

Substrate composition at the channel sites (D4, D28A) ranged from stable to highly variable. Although sand was present at both channel sites during 1994, it comprised a larger portion of the substrate at D4-C only. The remaining sectors were dominated by fines throughout much of the year.

Substrate composition at the non-channel sites (D7, D11, D19, D41A) was stable and consisted primarily of fines.

The composition of inorganic material has historically fluctuated seasonally at many of the benthic sites. This was especially evident at D28A, where fines were reduced and sand was abundant during the spring runoff period. At D19-R, the normally fine substrate became noticeably sandy in late summer and early fall.

With the exception of D28A-L and D19-R, the organic content at all sites was consistently low and stable. These two sites normally have highly variable substrate composition, and the 1994 fluctuations are within the range of values encountered in the past.

Benthic Macrofauna Analysis

Fluctuations in total abundance and abundance of the four most abundant species in 1994 were used to investigate recent trends in the benthic community. Results for each site are discussed below.

Site D41A

Site D41A is in a shoal region of San Pablo Bay. Water depth varies with the tide, ranging from 3 to 10 feet. D41A was added to the DWR/USBR Compliance Monitoring Benthic Sampling program in 1991, and is the westernmost and most saline of the benthic monitoring sites. Surface specific conductance in San Pablo Bay was relatively stable at 35,000-43,100 µS/cm throughout much of the year, with slightly lower values in March and December. Total abundance of all organisms at D41A was highest in the summer and

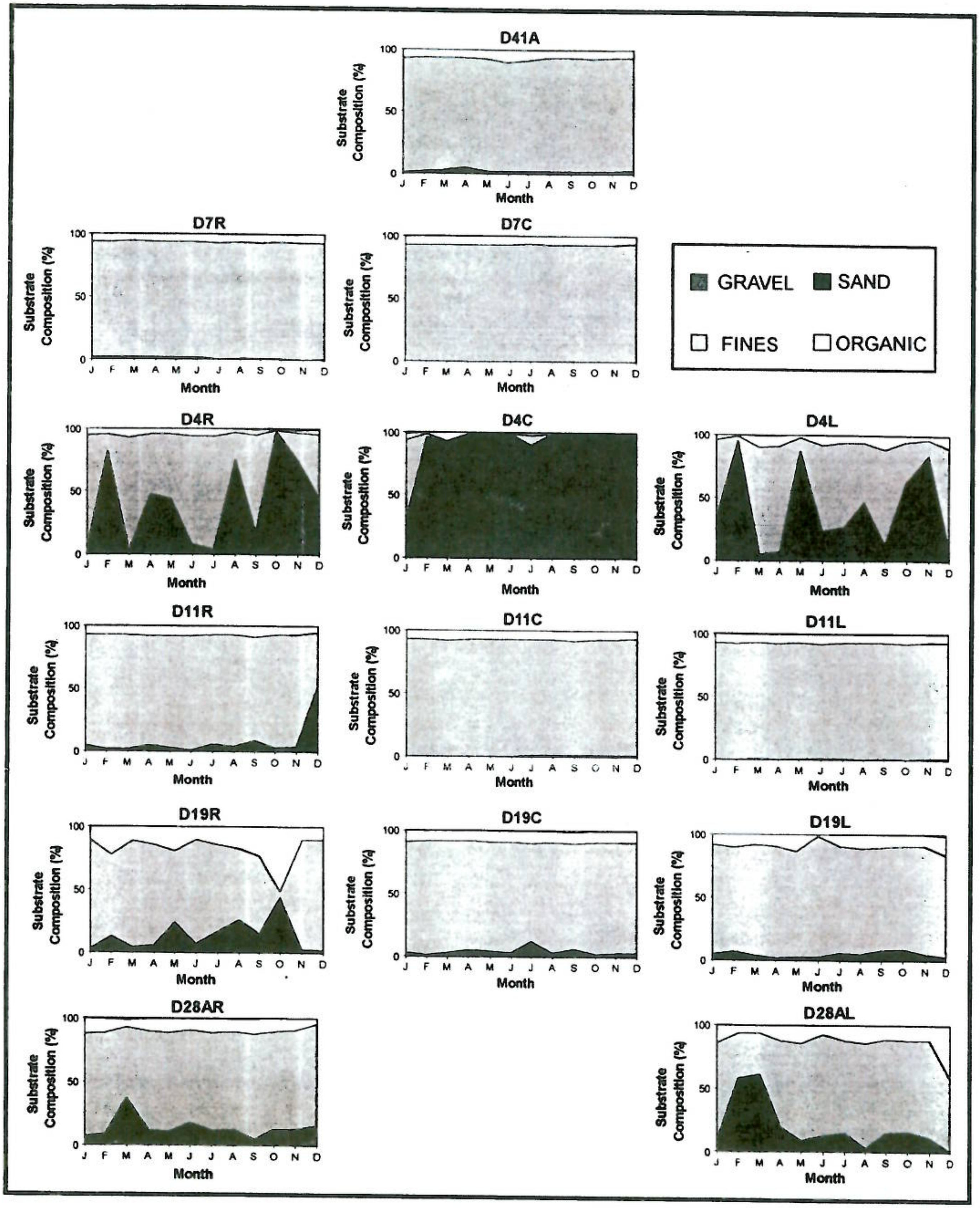

Figure 24
PERCENT SUBSTRATE COMPOSITION AT BENTHIC MONITORING SITES, 1994

winter, and peaked in July at 14,600 individuals/m^2 (Figure 25). The lowest total abundance was found in April at 4,000 individuals/m^2. The changes in total abundance were primarily driven by concentrations of two dominant introduced organisms, the tube dwelling amphipod *Ampelisca abdita*, and the Asian clam *Potamocorbula amurensis.*

The marine mussel *Musculista senhousia* was the least abundant of the four dominant organisms at D41A in 1994. *M. senhousia* remained at or below 100 individuals/m^2, except in November when it peaked at 600 individuals/m^2.

The benthic amphipod *Corophium heteroceratum* was slightly more abundant than *M. senhousia*. Populations of this introduced species ranged from 13 individuals/m^2 in March to 1,064 individuals/m^2 in October.

The introduced Asian clam *Potamocorbula* amurensis was the second most abundant organism at D41A in 1994. Populations of *P. amurensis* were uncharacteristically low, at less than 1,000 individuals/m^2. *P. amurensis* had been found at densities of nearly 30,000 individuals/m^2 in 1993.

The introduced arthropod *Ampelisca abdita* was by far the most abundant organism at D41A in 1994. Populations ranged from 13,000 individuals/m^2 in January to 2,300 individuals/m^2 in April. Late spring, early summer, and winter populations exceeded 10,000 individuals/m^2.

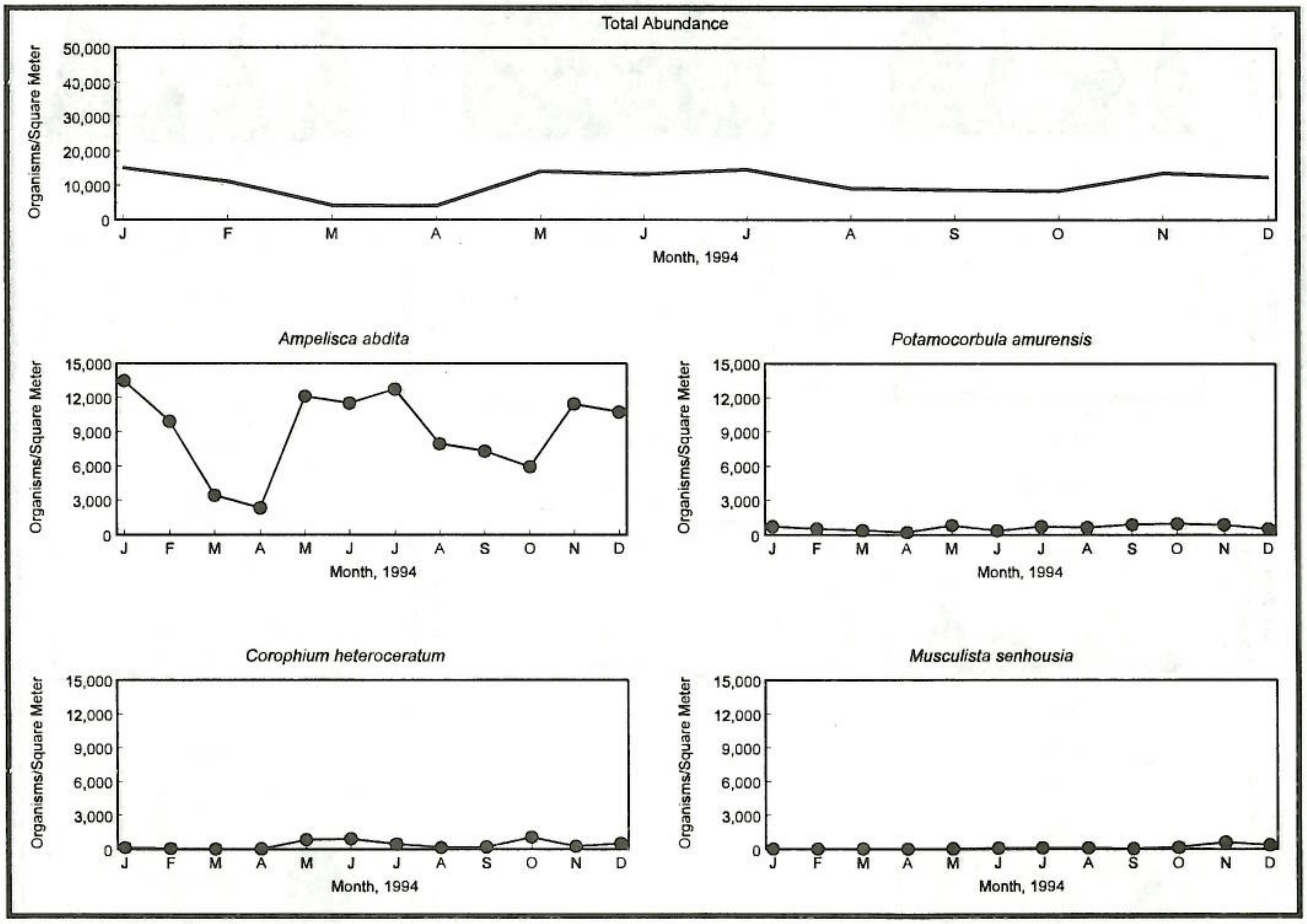

Figure 25
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D41A

Site D7

Site D7 is in a shoal region of Suisun Bay. Water depth varies with the tide, ranging from 3 to 9 feet. Surface specific conductance ranged from 1,000 to 20,600 µS/cm and was often above 14,000 µS/cm, except during the high outflow months of March-May. Figure 26 shows that total abundance peaked in July at over 13,000 individuals/m^2 and peaked again in December at 10,000 individuals/m^2. Abundance at D7 was primarily driven by the introduced species *Corophium alienense* and *P. amurensis*.

The introduced arthropod *Grandidierella japonica* was the least abundant of the four dominant organisms at D7 in 1994. Populations were low throughout most of the year (less than 50 individuals/m^2) but peaked dramatically in December at nearly 4,000 individuals/m^2.

The anthropod *Nippoleucon hinumensis* was slightly more abundant than *G. japonica*. *N. hinumensis* populations peaked in February and December at 2,400 individuals/m^2. From April through October, populations were less than 160 individuals/m^2, and in July and August, populations dropped to zero.

P. amurensis was unusually dense and the second most abundant species at D7 in 1994. Populations *of P. amurensis* were less than 1,000 individuals/m^2 in January-June and gradually increased to a peak of 4,400 individuals/m^2 in October.

The arthropod *Corophium alienense* was the most abundant organism at D7. Spring populations gradually increased to a peak in July of 9,000 individuals/m^2 and then dropped to 900 individuals/m^2 by October.

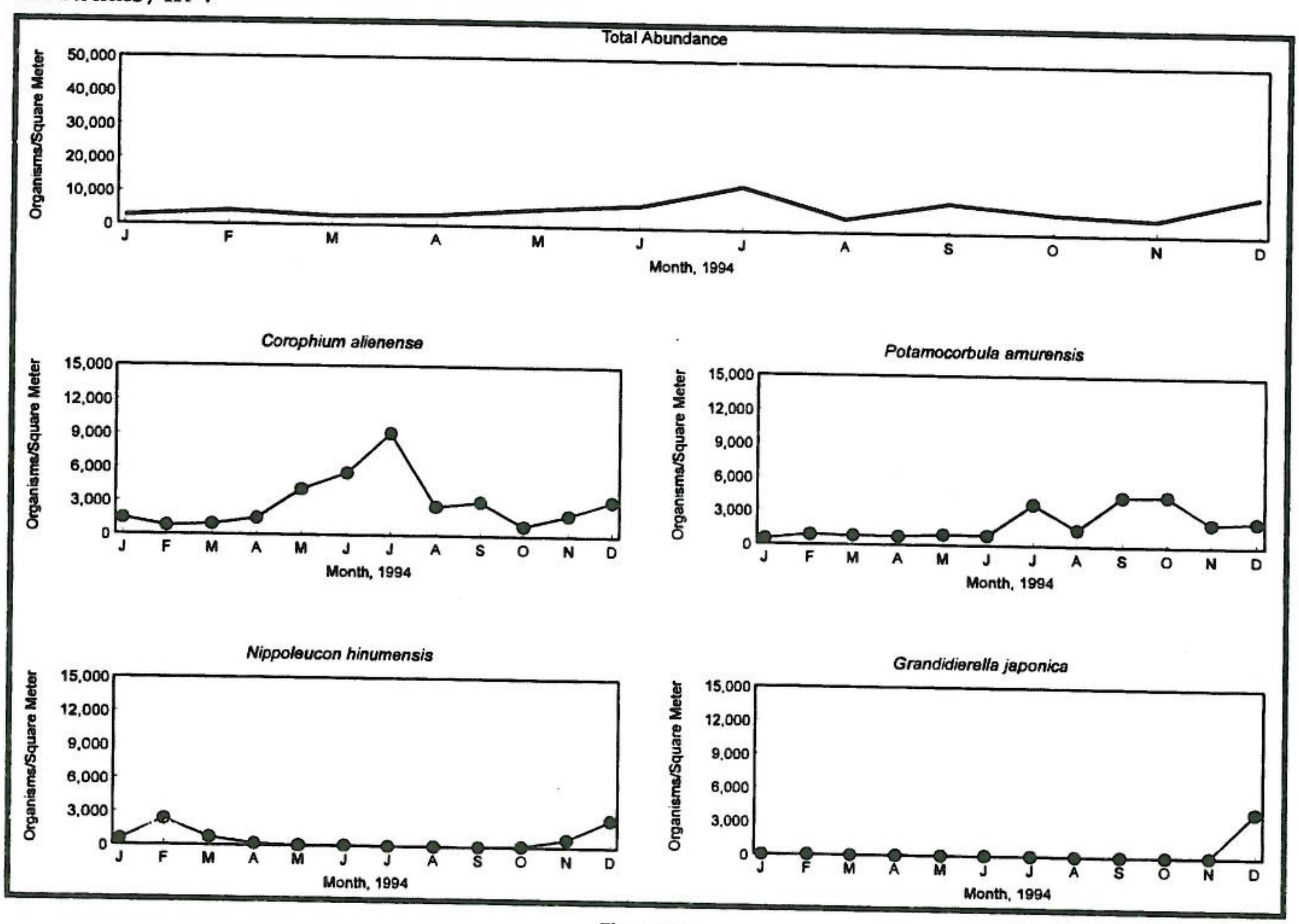

Figure 26
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D7

Site D11

Site D11 is in the Center of Sherman Lake, a flooded tract in the western Delta. Water depth is 6-15 feet, influenced by the tide. In 1994, surface specific conductance ranged from 385 to 6,780 µS/cm and was often higher than 3,500 µS/cm. Total abundance was less than 12,000 individuals/m^2 throughout the year, except for a peak of 12,000 individuals/m^2 in June (Figure 27). Abundance at D11 was primarily driven by *Corophium stimpsoni*, a native arthropod species, and the introduced Asian clam *Corbicula fluminea*.

The tubificid worm, *Limnodrilus hoffmeisteri*, was the least abundant of the four dominant organisms at D11 in 1994. Abundance was highest in the spring, peaking at nearly 700 individuals/m^2 in April. Populations gradually fell to less than 100 individuals/m^2 by October, and remained low for the rest of the year

Gammarus daiberi, an introduced arthropod species, was slightly more abundant at D11 in 1994. *G. daiberi* populations rose steadily from 13 individuals/m^2 in January to nearly 3,000 individuals/m^2 in June, fell sharply to under 100 individuals/m^2 in July, and then rose steadily again through December, finishing the year at nearly 1000 individuals/m^2.

Corbicula fluminea, the second most abundant organism at D11 in 1994, had two population peaks — in June, at 3,500 individuals/m^2, and in December, at 4,500 individuals/m^2.

Corophium stimpsoni, the most abundant organism at D11 in 1994, peaked dramatically at 13,600 individuals/m^2 in June. Populations dropped to a low of 2,001 individuals/m^2 in August and recovered in September with a small peak of 4,560 individuals/m^2.

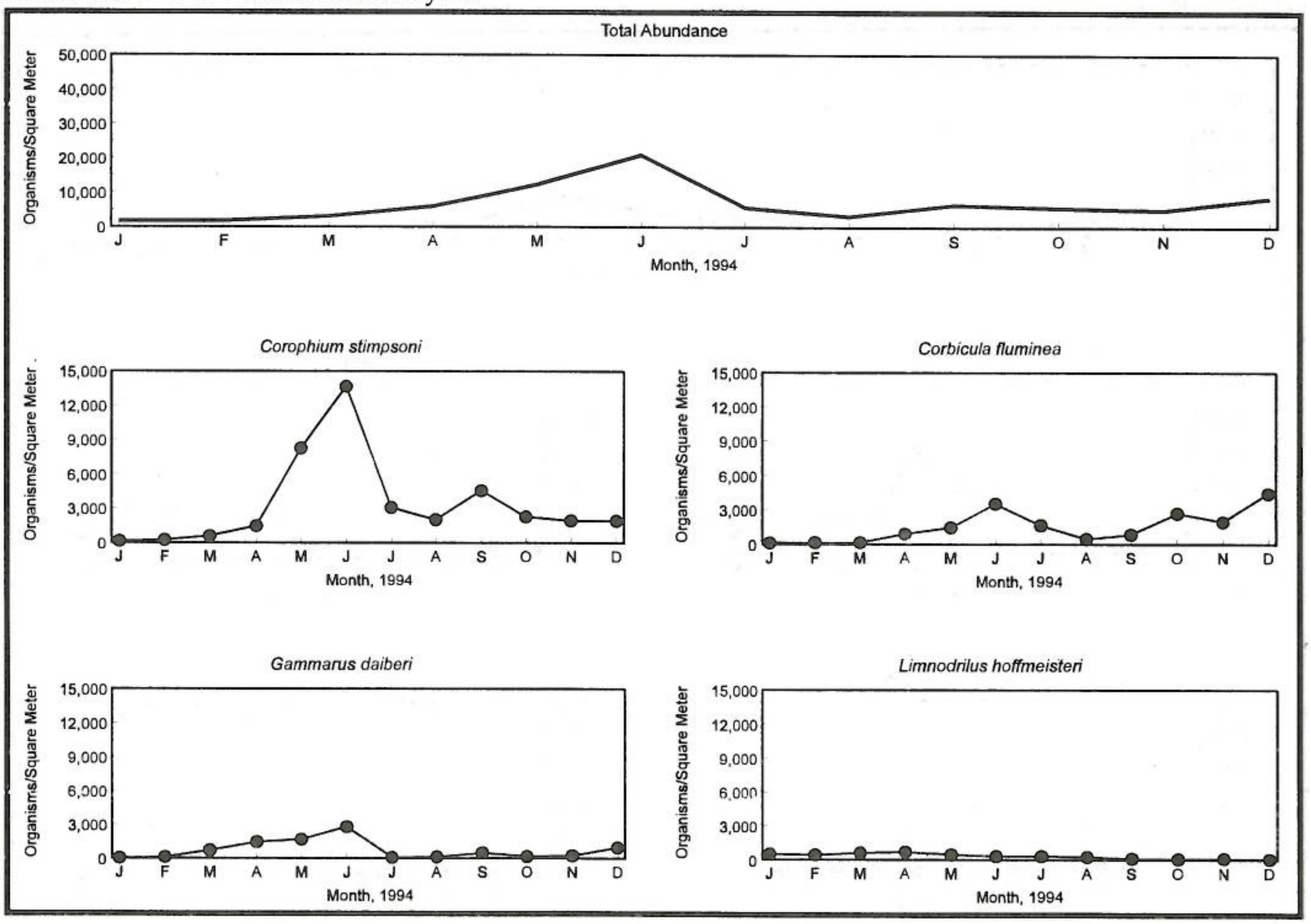

Figure 27
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D11

Site D4

Site D4 is near the mouth of the Sacramento River near Collinsville. Samples are taken in the swift water channel midstream and at both banks, where current velocity is less. D4 is subject to a wide range of flows during all water year types. Water depth is variable among the three sectors: 21-32 feet at D4-L; 10-16 feet at D4-R; and 30-39 feet at D4-C. In 1994, surface specific conductance ranged from 370 μS/cm to 8,900 μS/cm and was often above 4,855 μS/cm. Total organism abundance peaked in June at 44,500 individuals/m^2, dropped below 4,500 individuals/m^2 by July, and remained below 8,000 individuals/m^2 through the rest of the year (Figure 28). Each of the four most abundant species significantly influenced total abundance during 1994.

The recently introduced arthropod species, *Gammarus daiberi*, was the least abundant of the four top species at D4 in 1994. This relatively salt-intolerant species has become a significant inhabitant at the eastern sites in the benthic sampling program. Populations of *G. daiberi* peaked in June at 10,500 individuals/m^2, dropped dramatically to less than 200 individuals/m^2 in July, and remained under 1,000 individuals/m^2 for the rest of the year.

Generally, the native, tube-dwelling polychaete *Varichaetadrilus angustipenis* was slightly more abundant than *G. daiberi* in 1994, though populations never exceeded 2,500 individuals/m^2 over the course of the year. *V. angustipenis* populations were consistent with the lowest density reached in July, at just over 1,000 individuals/m^2.

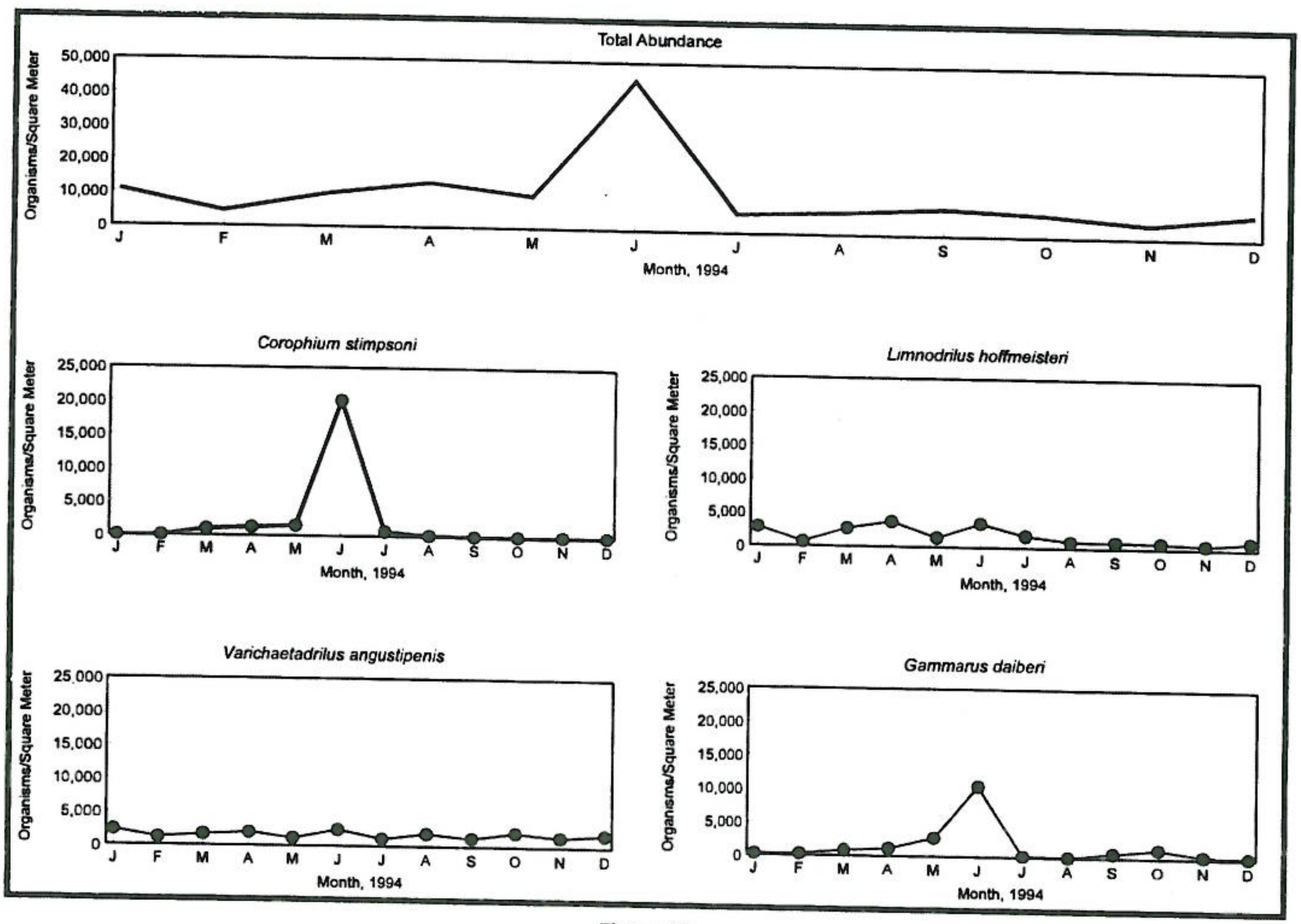

Figure 28
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D4

The tube-dwelling polychaete *Limnodrilus hoffmeisteri* was slightly more abundant than *V. angustipenis* in 1994. Populations peaked in April at 3,700 individuals/m^2, remained relatively high throughout the summer, and declined to 500 individuals/m^2 by November.

Corophium stimpsoni was the most abundant organism at D4 in 1994. Throughout the year, populations of *C. stimpsoni* were less than 1,000 individuals/m^2. In June, however, populations increased dramatically to 20,000 individuals/m^2 and dropped quickly to 660 individuals/m^2 in July. Populations continued to decrease to zero by November.

Site D19

Site D19 is in the northwest corner of Franks Tract, a shallow submerged tract in the central Delta. Water depth varies with the tide and ranges from about 6 to 10 feet. Specific conductance ranged from 285 to 856 µS/cm and was often above 544 µS/cm in 1994. Franks Tract is characterized by low current velocities, a stable substrate composition high in fines, and a brackish environment. D19 is the only sampling site in this study that is not dominated by introduced species.

With the exception of Site D28, Site D19 had the highest level of total organism abundance of all monitoring sites, exceeding 10,000 organisms/m^2 throughout the year. Figure 29 shows a population peak in June of 28,017 individuals/m^2 and another in October of 34,713 individuals/m^2.

The common tubificid worm *Limnodrilus hoffmeisteri* was abundant in the spring, reaching a peak density of 7,000 individuals/m^2 in March. Populations dropped off sharply by

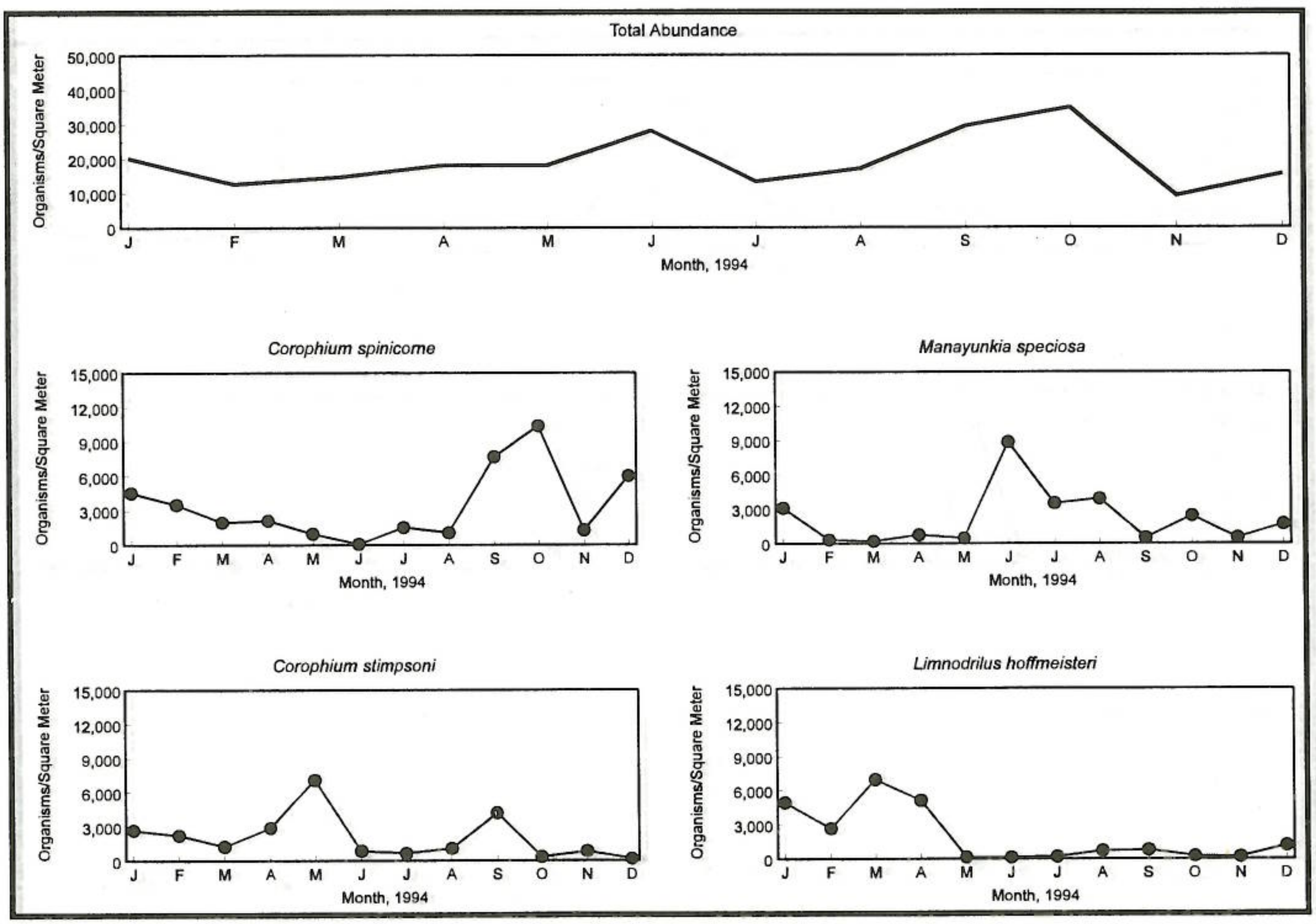

Figure 29
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D19

May to less than 100 individuals/m^2 and remained low through December.

Corophium stimpsoni populations were low in the early spring, peaked in May at 7,000 individuals/m^2, and fell to 800 individuals/m^2 by June. Another small peak of 4,000 individuals/m^2 occurred in September. Fall and winter levels of *C. stimpsoni* were less than 3,000 organisms/m^2.

The tube-building colonial polychaete worm *Manayunkia speciosa* was slightly more abundant than *C. stimpsoni*. Late-winter and spring populations of *M. speciosa* were less than 1,000 individuals/m^2 and increased dramatically in June to nearly 9,000 individuals/m^2. Populations then slowly declined to 500 individuals/m^2 by November.

The most abundant species at D19 in 1994 was *Corophium spinicorne*. Populations gradually declined from 4,500 individuals/m^2 in January to 60 individuals/m^2 in June, and then gradually rebounded to peak at over 10,000 individuals/m^2 in October.

Site D28A

Site D28A is in Old River immediately upstream from its junction with Rock Slough. Old River is a natural approach channel to Clifton Court Forebay in the southern Delta. Water depth along both banks varies from 12 to 20 feet. In 1994, specific conductance ranged from 342 to 902 µS/cm and was often above 544 µS/cm. D28A had the highest total abundance of any site sampled in this study, with February-June and December levels greater than 25,000 individuals/m^2 (Figure 30). Total abundance reached a maximum in June, at 45,600 individuals/m^2.

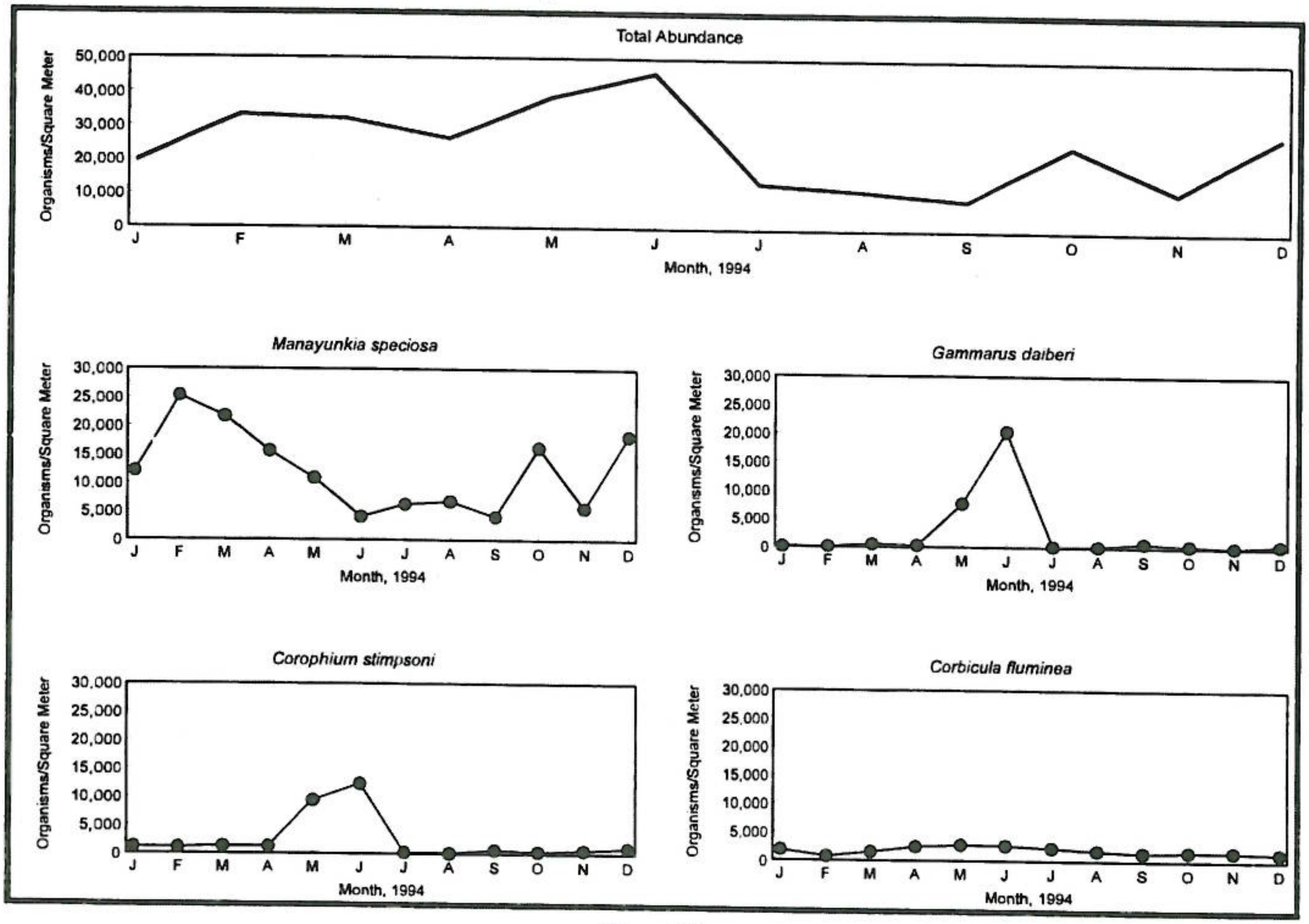

Figure 30
TOTAL ABUNDANCE AND ABUNDANCE OF THE FOUR MOST ABUNDANT ORGANISMS, SITE D28A

The introduced freshwater clam *Corbicula fluminea* was the least abundant of the four top benthic organisms at D28A. *C fluminea* populations gradually increased to a peak of nearly 3,000 individuals/m^2 in May, and then declined slowly to 1,300 individuals/m^2 by December.

The third most abundant organism at D28A in 1994 was *Corophium stimpsoni*. Populations at D28A followed the pattern observed at other Delta stations. Populations at D28A were low, at around 1,000 individuals/m^2, through the winter and early spring, peaked at 12,000 individuals/m^2 in June, declined to 70 individuals/m^2 in July, and remained low for the rest of the year.

Gammarus daiberi was also common at Site D28A. Populations were less than 200 individuals/m^2 for January-April and increased dramatically to 20,000 individuals/m^2 by June. The population crashed to 170 individuals/m^2 in July, and grew slowly to nearly 500 individuals/m^2 by December.

Manayunkia speciosa was the most abundant organism at D28A in 1994. Populations peaked at 25,000 individuals/m^2 in February and gradually declined through the spring to a minimum of 4,034 individuals/m^2 in June. Summer populations were relatively low, at less than 7,000 individuals/m^2 through September. Populations peaked again at 16,000 individuals/m^2 in October and 18,000 individuals/m^2 in December of 1994.

Chapter 5

DISSOLVED OXYGEN CONDITIONS IN THE STOCKTON SHIP CHANNEL

Dissolved oxygen concentrations in the Stockton Ship Channel are closely monitored during the late summer and early fall of each year because levels often drop below 5.0 mg/L due to low streamflow, warm water temperature, and high biochemical oxygen demand. Low dissolved oxygen levels can cause physiological stress to fish and block upstream migration of salmon.

Due to concern over the potential adverse effects of low dissolved oxygen concentrations, the Department of Water Resources, in coordination with Department of Fish and Game and U.S. Bureau of Reclamation, usually installs a rock barrier across the head of Old River in late summer or early fall to increase net downstream flow past Stockton into the ship channel.[1] In 1994, the barrier was completed on September 7. Because of a dry summer and early fall, average daily flow in the San Joaquin River past Vernalis in August and September was slightly less than 900 cubic feet per second, and net flow past Stockton ranged from –717 to +168 cfs. Reverse flow conditions dominated the hydrodynamic pattern during this period, reducing improvements attributable to placement of the barrier.

Compliance monitoring of dissolved oxygen levels in the Stockton Ship Channel was conducted in August through November 1994. During each monitoring run, 14 sites were sampled from Prisoners Point in the central Delta to the Stockton Turning Basin (Figure 31). Discrete samples were taken at each site for dissolved oxygen and water temperature at the surface (1 meter depth) and bottom of the water column at ebb slack tide. Results are summarized in Figure 32. Monitoring of the channel by vessel is supplemented by continuous year-round automated dissolved oxygen monitoring at the Rough and Ready (Stockton) multiparameter water quality recording station. Because of the full monitoring effort in the area, planning for special studies, scheduling of the Old River closure, and other activities can be conducted in response to deteriorating dissolved oxygen conditions in the ship channel.

Results of monitoring by vessel show a significant dissolved oxygen sag at the eastern end of the channel from August through early October. The pre-closure runs on August 5, August 22, and September 6 confirmed the presence of the sag, with the lowest values in the Rough and Ready Island area from Light 40 (discrete compliance monitoring site P8) through Light 48. Bottom dissolved oxygen levels ranged from 3.8 to 5.5 mg/L, and surface levels ranged from 4.0 to 5.9 mg/L. These low dissolved oxygen levels were apparently due to warm water temperature (24-26°C), reduced tidal circulation, and reverse flow at Stockton.

Post-closure monitoring on September 19 and October 3 showed continued presence of the dissolved oxygen sag. However, there was a westward shift of the maximum sag area. On September 19, the sag had localized in the Light 40 to 43 area near Rough and Ready Island, with all surface and bottom dissolved oxygen levels less than 5.0 mg/L. By October 3, the maximum sag area had intensified and moved farther west, to the Light 28 to 43 region. In that area, bottom dissolved oxygen levels ranged from 4.1 to

1 When late summer and early fall flows in the San Joaquin River are high, the barrier may not be constructed.

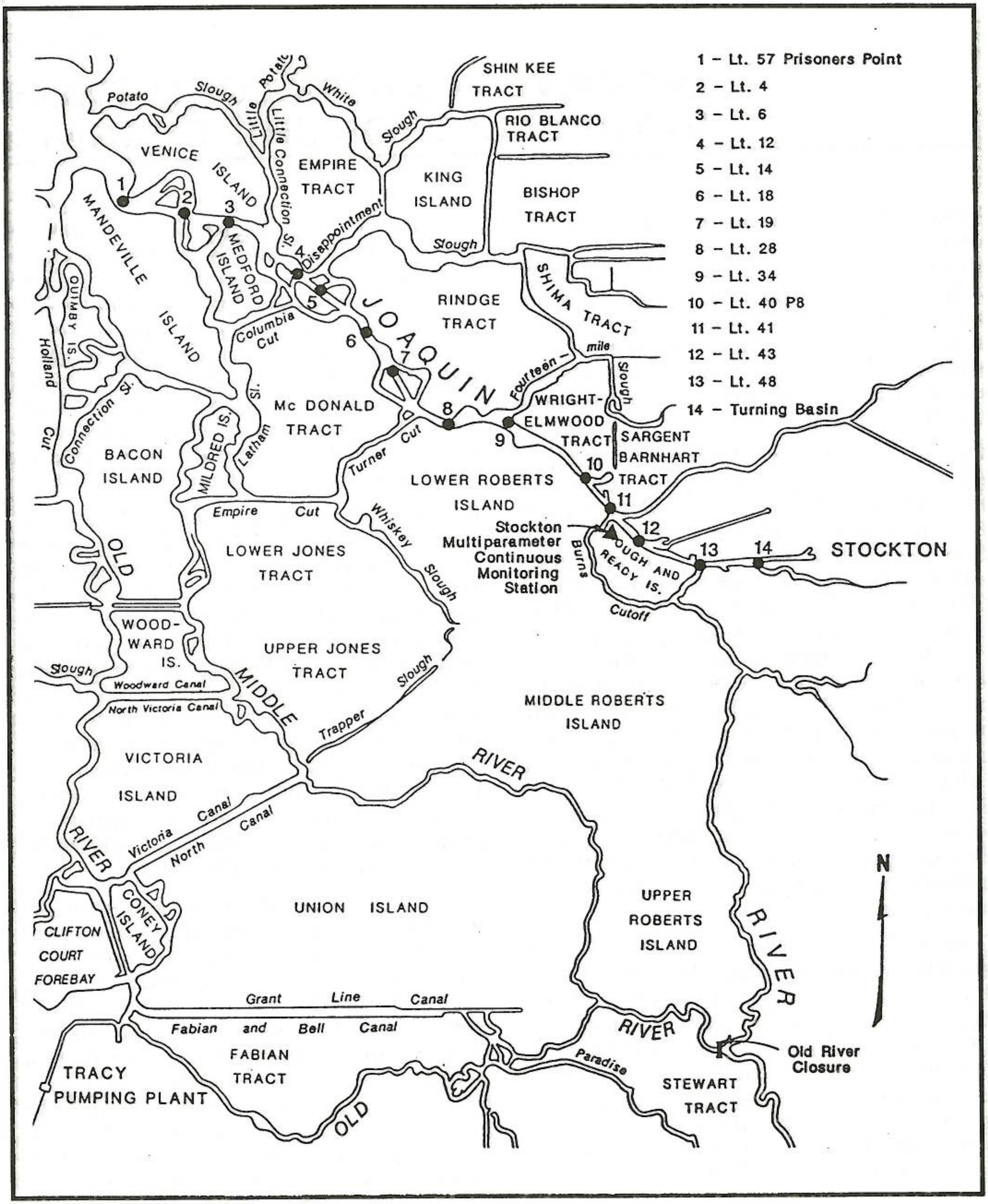

Figure 31
DISSOLVED OXYGEN MONITORING SITES

4.9 mg/L, and surface levels ranged from 4.2 to 5.1 mg/L. Shifting of the maximum sag zone westward and the improved (>5.0 mg/L) dissolved oxygen levels in the post-closure studies at Light 48 (at the eastern end of Rough and Ready Island and at the juncture of the San Joaquin River with the Stockton Ship Channel) on September 19 and October 3 were probably the result of locally improved flow conditions as a result of placement of the closure. In spite of the closure, however, intermittent reverse flows continued at Stockton.

Dissolved oxygen monitoring in the channel on October 18 showed continued improvement over conditions measured in previous monitoring. By mid-October, minimum bottom dissolved oxygen levels in the area of maximum sag had improved to 5.6 to 7.0 mg/L, and surface dissolved oxygen levels there had improved to 5.7-6.9 mg/L. Improved channel flow conditions and cooler water temperatures (16-19°C) had apparently brought about the higher dissolved oxygen levels. In October, average daily San Joaquin River flow past Vernalis approached 1,400 cfs, and net daily flow past Stockton ranged from –309 to +391 cfs.

In November, cooler water temperature (10-12°C) and cumulative effects from placement of the Old River barrier finally brought about a significant improvement in dissolved oxygen levels in the channel. Monitoring on November 18 showed no sag in the channel; dissolved oxygen levels throughout the channel were greater than 8.7 mg/L. Levels in the eastern channel were 8.7-9.3 mg/L and those in the western channel were 9.5-10.1 mg/L. Because of the dry fall, average daily flow in the San Joaquin River past Vernalis barely exceeded 1,300 cfs in November, and net flow past Stockton ranged from –308 to +224 cfs. Removal of the barrier was completed on November 30.

The highly variable and apparently anomalous dissolved oxygen values measured in the Stockton Turning Basin on September 19, and to a lesser extent on October 3, were the result of its unique location and reflect conditions that are independent of the main downstream channel. The basin is at the dead-end, eastern terminus of the ship channel and is subject to reduced tidal action, reduced water circulation, and extended water residence time. Historically, a series of intense algal blooms composed primarily of Cryptomonads and green flagellated algae produce stratified dissolved oxygen conditions in the water column of the Turning Basin in late summer and early fall. In 1994, the dominant bloom organism was the notorious taste and odor causing blue-green alga *Anacytis* sp. On September 19, the dissolved oxygen level was exceptionally high at the surface (14.4 mg/L) and exceptionally low at the bottom (1.5 mg/L). Bloom conditions in the basin were further confirmed by the "fluorescent" green of the basin waters on September 19.

The low dissolved oxygen conditions at or near the bottom of the Turning Basin are further degraded by high BOD loadings. These loadings are caused by dead or dying algae settling out of the water column during and following a bloom and from extensive boating activities in the harbor.

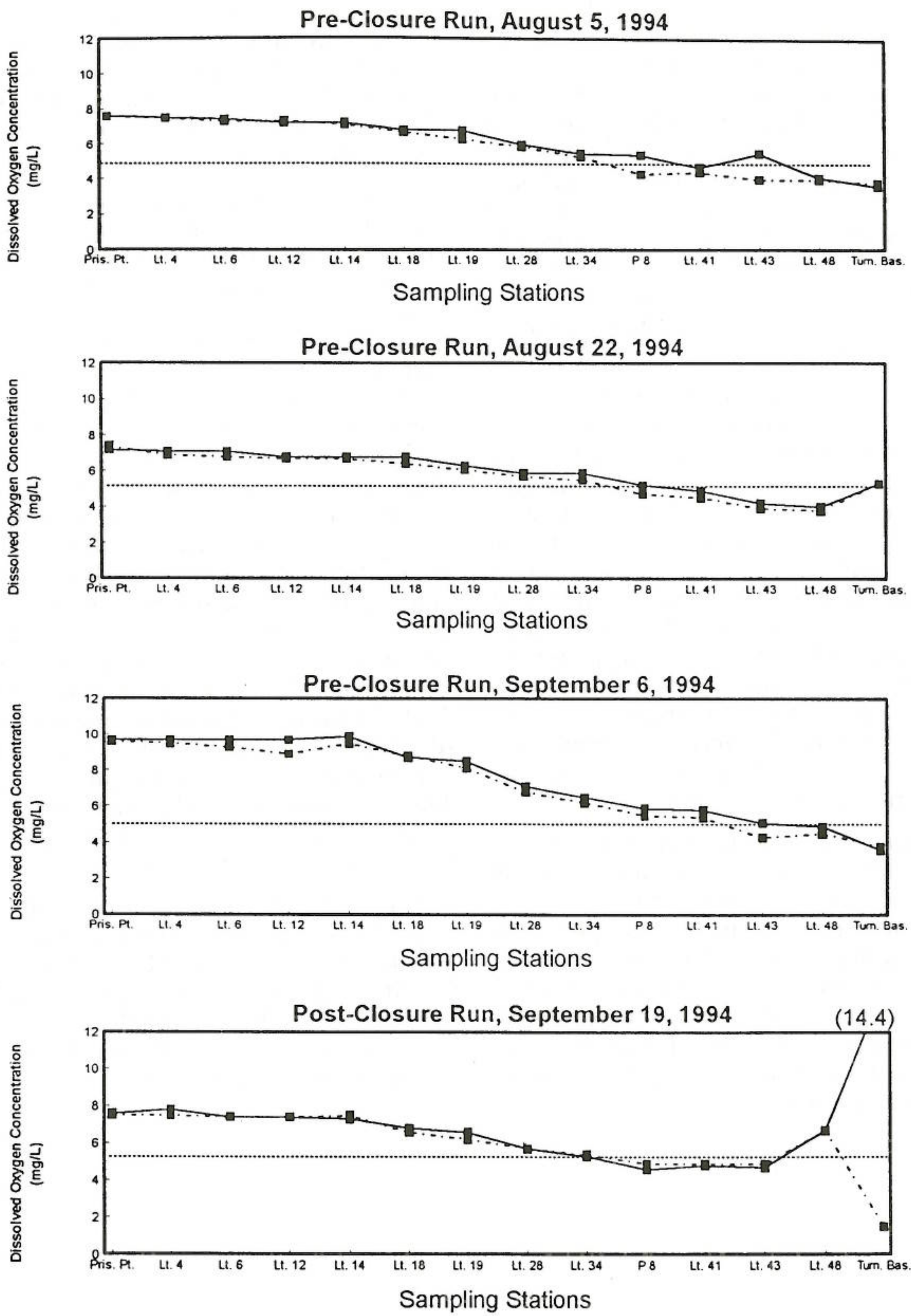

Figure 32
DISSOLVED OXYGEN CONCENTRATIONS IN THE STOCKTON SHIP CHANNEL, 1994

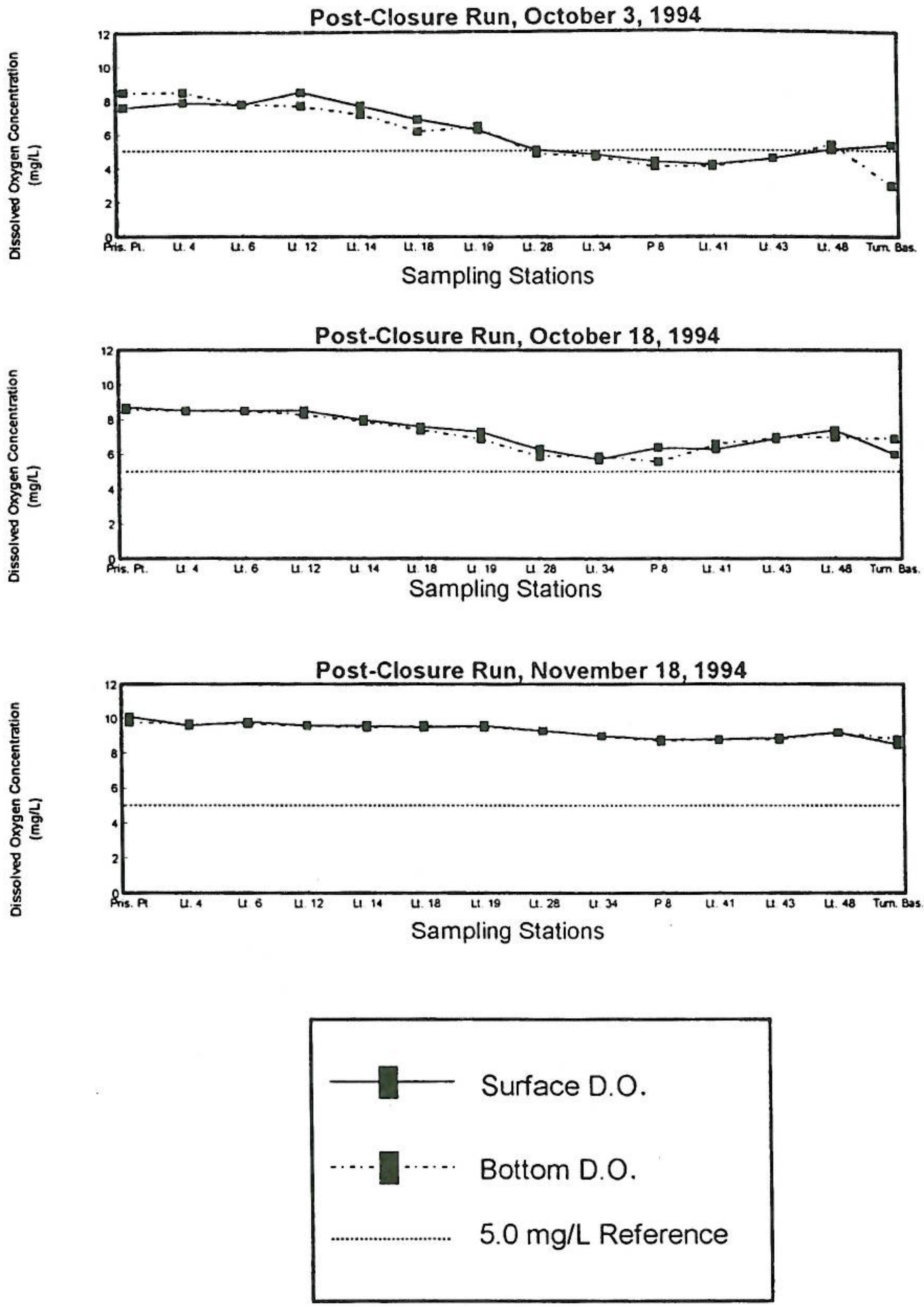

Figure 32 (continued)
DISSOLVED OXYGEN CONCENTRATIONS IN THE STOCKTON SHIP CHANNEL, 1994

Chapter 6
TRACE METALS AND ORGANIC COMPOUNDS

Concentrations of 9 trace metals and 41 chlorinated organic pesticides are measured biannually (spring and fall) at 11 sites in the Delta and Suisun Bay as part of the water quality monitoring program required by Decision 1485. Results are used to indicate long-term changes in levels of potentially toxic substances.

Although some of the compounds monitored occur naturally in Bay/Delta waters, many occur as a result of agricultural, urban, and industrial activity. Elevated concentrations of trace metals, organic pesticides, and other pollutants are of concern because they may adversely affect water quality and the biological resources of San Francisco Bay and the Delta[1,2].

This chapter compares trace metal and pesticide concentrations measured in 1994 to those measured in the six previous years (1987-1992) of drought and a wet year (1993).

Trace Metals

During 1994, six of the nine trace metals monitored were found at concentrations above the minimum reporting limit[3] (Table 2). Total metal concentrations are derived from the concentrations of metals in both the dissolved and suspended fractions of the water sample.

The 1994 concentrations of trace metals followed a pattern similar to those of the previous years:

- Arsenic was consistently detected in both the dissolved and total metal samples.
- Total iron and manganese were consistently above minimum reporting limits.
- Dissolved and total cadmium, dissolved and total lead, and total mercury were not detected, and dissolved chromium was rarely detected. In 1994, dissolved chromium was detected only at Honker Bay near Wheeler Point (Site D9).

Total and dissolved trace metal concentrations measured in 1994 were within the range of values measured in previous drought years. In addition, the frequency of detection of commonly-detected trace metals such as dissolved and total copper, iron, manganese, and zinc in 1994 was similar to the frequency of detection in the previous drought years.

The Department of Health Services has established primary drinking water standards for dissolved arsenic, cadmium, chromium, lead, and mercury and secondary standards for dissolved copper, iron, manganese, and zinc[4]. Primary drinking water standards are based on National Primary Drinking Water Regulations (40CFR, Part 141) and are the maximum permissible contaminant levels in water to protect human health when the water is used continuously for drinking or cooking. Secondary drinking water standards are based on the Secondary Drinking

1 D.J.H. Phillips. *Toxic Contaminants in the San Francisco Bay Delta and Their Possible Biological Effects*. Aquatic Habitat Institute, Richmond, CA. 1987.

2 H.C. Bailey, C. Alexander, C. Digiorgio, M. Miller, S.I. Doroshov, D.E. Hinton. "The Effect of Agricultural Discharge on Striped Bass (*Morone saxatilis*) in California's Sacramento-San Joaquin Drainage". Ecotoxicology 3:123-142. 1994.

3 The minimum reporting limit is the lowest level of detection at the 99 percent confidence level of the laboratory conducting the analyses. Bryte Chemical Laboratory conducted the trace metal analyses for the Department of Water Resources.

4 Department of Health Services. "Chemical and Physical Quality", in *California Domestic Water Quality and Monitoring Regulations*. California Administrative Code, Title 22, Division 4, Chapter 15, pp. 10-15. 1989.

Water Regulations (40CFR, Part 143) and are the maximum permissible contaminant levels to assure that taste, odor, or appearance of drinking water are not adversely affected. Secondary drinking water standards are not based on human health concerns.

Dissolved and total trace metals did not exceed the Primary Drinking Water Standards in 1994. A secondary drinking water standard was exceeded for dissolved manganese in the San Joaquin River at Mossdale (Site C7). Dissolved manganese levels above the secondary drinking water standard were detected previously in the San Joaquin River at Buckley Cove (Site P8) in May 1987 and May 1991 and at Mossdale in September 1991. The San Joaquin River drains an extensive agricultural area in the San Joaquin Valley, and the upstream source of manganese to the river is probably agricultural. Manganese and its salts are used extensively in fertilizers, especially in manganese-deficient soils.[5] Many manganese salts such as the chlorides, nitrates, and sulfates are highly soluble in water and their presence in irrigation return water could contribute to the elevated dissolved manganese levels in the San Joaquin River.

Table 2
DISSOLVED AND TOTAL TRACE METAL CONCENTRATIONS MEASURED DURING 1994[1]
(µg/L)

Site	Date	As D......T	Cd D......T	Cr D......T	Cu D......T	Fe D......T	Pb D......T	Mn D......T	Zn D......T	Hg T
C3	05-07	2......2	*......*	*......*	*......*	30......400	*......*	12......16	*......20	*
	09-02	2......2	*......*	*......*	*......*	37......700	*......*	7......22	*......7	*
C7	05-07	2......2	*......*	*......*	*......*	10......2400	*......*	43......110	*......*	*
	09-02	2......4	*......*	*......5	*......*	8......3500	*......*	80......288	*......13	*
D4	05-11	2......3	*......*	*......6	*......8	20......3100	*......*	*......45	*......10	*
	09-03	2......3	*......*	*......*	*......*	*......1100	*......*	12......41	5......14	*
D6	05-12	2......3	*......*	*......*	8......11	80......1600	*......*	*......24	*......10	*
	09-08	3......3	*......*	*......*	6......7	*......800	*......*	*......18	*......5	*
D9	05-11	2......3	*......*	11......15	6......10	60......3400	*......*	*......48	10......10	*
	09-03	2......3	*......*	*......*	11......12	*......2000	*......*	8......66	*......15	*
D11	05-12	2......2	*......*	*......6	5......8	40......1700	*......*	*......30	*......20	*
	09-08	2......2	*......*	*......*	16......19	6......700	*......*	12......35	*......8	*
D12	05-12	2......4	*......*	*......*	6......8	20......1500	*......*	*......28	*......40	*
	09-08	2......2	*......*	*......*	*......12	*......700	*......*	19......37	*......7	*
D19	05-11	2......2	*......*	*......*	*......*	30......900	*......*	7......14	*......*	*
	09-03	2......2	*......*	*......*	*......*	22......700	*......*	13......24	*......*	*
D14A	05-12	2......2	*......*	*......*	*......5	*......600	*......*	*......10	*......30	*
	09-08	2......2	*......*	*......*	*......11	12......500	*......*	7......24	6......8	*
D28A	05-08	2......2	*......*	*......*	*......*	30......800	*......*	*......10	*......30	*
	09-02	2......2	*......*	*......*	*......*	48......500	*......*	11......26	*......7	*
P8	05-08	2......2	*......*	*......*	*......*	30......900	*......*	26......59	20......20	*
	09-02	3......3	*......*	*......*	*......6	17......500	*......*	33......69	6......7	*

D = Dissolved, T = Total, and * = Below Minimum Reporting Limit.
[1] The minimum reporting limit was 1 µg/L for mercury and arsenic and 5 µg/L for all others.

5 Summarized in J.E. McKee and H.W. Wolf, *Water Quality Criteria*, 2nd Ed. Publication 3A, State Water Resources Control Board, Sacramento, 1963. 548 pp.

Trace metals such as manganese can be leached out of bottom sediments into the water column under anaerobic conditions.[6] Anaerobic conditions observed in the eastern reach of the Stockton Ship Channel near Buckley Cove could contribute to concentrations already existing from upstream sources.

The most recent ambient water quality criteria were established by the Environmental Protection Agency in 1986. These criteria contain chronic and acute toxicity levels for freshwater and marine aquatic biota for dissolved trace metals (Table 3). These criteria, which are to protect freshwater and marine organisms from adverse effects, are often lower than drinking water standards and usually do not have regulatory impact.

Since 1987, levels of dissolved trace metals in the Bay/Delta system have occasionally exceeded the toxicity levels for marine and freshwater organisms. In 1994, May dissolved chromium levels at Honker Bay near Wheeler Point in the western Delta equaled and September dissolved copper levels at Sherman Island near Antioch (Site D11) exceeded the freshwater chronic toxicity levels for these trace metals. Dissolved copper also exceeded the marine chronic and acute toxicity levels of 2.9 µg/L in September and May in Suisun Bay off Bulls Head Point near Martinez (Site D6), Honker Bay, and Sherman Lake and in May in the San Joaquin River at the Antioch Ship Channel (Site D12). The salts of copper and chromium are widely used in the metal finishing, fabrication, textile, and paint industries. In addition, some chromium salts are effective as corrosion inhibitors and are used in industrial cooling systems. A copper salt, copper sulfate, is used extensively for reduction and control of undesirable plankton growth in water supply

Table 3
DISSOLVED AND TOTAL CONCENTRATIONS OF TRACE METALS MEASURED AND CORRESPONDING DISSOLVED TOXICITY LEVELS[1,2] AND DRINKING WATER STANDARDS[3]

	Range of Values, Trace Metals (µg/L)								
	As	Cd	Cr	Cu	Fe	Pb	Mn	Zn	Hg
Dissolved Concentrations									
1987-1993	2-5	*	*–11	*–149	*–608	*–12	*–126	*–163	—
1994	2-3	*	*–11	*–16	*–80	*	*–80	*–20	—
Total Concentrations									
1987-1993	2-6	*	*–18	*–478	300-6500	*–85	10-388	*–590	*
1994	2-4	*	*–15	*–19	400-3500	*	10-288	*–40	*

	Levels and Standards, Trace Metals (µg/L)								
	As	Cd	Cr	Cu	Fe	Pb	Mn	Zn	Hg
Freshwater									
Acute Toxicity	360	3.9	16	18	1000	82	—	120	2.4
Chronic Toxicity	190	1.1	11	12	—	3.2	—	110	0.012
Marine									
Acute Toxicity	69	43	1100	2.9	—	220	—	95	2.1
Chronic Toxicity	36	9.3	50	2.9	—	8.5	—	86	0.025
Drinking Water Standards									
Primary	50	10	50			50			2
Secondary				1000	300		50	5000	

* Below minimum reporting limit.
1 U.S. Environmental Protection Agency, *Quality Criteria for Water 1986*. Office of Regulations and Standards. Washington, DC, EPA 440/5-86-001. 1986.
2 U.S. Environmental Protection Agency, *Federal Register* 56(223), November 19, 1991, Proposed Rules.
3 Department of Health Services, Public Water Supply Branch. "Chemical and Physical Quality" IN *California Domestic Water Quality and Monitoring Regulation*. California Administrative Code, Title 22, Division 4, Chapter 15, 1990.

6 Summarized in W. Stumm and J.J. Morgan, *Aquatic Chemistry*, 2nd Ed. John Wiley and Sons, New York, 1981. 780 pp.

reservoirs, tanks, conveyance channels, and natural water bodies.[7] Use of these trace metals for any of the purposes just described in the drainages to the Delta and in the nearby industrial areas of Pittsburg and Antioch could account for these levels.

Organic Compounds

The list of synthetic organic compounds in the water quality monitoring program has expanded over the years as a result of increased analytical capabilities. The number of compounds monitored increased from 4 to 25 in 1987 and from 25 to 39 in 1988 (Table 4).

Concentrations of chlorinated organic pesticides above the minimum reporting limit were rarely detected between 1987 and 1993 (Table 5). No organic pesticides were detected in 1987, 1990, 1991, 1992, and 1993. In 1989, diuron was detected at Mossdale (C7) and Buckley Cove (P8) on the San Joaquin River. Diuron was also detected at Buckley Cover in 1988. In addition, endosulfan sulfate was also detected at Mossdale in 1989. The insecticide carbophenothion, a chemical not routinely monitored, was also detected at Buckley Cove in September 1989. Finally, unidentified compounds with concentrations between 0.02 and 0.05 µg/L were detected during 1989. Two of the unidentified compounds were detected in the San Joaquin River at Buckley Cove (P8), one compound each was detected at Franks Tract (D19), the Antioch Ship Channel (D12), and at Sherman Lake (D11).

All of the pesticides detected in the Delta from 1987 through 1993 appear to be consistent with historical patterns of pesticide usage within the system. Diuron and endosulfan sulfate are pesticides that have been applied to many crops grown in the Delta or drainages to the Delta. Diuron is an herbicide applied to crops such as alfalfa, cotton, grapes, barley, and wheat to kill broadleaf weeds. Concentrations measured in the Delta (0.09 to 0.50 µg/L) were far below those known to affect fish. Chronic toxicity tests in flow-through systems indicated rainbow and cutthroat trout can survive indefinitely at concentrations of 140 and 500 µg/L, respectively.[8] Endosulfan sulfate is an insecticide applied to various vegetable, fruit, nut, and grain crops. The concentration of endosulfan sulfate measured (0.04 µg/L) was below the reported freshwater acute (0.22 µg/L) and chronic (0.056 µg/L) toxicity levels, but exceeded the marine acute (0.034 µg/L) and chronic (0.0087 µg/L) toxicity levels.[9] Carbophenothion is an organo-phosphate class insecticide and acaricide. This chemical is used to control insects and mites in fruit, cotton, nuts, vegetables, maize, and other row crops. Carbophenothion is highly toxic to fish, crustaceans, marine organisms, and amphibians. However, the measured concentration at Buckley Cove in 1989 (0.01 µg/L) was below the acute toxicity level for water shrimp (5.2 µg/L)[10], bluegill (13 µg/L)[11], and rainbow trout (56 µg/L)[12].

In 1994, the compound simazine was detected at levels exceeding the minimum reporting limit at all monitored sites. Simazine concentrations ranged from 0.07 µg/L at Mossdale to 7.47 µg/L at Old River (D28A). Simazine is a selective triazine herbicide used to control broadleaf weeds and annual grasses in berry fruit, vegetable, and ornamental crops and in orchards and vineyards.

7 McKee and Wolf, cited.

8 W.W. Johnson and M.T. Finley. *Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates.* U.S. Fish and Wildlife Service, Publication 137. 1980.

9 U.S. Environmental Protection Agency. *Quality Criteria for Water, 1986.* Office of Regulations and Standards, EPA 440/5-86-001. 1986.

10 Johnson and Finley. 1980.

11 U.S. Environmental Protection Agency. 1986.

12 K. Verschueren. *Handbook of Environmental Data on Organic Chemicals.* Van Nostrand Reinhold, New York. 1983.

Table 4
TOXICITY LEVELS, DRINKING WATER STANDARDS, AND MINIMUM REPORTING LIMITS FOR SYNTHETIC ORGANIC COMPOUNDS TESTED FOR IN THE COMPLIANCE MONITORING PROGRAM

	Toxicity Levels[1,2] (µg/L)				Drinking Water Standards[3] (µg/L)		Minimum Reporting Limit
	Freshwater		Marine				
Compound	Acute	Chronic	Acute	Chronic	Primary	Secondary	(µg/L)
Alachlor							0.05
Aldrin	3		1.3				0.01
Atrazine					0.003		0.02
BHC, Alpha							0.01
BHC, Beta							0.01
BHC, Delta							0.01
BHC, Gamma	2	0.08	0.16		0.004		0.01
Captan							0.02
Chlordane	2.4	0.0043	0.09	0.004	0.0001		0.05
Chlorothalonil							0.01
Chlorpropham							0.02
Chlorpyrifos							0.01
DCPA							0.01
DDD							0.01
DDE	1.050		14				0.01
DDT	1.1	0.001	0.13	0.001			0.01
Dichloran							0.01
Dicofol							0.01
Dieldrin	2.5	0.0019	0.71	0.0019			0.01
Diuron							0.25
Endosulfan Sulfate	0.22	0.056	0.034	0.0087			0.02
Endosulfan	0.22	0.056	0.034	0.0087			0.01
Endosulfan I	0.22	0.056	0.034	0.0087			0.01
Endosulfan II	0.22	0.056	0.034	0.0087			0.01
Endrin	0.18	0.0023	0.037	0.0023	0.0002		0.01
Endrin Aldehyde							0.01
Heptachlor	0.52	0.0038	0.053	0.0036	0.00001		0.01
Heptachlor Epoxide	0.52	0.0038	0.053	0.0036	0.00001		0.01
Methoxychlor	0.012	0.03		0.03	0.1		0.05
PCB	2	0.014	10	0.03			0.10
PCB-1016	2	0.014	10	0.03			0.10
PCB-1221	2	0.014	10	0.03			0.10
PCB-1232	2	0.014	10	0.03			0.10
PCB-1242	2	0.014	10	0.03			0.10
PCB-1248	2	0.014	10	0.03			0.10
PCB-1254	2	0.014	10	0.03			0.10
PCB-1260	2	0.014	10	0.03			0.10
PCNB							0.01
Simazine					0.010		0.02
Thiobencarb					0.07	0.001	0.02
Toxaphene	0.73	0.0002	0.21	0.0002	0.005		0.10

1 EPA. "Water Quality Criteria Summary". In: *Quality Criteria for Water, 1986.* Office of Water Regulations and Standards. EPA 440/5-86-001. May 1, 1986. pp. 6-10.
2 EPA-Federal Register, 56(223), November 19, 1991. Proposed Rules.
3 Department of Health Services, Public Water Supply Branch, "Chemical and Physical Quality". In: *California Domestic Water Quality and Monitoring Regulations.* California Administrative Code, Title 22, Division 4, 1990.

Table 5
CHLORINATED ORGANIC COMPOUNDS WITH LEVELS EXCEEDING THE MINIMUM REPORTING LIMIT, 1987 to 1994

		Organic Pesticide (µg/L)			
Site	Date	Diuron	Endosulfan Sulfate	Carbo-phenothion	Simazine
C3	05-11-94	-	-	-	0.150
C7	05-11-89	0.090	-	-	-
	09-05-89	-	0.040	-	-
	05-02-94	-	-	-	0.070
D4	05-05-94	-	-	-	0.120
D6	05-06-94	-	-	-	0.100
D9	05-05-94	-	-	-	0.170
D11	05-06-94	-	-	-	0.100
D12	05-06-94	-	-	-	0.130
D14A	05-06-94	-	-	-	0.140
D19	05-05-94	-	-	-	0.160
D28A	05-04-94	-	-	-	7.470
P8	09-02-88	0.100	-	-	-
	05-10-89	0.500	-	-	-
	09-06-89	-	-	0.010	-
	05-04-94	-	-	-	0.100

This chemical is usually applied in the spring as a pre-emergence herbicide. Simazine has been reported to have a low toxicity to most aquatic species. The 48-hour LC50 for simazine in rainbow trout is 56 mg/L[13], a concentration dramatically higher than the highest concentration of 7.47 µg/L (0.00747 mg/L) detected at Old River in May 1994. The Environmental Protection Agency has set a Lifetime Health Advisory for simazine in drinking water at 1 µg/L. EPA believes that water containing simazine at or below this level is acceptable for drinking every day over one's lifetime and does not impose any health concerns.[14] Monitoring in the fall (September 1994) revealed that simazine concentrations at all sites had dropped to below the minimum reporting limit of 0.02 µg/L.

The Bryte Laboratory minimum reporting limits for chlordane, DDT, dieldrin, endosulfan sulfate, endosulfan, endosulfan I, endosulfan II, endrin, heptachlor, heptachlor expoxide, methoxychlor, PCB, and toxaphene exceeded the chronic freshwater and marine organism toxicity levels adopted in November 1991 by the Environmental Protection Agency (Table 4). Therefore, nondetection of these pesticides by the Compliance Monitoring Program does not permit a conclusion at this time that the pesticide levels are below the EPA toxicity levels.

13 C. Sine, (chief editor). *Farm Chemicals Handbook 1993.* Meister Publishing, Willoughby, OH. 1993.

14 U.S. Environmental Protection Agency. *National Pesticide Survey: Simazine.* Office of Water, Office of Pesticides and Toxic Substances, USEPA, Washington DC. 1990.

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