State of California
The Resources Agency
Department of Water Resources
Division of Environmental Services

Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2004

Report to the State Water Resources Control Board
in accordance with Water Right Decision 1641.

December 2006

Arnold Schwarzenegger	**Mike Chrisman**	**Lester A. Snow**
Governor	Secretary for Resources	Director
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Barbara McDonnell
Chief, Division of Environmental Services

This report was prepared under the supervision of

Dean F. Messer
Chief, Bay-Delta Monitoring and Analysis Section

By

Rachel Barnett	Fish and Wildlife Scientific Aide
Tiffany Brown	Environmental Scientist
Michael Dempsey	Control System Tech. II
Karen Gehrts	Environmental Scientist
Philip Giovannini	Environmental Scientist
Kathy Hieb	Associate Fisheries Biologist
Brianne Noble	Environmental Scientist
Marc Vayssières	Environmental Scientist

With assistance from:

Lloyd Brenn	Chief Engineer, Fisheries Vessel
Nick Sakata	Mate, Research Vessel
Eric Santos	Chief Engineer, Fisheries Vessel
Gregg Schmidt	Mate, Fisheries Vessel
Scott Waller	Water Resources Engineering Associate

Editorial and design services were provided by

Nikki Blomquist	Research Writer, Division of Planning and Local Assistance

Chapter 1. Introduction

The State Water Resources Control Board (SWRCB) establishes water quality objectives and monitoring plans to protect a variety of the beneficial uses of water within the upper San Francisco Estuary. The SWRCB ensures that these objectives are met in part by the inclusion of water quality monitoring requirements into water right decisions issued to the Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) as conditions for operating the State Water Project (SWP) and Central Valley Project (CVP), respectively. These requirements include minimum outflows, limits to water exportation by the SWP and CVP, and maximum allowable salinity levels. In addition, DWR and USBR are required to conduct a comprehensive monitoring program to determine compliance with the water quality objectives and report the findings to the SWRCB. Water quality objectives were issued in December 1999 by Water Right Decision 1641 (D-1641) (SWRCB 1999).

Data collected since 1975 by the Environmental Monitoring Program (EMP) are stored and managed by DWR and the Department of Fish and Game (DFG). DWR manages phytoplankton data and macro-benthic organism data, as well as environmental water quality data from both discrete and continuous monitoring stations. DFG manages all zooplankton data. Internet access and download of the EMP data are available through the Bay Delta and Tributaries Database (BDAT) at www.baydelta.ca.gov.[1]

This report, entitled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2004*, summarizes the findings of the EMP for calendar year 2004. Separate chapters are devoted to the water quality, benthic, phytoplankton, zooplankton, and special study components of the EMP. Within each chapter, the major patterns and trends demonstrated by the water quality and biological data within and between years are described in the text and displayed in summary plots and tables. This report is submitted to the SWRCB to fulfill the reporting requirements of D-1641.

Reference

[SWRCB] State Water Resources Control Board. 1999. *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh*. Sacramento, California.

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[1] For specific questions regarding availability of EMP data on BDAT, contact Mr. Karl Jacobs, Chief, Interagency Information System Services Section, Department of Water Resources, Division of Environmental Services, 901 P Street, Sacramento, CA, 95814; telephone at (916) 651-9581; or by e-mail at kjacobs@water.ca.gov.

Chapter 2. Hydrologic Conditions

Introduction

Hydrologic conditions are typically discussed in terms of "water years" which begin on October 1 of a calendar year and end on September 30 of the following year. The chronological period covered by this report includes parts of two water years: the last nine months of water year 2004 (January through September 2004) and the first three months of water year 2005 (October through December 2004). To concisely describe hydraulic conditions in the Bay-Delta during this period, this chapter will discuss water year 2004, which runs from October 1, 2003, through September 30, 2004.

Methods

Water years are classified using the Sacramento Valley 40-30-30 Water Year Hydrological Classification Index[1,2] (the Sacramento Valley Index) and the San Joaquin Valley 60-20-20 Water Year Hydrological Classification Index[3,4] (the San Joaquin Valley Index) (SWRCB 1999). The Sacramento Valley Index is used to characterize water years statewide because the predominance of precipitation falls within the northern half of the state and much of that precipitation flows down the Sacramento River through the upper San Francisco Estuary (Estuary). The index is also used because the Sacramento River watershed provides the majority of water to the State Water Project and to the Central Valley Project (SWRCB 1999). Using this index[5], water year 2004 was classified as "Below Normal". Although the San Joaquin Valley Index is used predominantly for regional applications, it provides supporting information about water conditions within the San Joaquin Valley. Using the San Joaquin Valley Index[6], water year 2004 was classified as "Dry". Figures 2-1 and 2-2 summarize these findings and include the prior 10 years for reference.

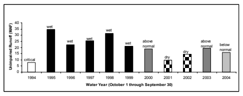

Figure 2-1 Sacramento River Hydrologic Region 40-30-30 Indices from 1994 through 2004.

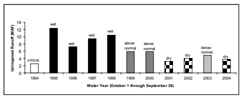

Figure 2-2 San Joaquin River Hydrologic Region 60-20-20 Indices from 1994 through 2004.

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[1] The Sacramento Valley 40-30-30 Water Year Hydrological Index is equal to 0.4X current April to July unimpaired runoff + 0.3X current October to March unimpaired runoff + 0.3X previous year's index (if the previous year's index exceeds 10.0, then 10.0 is used).

[2] Sacramento River unimpaired runoff is the sum of Sacramento River flow at Bend Bridge, Feather River flow to Lake Oroville, Yuba river flow at Smartville, and American River flow to Folsom Lake (SWRCB 1999).

[3] The San Joaquin 60-20-20 Water Year Hydrological Classification Index is equal to 0.6X current April to July unimpaired runoff + 0.2X current October to March unimpaired runoff + 0.2 previous year's index (if the previous year's index exceeds 4.5, then 4.5 is used).

[4] San Joaquin River unimpaired runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

[5] Using the Sacramento Valley Index, water years are defined as follows: (1) a "Wet" year occurs when the index is equal to or greater than 9.2; (2) an "Above Normal" year occurs when the index is greater that 7.8, but less than 9.2; (3) a "Below Normal" year occurs when the index is greater than 6.5, but equal to or less than 7.8; (4) a "Dry" year occurs when the index is greater than 5.4, but equal to or less than 6.5; and (5) a "Critical" year occurs when the index is equal to or less than 5.0 (SWRCB 1999).

[6] Using the San Joaquin Valley Index, water years are defined as follows: (1) a "Wet" year occurs when the index is equal to or greater than 3.8; (2) an "Above Normal" year occurs when the index is greater than 3.1, but less than 3.8; (3) a "Below Normal" year occurs when the index is greater than 2.5, but equal to or less than 3.1; (4) a "Dry" year occurs when the index is greater than 2.1, but equal to or less than 2.5; and (5) a "Critical" year occurs when the index is equal to or less than 2.1 (SWRCB 1999).

Water year 2004 was classified as below normal for precipitation, below normal for seasonal runoff, above normal for reservoir storage, and below normal for snow water content. Statewide figures for May 1 are summarized in Table 2-1 and include the prior four years for reference.

Accounting for precipitation, runoff, reservoir storage and snowpack water content, the unimpaired runoff for the Sacramento River was below normal for 2004. Unimpaired runoff for the San Joaquin River was low for 2004. Table 2-2 summarizes these conditions and Figure 2-3 compares these flow periods with water years 1994-2004.

The Net Delta Outflow Index[7] (Figure 2-4) is used to determine the freshwater outflow from the Estuary. Much of the water that flows through the Estuary does so during the late winter and early spring months. Water year 2004 had maximum Delta outflow indices exceeding 3,600,000 acre-feet in March and minimum outflow indices approaching 257,000 acre-feet in September.

Summary

Water year 2004 conditions contrast with those in water year 2003, which were designated as “Above Normal” for the Sacramento Valley Index and “Below Normal” for the San Joaquin Valley Index. Figure 2-1 shows unimpaired runoff and water year designations for Sacramento and San Joaquin rivers for the 10-year period from 1993 to 2003. Unimpaired runoff in water year 2004 was higher than in the previous two years due to above-normal precipitation, reservoir storage, and snowpack water content (CDEC 2005). Statewide figures for precipitation, runoff, reservoir storage, and snowpack water content in recent years are summarized in Table 2-1.

Water year 2004 had higher unimpaired runoff than water year 2003, with a value of 16.04 million acre-feet in the Sacramento Valley River basin and 3.81 million acre-feet in the San Joaquin Valley River basin. Table 2-2 summarizes streamflow conditions in these rivers during the 2004 water year.

The Net Delta Outflow (NDO) from the Estuary for water years 2001 through 2004 is shown in Figure 2-2. This NDO is an estimate of average daily outflow at Chipps Island and is calculated as:

$$\mathbf{NDO = Q_{Tot} + Q_{Precp} - Q_{Gcd} - Q_{Misdv}}$$

Where:

$\mathbf{NDO}$ = Net Delta outflow (cfs)
$\mathbf{Q_{Tot}}$ = Total Delta inflow (cfs)
$\mathbf{Q_{Precp}}$ = Total precipitation runoff (cfs)
$\mathbf{Q_{Gcd}}$ = Total consumption in Delta (cfs)
$\mathbf{Q_{Misdv}}$ = Total flooded island and island storage diversions (cfs)

Water Year	*Precipitation (% of normal)*	*Seasonal Runoff (% of normal)*	*Reservoir Storage (% of normal)*	*Snow Water Content (% of normal)*
2000	90	90	100	50
2001	75	45	100	65
2002	80	80	100	60
2003	110	100	105	105
2004	90	90	100	50

Table 2-1 Summary of the major hydrologic characteristics of water years 2000-2004

	Sacramento River			*San Joaquin River*		
Year	*Oct. 1-Mar. 30 (maf)*	*Apr. 1-Jul. 30 (maf)*	*Whole Year (maf)*	*Oct. 1-Mar. 30 (maf)*	*Apr. 1-Jul. 30 (maf)*	*Whole Year (maf)*
2000	12.06	5.96	18.90	1.98	3.78	5.90
2001	5.64	3.46	9.81	0.92	2.23	3.18
2002	9.32	4.57	14.60	1.27	2.75	4.06
2003	10.71	7.74	19.31	1.25	3.49	4.87
2004	10.95	4.40	16.04	1.51	2.25	3.81

Table 2-2 Average streamflow for the Sacramento and San Joaquin rivers during water years 2000-2004.

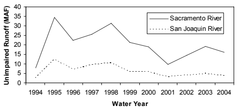

Figure 2-3 Unimpaired runoff for the Sacramento and San Joaquin Rivers for water years 1994-2004

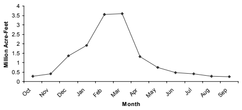

Figure 2-4 Net Delta Outflow Indices, 2004

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[7] The Net Delta Outflow Index (NDOI) is a calculation of freshwater outflow from the Delta past Chipps Island. The NDOI includes a factor dependent upon inflows of the Yolo Bypass System, the eastside stream system (the Mokelumne, Cosumnes, and Calaveras rivers), the San Joaquin River at Vernalis, the Sacramento Regional Treatment Plant, and miscellaneous Delta inflows (Bear Creek, Dry Creek, Stockton Diverting Canal, French Camp Slough, Marsh Creek, and Morrison Creek).

References

[CDEC] California Data Exchange Center. 2005. [online] Available via the Internet at http://cdec.water.ca.gov [accessed February 2006].

[SWRCB] State Water Resources Control Board. 1999. Water Rights Decision 1641. State Water Resources Control Board; Sacramento, CA.

Figure 2-1 Sacramento River Hydrologic Region 40-30-30 Indices from 1994 through 2004. Values given in million acre-feet (maf)

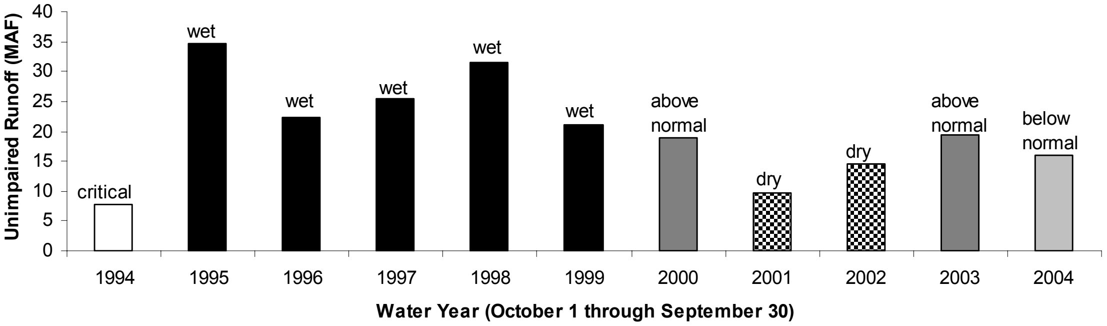


Figure 2-2 San Joaquin River Hydrologic Region 60-20-20 Indices from 1994 through 2004. Values given in million acre-feet (maf)

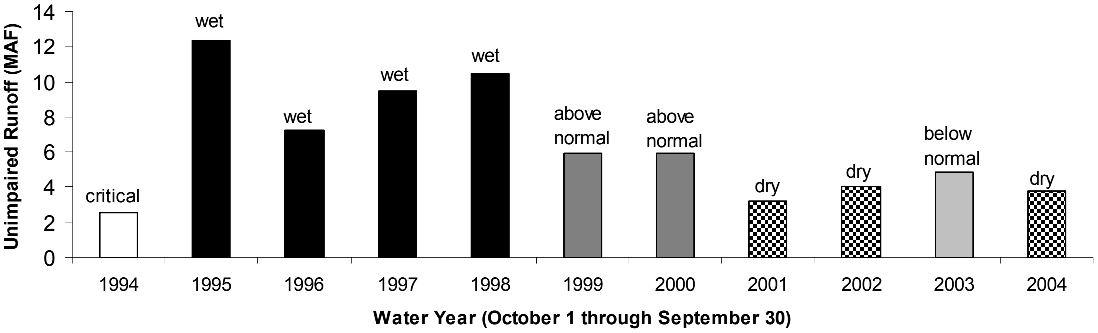


Figure 2-3 Unimpaired runoff for the Sacramento and San Joaquin Rivers for water years 1994-2004. Values given in million acre-feet (maf)

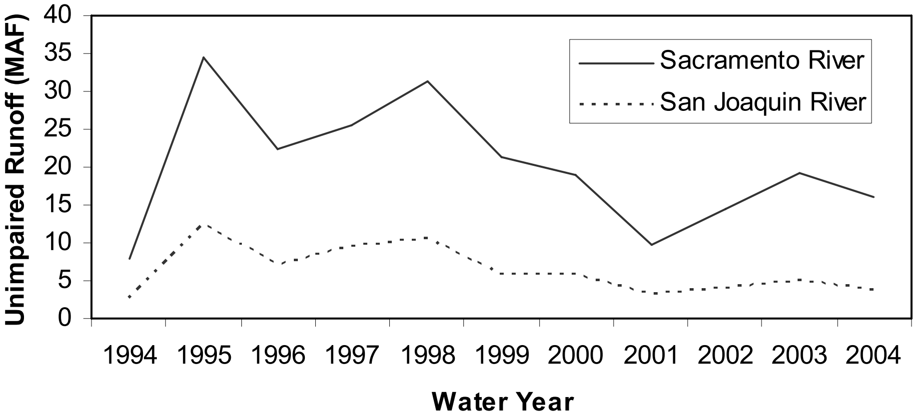


Figure 2-4 Net Delta Outflow Indices, 2004

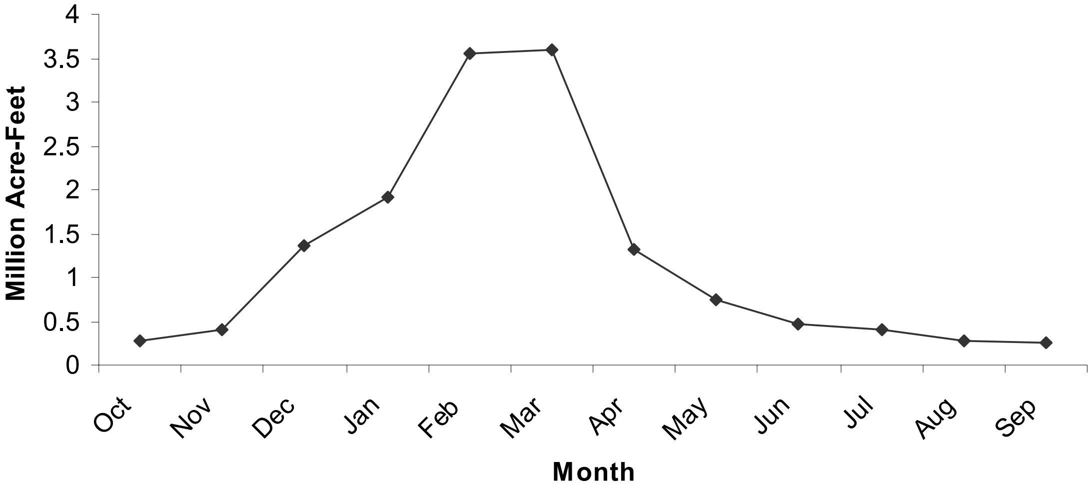


Table 2-1 Summary of the major hydrologic characteristics of water years 2000-2004

Water Year	Precipitation (% of normal)	Seasonal Runoff (% of normal)	Reservoir Storage (% of normal)	Snow Water Content (% of normal)
2000	90	90	100	50
2001	75	45	100	65
2002	80	80	100	60
2003	110	100	105	105
2004	90	90	100	50

Table 2-2 Average streamflow for the Sacramento and San Joaquin rivers during water years 2000-2004. All values in million acre-feet (maf).

	Sacramento River			San Joaquin River		
Year	Oct. 1-Mar. 30 (maf)	Apr. 1-Jul. 30 (maf)	Whole Year (maf)	Oct. 1-Mar. 30 (maf)	Apr. 1-Jul. 30 (maf)	Whole Year (maf)
2000	12.06	5.96	18.90	1.98	3.78	5.90
2001	5.64	3.46	9.81	0.92	2.23	3.18
2002	9.32	4.57	14.60	1.27	2.75	4.06
2003	10.71	7.74	19.31	1.25	3.49	4.87
2004	10.95	4.40	16.04	1.51	2.25	3.81

Chapter 3. Water Quality Monitoring

Introduction

Water quality monitoring in 2004 continued according to the amended protocol implemented by the Department of Water Resources (DWR) in 1996, with the incorporation of some of the changes recommended by the 2001-2002 Environmental Monitoring Program (EMP) review (http://www.iep.ca.gov/emp/EMP_Review_Final.html). Discrete water quality sampling sites included the 11 representative sites as described in the 1996 Water Quality Report (DWR 2001), with the addition of two more sampling sites in May 2004 and a move from Station C3 to C3A in November 2004.

In May 2004 two monitoring stations, D41A and D19, were added as discrete water quality sampling sites according to recommendations from the 2001-2002 EMP review. Station D41A is a new monitoring station in the San Pablo Bay near the mouth of the Petaluma River. Station D19 is on Frank's Tract on the lower San Joaquin River and is a historical monitoring station that has been reinstated.

Monitoring in the Sacramento River at Station C3 was discontinued in November 2004 and moved to the nearby Station C3A. The US Bureau of Reclamation (USBR), which maintained a continuous recorder at Station C3, stopped collecting data at this station in September 2003. Consequently, USBR decided to remove the station platform because it was potentially unsafe, which eliminated the ability of the EMP to use the site as a monitoring station. The EMP performed a one-year comparison study between stations C3 and C3A, which demonstrated that there is very little difference between the two sites (http://www.iep.ca.gov/emp/news_items/C3_discontinued.html). Based on this study, the State Water Resources Control Board (SWRCB) approved moving mandated monitoring to Station C3A. For the purposes of this chapter, the data for stations C3 and C3A are reported as a single station, with the data for January through October representing Station C3 and the data for November and December representing Station C3A.

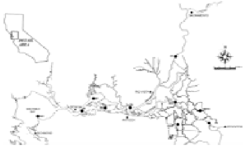
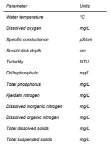


Figure 3-1 Water quality monitoring stations

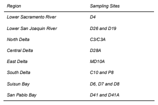
Discrete samples were taken monthly at each site (Figure 3-1). Data were recorded within one hour of high slack tide and the time of each sample was recorded to the nearest five minutes of Pacific Standard Time. A qualitative statement of weather conditions (i.e., wind conditions and cloud cover) was recorded for each cruise. Samples were analyzed for the 15 physical and chemical parameters in Table 3-1. The complete database is available online at http://baydelta.water.ca.gov.



Parameter	*Units*
Water temperature	*°C*
Dissolved oxygen	*mg/L*
Specific conductance	*µS/cm*
Secchi disk depth	*cm*
Turbidity	*NTU*
Orthophosphate	*mg/L*
Total phosphorus	*mg/L*
Kjeldahl nitrogen	*mg/L*
Dissolved inorganic nitrogen	*mg/L*
Dissolved organic nitrogen	*mg/L*
Total dissolved solids	*mg/L*
Total suspended solids	*mg/L*

Table 3-1 Water quality parameters measured

As shown in Table 3-2, 13 sampling sites were used in this study to represent eight regions of the Bay-Delta system. In previous reports, data from multiple sample sites within each region have been averaged according to hierarchical cluster analysis; however, for clarity, data results in this report are shown for each sample site.



Region	*Sampling Sites*
Lower Sacramento River	*D4*
Lower San Joaquin River	*D26 and D19*
North Delta	*C3/C3A*
Central Delta	*D28A*
East Delta	*MD10A*
South Delta	*C10 and P8*
Suisun Bay	*D6, D7 and D8*
San Pablo Bay	*D41 and D41A*

Table 3-2 Water quality sampling sites and regions

Parameters Measured

Except as noted, all discrete water quality samples were obtained with shipboard sampling equipment using the DWR research vessel *San Carlos*. Supplemental discrete samples were taken with mobile laboratory equipment at sites in the south Delta (site C10A) and in the north Delta (site C3/C3A). Secchi disk depth is not taken at site C10 due to restrictions of the sample site, which requires sampling equipment to be deployed from a bridge.

Water Temperature

Water temperature was measured in degrees Celsius (°C) with a YSI thermistor. For all sites except the south Delta, temperature was measured from water collected at a depth of 1 meter. In the south Delta, temperature was measured by submerging the YSI thermistor to a depth of 1 meter.

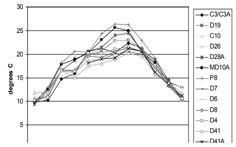


Figure 3-2 Water temperature

A water temperature minimum of 9.4 °C was recorded in January 2004 at Station D28A in the central Delta (Figures 3-2 and 3-3). This minimum temperature represents an increase of 0.3 °C over the previously recorded minimum for the 2003 period and a 1.3 °C increase over the minimum reported for the 2001-2002 period (DWR 2004; DWR 2006).

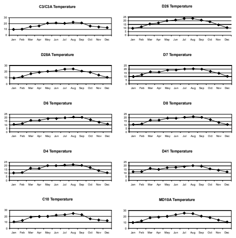


Figure 3-3 Water temperature (°C)

Temperature minima at most sites during 2004 occurred during January and December. The timing of these temperature minima is the same as the 2003 study period (DWR 2006).

A water temperature maximum of 26.4 °C was recorded at Station P8 in the south Delta. This maximum is a 0.8 °C decrease from the temperature maximum reported for the 2003 study period (DWR 2006). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

Dissolved Oxygen

Dissolved oxygen was measured using the modified Winkler iodometric method described in *Standard Methods* (APHA 1992). A sample aliquot was collected at a depth of 1 meter. The samples were collected in 300-mL glass-stoppered bottles and immediately analyzed.

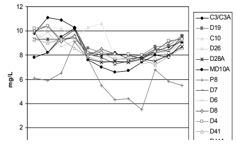


Figure 3-4 Dissolved oxygen

During 2004, dissolved oxygen concentrations ranged from 3.5 mg/L at site P8 in the south Delta in September to 11.1 mg/L at site C3 in the north Delta in February (Figures 3-4 and 3-5). Strong seasonal trends were evident in most regions, with dissolved oxygen concentrations decreasing during the summer and rising in the winter. Seasonal changes were not as apparent as in previous years; however, sites C3, D26, D28A, D6, D7, and D8 continued to show reduced seasonal dissolved oxygen levels coinciding with warmer summer and fall water temperatures. An exception to this was noted at sites P8 and C10 in the south Delta. Both sites showed poor correlation between temperature and dissolved oxygen levels, as well as weak seasonal patterns. Site P8 also showed the greatest degree of variability in dissolved oxygen levels, varying by almost 6.0 mg/L over the year.

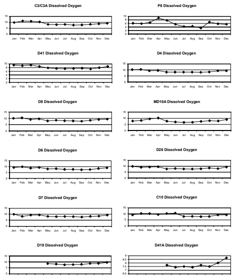


Figure 3-5 Dissolved oxygen (mg/L)

Specific Conductance

Specific conductance, an estimate of salinity, was determined from samples collected at a depth of 1 meter. The samples were analyzed for specific conductance using a Seabird model CTD 911+ data logger, with temperature compensation set to 25 °C.

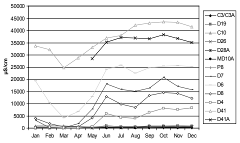


Figure 3-6 Specific conductance

Specific conductance varied greatly between sites monitored, ranging from 120 µS/cm at site C3 in the north Delta in April to 43,495 µS/cm at site D41 in San Pablo Bay in October (Figures 3-6 and 3-7). This range of specific conductance was slightly greater than the 138-43,413 µS/cm range reported for the 2003 study period (DWR 2006).

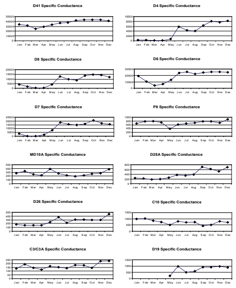


Figure 3-7 Specific conductance (µS/cm)

Specific conductance generally increased from east to west and was well correlated to inflows and tidal action. Maximum values occurred in the summer and fall when flows through the Delta were low and marine intrusion was most pronounced.

Sites with high average specific conductivity such as D4, D6, D7, D8, D41, and D41A tended to show stronger seasonal variations, with specific conductance varying from a low in March to a high in October. At sites with lower specific conductance, this seasonal trend was less apparent.

Specific conductance dropped noticeably at most sites in March and April. Downstream sites showed the most variability. Upstream sites with low specific conductance, such as site C3, had the least variation and showed few or no apparent seasonal trends.

Secchi Disk Depth

Water transparency was measured to the nearest centimeter using a 20-cm diameter Secchi disk attached to a 2.5-m rod marked in centimeters. Secchi disk transparency was recorded as the average depth at which sight of the disk was lost as it was lowered into the water column, and the depth at which it could be seen again as it was raised.

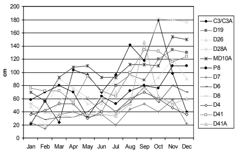


Figure 3-8 Secchi disk depth

A Secchi depth minimum of 14 cm was recorded at sampling site D7 in the Suisun Bay in February (Figures 3-8 and 3-9). A Secchi depth maximum of 182 cm was recorded at sampling site D28A in the central Delta in October. By comparison, Secchi values during 2003 ranged from 12 to 212 cm (DWR 2006). The long-term increase in transparency values noted in a previous report (DWR 2001) was not discernable in the 2004 data.

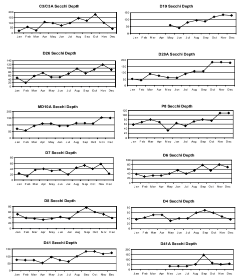


Figure 3-9 Secchi disk depth (cm)

Secchi disk depth varied considerably at all sites, with little apparent seasonal correlation. Overall, peak Secchi depths occurred in the fall (October and November).

Average Secchi depths were lowest at sites D6, D7, D8, and D4, while sites D28A, MD10A, D19, and D41 had the highest overall average Secchi depths.

Turbidity

Turbidity is a measure of the optical properties of water and substances contained in the water that cause light to be scattered and absorbed rather than transmitted in straight lines (APHA 1992). Turbidity is caused by soluble organic compounds, plankton, and suspended matter such as clay, silt, inorganic substances, and organic matter.

Turbidity was determined from samples collected at a depth of 1 meter. The samples were pumped through a Turner Model 10 flow-through nephelometer that was calibrated with a reference sample of formazin suspension at 40 nephelometric turbidity units (NTU) according to Standard Reference protocol 214-A (APHA 1992).

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from a maximum of 85.6 NTU to a minimum of 3.7 NTU. This range of turbidity was slightly greater than the 2.9 to 71 NTU range reported for 2003 (DWR 2006).

Turbidity levels at some sites exhibited a seasonal pattern of high turbidity in the early spring, followed by decreasing turbidity in spring and fall; however, some sites showed no consistent seasonal pattern.

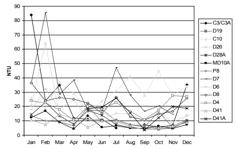


Figure 3-10 Turbidity

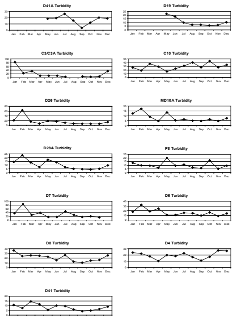


Figure 3-11 Turbidity (NTU)

Orthophosphate

Orthophosphate is soluble inorganic phosphate, the phosphorus compound most immediately available for assimilation by phytoplankton. Orthophosphate concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory[1] for analysis according to the USEPA (1983) colormetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate was 0.01 mg/L.

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest values—recorded at Station MD10A in April, July, and October 2004—showed orthophosphate levels at 0.02 mg/L. The 2003 study period also showed the lowest values (<0.01 mg/L) of orthophosphate occurring at site MD10A (DWR 2006).

The highest value of orthophosphate, 0.48 mg/L, was recorded at site P8 in the south Delta in February 2004. In the 2003 study period, site P8 also showed the highest orthophosphate concentration (0.29 mg/L) in February (DWR 2006).

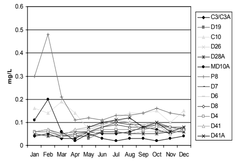


Figure 3-12 Orthophosphate

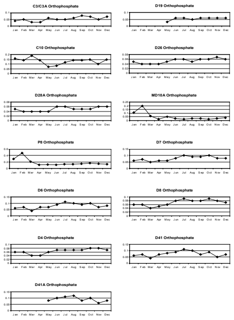


Figure 3-13 Orthophosphate (mg/L)

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[1] Bryte Chemical Laboratory, Department of Water Resources, 1450 Riverbank Road, West Sacramento, CA 95605

Total Phosphorus

Total phosphorus is the sum of all phosphorous compounds in the sample. This parameter includes phosphorus compounds that are bioavailable, as well as those that are not. Phosphorus that is unavailable for bioassimilation includes phosphorus compounds that are incorporated into biological tissue and insoluble mineral particles.

Total phosphorus concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colormetric semi-automated method 365.4. The minimum reporting limit for total phosphorus was 0.01 mg/L.

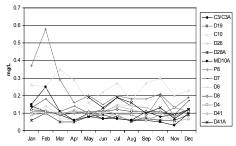


Figure 3-14 Total phosphorus

Values for total phosphorus varied considerably between sites and across seasons (Figures 3-14 and 3-15) and showed distributions similar to those reported for orthophosphate. The lowest value of 0.03 mg/L was recorded in the east Delta at site MD10A in November 2004. This value is slightly lower than the minimum value of 0.04 mg/L recorded for the 2003 study period at site MD10A in March (DWR 2006). A maximum value of 0.58 mg/L was recorded at site P8 in February 2004. This value is higher than the maximum value of 0.38 mg/L recorded in 2003 in the south Delta region (DWR 2006).

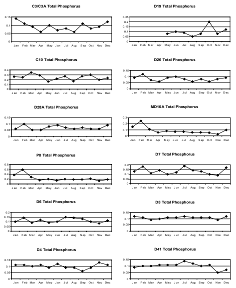


Figure 3-15 Total phosphorus (mg/L)

Except for those in the south and east Delta regions, all sites showed total phosphorus levels at or below 0.19 mg/L during the spring (March through May). Total phosphorus levels at these sites never exceeded 0.19 mg/L.

Kjeldahl Nitrogen

Kjeldahl nitrogen is nitrogen in the form of organic proteins or ammonia, their decomposition product, as measured by the Kjeldahl method (APHA 1992).

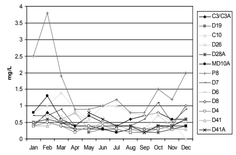


Figure 3-16 Kjeldahl nitrogen

Kjeldahl nitrogen concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colormetric semi-automated method 352.1. The minimum reporting limit for Kjeldahl nitrogen is 0.01 mg/L.

Kjeldahl nitrogen concentrations ranged from 3.8 mg/L at Station P8 in the south Delta in February to undetectable levels (<0.01 mg/L) at site C10 in December 2004 (Figures 3-16 and 3-17). Kjeldahl nitrogen levels during the 2003 study period also peaked at site P8 with a high of 2.2 mg/L (DWR 2006).

Kjeldahl nitrogen concentrations were generally highest in the south Delta region (Sites P8 and C10). The two south Delta sites also showed the greatest variability. No strong seasonal or interannual trends were apparent among all the sites.

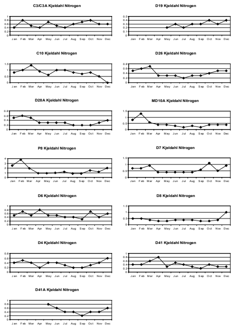


Figure 3-17 Kjeldahl nitrogen (mg/L)

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is a measure of total ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2), the nitrogen forms immediately available for assimilation by phytoplankton. DIN was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis for total ammonia according to the USEPA (1983) colormetric, automated, phenate method 350.1; and for nitrate and nitrite according to the colormetric automated cadmium reduction method 353.2 (USEPA 1983). DIN was calculated as the sum of total ammonia plus nitrate and nitrite. The minimum reporting limit for inorganic nitrogen was 0.01 mg/L.

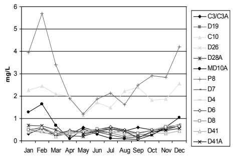


Figure 3-18 Dissolved inorganic nitrogen

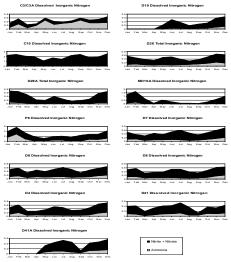


Figure 3-19 Dissolved inorganic nitrogen (mg/L)

DIN concentrations ranged from 5.7 mg/L in the south Delta (site P8) in February to 0.1 mg/L in the east Delta (site MD10A) in August (Figures 3-18 and 3-19). This range is slightly larger than during the 2003 study period, which recorded a maximum of 4.7 mg/L at Station P8 and a minimum value of 0.07 mg/L at Station MD10A.

DIN values were consistently high in south Delta stations C10 and P8 with all values greater than 1.0 mg/L. In contrast, all other stations had most DIN values below 1.0 mg/L. The high values observed in the south Delta may be due to runoff and drainage from agricultural operations on the San Joaquin River.

Concentrations in the south Delta also showed the greatest degree of seasonal variability. By contrast, DIN concentrations in the Suisun Bay (stations D6, D7, and D8) showed only minor seasonal variations. All regions showed some seasonal variation with DIN values lowest in August and September, when water temperatures and phytoplankton growth were highest and inflows were lowest, followed by increases in late fall and winter.

Dissolved Organic Nitrogen

Organic nitrogen is defined functionally as nitrogen that is bound to carbon containing compounds in the tri-negative oxidation state. This form of nitrogen must be mineralized or decomposed before it can be used by aquatic and terrestrial plants. It does not include all organic nitrogen compounds, but does include proteins, peptides, nucleic acids, urea, and numerous synthetic organic compounds (APHA 1992).

Dissolved organic nitrogen (DON) was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colormetric, semi-automated method 351.2. The minimum reporting limit for DON was 0.10 mg/L.

DON concentrations ranged from 2.4 mg/L at Station P8 in the east Delta in January to concentrations below detectable levels (< 0.10 mg/L) at Station C3 in May and July, Station D19 in September, Station D26 in August, Station D28A in September, and Station D4 in April 2004 (Figures 3-20 and 3-21). Peak DON levels during the 2003 study period were considerably lower, reaching a maximum of 1.8 mg/L at Station P8 in March 2003 (DWR 2006).

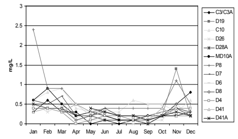


Figure 3-20 Dissolved organic nitrogen

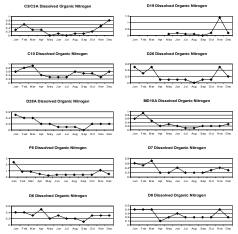


Figure 3-21 Dissolved organic nitrogen (mg/L)

DON concentrations showed no clear seasonal or inter-annual pattern of variation; however, most sites showed increases in DON concentrations during the winter, and most sites had consistently low DON during April 2004.

Total Dissolved Solids

Total dissolved solids (TDS) are a measure of the solid fraction of a sample able to pass through a filter. The amount of dissolved solids gives a general indication of the suitability of the water as a drinking source and for certain agricultural and industrial uses.

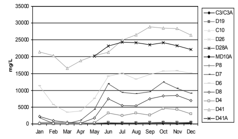


Figure 3-22 Total dissolved solids

Total dissolved solids were measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis using USEPA (1983) method 160.1.

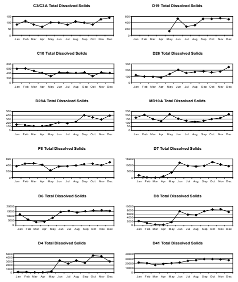


Figure 3-23 Total dissolved solids (mg/L)

TDS in the Bay-Delta covered a wide range from 67 mg/L in the north Delta (site C3/C3A) in April 2004 to 28,840 mg/L in the San Pablo Bay (site D41) in September (Figures 3-22 and 3-23). The values covered a smaller range than the 2003 study period, which had a range of 76 mg/L to 33,060 mg/L. The high values seen in San Pablo and Suisun bays and the western Delta are likely due to tidal influences; e.g. seawater entering the bays and, eventually, the Delta. The lower TDS values seen at site C3 are likely due to spring flows of low TDS freshwater entering the Delta from the Sacramento Valley basin.

All sites subject to significant tidal exchange (sites D41, D41A, D6, D7, D8, and D4) showed increasing TDS concentrations the closer they were to the coast. These sites also showed high seasonal variability in TDS concentrations. For these sites, low TDS values occurred in March and the highest values occurred at year's end.

Total Suspended Solids

Suspended solids are the solids that are retained on a filter after a water sample has been filtered. Suspended solids include a wide variety of material such as silt and living or decaying organic matter. High amounts of suspended solids block light penetration into the water column and increase heat absorption.

Total suspended solids (TSS) may increase in surface waters due to increases in flow rate, as higher velocities increase water's capacity to suspend solids. Runoff from heavy rains can simultaneously introduce large amounts of solids into surface waters and provide the capacity for their suspension. Therefore, suspended solids concentrations can vary significantly over relatively short time periods.

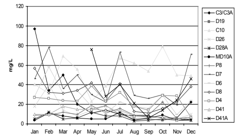


Figure 3-24 Total suspended solids

Water samples for TSS analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory using USEPA (1983) method 160.2.

TSS in the San Francisco Bay-Delta varied over a wide range, from 97 mg/L at Station C3 in January to 3.0 mg/L at Station D28A in August (Figures 3-24 and 3-25). These results are in contrast to the 2003 study period, where the highest TSS value was recorded in Suisun Bay (96 mg/L) and the lowest TSS values were 2.0 mg/L at several sites (DWR 2006).

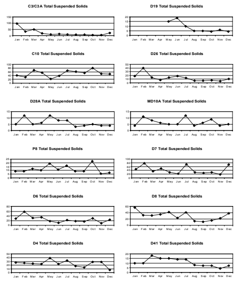


Figure 3-25 Total suspended solids (mg/L)

TSS values at most sites showed "pulse" increases at various times during the year. These increases did not show any discernable seasonal pattern. Although winter pulse variations may be due to rain or hydrological events, variations in TSS at other times may reflect changing levels of organic matter.

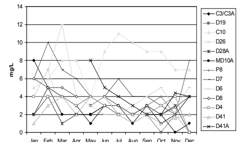


Figure 3-26 Volatile suspended solids (mg/L)

Volatile Suspended Solids

The measurement of volatile suspended solids (VSS) provides a relative indicator of the amount of organic matter present in the water sample. Water samples for VSS analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for VSS according to EPA Method 160.4 (EPA 1983). The minimum reporting level for VSS in these analyses was 1.0 mg/L.

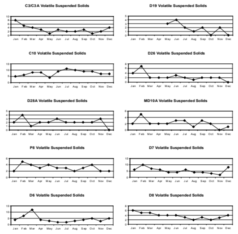


Figure 3-27 Volatile suspended solids (mg/L)

Volatile suspended solid levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions, and reached a high of 12.0 mg/L in the Suisun Bay (site D6) in March (Figures 3-26 and 3-27). These results were similar to those observed in the 2003 reporting period (DWR 2006). Most sites showed a high degree of variability, with no apparent seasonal trends.

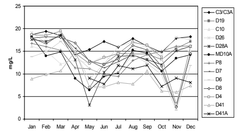


Figure 3-28 Silica

Silica

Water samples for silica analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for silica according to EPA Method 200.7 (EPA 1983). The minimum reporting level for silica in these analyses was 0.1 mg/L.

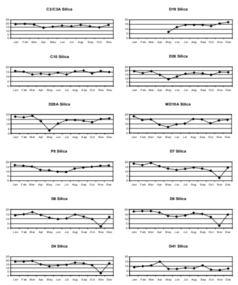


Figure 3-29 Silica (mg/L)

Silica concentrations ranged from 19.5 mg/L in the lower Sacramento River (site D4) in March to 2.0 mg/L in Suisun Bay (site D6) in November 2004 (Figures 3-28 and 3-29). These values are in contrast to those observed in the 2003 reporting period, with its range of 26 mg/L at site D6 in January to

4.8 mg/L at site D41 in March (DWR 2006). In comparison with the 2003 period, silica values appeared slightly less variable; however, the apparent seasonal trend of declining silica levels in spring months followed by increased silica concentrations in late summer was also observed at the majority of sites.

Chloride

Water samples for chloride analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for chloride according to EPA Method 300.0 (EPA 1983).

Chloride concentrations in the Bay-Delta varied over a wide range from 15,800 mg/L in San Pablo Bay (site D41) in October to 3 mg/L in the north Delta (site C3) in April (Figures 3-30 and 3-31). These results are very similar to those observed in the 2003 reporting period, which recorded 16,500 mg/L chloride in the San Pablo Bay (site D41) in November 2003 and 3 mg/L in the north Delta (site C3) in August 2003 (DWR 2006). The high values seen in San Pablo Bay are likely due to tidal influences (seawater entering the bay), while the low values seen at site C3 are likely due to spring flows of fresh water down the Sacramento River. Values of chloride concentrations are closely correlated to values reported for specific conductance and total dissolved solids (TDS) reported earlier in this chapter.

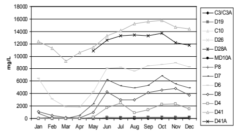


Figure 3-30 Chloride

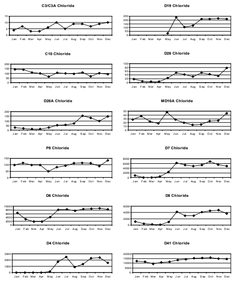


Figure 3-31 Chloride (mg/L)

Summary

DWR's monitoring and reporting of the water quality data shown here is mandated to ensure compliance with water quality objectives; to identify meaningful changes potentially about the operation of the State Water Project and the Central Valley Project; and to reveal trends in ecological changes potentially related to project operations. Flow rates, influenced by natural forces and project operations, are a primary determinant of water quality dynamics at each site described. However, flow rates are not measured as part of this sampling protocol, and therefore a more analytical treatment of these data in relation to flow rates is not included. These data are presented as a snapshot of the system. They allow a historical comparison of a wide range of water quality parameters and show an overall consistency with recent years.

References

[APHA] American Public Health Association. 1992. *Standard Methods for the Examination of Water and Wastewater.* 18th Edition, Washington DC.

[DWR] California Department of Water Resources. 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1996*. California Department of Water Resources, Sacramento, California.

[DWR] California Department of Water Resources. 2004. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2001-2002*. California Department of Water Resources, Sacramento, California.

[DWR] California Department of Water Resources. 2006. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2003*. California Department of Water Resources, Sacramento, California.

[USEPA] U.S. Environmental Protection Agency. 1983. *Methods for Chemical Analysis of Water and Wastes*. Technical Report EPA-600/4-79-020.

Figure 3-1 Water quality monitoring stations

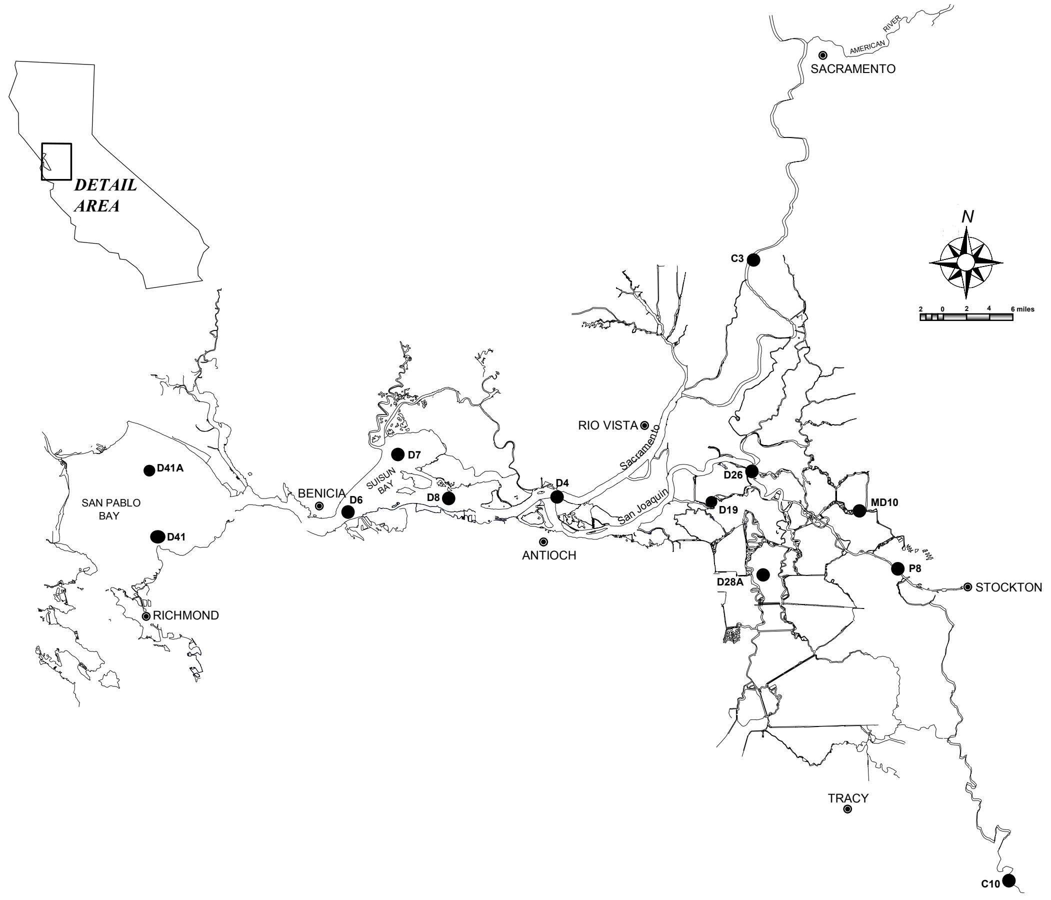


Figure 3-2 Water temperature

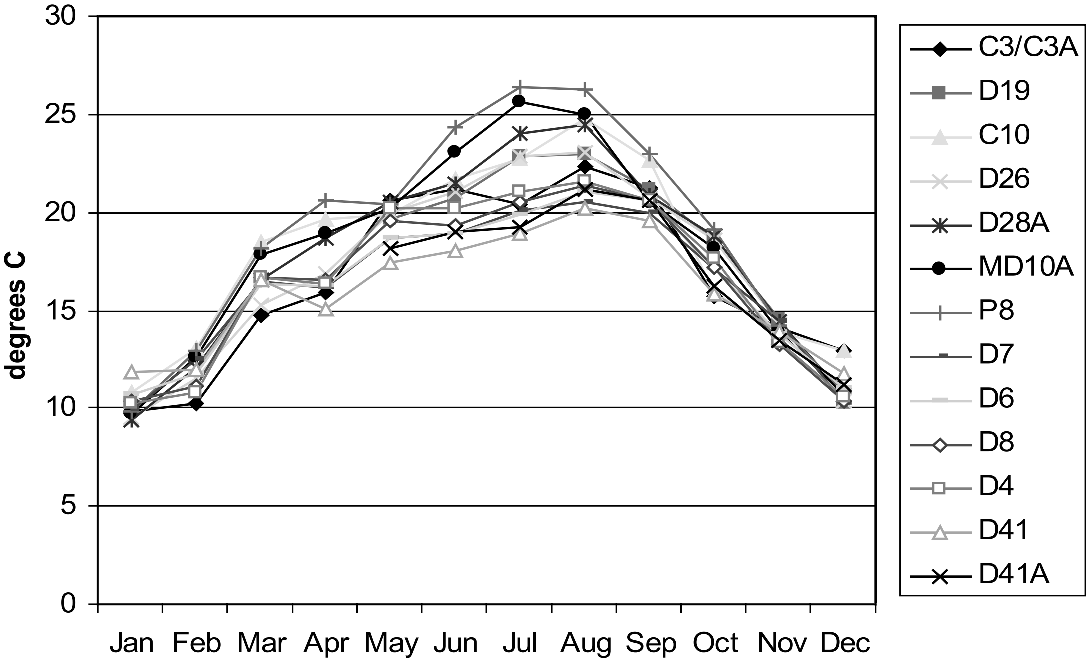
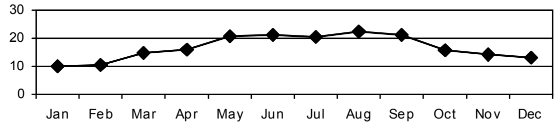
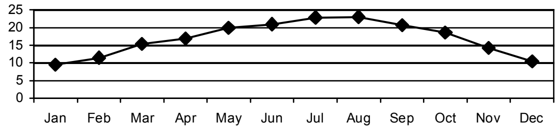


Figure 3-3 Water temperature (°C)

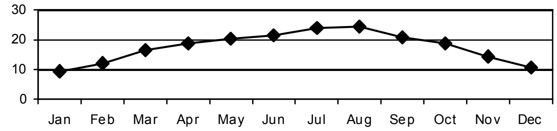
C3/C3A Temperature



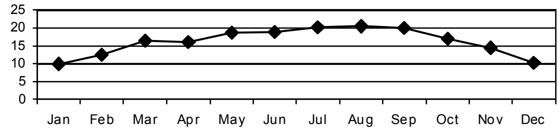
D26 Temperature



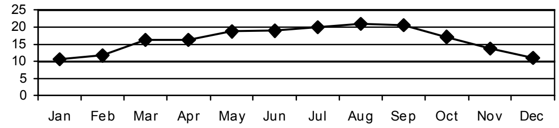
D28A Temperature



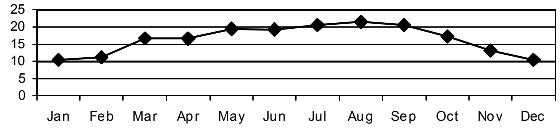
D7 Temperature



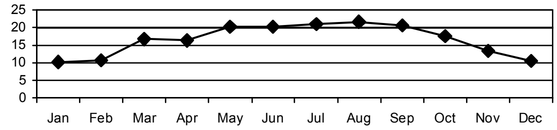
D6 Temperature



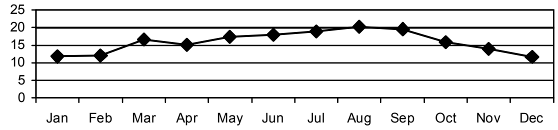
D8 Temperature



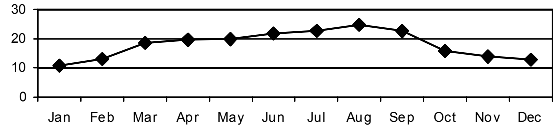
D4 Temperature



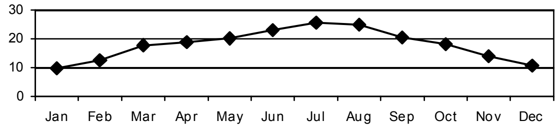
D41 Temperature



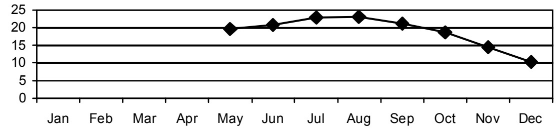
C10 Temperature



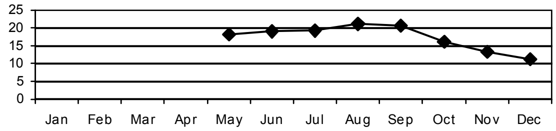
MD10A Temperature



D19 Temperature



D41A Temperature



P8 Temperature

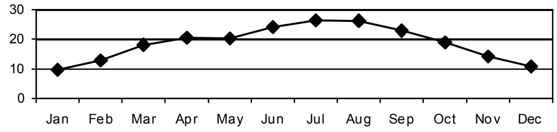


Figure 3-4 Dissolved oxygen

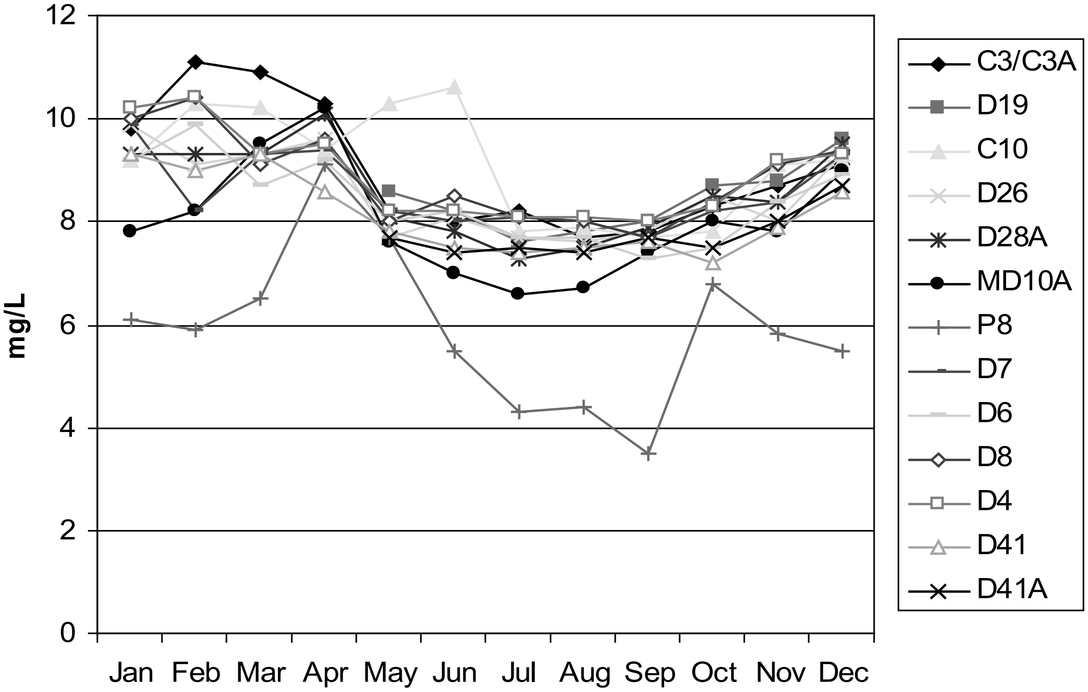
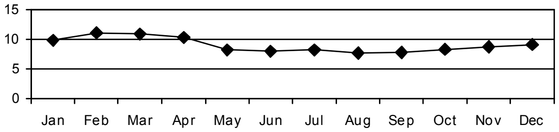
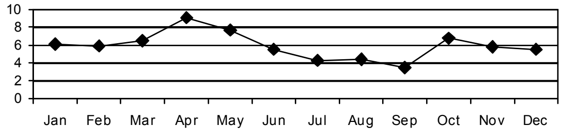


Figure 3-5 Dissolved oxygen (mg/L)

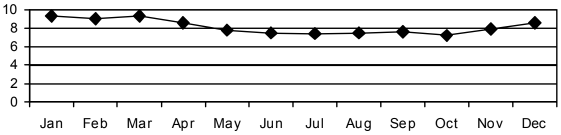
C3/C3A Dissolved Oxygen



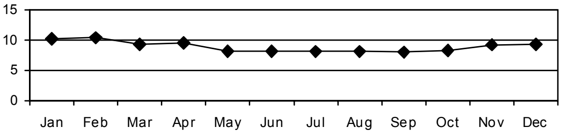
P8 Dissolved Oxygen



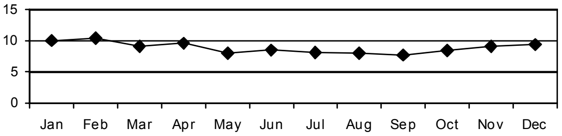
D41 Dissolved Oxygen



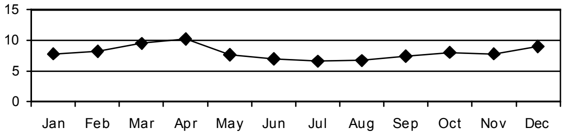
D4 Dissolved Oxygen



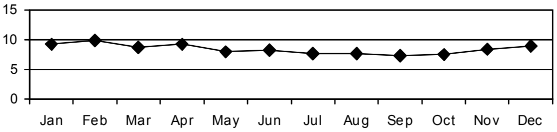
D8 Dissolved Oxygen



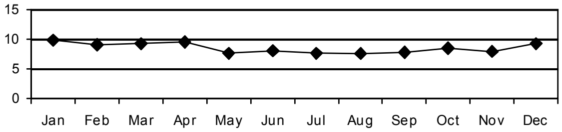
MD10A Dissolved Oxygen



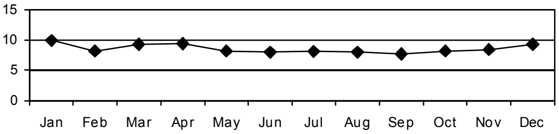
D6 Dissolved Oxygen



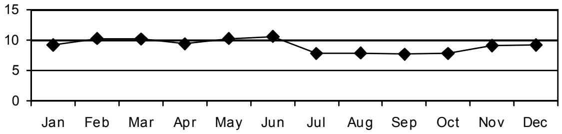
D26 Dissolved Oxygen



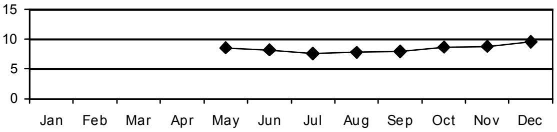
D7 Dissolved Oxygen



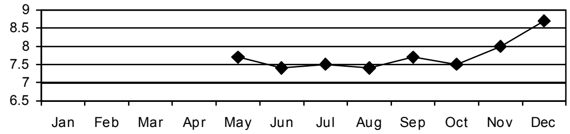
C10 Dissolved Oxygen



D19 Dissolved Oxygen



D41A Dissolved Oxygen



D28A Dissolved Oxygen

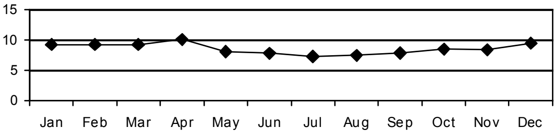


Figure 3-6 Specific conductance

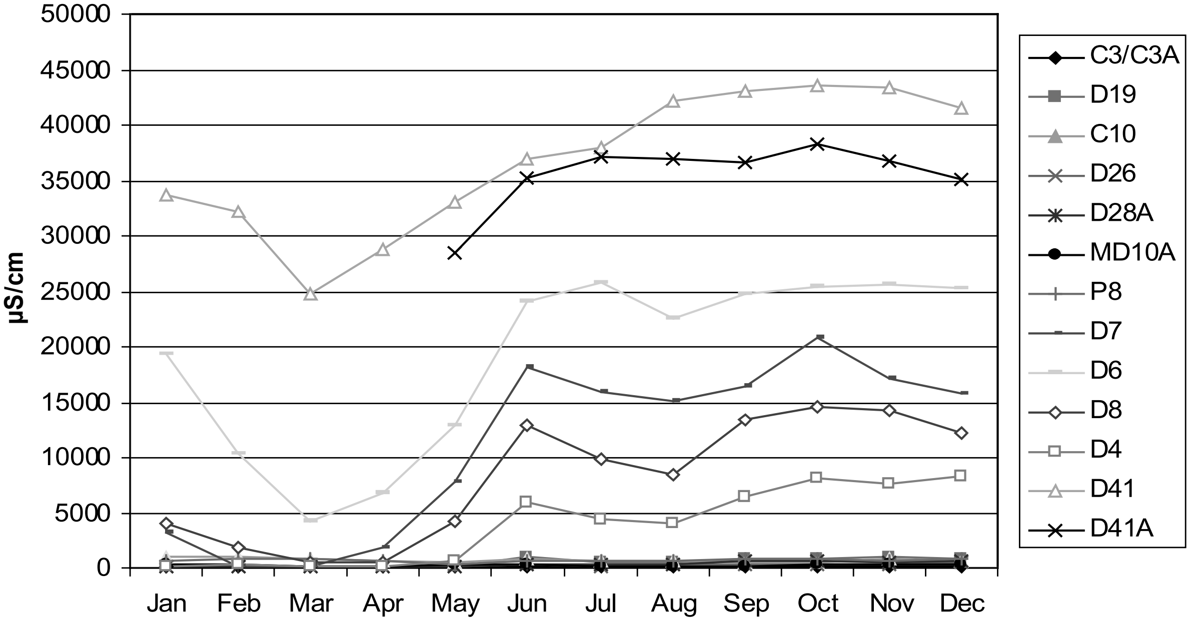
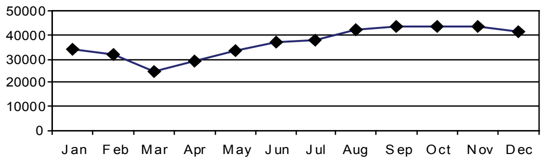
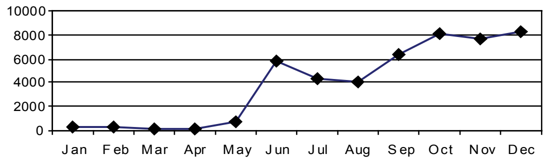


Figure 3-7 Specific conductance (µS/cm)

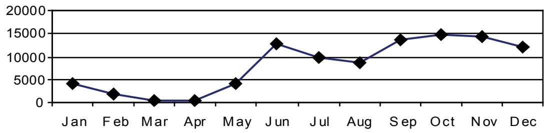
D41 Specific Conductance



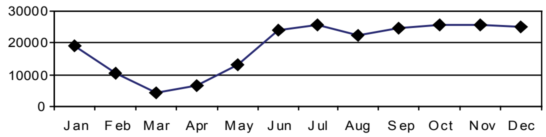
D4 Specific Conductance



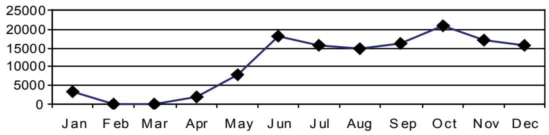
D8 Specific Conductance



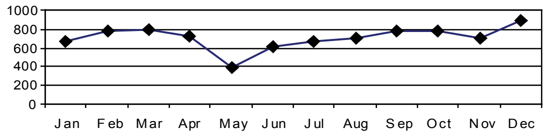
D6 Specific Conductance



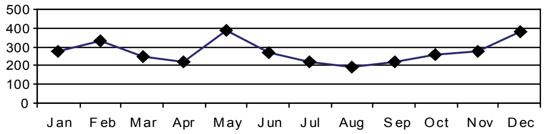
D7 Specific Conductance



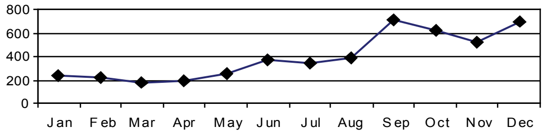
P8 Specific Conductance



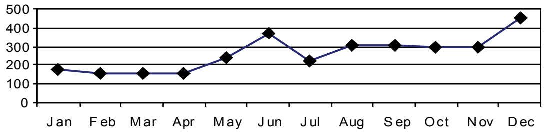
MD10A Specific Conductance



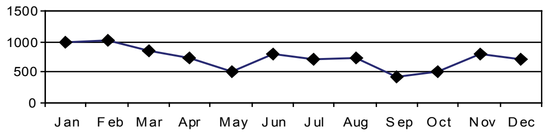
D28A Specific Conductance



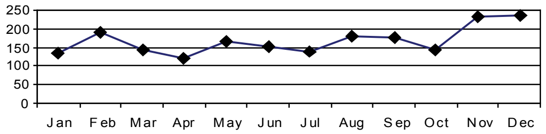
D26 Specific Conductance



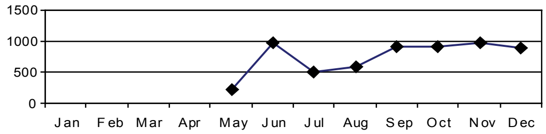
C10 Specific Conductance



C3/C3A Specific Conductance



D19 Specific Conductance



D41A Specific Conductance

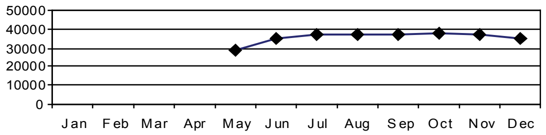


Figure 3-8 Secchi disk depth

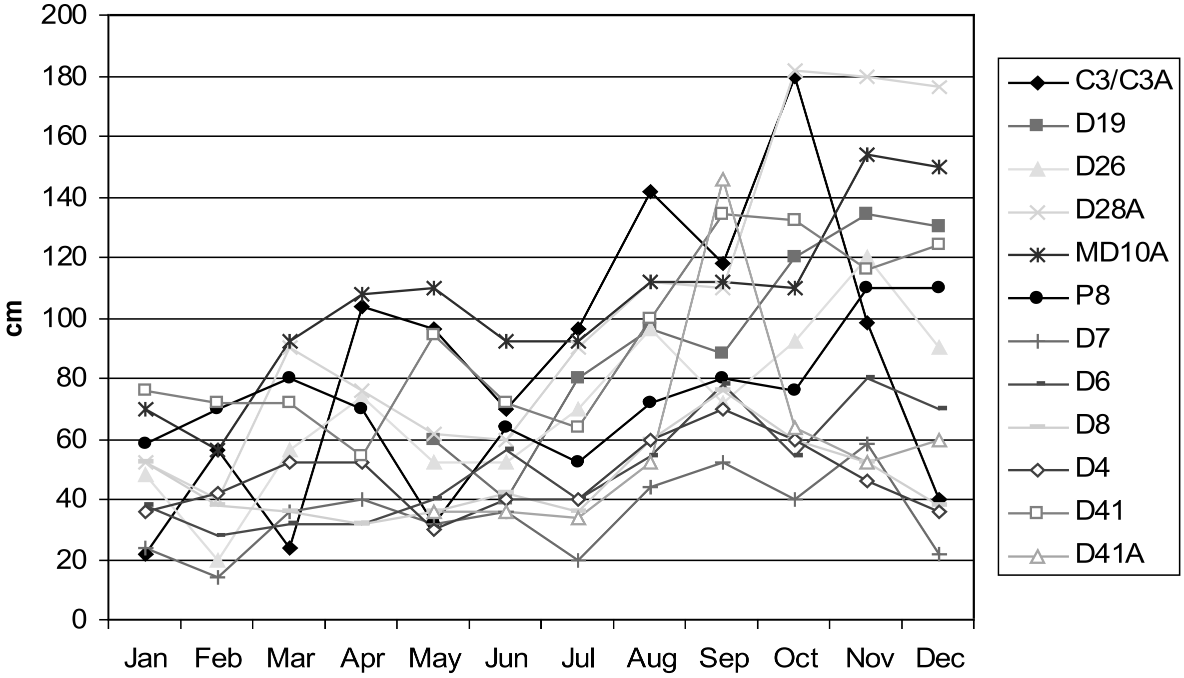
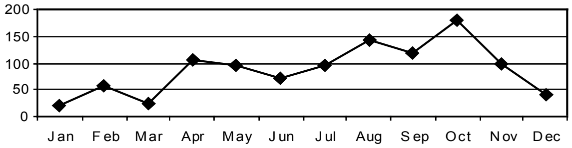
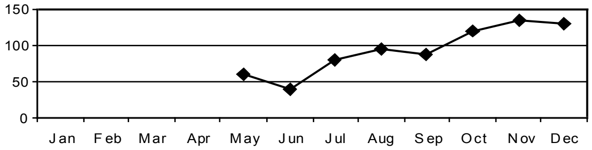


Figure 3-9 Secchi disk depth (cm)

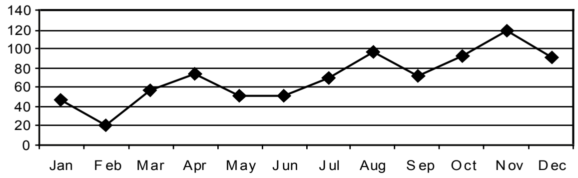
C3/C3A Secchi Depth



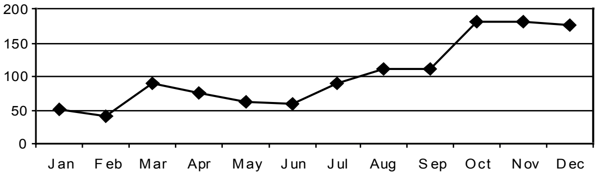
D19 Secchi Depth



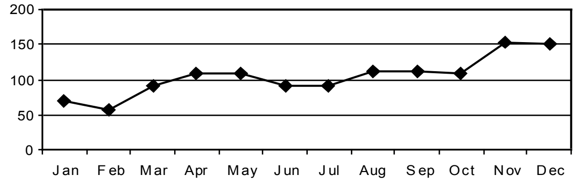
D26 Secchi Depth



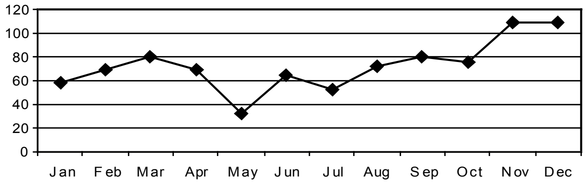
D28A Secchi Depth



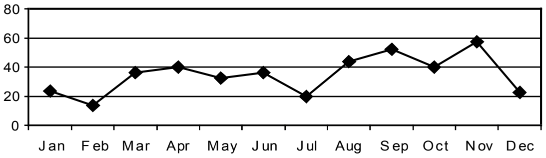
MD10A Secchi Depth



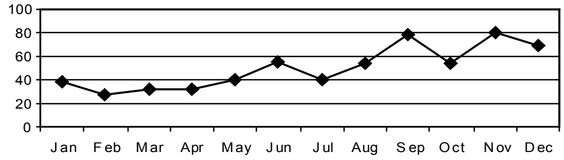
P8 Secchi Depth



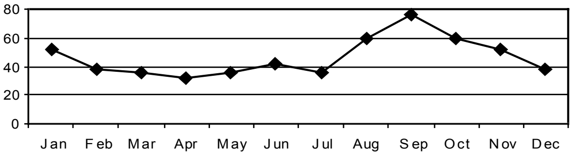
D7 Secchi Depth



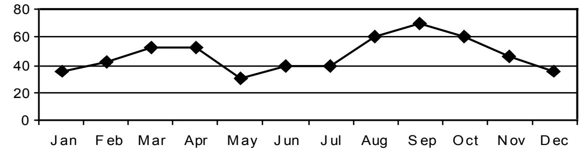
D6 Secchi Depth



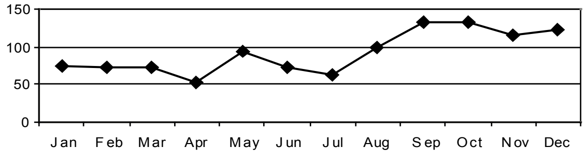
D8 Secchi Depth



D4 Secchi Depth



D41 Secchi Depth



D41A Secchi Depth

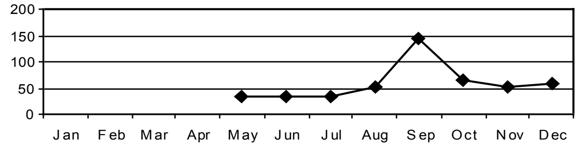


Figure 3-10 Turbidity

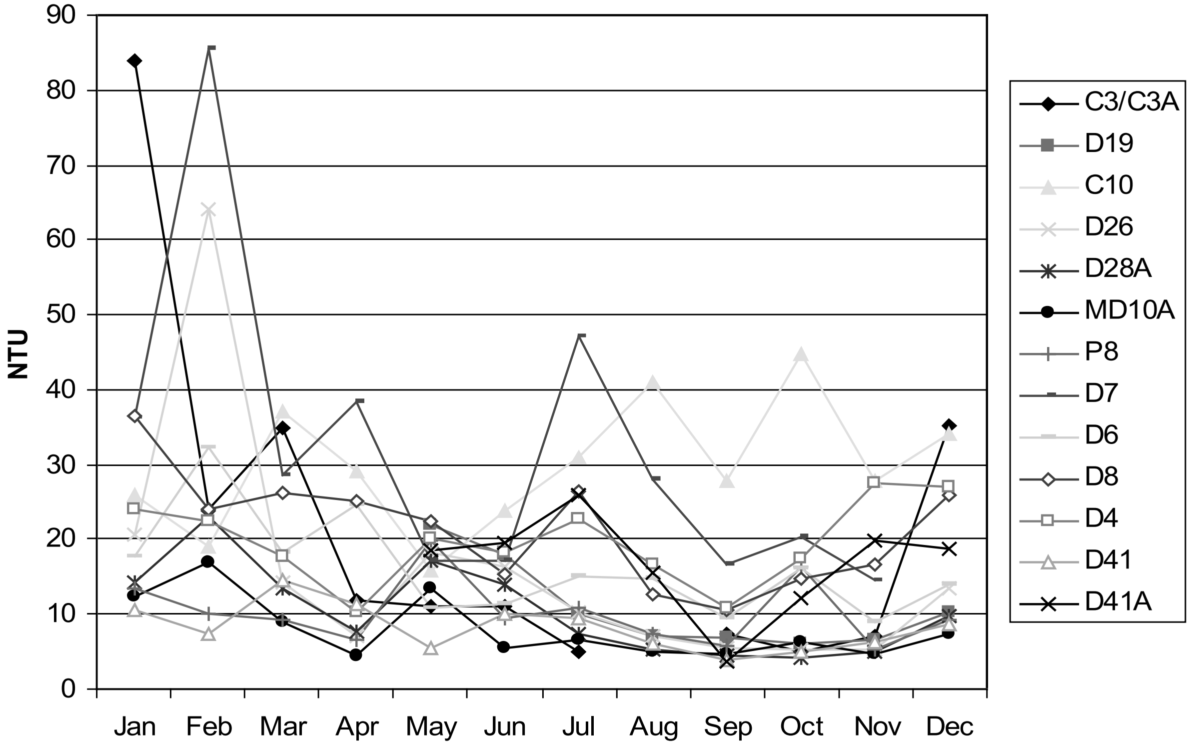


Figure 3-11 Turbidity (NTU)

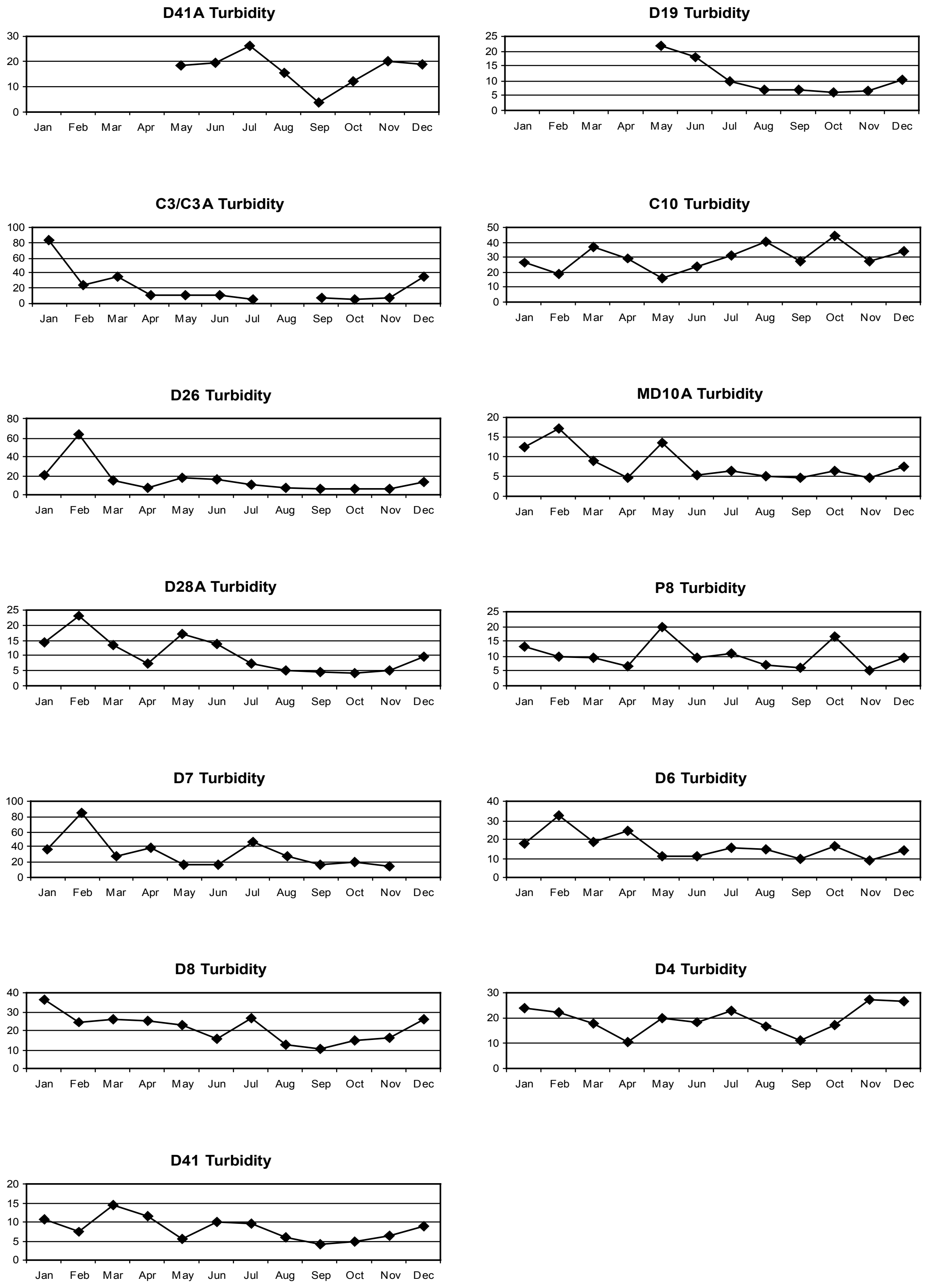


Figure 3-12 Orthophosphate

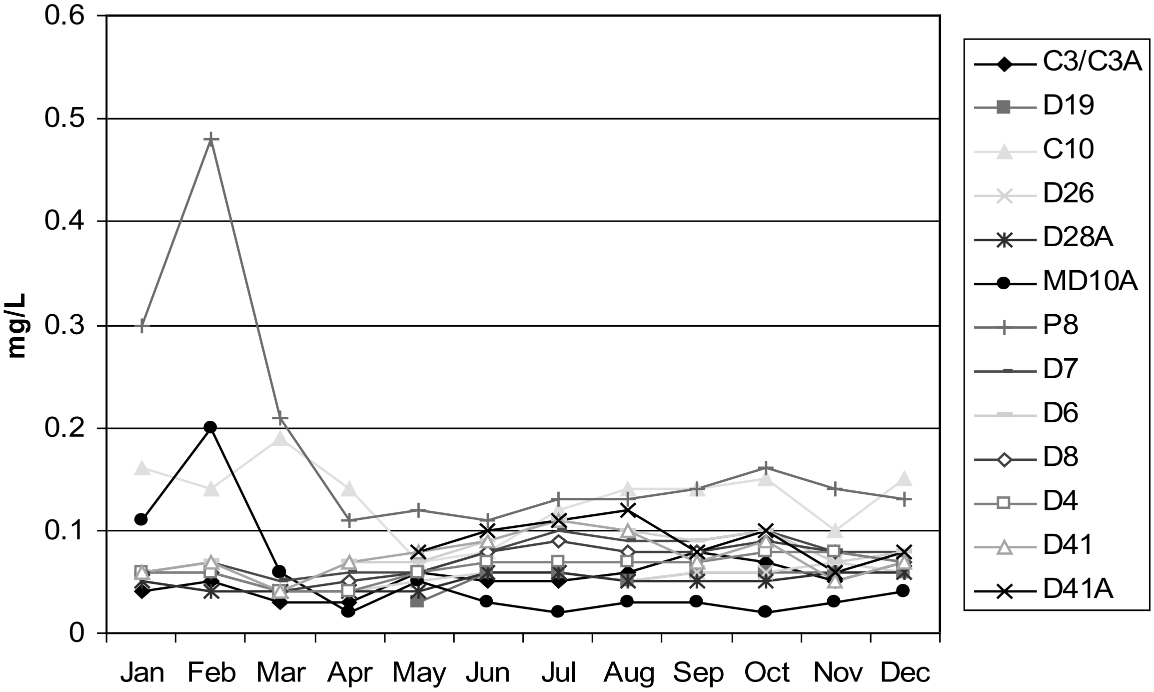


Figure 3-13 Orthophosphate (mg/L)

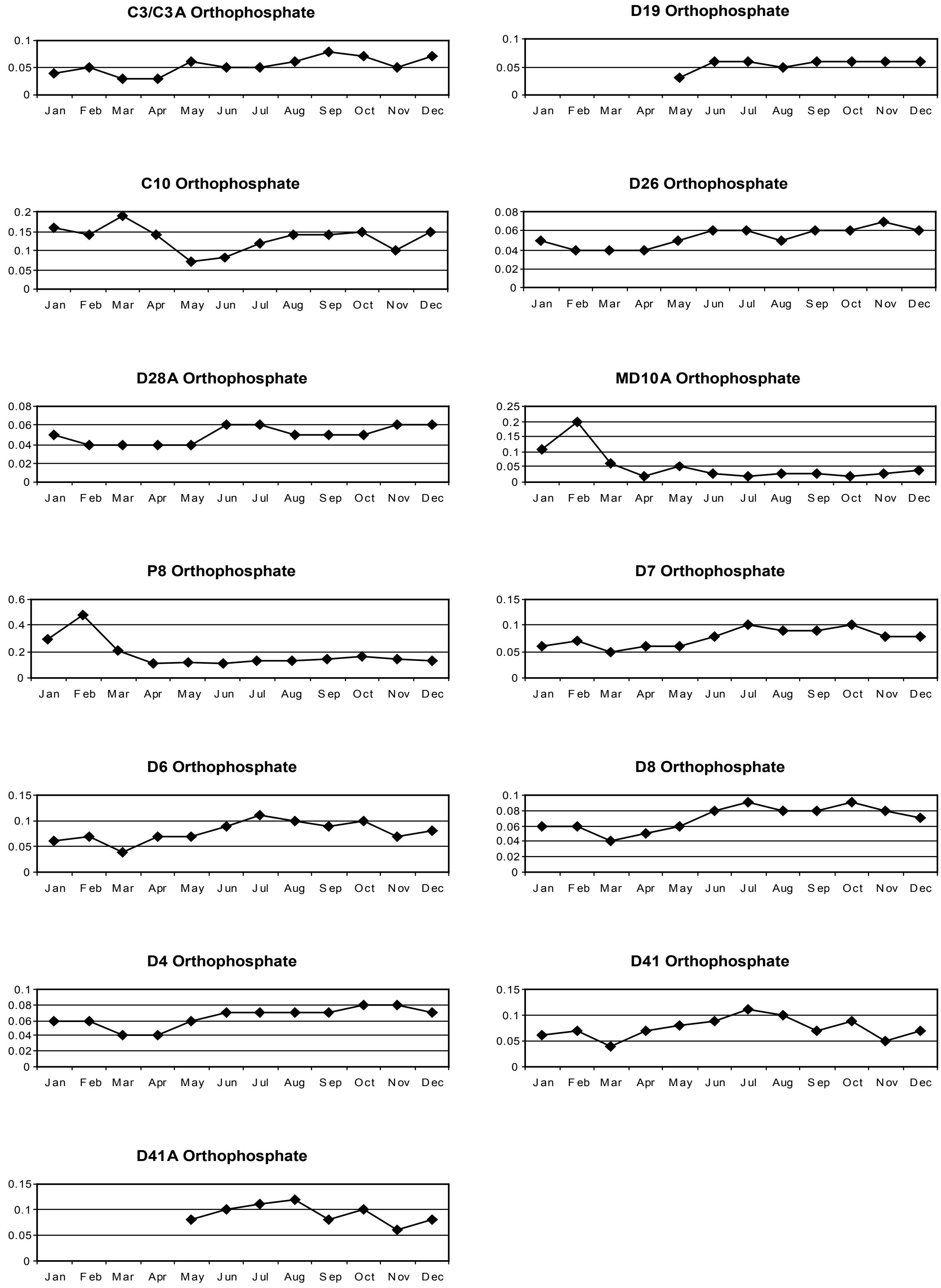


Figure 3-14 Total phosphorus

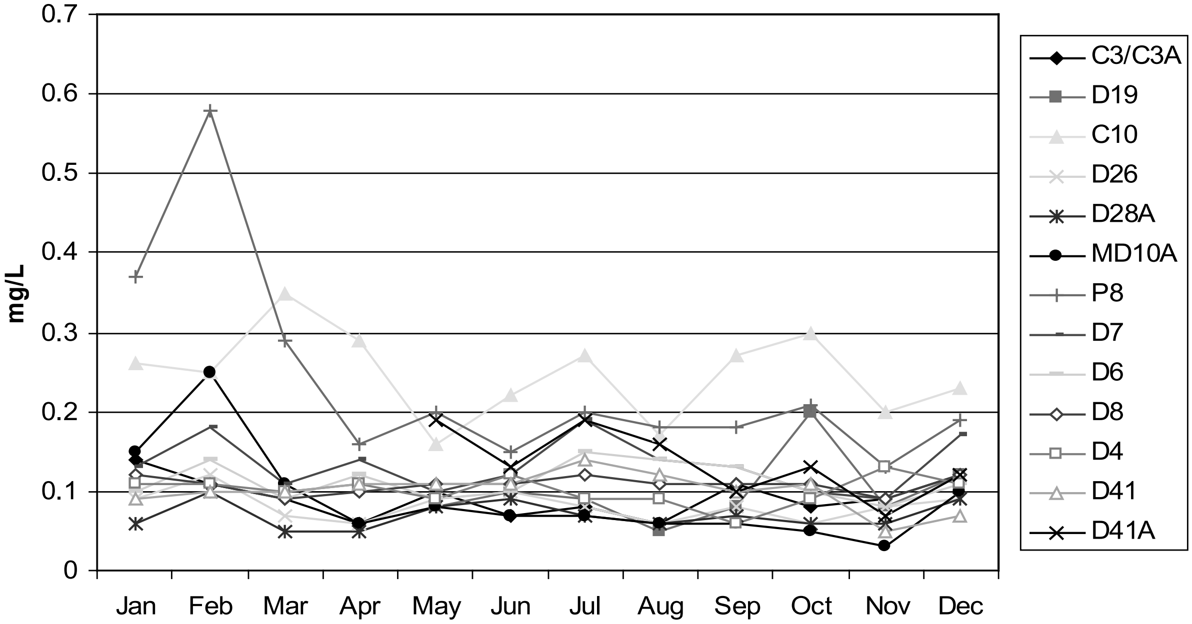
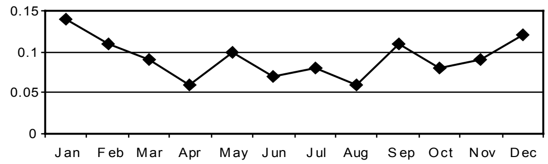
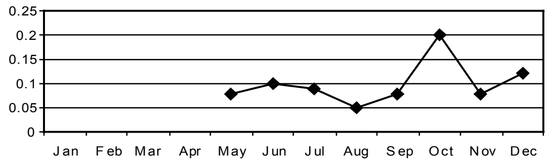


Figure 3-15 Total phosphorus (mg/L)

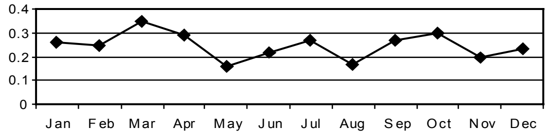
C3/C3A Total Phosphorus



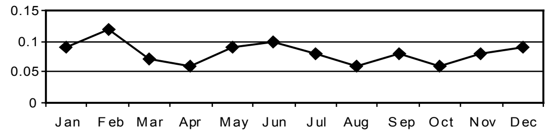
D19 Total Phosphorus



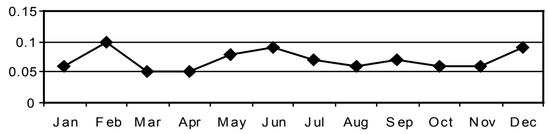
C10 Total Phosphorus



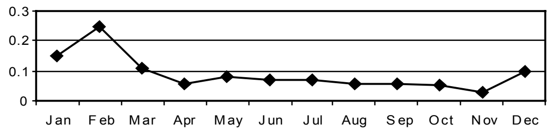
D26 Total Phosphorus



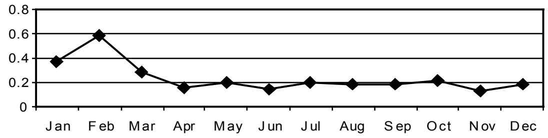
D28A Total Phosphorus



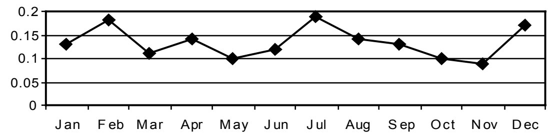
MD10A Total Phosphorus



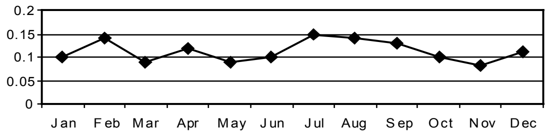
P8 Total Phosphorus



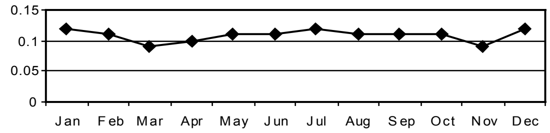
D7 Total Phosphorus



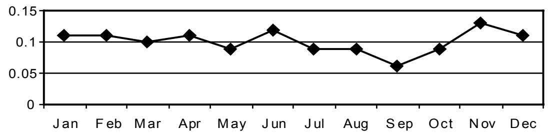
D6 Total Phosphorus



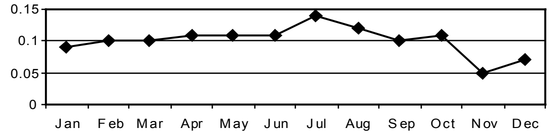
D8 Total Phosphorus



D4 Total Phosphorus



D41 Total Phosphorus



D41A Total Phosphorus

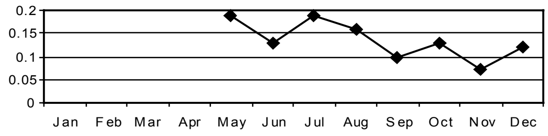


Figure 3-16 Kjeldahl nitrogen

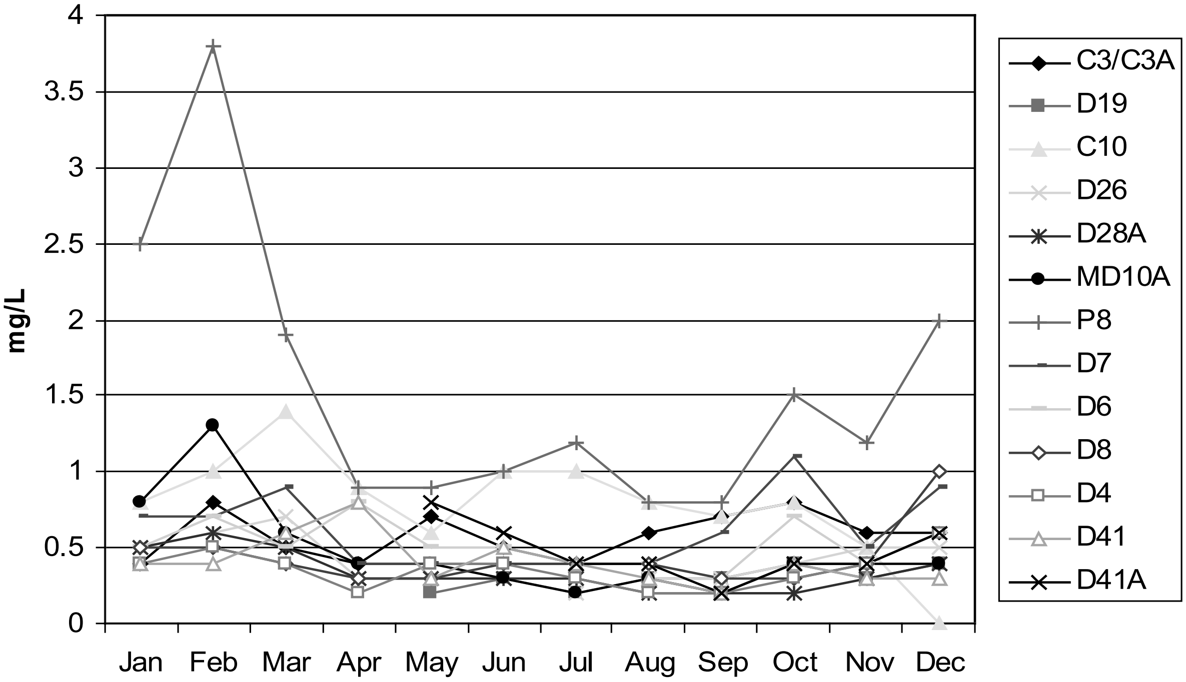
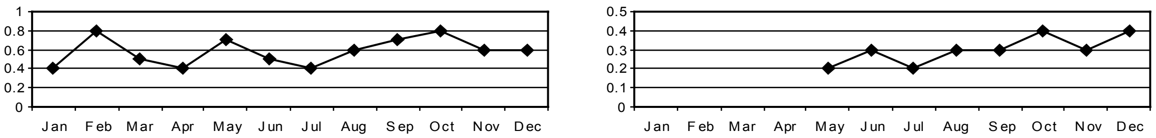
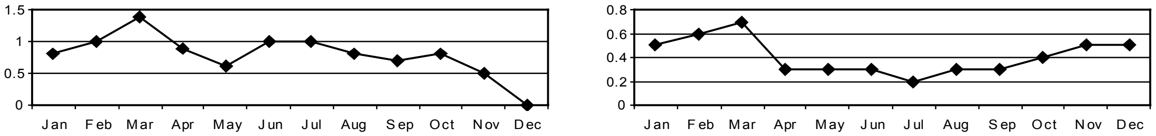


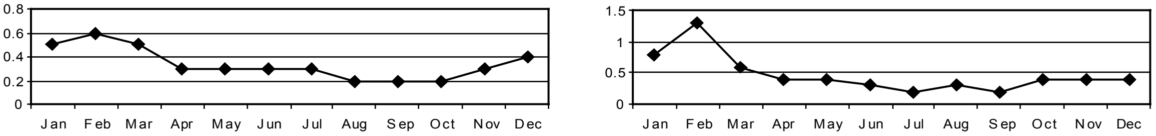
Figure 3-17 Kjeldahl nitrogen (mg/L)


C3/C3A Kjeldahl Nitrogen

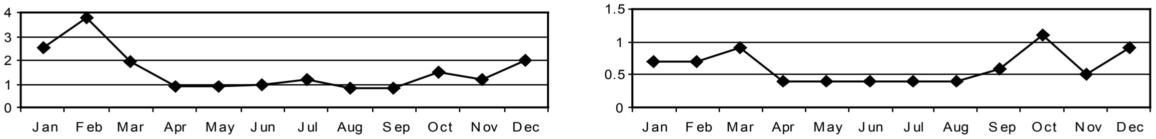
D19 Kjeldahl Nitrogen


C10 Kjeldahl Nitrogen

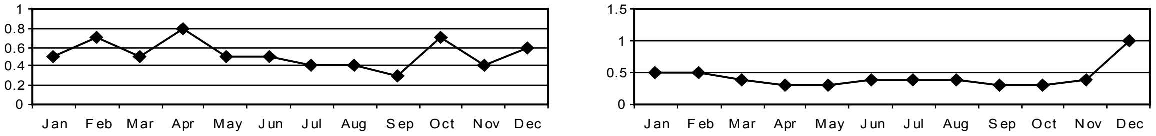
D26 Kjeldahl Nitrogen


D28A Kjeldahl Nitrogen

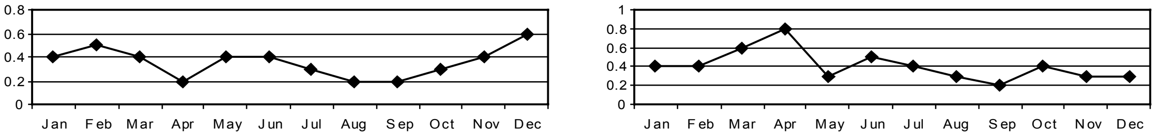
MD10A Kjeldahl Nitrogen


P8 Kjeldahl Nitrogen

D7 Kjeldahl Nitrogen


D6 Kjeldahl Nitrogen

D8 Kjeldahl Nitrogen


D4 Kjeldahl Nitrogen

D41 Kjeldahl Nitrogen

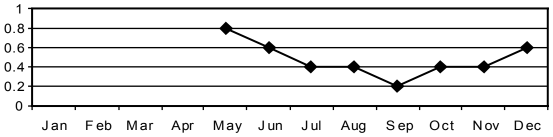

D41A Kjeldahl Nitrogen

Figure 3-18 Dissolved inorganic nitrogen

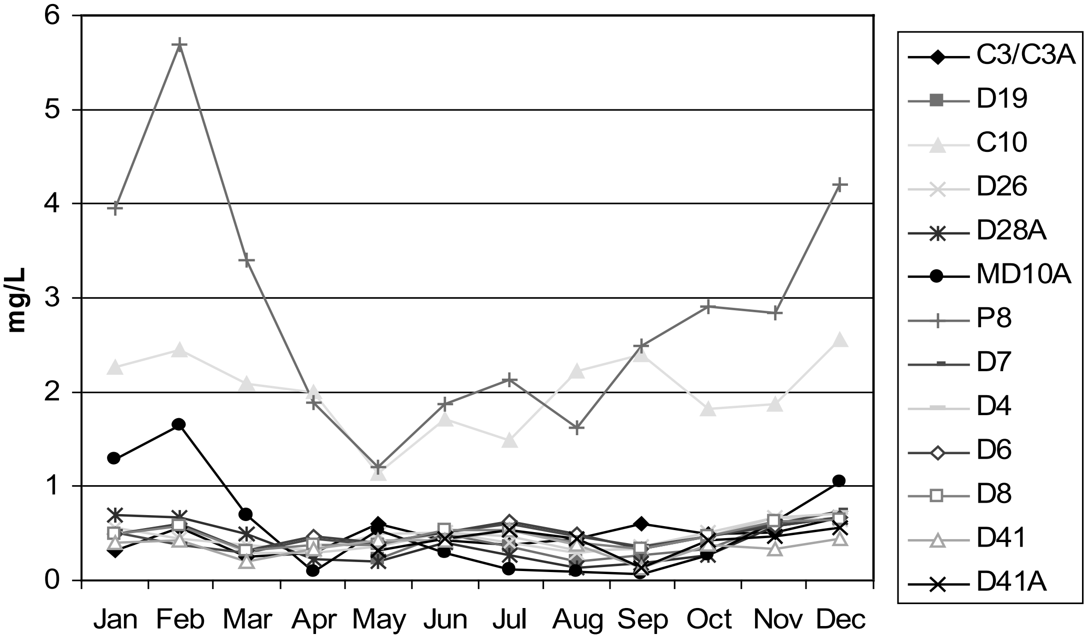
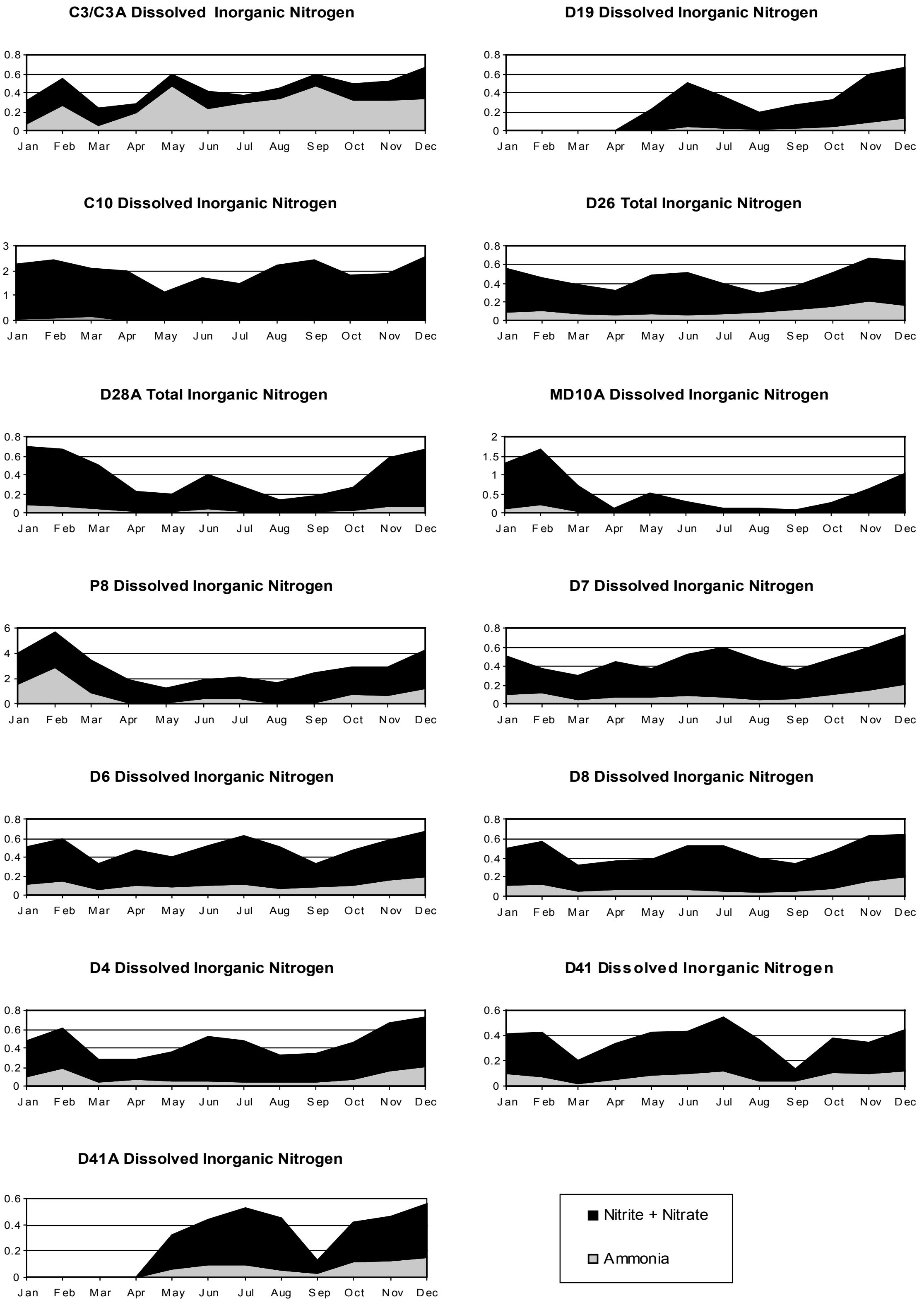


Figure 3-19 Dissolved inorganic nitrogen (mg/L)



C3/C3A Dissolved Inorganic Nitrogen

D19 Dissolved Inorganic Nitrogen

C10 Dissolved Inorganic Nitrogen

D26 Total Inorganic Nitrogen

D28A Total Inorganic Nitrogen

MD10A Dissolved Inorganic Nitrogen

P8 Dissolved Inorganic Nitrogen

D7 Dissolved Inorganic Nitrogen

D6 Dissolved Inorganic Nitrogen

D8 Dissolved Inorganic Nitrogen

D4 Dissolved Inorganic Nitrogen

D41 Dissolved Inorganic Nitrogen

D41A Dissolved Inorganic Nitrogen

Figure 3-20 Dissolved organic nitrogen

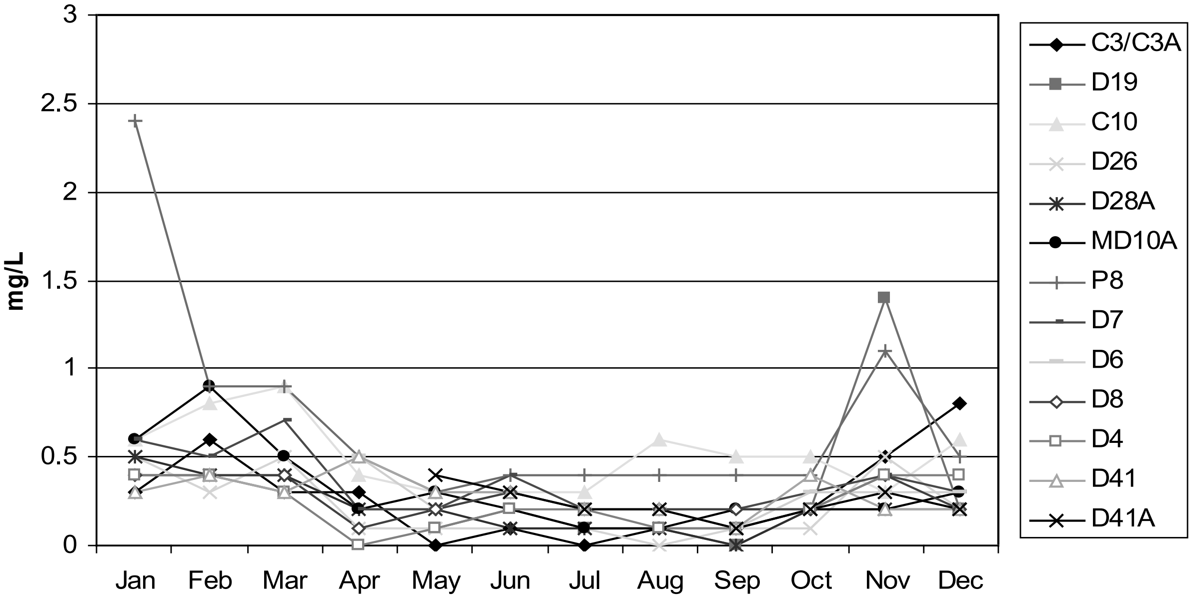
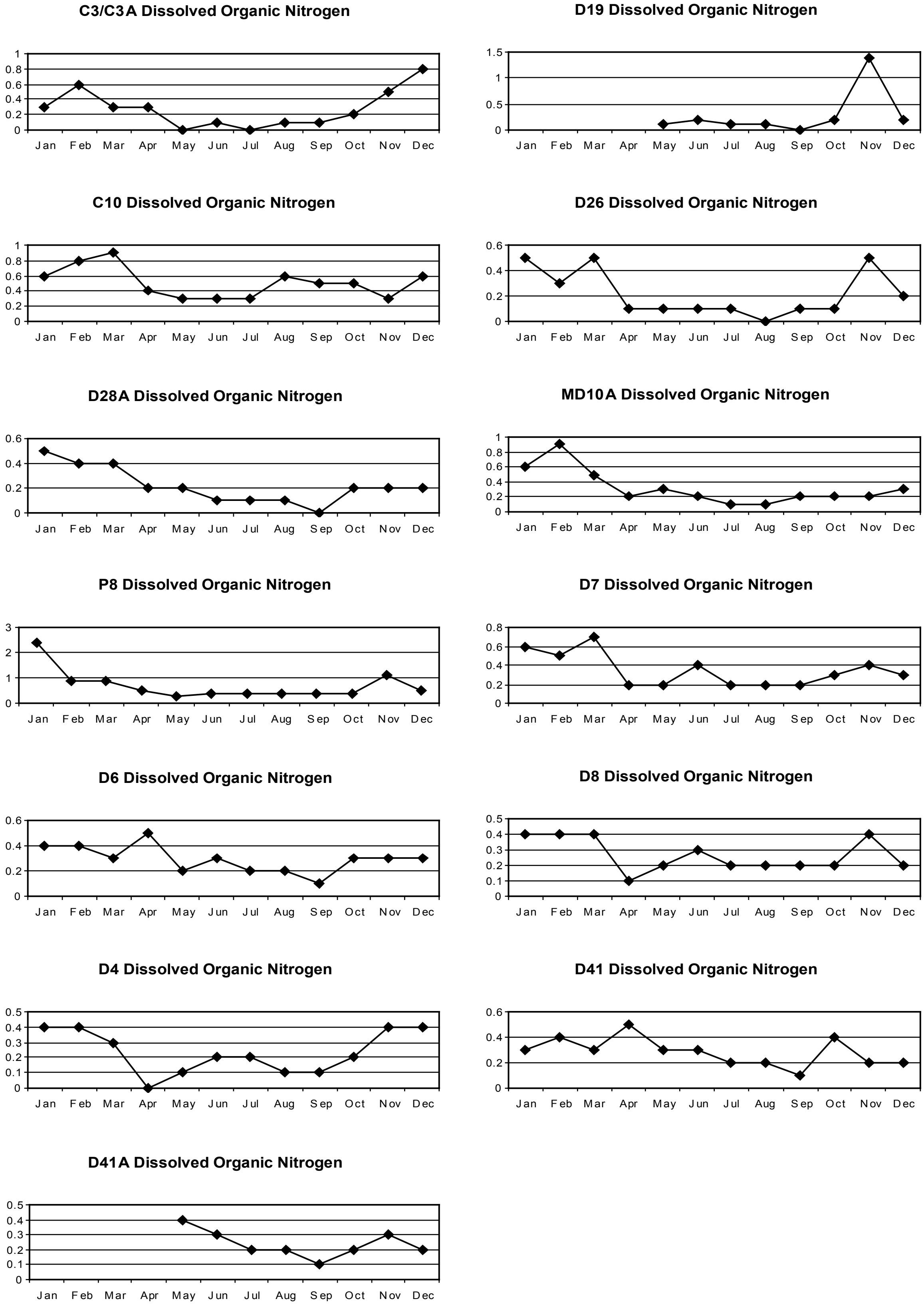


Figure 3-21 Dissolved organic nitrogen (mg/L)



C3/C3A Dissolved Organic Nitrogen

D19 Dissolved Organic Nitrogen

C10 Dissolved Organic Nitrogen

D26 Dissolved Organic Nitrogen

D28A Dissolved Organic Nitrogen

MD10A Dissolved Organic Nitrogen

P8 Dissolved Organic Nitrogen

D7 Dissolved Organic Nitrogen

D6 Dissolved Organic Nitrogen

D8 Dissolved Organic Nitrogen

D4 Dissolved Organic Nitrogen

D41 Dissolved Organic Nitrogen

D41A Dissolved Organic Nitrogen

Figure 3-22 Total dissolved solids

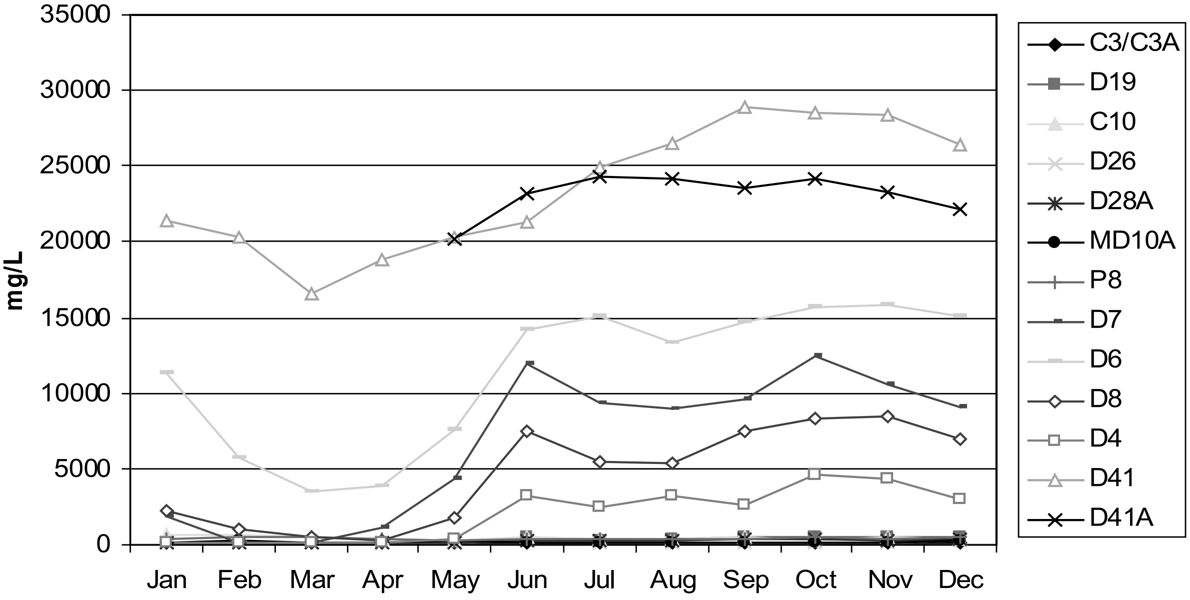
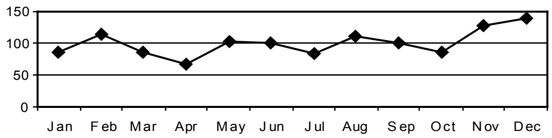
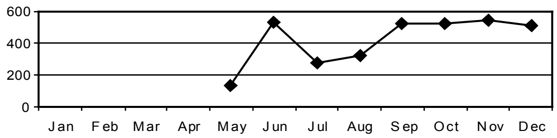


Figure 3-23 Total dissolved solids (mg/L)

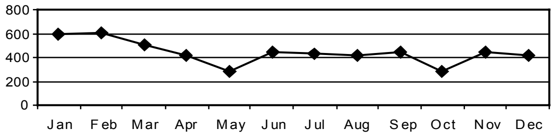
C3/C3A Total Dissolved Solids



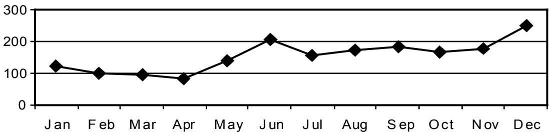
D19 Total Dissolved Solids



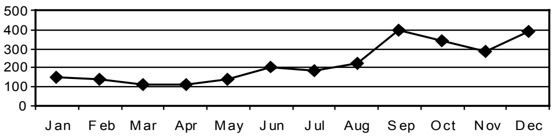
C10 Total Dissolved Solids



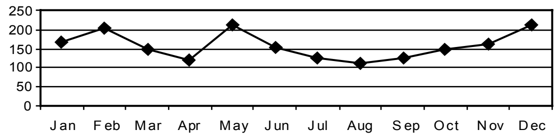
D26 Total Dissolved Solids



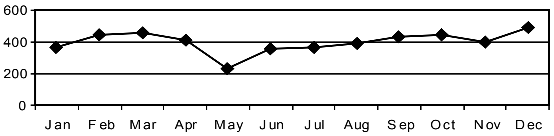
D28A Total Dissolved Solids



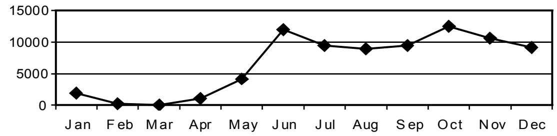
MD10A Total Dissolved Solids



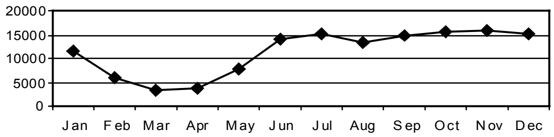
P8 Total Dissolved Solids



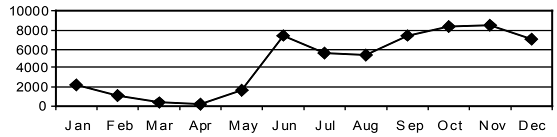
D7 Total Dissolved Solids



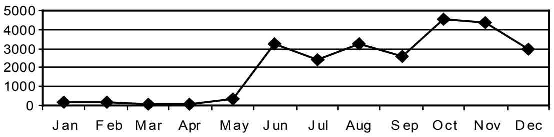
D6 Total Dissolved Solids



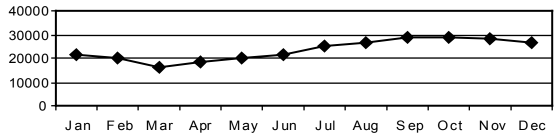
D8 Total Dissolved Solids



D4 Total Dissolved Solids



D41 Total Dissolved Solids



D41A Total Dissolved Solids

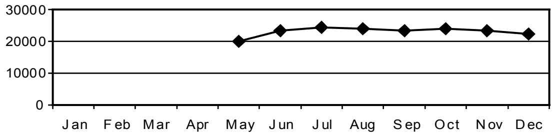


Figure 3-24 Total suspended solids

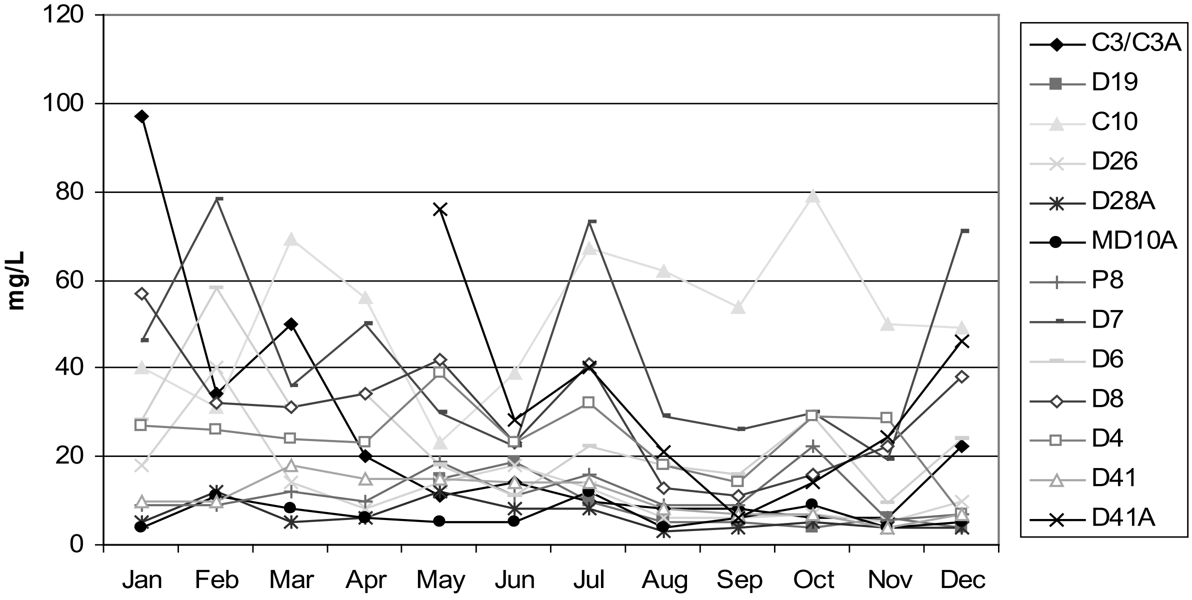
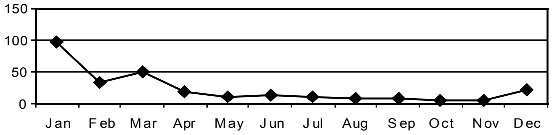
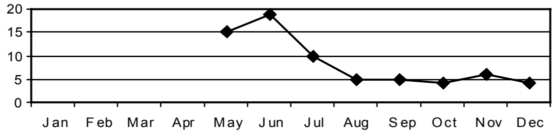


Figure 3-25 Total suspended solids (mg/L)

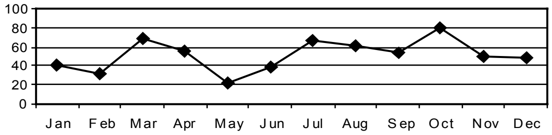
C3/C3A Total Suspended Solids



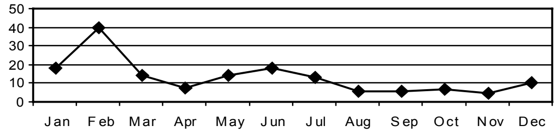
D19 Total Suspended Solids



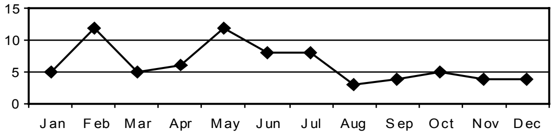
C10 Total Suspended Solids



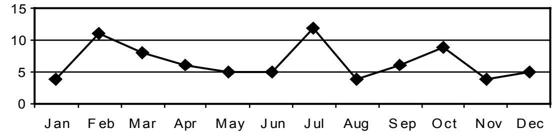
D26 Total Suspended Solids



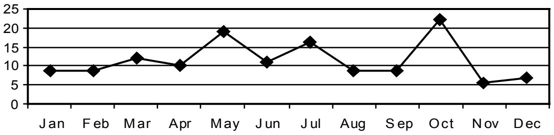
D28A Total Suspended Solids



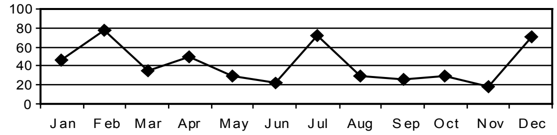
MD10A Total Suspended Solids



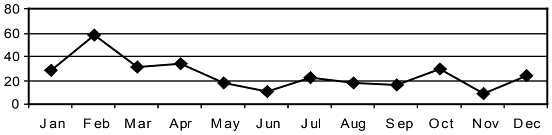
P8 Total Suspended Solids



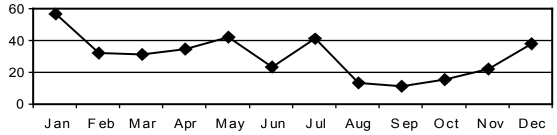
D7 Total Suspended Solids



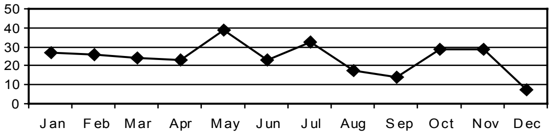
D6 Total Suspended Solids



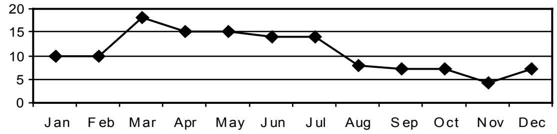
D8 Total Suspended Solids



D4 Total Suspended Solids



D41 Total Suspended Solids



D41A Total Suspended Solids

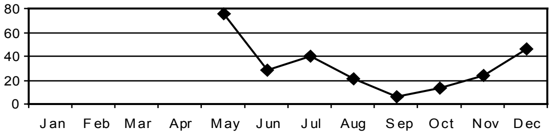


Figure 3-26 Volatile suspended solids (mg/L)

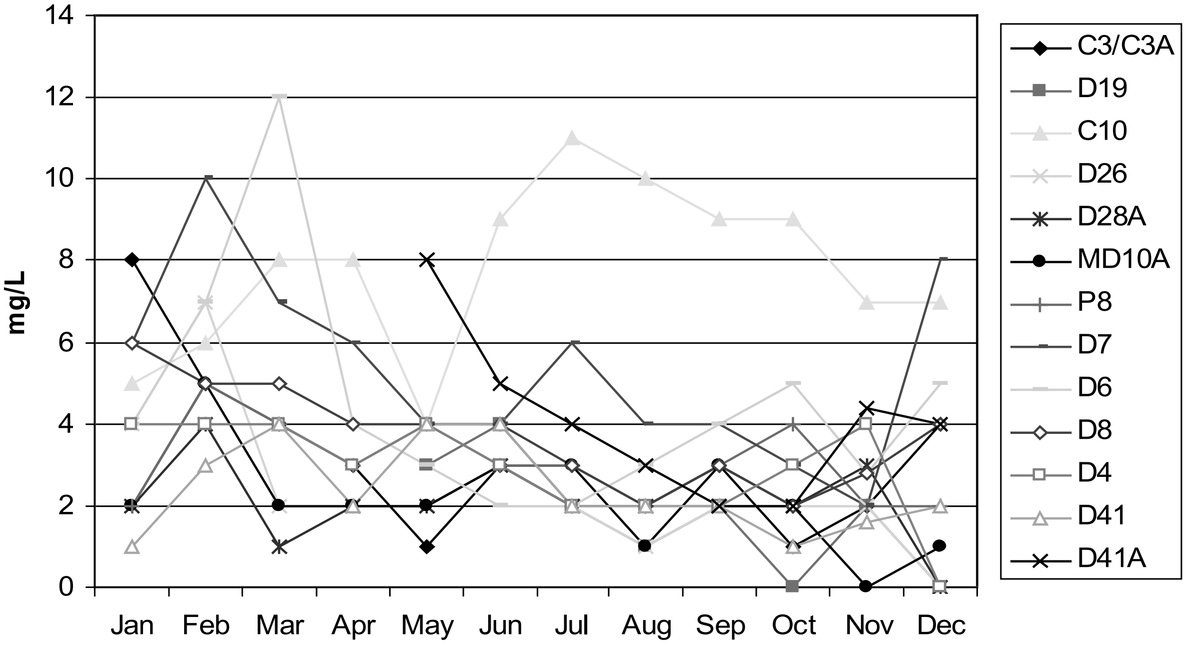
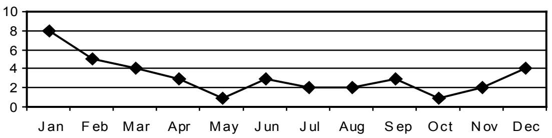
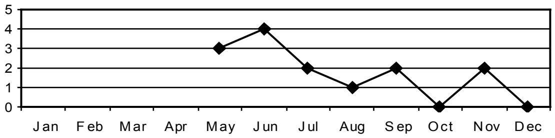
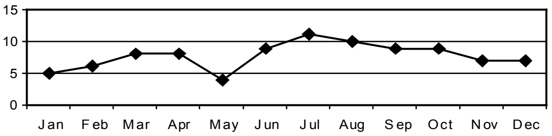
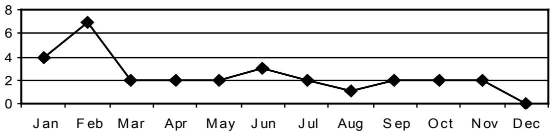


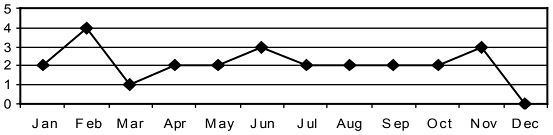
Figure 3-27 Volatile suspended solids (mg/L)

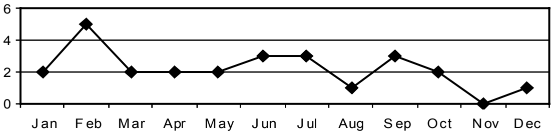

C3/C3A Volatile Suspended Solids

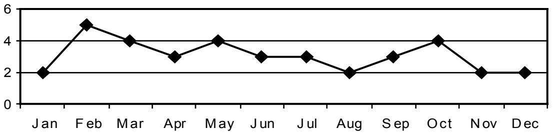

D19 Volatile Suspended Solids

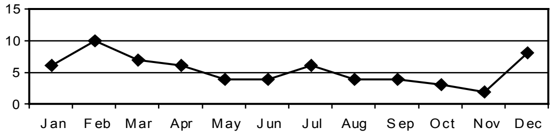

C10 Volatile Suspended Solids

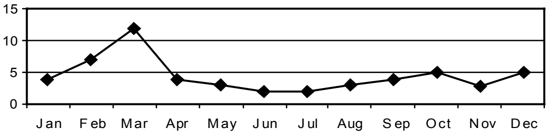

D26 Volatile Suspended Solids

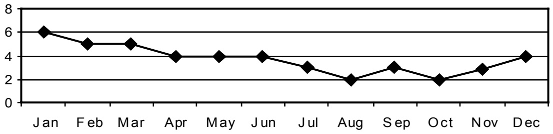

D28A Volatile Suspended Solids

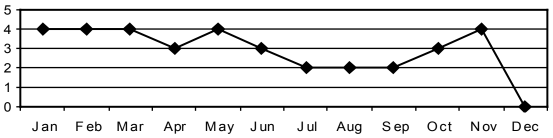

MD10A Volatile Suspended Solids

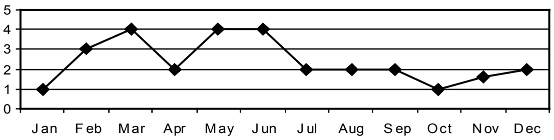

P8 Volatile Suspended Solids


D7 Volatile Suspended Solids


D6 Volatile Suspended Solids


D8 Volatile Suspended Solids


D4 Volatile Suspended Solids


D41 Volatile Suspended Solids

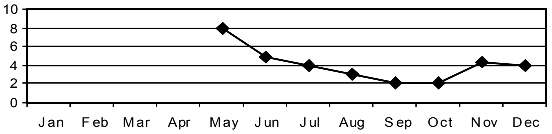

D41A Volatile Suspended Solids

Figure 3-28 Silica

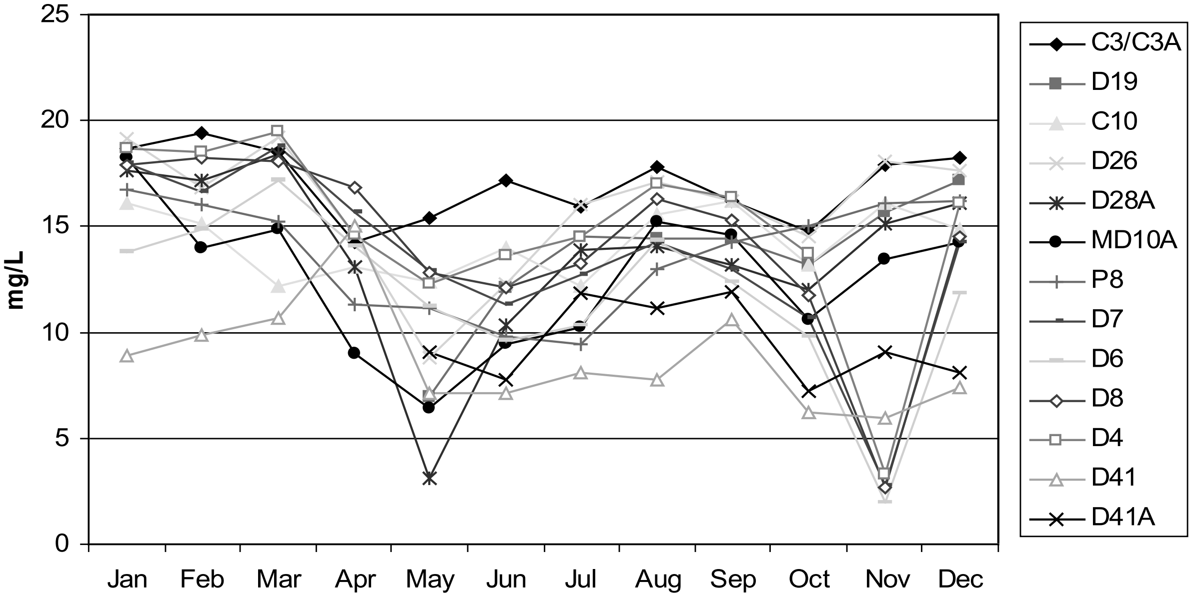
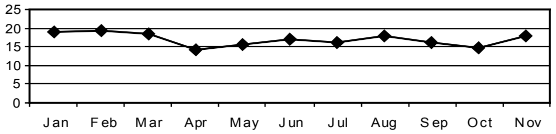
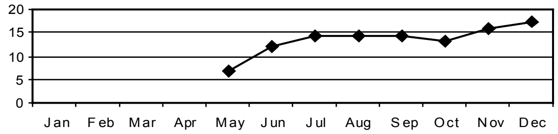


Figure 3-29 Silica (mg/L)

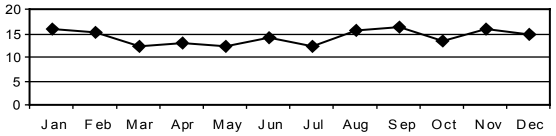
C3/C3A Silica



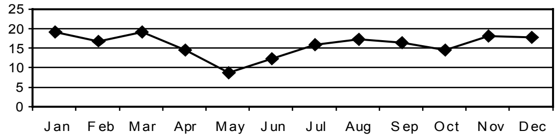
D19 Silica



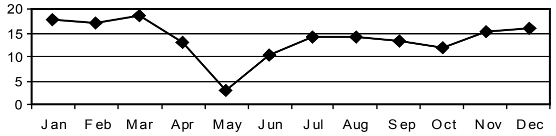
C10 Silica



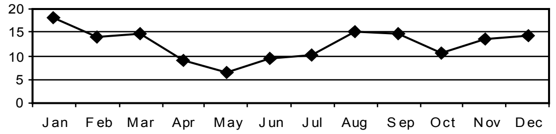
D26 Silica



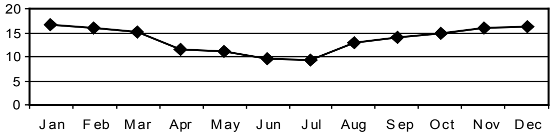
D28A Silica



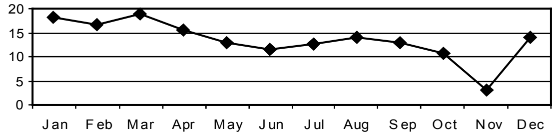
MD10A Silica



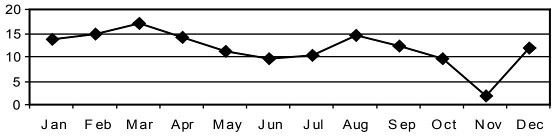
P8 Silica



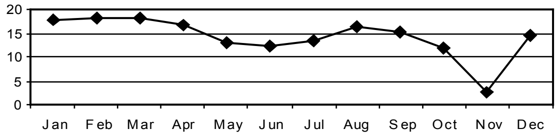
D7 Silica



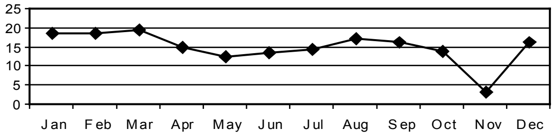
D6 Silica



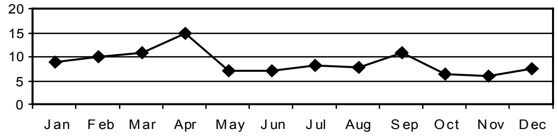
D8 Silica



D4 Silica



D41 Silica



D41A Silica

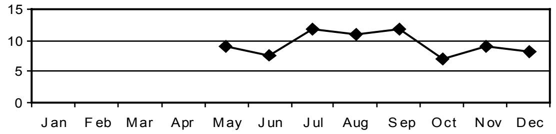


Figure 3-30 Chloride

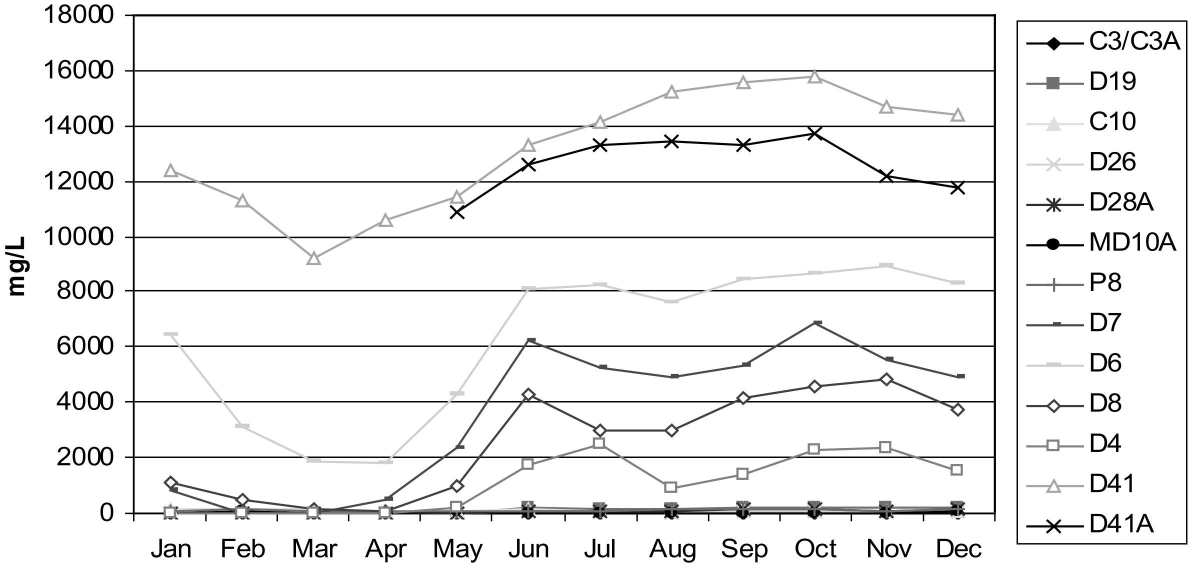
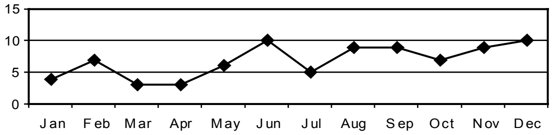
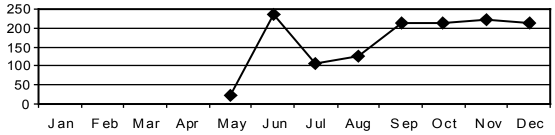


Figure 3-31 Chloride (mg/L)

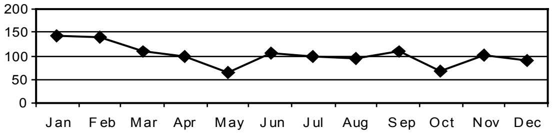
C3/C3A Chloride



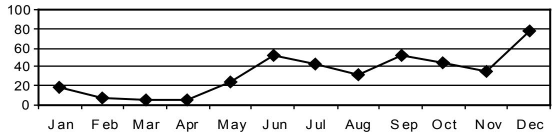
D19 Chloride



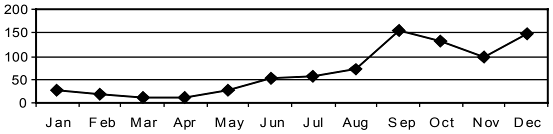
C10 Chloride



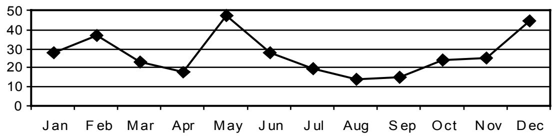
D26 Chloride



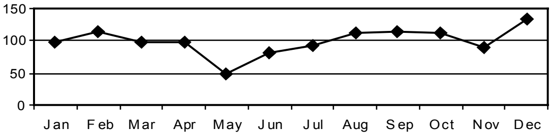
D28A Chloride



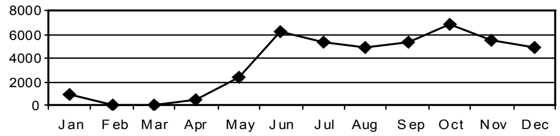
MD10A Chloride



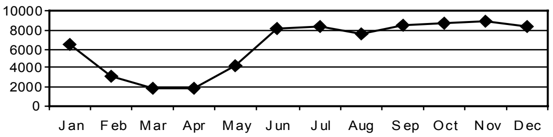
P8 Chloride



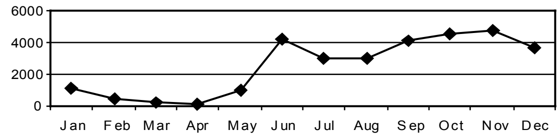
D7 Chloride



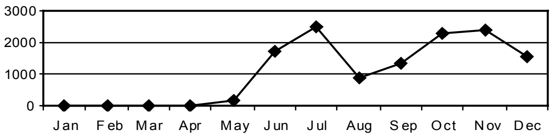
D6 Chloride



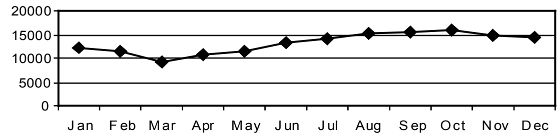
D8 Chloride



D4 Chloride



D41 Chloride



D41A Chloride

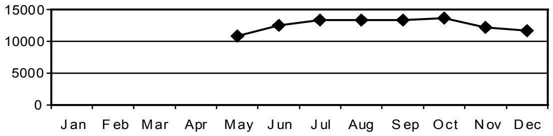


Table 3-1 Water quality parameters measured

Parameter	Units
Water temperature	°C
Dissolved oxygen	mg/L
Specific conductance	µS/cm
Secchi disk depth	cm
Turbidity	NTU
Orthophosphate	mg/L
Total phosphorus	mg/L
Kjeldahl nitrogen	mg/L
Dissolved inorganic nitrogen	mg/L
Dissolved organic nitrogen	mg/L
Total dissolved solids	mg/L
Total suspended solids	mg/L
Volatile suspended solids	mg/L
Silica	mg/L
Chloride	mg/L

Table 3-2 Water quality sampling sites and regions

Region	Sampling Sites
Lower Sacramento River	D4
Lower San Joaquin River	D26 and D19
North Delta	C3/C3A
Central Delta	D28A
East Delta	MD10A
South Delta	C10 and P8
Suisun Bay	D6, D7 and D8
San Pablo Bay	D41 and D41A

Chapter 4. Phytoplankton and Chlorophyll

Introduction

The California Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll *a* samples to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (Estuary). The eleven sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays. This chapter describes the results of these monitoring efforts for calendar year 2004.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes that influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular colonial or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect pH, dissolved oxygen, color, taste, and odor; under certain conditions, some species can form noxious blooms resulting in animal deaths and human illness (Carmichael 1981). In freshwater, cyanobacteria (class Cyanophyceae) are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (Van Den Hoek and others 1995). In addition to being an important food source for zooplankton, macroinvertebrates, and some species of fish, phytoplankton species assemblages can be useful in assessing water quality (Gannon and Stemberger 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes; hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (APHA 1998). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with physiochemical and other biological data (APHA 1998).

Chlorophylls are complex phytopigment molecules found in all photosynthetic organisms, including phytoplankton. There are several types of chlorophyll identified by slight differences in their molecular structure and constituents. These include chlorophyll *a*, *b*, *c*, and *d*. Chlorophyll *a* is the principal photosynthetic pigment and is common to all phytoplankton. Chlorophyll *a* is thus used as a measure of phytoplankton biomass.

In addition to chlorophyll *a*, water samples were analyzed for pheophytin *a*. Pheophytin *a* is a primary degradation product of chlorophyll *a* and its concentration, relative to chlorophyll *a*, is useful for estimating the general physiological state of phytoplankton populations. When phytoplankton are actively growing, the concentrations of pheophytin *a* are normally expected to be low in relation to chlorophyll *a*. Conversely, when the phytoplankton have died and are decaying, levels of pheophytin *a* are expected to be high in relation to chlorophyll *a*.

Phytoplankton biomass and resulting chlorophyll *a* concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, *Corbula amurensis* (Alpine and Cloern 1992). Well-established benthic populations of *C. amurensis* in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll *a* concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. The samples were stored in 50-mL glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed. Phytoplankton identification and enumeration were performed at DWR's Bryte Laboratory according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 15 hours. The aliquot volume, normally 10 mL, was adjusted according to the algal population density and turbidity of the sample. Phytoplankton were enumerated in 20 randomly chosen fields of a Whipple ocular micrometer grid for each settled aliquot. Sample analysis was conducted at a magnification of 700X using a Wilde M-40 inverted microscope.

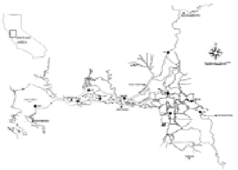


Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

Organism counts for each sample can be converted to organisms/mL using the following formula:

$$\textbf{Organisms} = (C \times Ac) / (V \times Af \times F)$$

where:

Organisms = Number of organisms (#/mL)
C = Count obtained

Ac = Area of cell bottom (mm^2)
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:

Organisms = C / cV
where:

cV = Counted volume (mL)

(Note: cV = Ac /(V x Af x F))

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1) using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. Approximately 500 mL of water was passed through a 47-mm-diameter glass fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to Standard Methods (APHA 1998) spectrophotometric procedure. Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1992). In addition, the percent chlorophyll *a* was calculated as the ratio of chlorophyll *a* concentration to chlorophyll *a* plus pheophytin *a* concentrations multiplied by 100.

Results

Phytoplankton Identification

Of the nine phytoplankton groups identified, the families Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Cryptophyceae constituted 96% of the organisms collected during 2004. Figure 4-2 shows the total phytoplankton contribution by group for all sites.

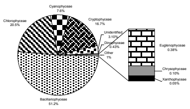
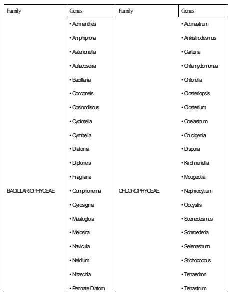


Figure 4-2 Total phytoplankton contribution by family at all stations

All organisms collected during 2004 fell into these nine categories:

- Bacillariophyceae (Diatoms)
- Chlorophyceae (Green algae)
- Chrysophyceae (Yellow-brown algae)
- Cryptophyceae (Cryptomonads)
- Cyanophyceae (Cyanobacteria)
- Dinophyceae (Dinoflagellates)
- Euglenophyceae (Euglenoids)
- Xanthophyceae (Yellow-green algae)
- Unidentified flagellates

Table 4-1 lists the genera found in each class in the upper Estuary.



Family	Genus	Family	Genus
BACILLARIOPHYCEAE	• Achnanthes	CHLOROPHYCEAE	• Actinastrum
	• Amphiprora		• Ankistrodesmus
	• Asterionella		• Carteria
	• Aulacoseira		• Chlamydomonas
	• Bacillaria		• Chlorella
	• Cocconeis		• Closteriopsis
	• Cosinodiscus		• Closterium
	• Cyclotella		• Coelastrum
	• Cymbella		• Crucigenia
	• Diatoma		• Dispora
	• Diploneis		• Kirchneriella
	• Fragilaria		• Mougeotia
	• Gomphonema		• Nephrocytium
	• Gyrosigma		• Oocystis
	• Mastogloia		• Scenedesmus
	• Melosira		• Schroederia
	• Navicula		• Selenastrum
	• Neidium		• Stichococcus
	• Nitzschia		• Tetraedron
	• Pennate Diatom		• Tetrastrum

Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2004

The 10 most common genera collected in 2004 were:

- *Cyclotella* (Bacillariophyceae)
- *Rhodomonas* (Cryptophyceae)
- *Skeletonema* (Bacillariophyceae)
- *Aulacoseira* (Bacillariophyceae)
- *Thalassiosira* (Bacillariophyceae)
- *Dispora* (Chlorophyceae)
- *Ankistrodesmus* (Chlorophyceae)
- Unidentified flagellates
- *Selenastrum* (Chlorophyceae)
- *Chlorella* (Chlorophyceae)

Figures 4-3 through 4-15 show phytoplankton abundance by group for each monitoring station in 2004. A list of all phytoplankton genera identified, their shape codes, and the total number counted can be found in the *Phytoplankton Dictionary,* which is available online at:
http://www.iep.ca.gov/emp/Metadata/phytoplankton_metadata.html .

Pigment Concentrations

Chlorophyll *a* concentrations generally showed some seasonal patterns. The highest chlorophyll *a* concentrations occurred during spring and summer for most stations, while the lowest concentrations occurred during late fall and winter.

Monthly chlorophyll *a* concentrations throughout much of the Estuary were relatively low when compared to historical data, with 96 percent of the 135 samples taken in 2004 having levels below 15 µg/L, and 76 percent of all samples having levels below 5 µg/L. The mean chlorophyll *a* concentration for all samples in 2004 was 5.26 µg/L, and the median value was 2.03 µg/L. The maximum chlorophyll *a* concentration in 2004 was 94.2 µg/L, recorded in July at the San Joaquin River at Vernalis (C10) monitoring site. Chlorophyll *a* maxima were recorded in the spring or summer at all stations, except in the Suisun Bay at Bulls Head near Martinez (D6) where the maximum was recorded in September. The minimum chlorophyll *a* concentration in 2004 was 0.43 µg/L, which was recorded in January at the Old River across the river from the Rancho Del Rio (D28A) monitoring location.

The highest chlorophyll *a* concentrations were measured at Vernalis, Buckley Cove, and Disappointment Slough (stations C10, P8, and MD10), with mean concentrations of 29.3, 7.8, and 6.2 µg/L, respectively. Mean yearly chlorophyll *a* concentrations recorded at the other Estuary locations ranged from 1.6 µg/L in Suisun Bay off Middle Point near Nichols (D8) to 3.8 µg/L in San Pablo Bay near Pinole Point (D41).

Pheophytin *a* concentrations remained fairly constant and did not show apparent seasonal patterns. Percent chlorophyll *a* concentrations, in relation to pheophytin *a*, ranged from 32 percent to 89 percent, with a mean of 65 percent and a median of 66 percent. In addition, 69 percent of the samples collected had chlorophyll *a* levels above 60 percent. In 2003, 80 percent of the samples collected had chlorophyll *a* levels above 60 percent.

The mean pheophytin *a* concentration for all samples in 2004 was 2.09 µg/L, and the median value was 1.19 µg/L. Mean and median pheophytin *a* values in 2003 were comparable with values of 1.82 µg/L and 0.96 µg/L, respectively.

Figures 4-16 through 4-28 show the results of chlorophyll *a* and pheophytin *a* analysis. (Note: there was no December chlorophyll data due to a laboratory error). All chlorophyll *a* and pheophytin *a* data can be found at:
http://www.iep.ca.gov/emp/data_index.html .

Site C10: South Delta

Station C10 demonstrated a distinct seasonal pattern with its highest pigment concentrations recorded during summer and the lowest recorded during winter (Figure 4-16). A maximum chlorophyll *a* concentration of 94.2 µg/L was recorded in July and was associated with the families Bacillariophyceae and Chlorophyceae (Figure 4-3). A minimum of 5.8 µg/L was recorded in February and was associated with families Cyanophyceae and Bacillariophyceae. The mean chlorophyll *a* concentration at Station C10 during 2004 was 29.3 µg/L, the highest of the thirteen monitoring stations. High chlorophyll *a* concentrations recorded during the summer, including one outlier, skewed the mean higher than the median (20.9 µg/L) (Figure 4-30). Chlorophyll *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean chlorophyll *a* value was 23.8 µg/L and the median was 14.7 µg/L.

The maximum pheophytin *a* concentration occurred in August (14.9 µg/L) and was associated with the phytoplankton family Bacillariophyceae. The minimum concentration was recorded in February (2.70 µg/L) and was associated with the same families as the chlorophyll minimum. In 2004 the mean pheophytin *a* concentration was 6.72 µg/L and the median was 5.30 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 4.68 µg/L and the median was 3.77 µg/L.

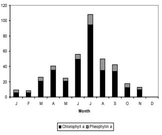


Figure 4-16 Chlorophyll *a* and Pheophytin *a* concentrations at station C10, 2004

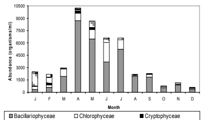


Figure 4-3 Phytoplankton family abundance at station C10, 2004

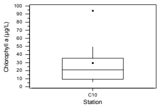


Figure 4-30 Chlorophyll *a* boxplot for station C10, 2004

Site P8: South Delta

The highest chlorophyll *a* concentrations at Station P8 were recorded during the spring and fall, while the lowest were recorded during the late fall and early winter (Figure 4-17). A maximum chlorophyll *a* concentration of 17.0 µg/L was recorded in April and was associated with the families Chlorophyceae and Bacillariophyceae (Figure 4-4). A minimum of 2.02 µg/L was recorded in January and was associated with the families Chlorophyceae and Cryptophyceae. The mean chlorophyll *a* concentration at Station P8 during 2004 was 7.80 µg/L. The mean and median values were identical (7.80 µg/L) (Figure 4-31). Chlorophyll *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean chlorophyll *a* value was 12.9 µg/L and the median was 9.4 µg/L.

The maximum pheophytin *a* concentration occurred in October (12.8 µg/L) and was associated with the families Cyanophyceae and Chlorophyceae. The minimum concentration occurred in January (2.69 µg/L) and was associated with the same phytoplankton families as the chlorophyll minimum. In 2004 the mean pheophytin *a* concentration was 5.62 µg/L and the median was 4.23 µg/L. Pheophytin *a* concentrations recorded in 2003 were higher (median) than in 2004. In 2003 the mean pheophytin *a* value was 5.21 µg/L and the median was 4.49 µg/L.

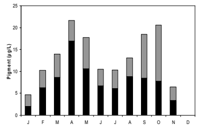


Figure 4-17 Chlorophyll *a* and Pheophytin *a* concentrations at station P8, 2004

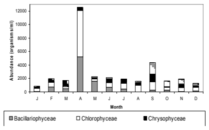


Figure 4-4 Phytoplankton family abundance at station P8, 2004

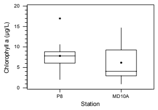


Figure 4-31 Chlorophyll *a* boxplots for stations P8 and MD10A, 2004

Site MD10A: East Delta

Chlorophyll *a* concentrations at Station MD10A were relatively high in April, June, July, and October and were relatively low in January and November (Figure 4-18). The maximum chlorophyll *a* concentration during

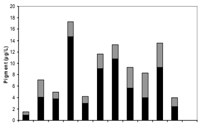


Figure 4-18 Chlorophyll *a* and Pheophytin *a* concentrations at station MD10A, 2004

2004 occurred in April (14.7 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Cryptophyceae (Figure 4-5). The minimum concentration occurred in January (0.92 µg/L) and was associated with the families Bacillariophyceae and Chlorophyceae. The mean chlorophyll *a* concentration at Station MD10A during 2004 was 6.15 µg/L. High chlorophyll *a* concentrations skewed the mean higher than the median (4.04 µg) (Figure 4-31). Chlorophyll *a* concentrations recorded in 2003 were lower (median) than in 2004. In 2003 the mean chlorophyll *a* value was 8.24 µg/L and the median was 3.77 µg/L.

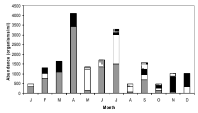


Figure 4-5 Phytoplankton family abundance at station MD10A, 2004

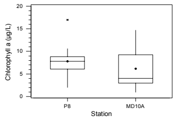


Figure 4-31 Chlorophyll *a* boxplots for stations P8 and MD10A, 2004

The maximum pheophytin *a* concentration occurred in September (4.35 µg/L) and was associated with the families Bacillariophyceae, Chlorophyceae, Cryptophyceae, and Cyanophyceae. The minimum concentration occurred in January (0.60 µg/L) and was associated with the same families as the chlorophyll minimum. In 2004 the mean pheophytin *a* concentration was 2.49 µg/L and the median was 2.56 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 2.21 µg/L and the median was 1.36 µg/L.

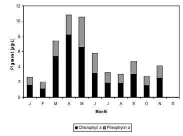


Figure 4-19 Chlorophyll *a* and Pheophytin *a* concentrations at station C3/C3A, 2004

Site C3/C3A: North Delta

Station C3/C3A demonstrated a clear seasonal pattern with its highest chlorophyll *a* concentrations recorded during spring and its lowest recorded during winter (Figure 4-19). The maximum chlorophyll *a* concentration during 2004 occurred in April (8.19 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Cryptophyceae (Figure 4-6). The minimum concentration occurred in February (1.14 µg/L) and was associated with the families Bacillariophyceae and Chlorophyceae. The mean chlorophyll concentration during 2004 at Station C3/C3A was 3.33 µg/L. High chlorophyll *a* concentrations recorded in March, April and May skewed the mean higher than the median (2.45 µg/L) (Figure 4-32). Chlorophyll *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean chlorophyll *a* value was 2.20 µg/L and the median was 1.85 µg/L.

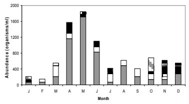


Figure 4-6 Phytoplankton family abundance at station C3/C3A, 2004

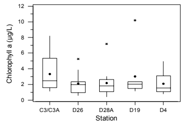


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

The maximum pheophytin *a* concentration occurred in May (3.95 µg/L) and was associated with the phytoplankton family Bacillariophyceae. The minimum concentration occurred in February (0.87 µg/L) and was associated with same families as the chlorophyll minimum. In 2004 the mean pheophytin *a* concentration was 1.86 µg/L and the median was 1.67 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 1.03 µg/L and the median was 0.91 µg/L.

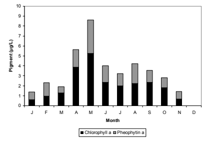


Figure 4-20 Chlorophyll *a* and Pheophytin *a* concentrations at station D26, 2004

Site D26: Lower San Joaquin River

Chlorophyll *a* concentrations were highest during spring and lowest during winter (Figure 4-20). The maximum chlorophyll *a* concentration during 2004 occurred in May (5.25 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Cryptophyceae (Figure 4-7). The minimum concentration occurred in January (0.59 µg/L) and was associated with the families Bacillariophyceae and unidentified flagellates. The mean chlorophyll *a* concentration at Station D26 during 2004 was 2.12 µg/L. High

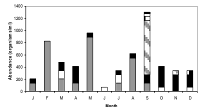


Figure 4-7 Phytoplankton family abundance at station D26, 2004

chlorophyll *a* concentrations recorded in the spring, including one outlier, skewed the mean slightly higher than the median (1.98 µg/L) (Figure 4-32). Chlorophyll *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean chlorophyll *a* value was 1.67 µg/L and the median was 1.92 µg/L.

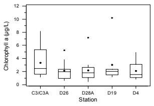


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

The maximum pheophytin *a* concentration occurred in May (3.36 µg/L) and was associated with the same phytoplankton families as the chlorophyll maximum. The minimum concentration occurred in March (0.65 µg/L) and was associated with the phytoplankton families Bacillariophyceae, Chlorophyceae, and Cryptophyceae. In 2004 the mean pheophytin *a* concentration was 1.43 µg/L and the median was 1.24 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 1.39 µg/L and the median was 0.80 µg/L.

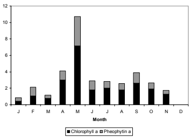


Figure 4-21 Chlorophyll *a* and Pheophytin *a* concentrations at station D28A, 2004

Site D28A: Central Delta

Chlorophyll *a* concentrations were highest during spring and lowest during winter (Figure 4-21). The maximum chlorophyll *a* concentration during 2004 occurred in May (7.16 µg/L) and was associated with the phytoplankton family Bacillariophyceae (Figure 4-8). The minimum concentration occurred in January (0.43 µg/L) and was associated with the Bacillariophyceae and Chlorophyceae families. The mean chlorophyll *a* concentration at Station D28A during 2004 was 2.18 µg/L. High chlorophyll *a* concentrations recorded in the spring, including one outlier, skewed the mean higher than the median (1.82 µg/L) (Figure 4-32). Chlorophyll *a* concentrations recorded in 2003 were higher (median) than in 2004. In 2003 the mean chlorophyll *a* value was 2.14 µg/L and the median was 2.11 µg/L.

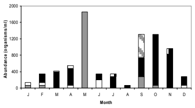


Figure 4-8 Phytoplankton family abundance at station D28A, 2004

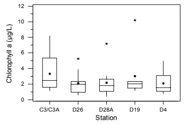


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

The maximum pheophytin *a* concentration occurred in May (3.54 µg/L) and was associated with the same families as the chlorophyll maximum. The minimum concentration occurred in March (0.40 µg/L) and was associated with the phytoplankton family Cryptophyceae and unidentified flagellates. In 2004 the mean pheophytin *a* concentration was 1.06 µg/L and the median was 0.82 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 0.72 µg/L and the median was 0.67 µg/L.

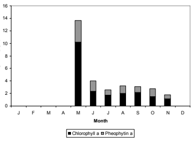


Figure 4-22 Chlorophyll *a* and Pheophytin *a* concentrations at station D19, 2004

Site D19: Central Delta

The highest chlorophyll *a* concentration was recorded in late spring and the lowest during late fall (Figure 4-22). (Note: for 2004, sampling started in May when the site was re-established) The maximum chlorophyll *a* concentration during 2004 occurred in May (10.2 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Cryptophyceae (Figure 4-9). The minimum concentration occurred in November (1.15 µg/L) and was associated with Cryptophyceae family. The mean chlorophyll *a* concentration at Station D19 during 2004 was 3.02 µg/L. The high chlorophyll *a* concentrations (outlier) in May as well as an incomplete data set skewed the mean outside the third quartile or 75th percentile and upper limit (Figure 4-32). Thus the median (2.03 µg/L) was much lower than the mean.

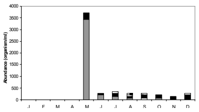


Figure 4-9 Phytoplankton family abundance at station D19, 2004

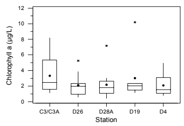


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

The maximum pheophytin *a* concentration occurred in May (3.47 µg/L) and was associated with the same families as the chlorophyll maximum. The minimum concentration occurred in November (0.65 µg/L) and was associated with the same families as the chlorophyll minimum. In 2004 the mean pheophytin *a* concentration was 1.43 µg/L and the median was 1.19 µg/L.

Site D4: Lower Sacramento River

Station D4 demonstrated a distinct seasonal pattern with its highest pigment concentrations recorded during spring and its lowest recorded during fall (Figure 4-23). The maximum chlorophyll *a* concentration during 2004 occurred in March (4.94 µg/L) and was associated with the phytoplankton families Bacillariophyceae, Chlorophyceae, and unidentified flagellates (Figure 4-10). The minimum concentration occurred in November (0.80 µg/L) and was associated with the Cryptophyceae family. The mean chlorophyll *a* concentration at Station D4 during 2004 was 2.08 µg/L. High chlorophyll *a* concentrations recorded in the spring skewed the mean higher than the median (1.54 µg/L) (Figure 4-32). Chlorophyll *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean chlorophyll *a* value was 2.36 µg/L and the median was 2.58 µg/L.

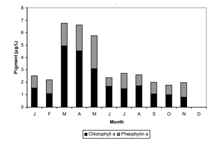


Figure 4-23 Chlorophyll *a* and Pheophytin *a* concentrations at station D4, 2004

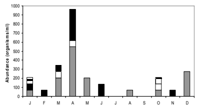


Figure 4-10 Phytoplankton family abundance at station D4, 2004

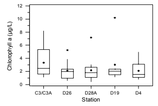


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

The maximum pheophytin *a* concentration occurred in May (2.65 µg/L) and was associated with the phytoplankton family Bacillariophyceae. The minimum concentration occurred in June (0.69 µg/L) and was associated with the family Cryptophyceae. In 2004 the mean pheophytin *a* concentration was 1.31 µg/L and the median was 1.12 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 0.97 µg/L and the median was 0.88 µg/L.

Site D8: Suisun Bay

Station D8 demonstrated a clear seasonal pattern with its highest chlorophyll *a* concentrations recorded during early and mid spring and its lowest recorded during late fall and winter (Figure 4-24). The maximum chlorophyll *a* concentration during 2004 occurred in April (3.75 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Chlorophyceae (Figure 4-11). The minimum concentration occurred in January (0.56 µg/L). No phytoplankton were identified in the January sample. The mean chlorophyll *a* concentration at Station D8 during 2004 was 1.56 µg/L. High chlorophyll *a* concentrations recorded in the spring and summer skewed the mean higher than the median (1.17 µg/L) (Figure 4-33). Chlorophyll *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean chlorophyll *a* value was 1.92 µg/L and the median was 1.46 µg/L.

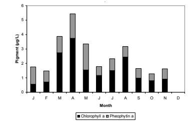


Figure 4-24 Chlorophyll *a* and Pheophytin *a* concentrations at station D8, 2004

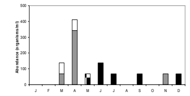


Figure 4-11 Phytoplankton family abundance at station D8, 2004

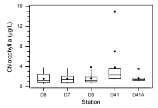


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

The maximum pheophytin *a* concentration occurred in May (1.81 µg/L) and was associated with the phytoplankton family unidentified flagellates. The minimum concentration occurred in October (0.48 µg/L). No phytoplankton were identified in the October sample. In 2004 the mean pheophytin *a* concentration was 0.97 µg/L and the median was 0.76 µg/L. Pheophytin *a* concentrations recorded in 2003 were higher (median) than in 2004. In 2003 the mean pheophytin *a* value was 0.85 µg/L and the median was 0.91 µg/L.

Site D7: Suisun Bay

Chlorophyll *a* concentrations at Station D7 were highest in early and mid spring and lowest in the late fall and early winter (Figure 4-25). The maximum chlorophyll *a* concentration during 2004 occurred in March (3.61 µg/L). No phytoplankton were identified in the March sample (Figure 4-12). The minimum concentration occurred in January (0.63 µg/L) and was associated with the families Bacillariophyceae, Chlorophyceae, and Cryptophyceae. The mean chlorophyll *a* concentration at Station D7 during 2004 was 1.59 µg/L. High chlorophyll *a* concentrations in March and April skewed the mean slightly higher than the median (1.38 µg/L) (Figure 4-33). Chlorophyll *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean chlorophyll *a* value was 2.10 µg/L and the median was 1.49 µg/L.

The maximum pheophytin *a* concentration occurred in April (2.51 µg/L); however, no phytoplankton were identified in the April sample. The minimum pheophytin *a* concentration occurred in June (0.20 µg/L); however, no phytoplankton were identified in the June sample. In 2004 the mean pheophytin *a* concentration was 1.26 µg/L and the median was 1.30 µg/L. Pheophytin *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean pheophytin *a* value was 1.57 µg/L and the median was 1.35 µg/L.

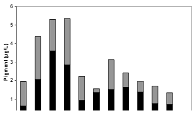


Figure 4-25 Chlorophyll *a* and Pheophytin *a* concentrations at station D7, 2004

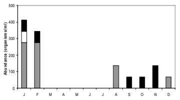


Figure 4-12 Phytoplankton family abundance at station D7, 2004

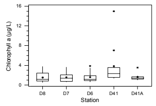


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

Site D6: Suisun Bay

The highest chlorophyll *a* concentrations at Station D6 were recorded during late summer and early fall and the lowest recorded during mid winter (Figure 4-26). The maximum chlorophyll *a* concentration during 2004 occurred in September (3.86 µg/L) and was associated with the phytoplankton family Cryptophyceae (Figure 4-13). The minimum concentration occurred in February (0.65 µg/L) and was associated with the Bacillariophyceae and Cryptophyceae families. The mean chlorophyll *a* concentration at Station D6 during 2004 was 1.61 µg/L. High chlorophyll *a* concentrations recorded in the late summer and early fall, including one outlier, skewed the mean higher than the median (1.16 µg/L) (Figure 4-33). Chlorophyll *a* concentrations recorded in 2003 were higher than in 2004. In 2003 the mean chlorophyll *a* value was 2.10 µg/L and the median was 1.68 µg/L.

The maximum pheophytin *a* concentration occurred in April (1.22 µg/L) and was associated with the same family Bacillariophyceae. The minimum concentration occurred in June (0.16 µg/L). No phytoplankton were identified in the June sample. In 2004 the mean pheophytin *a* concentration was 0.68 µg/L and the median was 0.70 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 0.63 µg/L and the median was 0.61 µg/L.

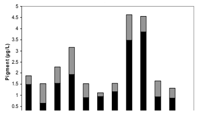


Figure 4-26 Chlorophyll *a* and Pheophytin *a* concentrations at station D6, 2004

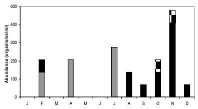


Figure 4-13 Phytoplankton family abundance at station D6, 2004

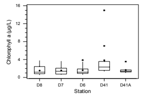


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

Site D41: San Pablo Bay

The highest chlorophyll *a* concentrations were recorded during early and mid spring, while the lowest were recorded in February and July (Figure 4-27). The maximum chlorophyll *a* concentration during 2004 occurred in March (15.0 µg/L) and was associated with the phytoplankton families Bacillariophyceae and Chlorophyceae (Figure 4-14). The minimum concentration occurred in February (1.40 µg/L) and was associated with the Cryptophyceae family and with unidentified flagellates. The mean chlorophyll *a* concentration at Station D41 during 2004 was 3.83 µg/L. The high chlorophyll *a* concentrations (outliers) in March and April skewed the mean outside the third quartile (75th percentile) and upper limit (Figure 4-33). Thus the median (2.34 µg/L) was much lower than the mean. Chlorophyll *a* concentrations recorded in 2003 were higher (median) than in 2004. In 2003 the mean chlorophyll *a* value was 3.55 µg/L and the median was 3.39 µg/L.

The maximum pheophytin *a* concentration occurred in March (2.02 µg/L) and was associated with the same families as the chlorophyll *a* maximum (Bacillariophyceae and Chlorophyceae). The minimum concentration occurred in July (0.18 µg/L). No phytoplankton were identified in the July sample. In 2004 the mean pheophytin *a* concentration was 0.80 µg/L and the median was 0.63 µg/L. Pheophytin *a* concentrations recorded in 2003 were lower than in 2004. In 2003 the mean pheophytin *a* value was 0.64 µg/L and the median was 0.55 µg/L.

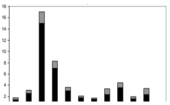


Figure 4-27 Chlorophyll *a* and Pheophytin *a* concentrations at station D41, 2004

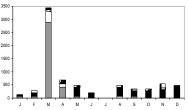


Figure 4-14 Phytoplankton family abundance at station D41, 2004

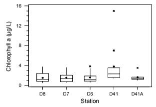


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

Site D41A: San Pablo Bay

The highest chlorophyll *a* concentration was recorded in late spring and the lowest during early summer (Figure 4-28). (Note: this is a newly added site and sampling commenced in May 2004.) The maximum chlorophyll *a* concentration during 2004 occurred in May (3.53 µg/L) and was associated with the phytoplankton family Cryptophyceae and unidentified flagellates (Figure 4-15). The minimum concentration occurred in June (1.04 µg/L). No phytoplankton were identified in the June sample. The mean chlorophyll *a* concentration at Station D41A during 2004 was 1.66 µg/L. The maximum chlorophyll *a* concentrations recorded in May skewed the mean higher than the median (1.38 µg/L) (Figure 4-33).

The maximum pheophytin *a* concentration occurred in May (2.32 µg/L) and was associated with the same families as the chlorophyll maximum. The minimum concentration occurred in September (0.25 µg/L) and was associated with the family Cryptophyceae. In 2004 the mean pheophytin *a* concentration was 0.82 µg/L and the median was 0.54 µg/L.

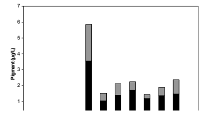


Figure 4-28 Chlorophyll *a* and Pheophytin *a* concentrations at station D41A, 2004

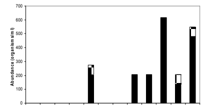


Figure 4-15 Phytoplankton family abundance at station D41A, 2004

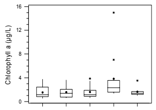


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2004. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following nine categories: diatoms, green algae, yellow-brown algae, cryptomonads, blue-green algae, dinoflagellates, euglenoids, yellow-green algae, and unidentified flagellates. The ten most common genera were *Cyclotella, Rhodomonas, Skeletonema*, *Aulacoseira, Thalassiosira, Dispora,* *Ankistrodesmus*, unidentified flagellates, *Selenastrum*, and *Chlorella*. Chlorophyll *a* concentrations showed a distinct seasonal pattern; values ranged from 0.43 µg/L to 94.2 µg/L. Pheophytin *a* concentrations did not show a seasonal pattern; values ranged from 0.16 µg/L to 14.9 µg/L. Overall, chlorophyll *a* concentrations were relatively low when compared with the historical data.

References

Alpine, A. E., and Cloern, J. E. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol. Oceanogr. 37: 946-955

[APHA] American Public Health Association, American Waterworks, and Water Environmental Federation. 1998. *Standard Methods for the Examination of Water and Wastewater.* 20th ed. Washington, D.C.: American Public Health Association.

Carmichael, W., ed. 1981. *The Water Environment, Algal Toxins and Health*. Plenum Press, New York, N.Y.

Gannon, J. E. and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. *Trans. Amer. Microsc*. 97:16.

Horne, A. and Goldman, C. 1994. Limnology. 2nd ed. New York, New York, McGraw-Hill, Inc.

Utermöhl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton Methodik. *Mitt. Int. Verh. Limnol.* 9: 38.

Van den Hoek, C., D.G. Mann, and H.M. Jahns. 1995. *Algae: An Introduction to Phycology*. Cambridge University Press, United Kingdom.

Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

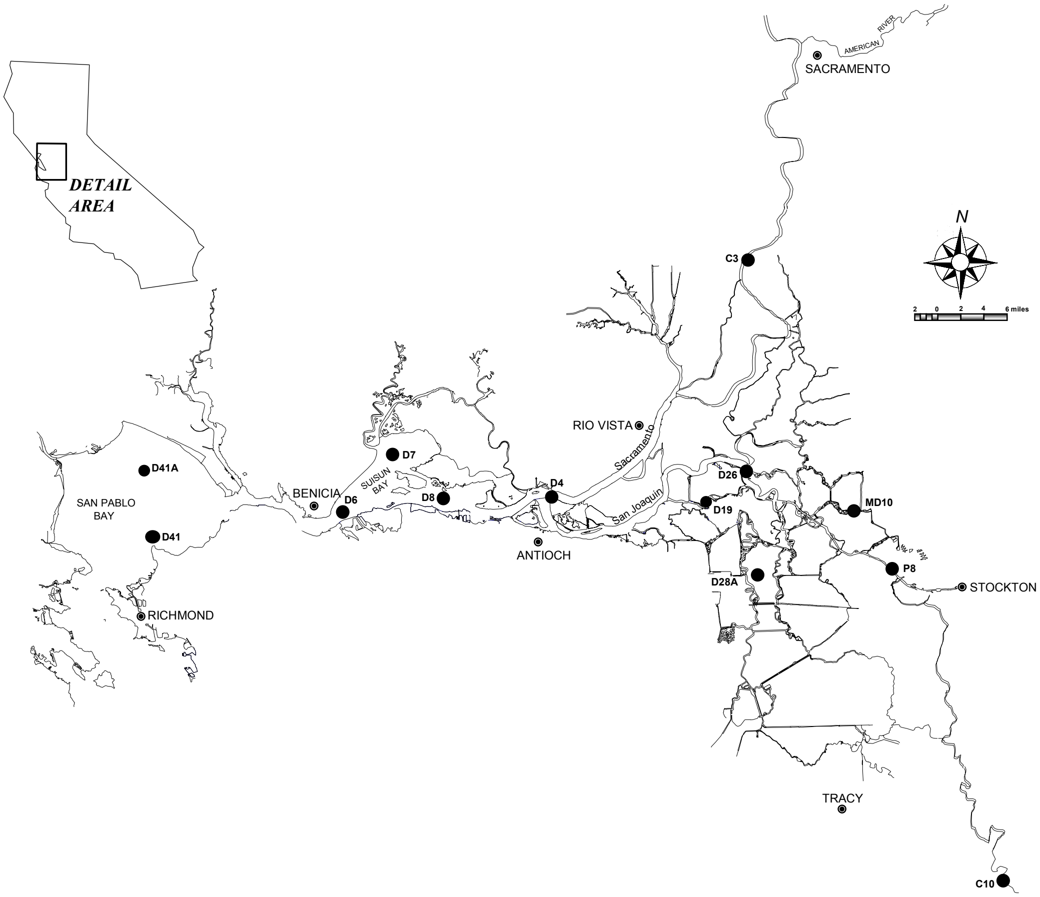


Figure 4-2 Total phytoplankton contribution by family at all stations

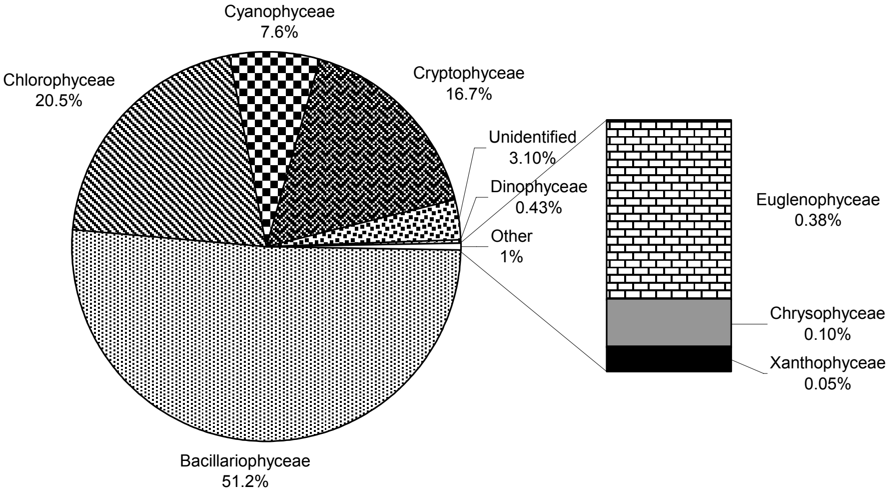


Figure 4-3 Phytoplankton family abundance at station C10, 2004

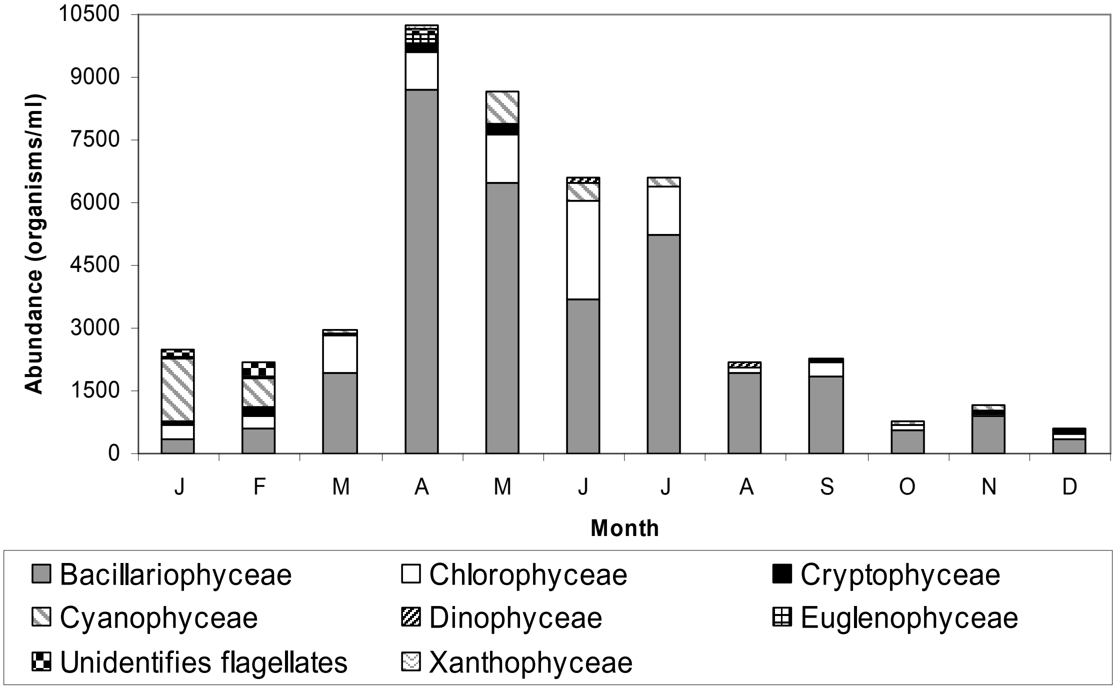


Figure 4-4 Phytoplankton family abundance at station P8, 2004

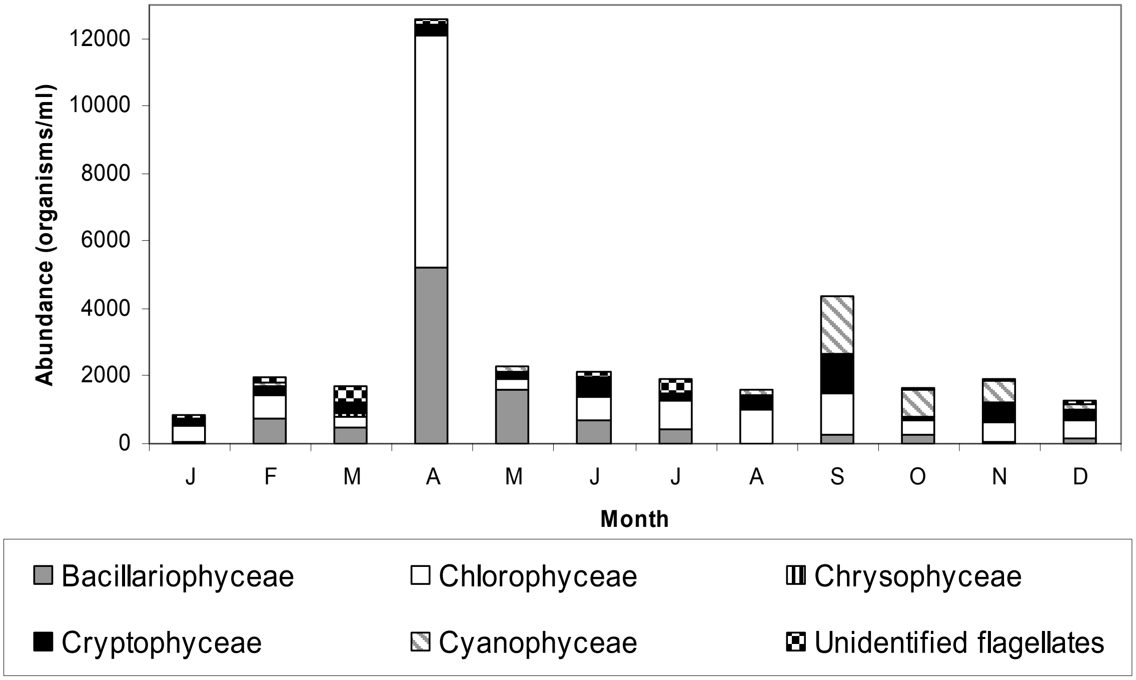


Figure 4-5 Phytoplankton family abundance at station MD10A, 2004

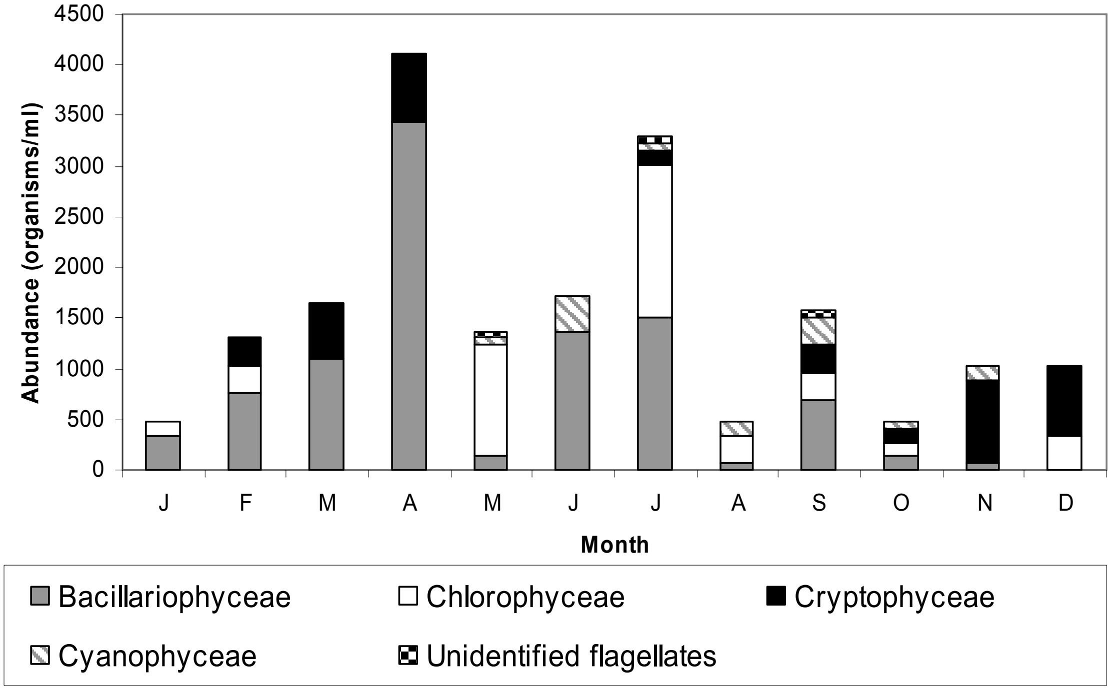


Figure 4-6 Phytoplankton family abundance at station C3/C3A, 2004

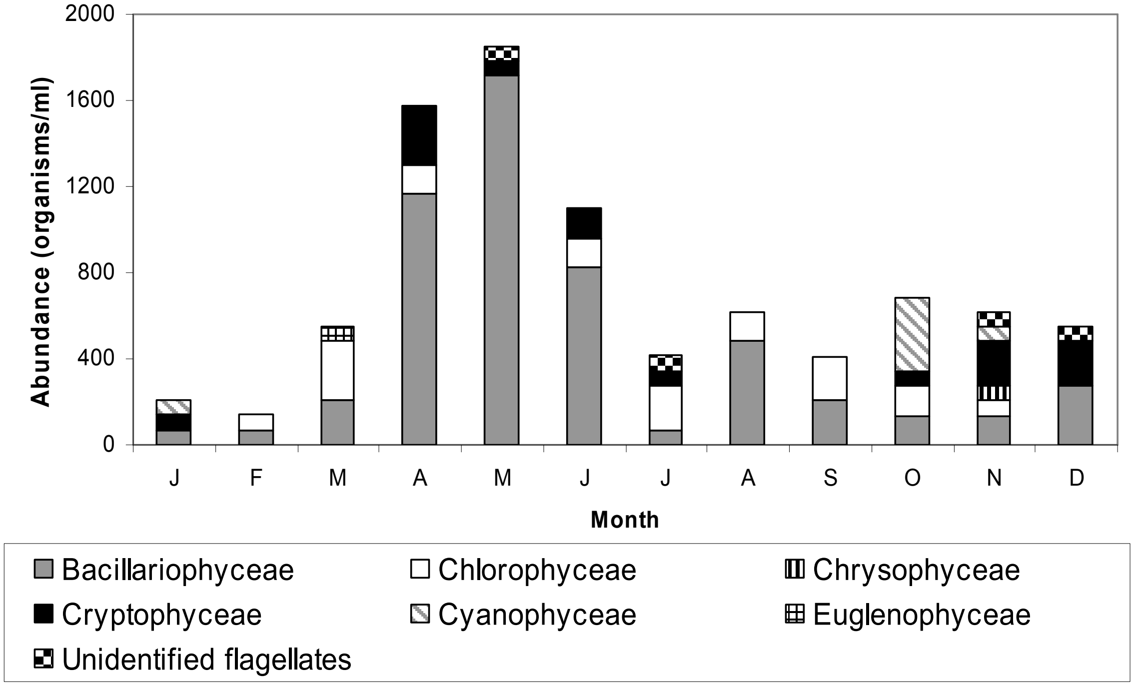


Figure 4-7 Phytoplankton family abundance at station D26, 2004

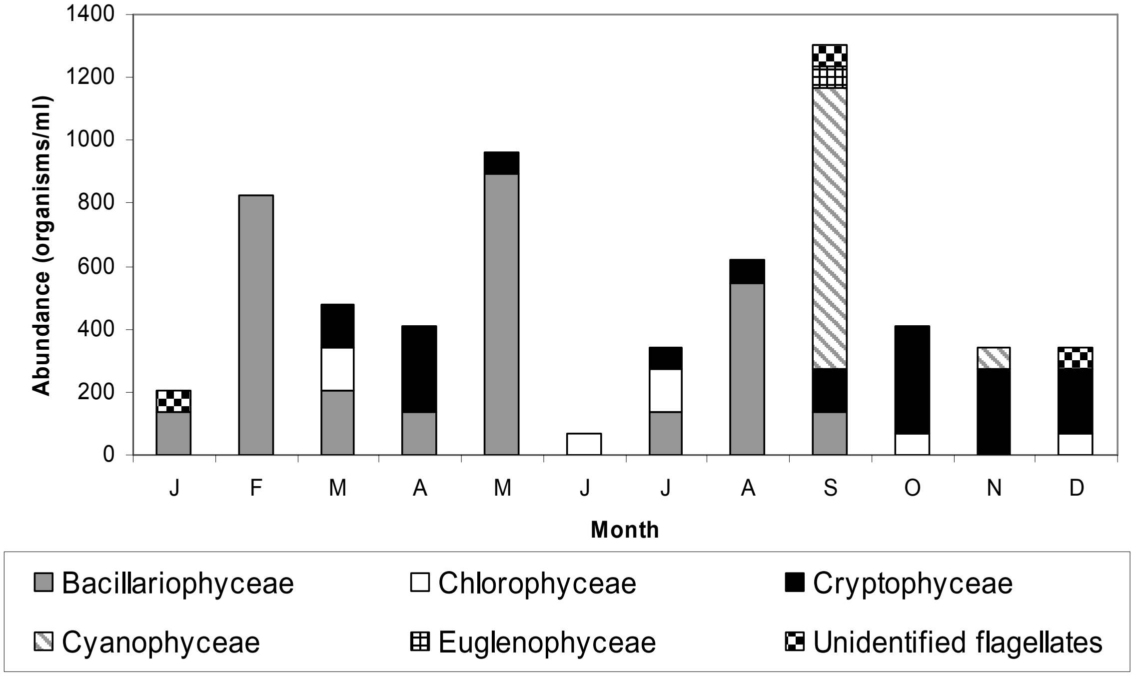


Figure 4-8 Phytoplankton family abundance at station D28A, 2004

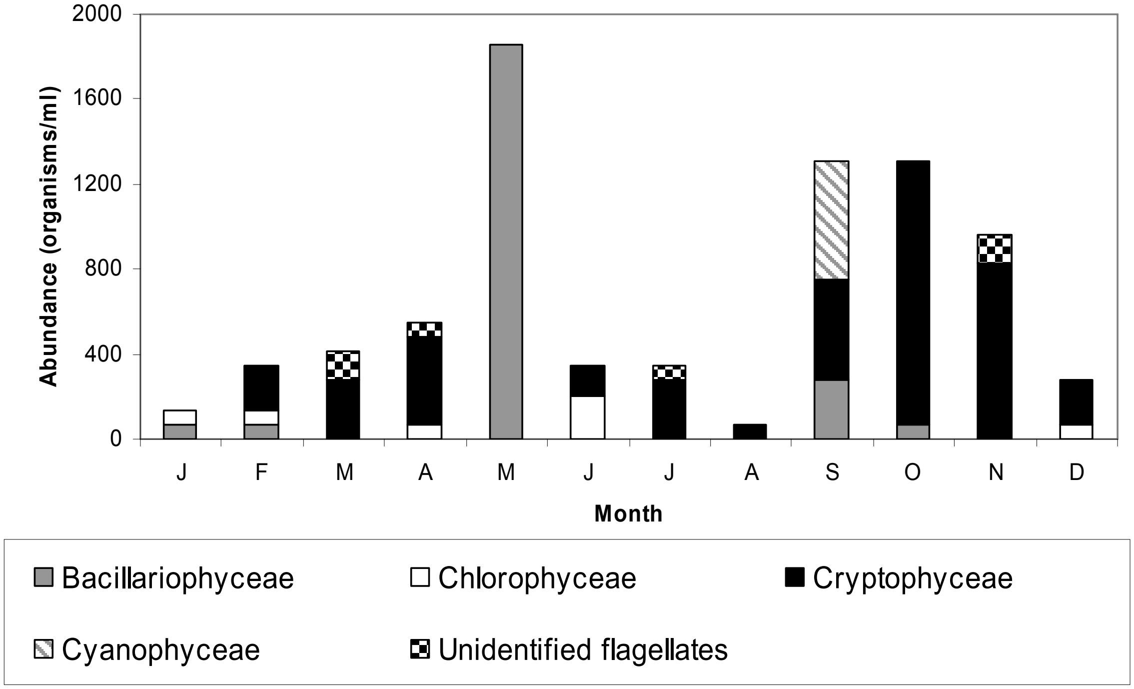


Figure 4-9 Phytoplankton family abundance at station D19, 2004

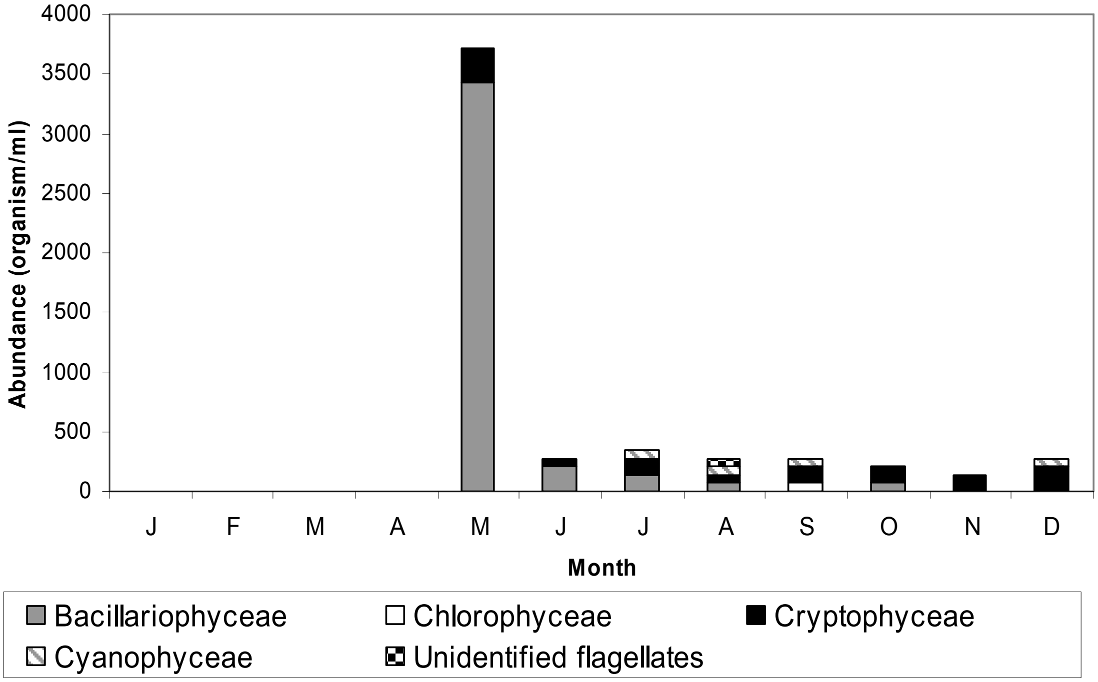


Figure 4-10 Phytoplankton family abundance at station D4, 2004

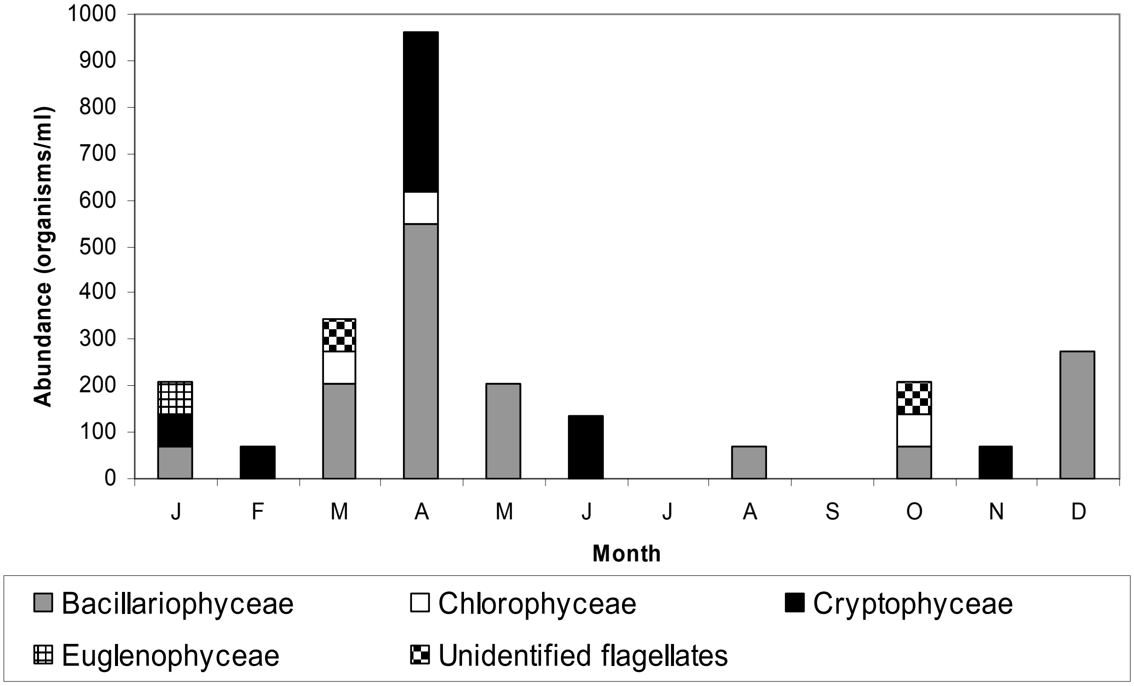


Figure 4-11 Phytoplankton family abundance at station D8, 2004

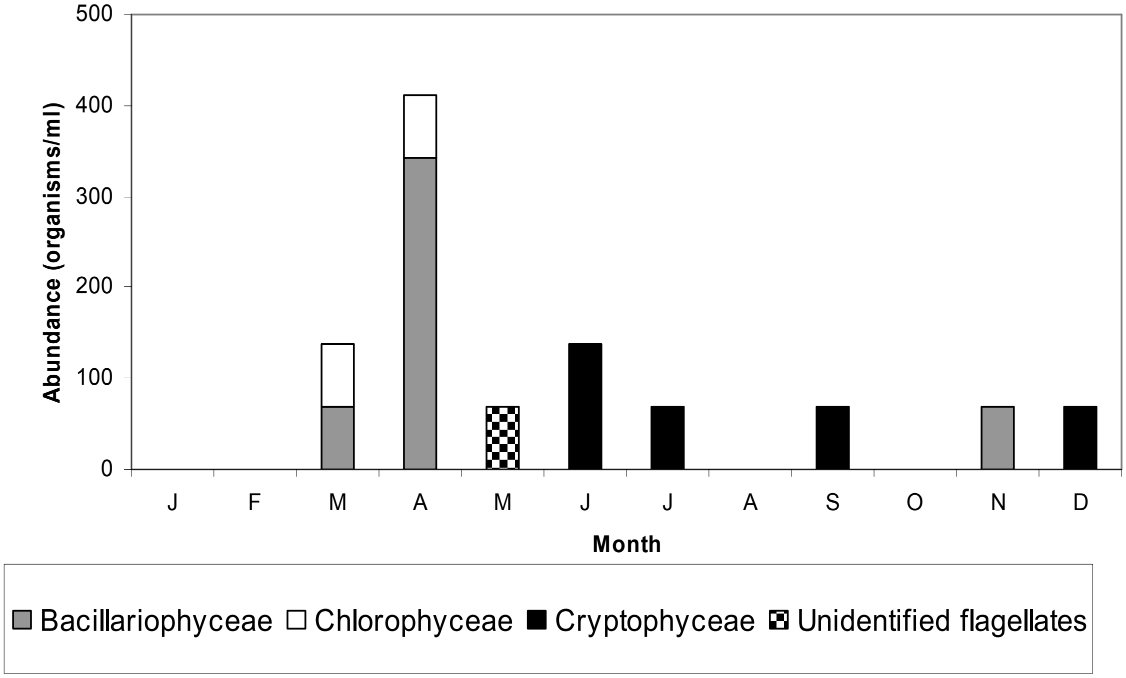


Figure 4-12 Phytoplankton family abundance at station D7, 2004

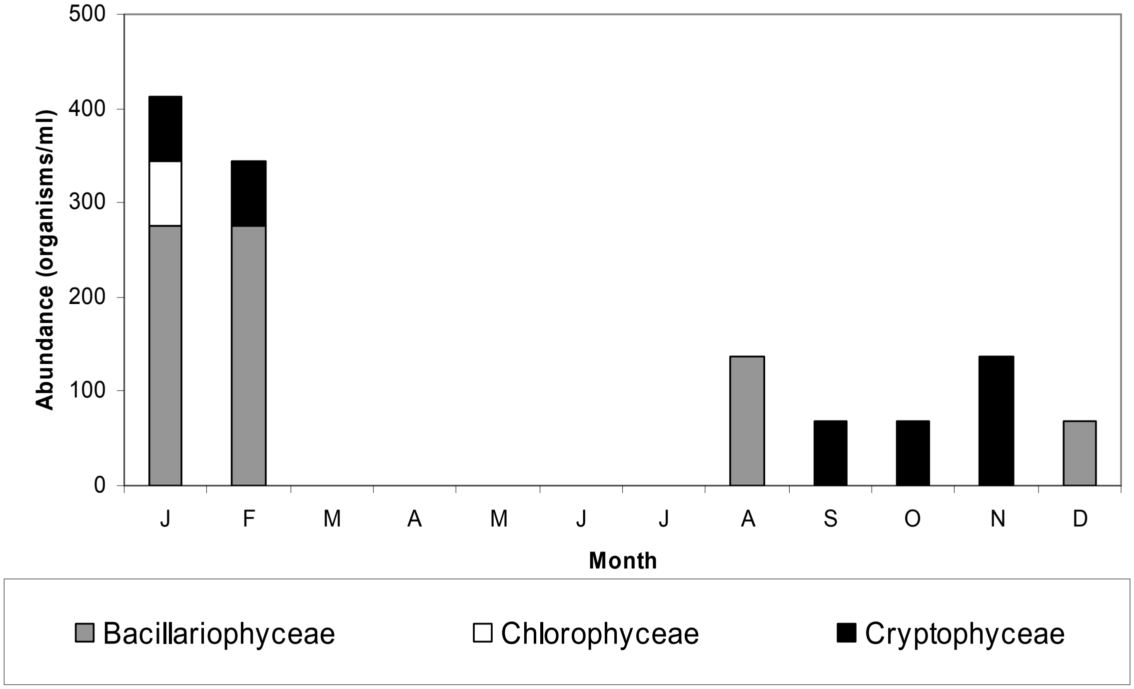


Figure 4-13 Phytoplankton family abundance at station D6, 2004

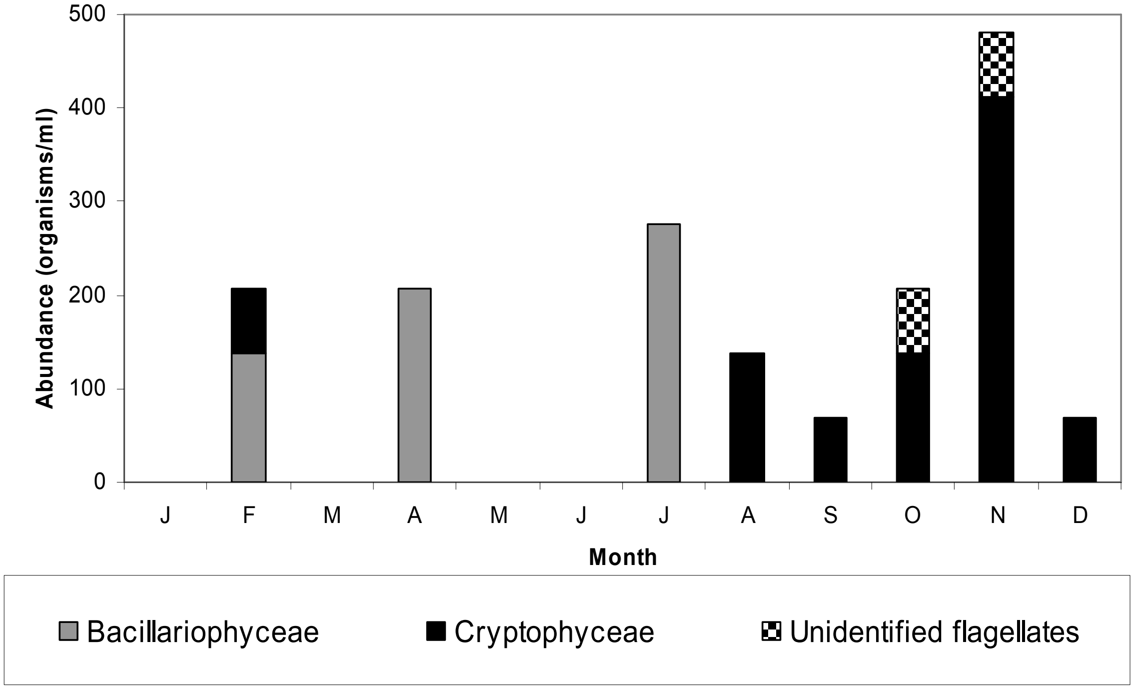


Figure 4-14 Phytoplankton family abundance at station D41, 2004

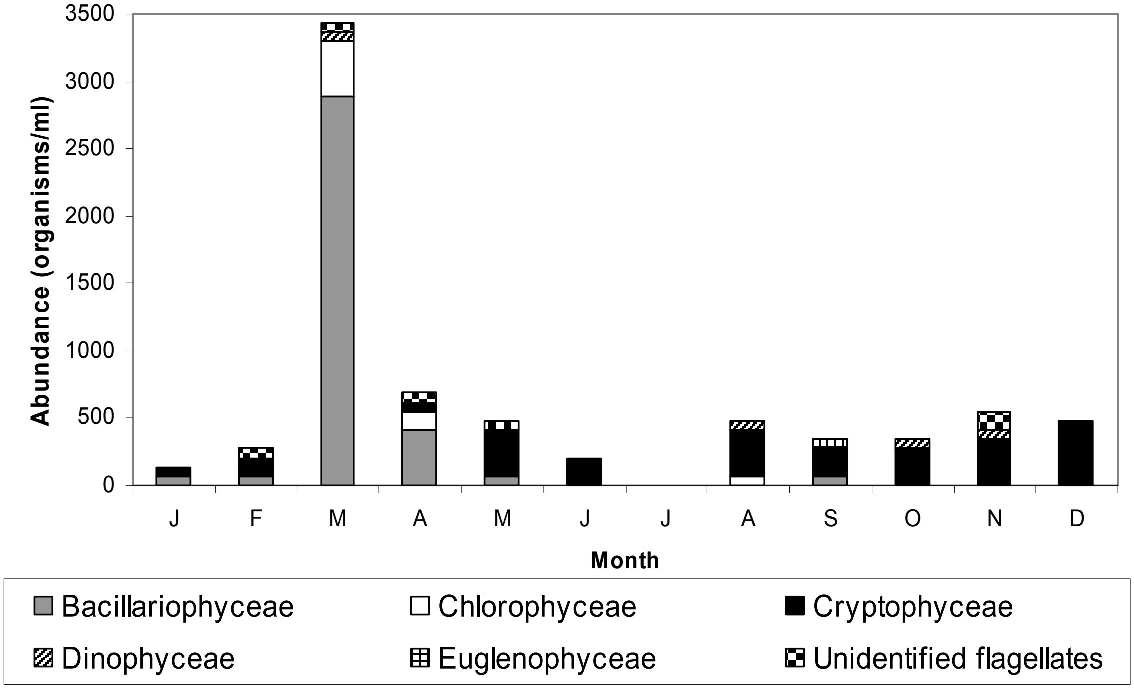


Figure 4-15 Phytoplankton family abundance at station D41A, 2004

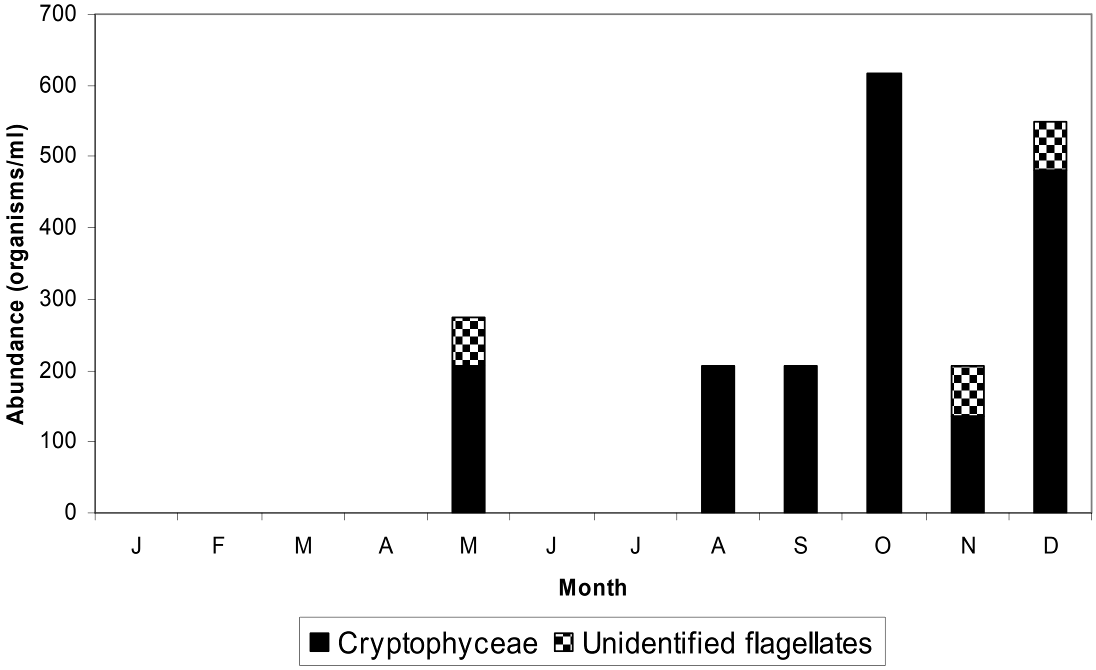


Figure 4-16 Chlorophyll *a* and Pheophytin *a* concentrations at station C10, 2004

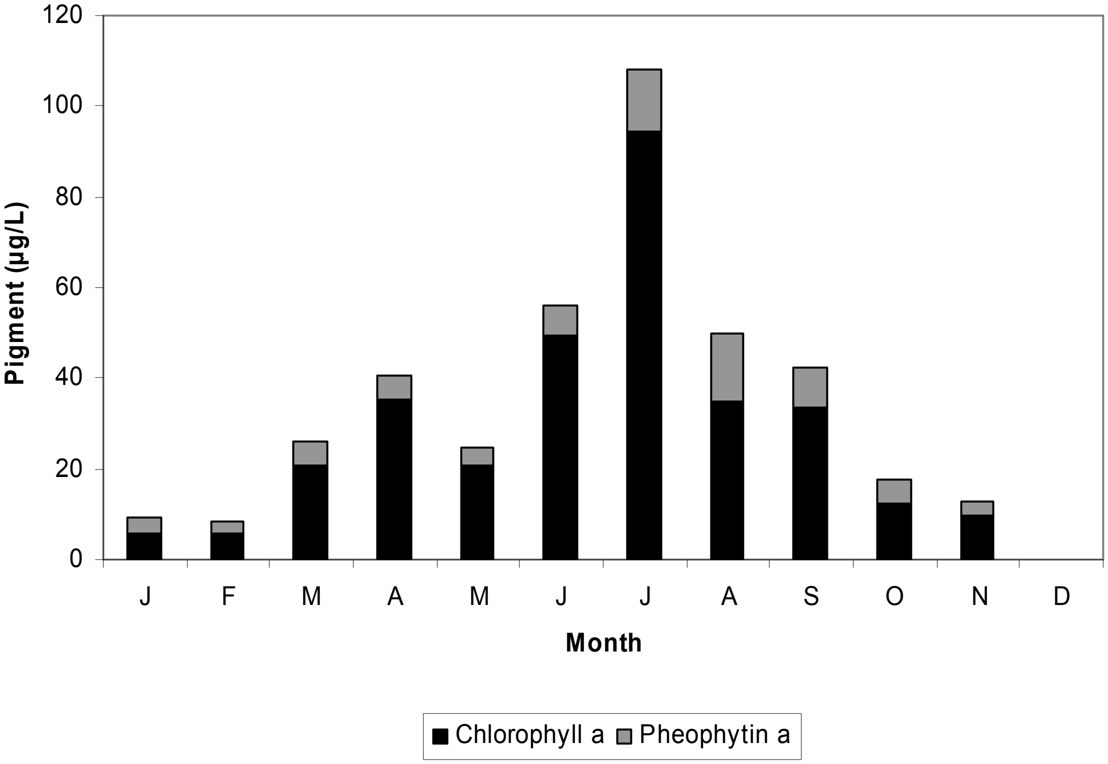


Figure 4-17 Chlorophyll *a* and Pheophytin *a* concentrations at station P8, 2004

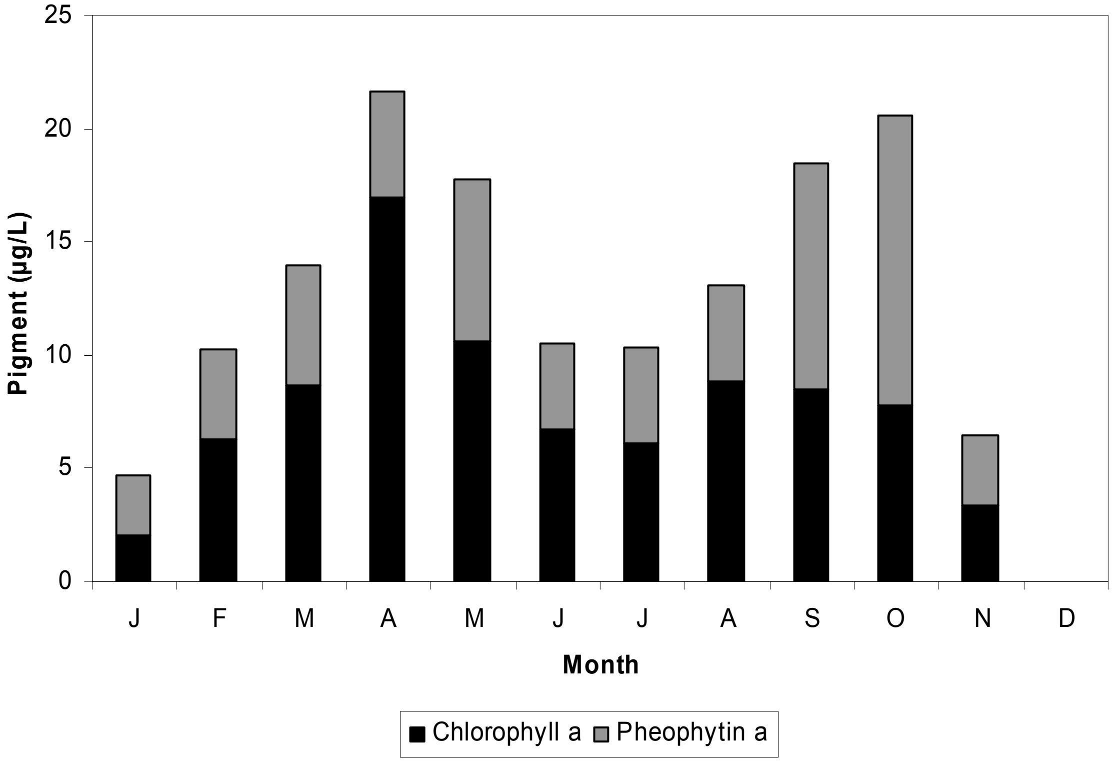


Figure 4-18 Chlorophyll *a* and Pheophytin *a* concentrations at station MD10A, 2004

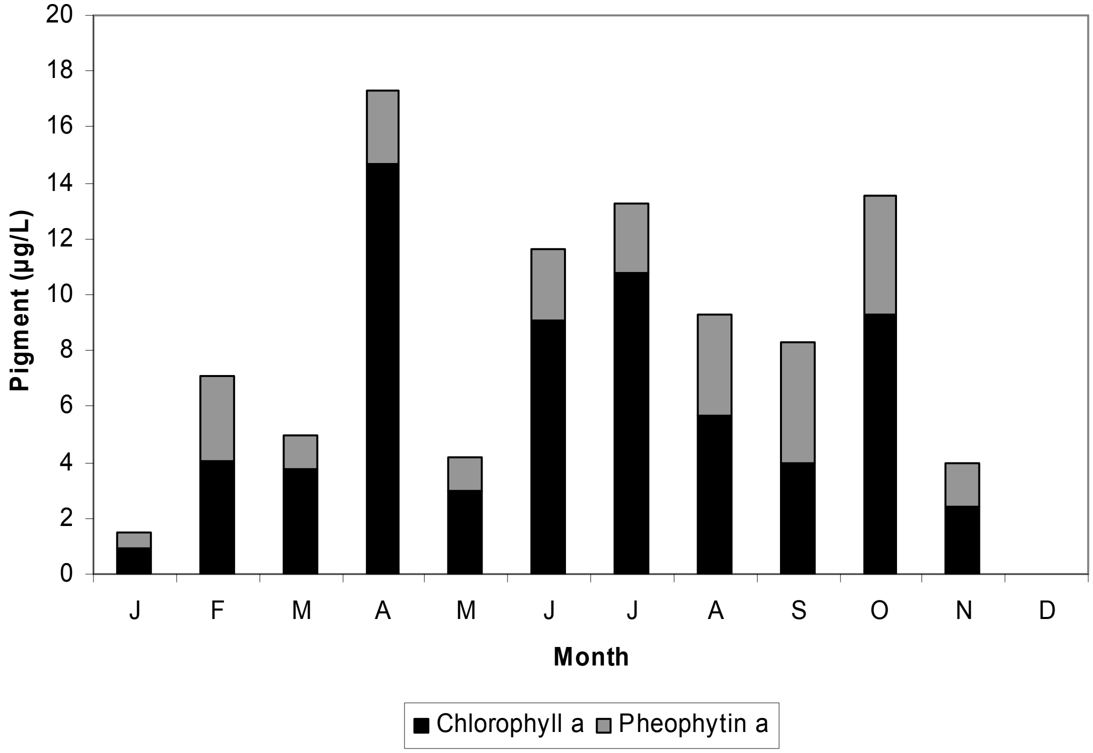


Figure 4-19 Chlorophyll *a* and Pheophytin *a* concentrations at station C3/C3A, 2004

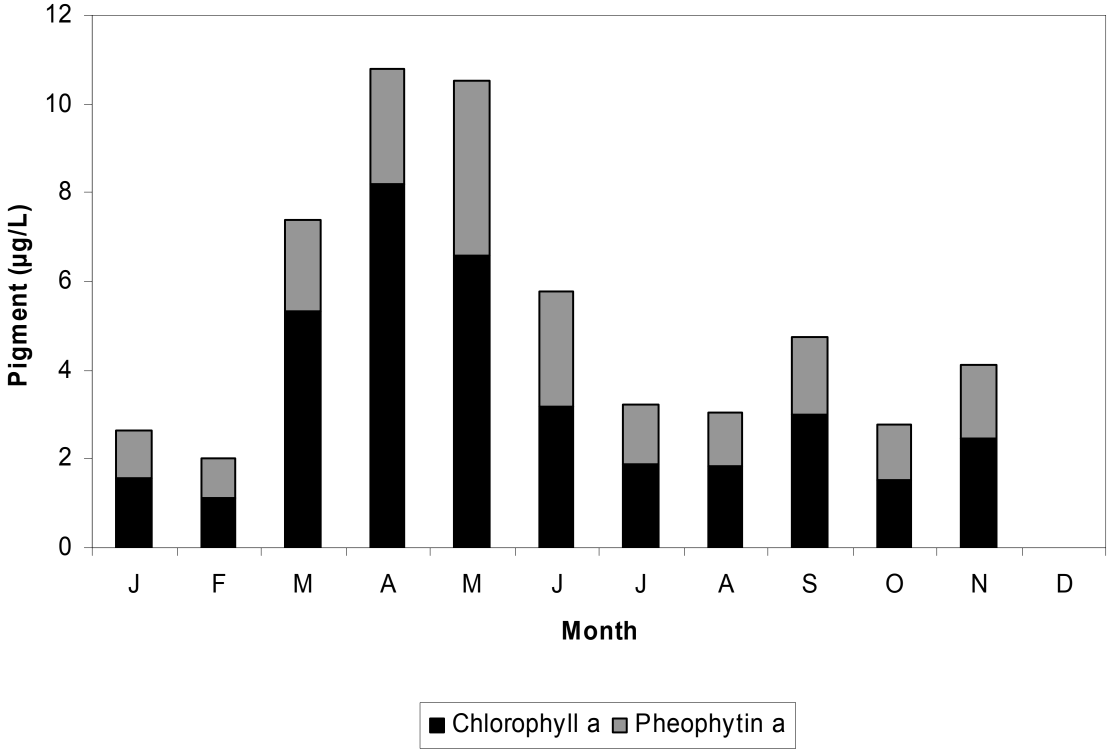


Figure 4-20 Chlorophyll *a* and Pheophytin *a* concentrations at station D26, 2004

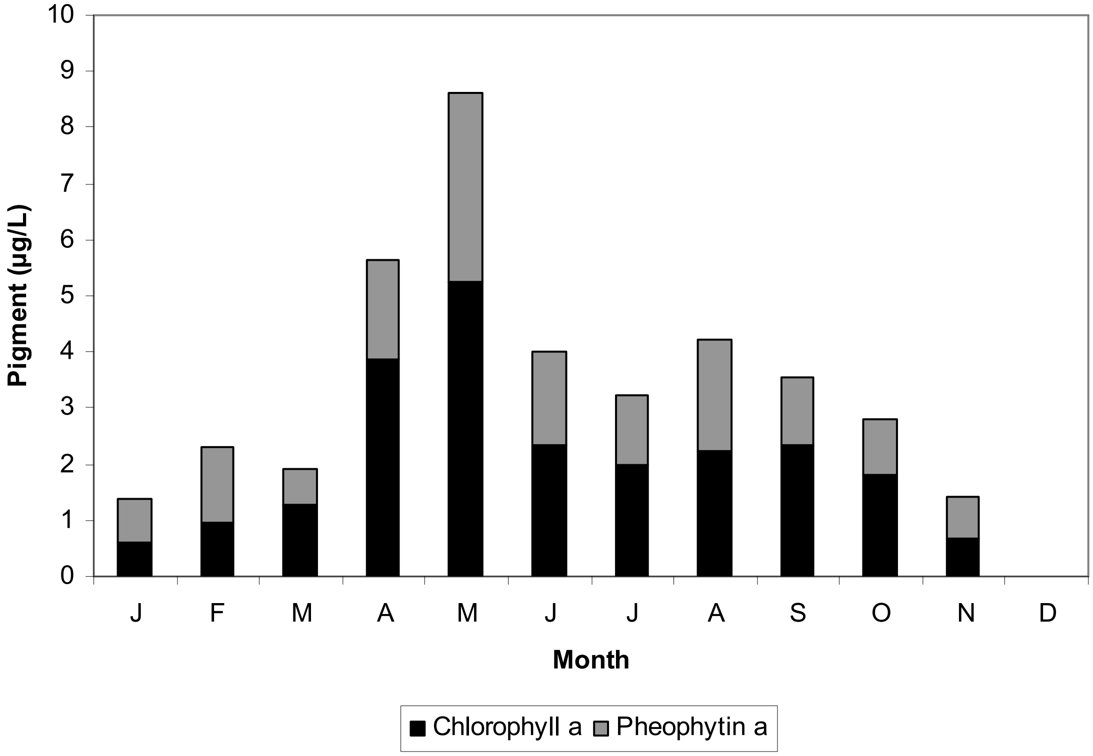


Figure 4-21 Chlorophyll *a* and Pheophytin *a* concentrations at station D28A, 2004

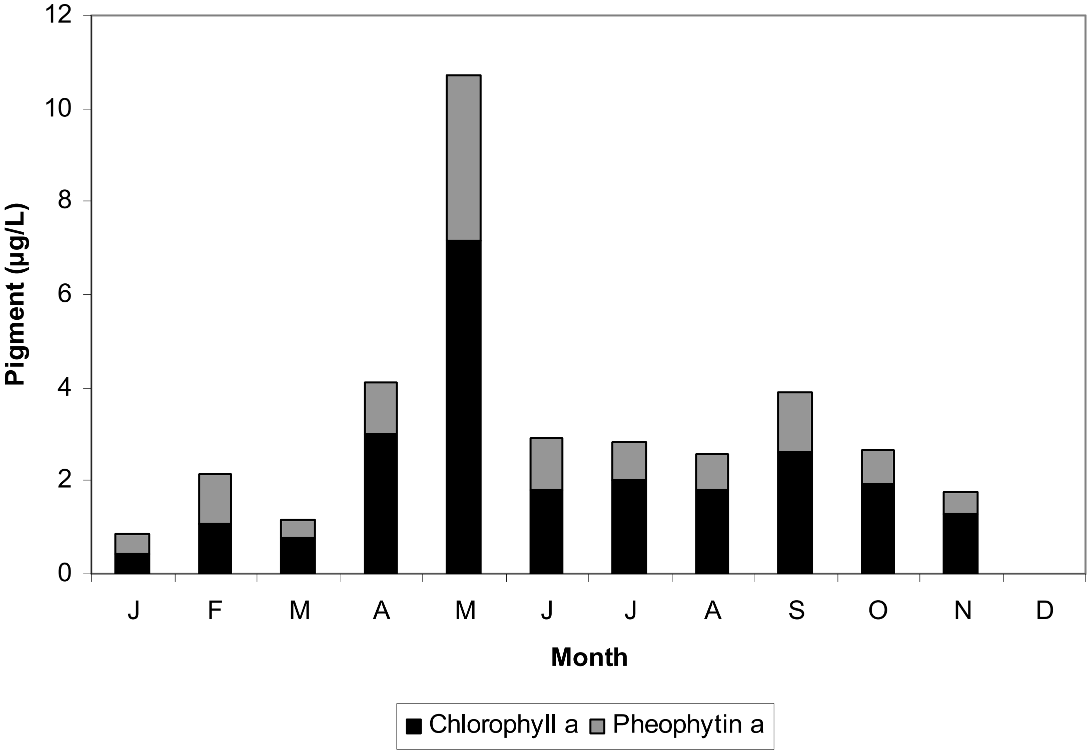


Figure 4-22 Chlorophyll *a* and Pheophytin *a* concentrations at station D19, 2004

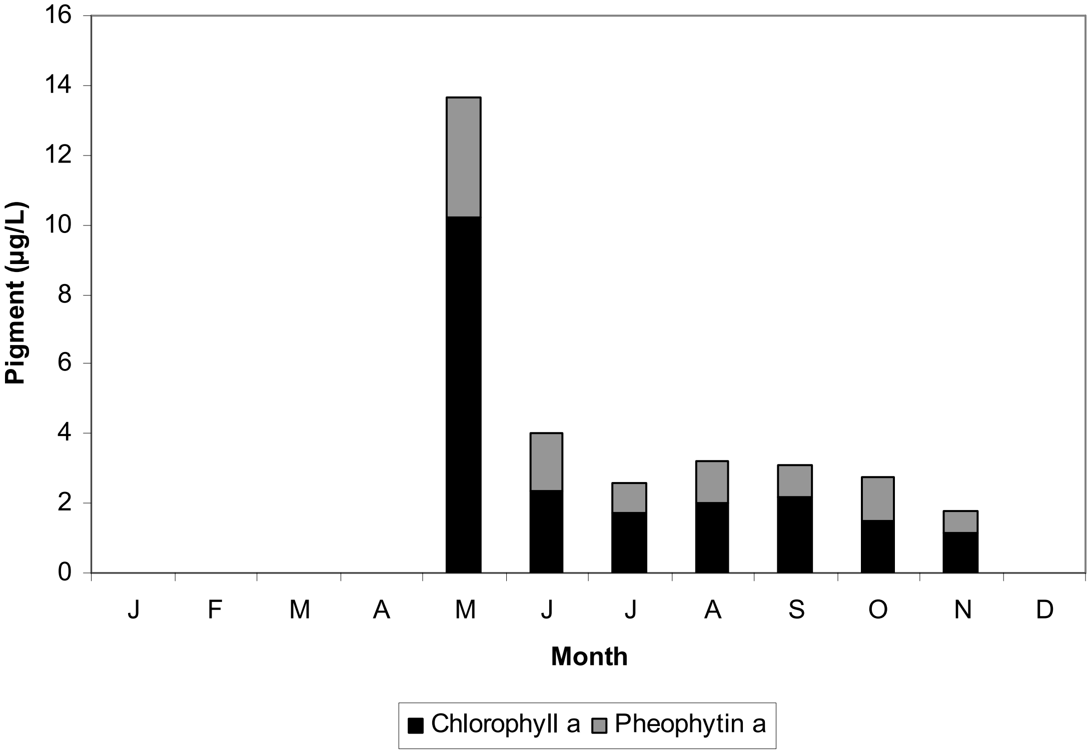


Figure 4-23 Chlorophyll *a* and Pheophytin *a* concentrations at station D4, 2004

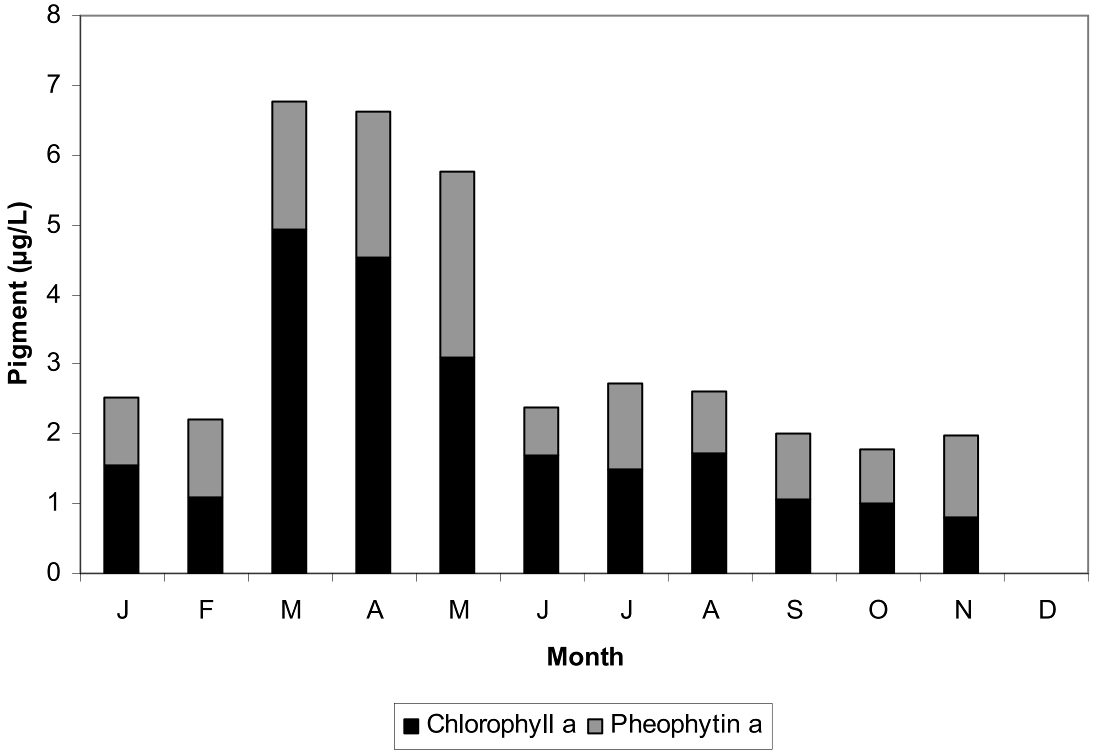


Figure 4-24 Chlorophyll *a* and Pheophytin *a* concentrations at station D8, 2004

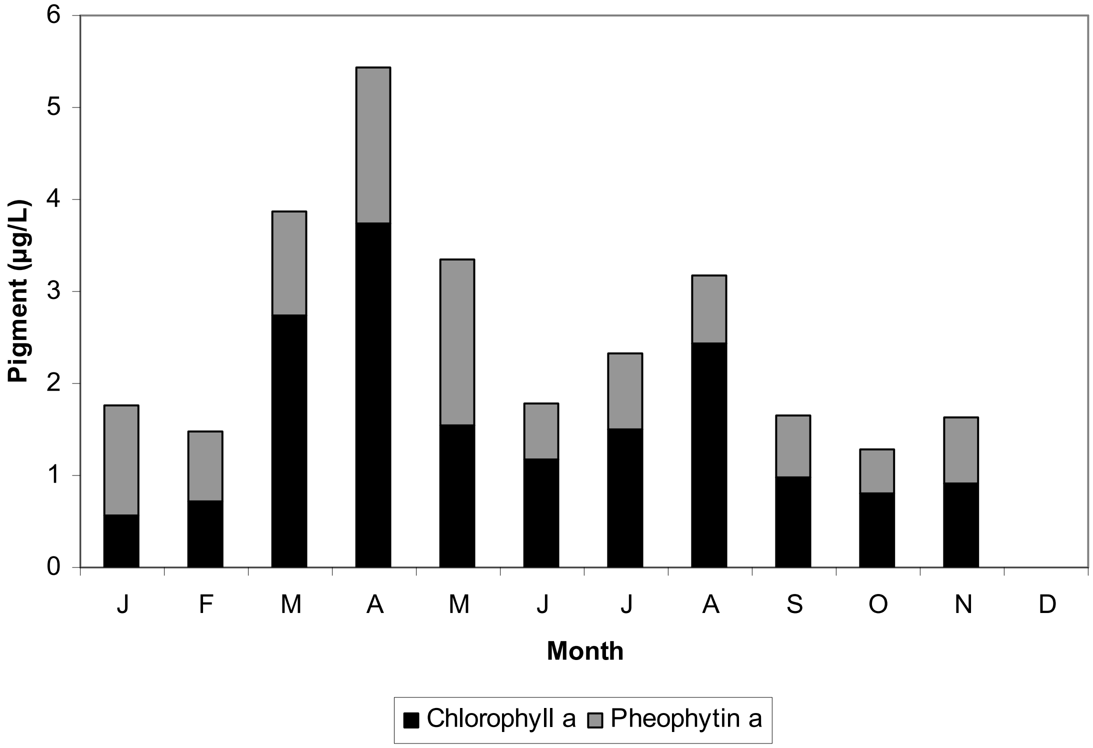


Figure 4-25 Chlorophyll *a* and Pheophytin *a* concentrations at station D7, 2004

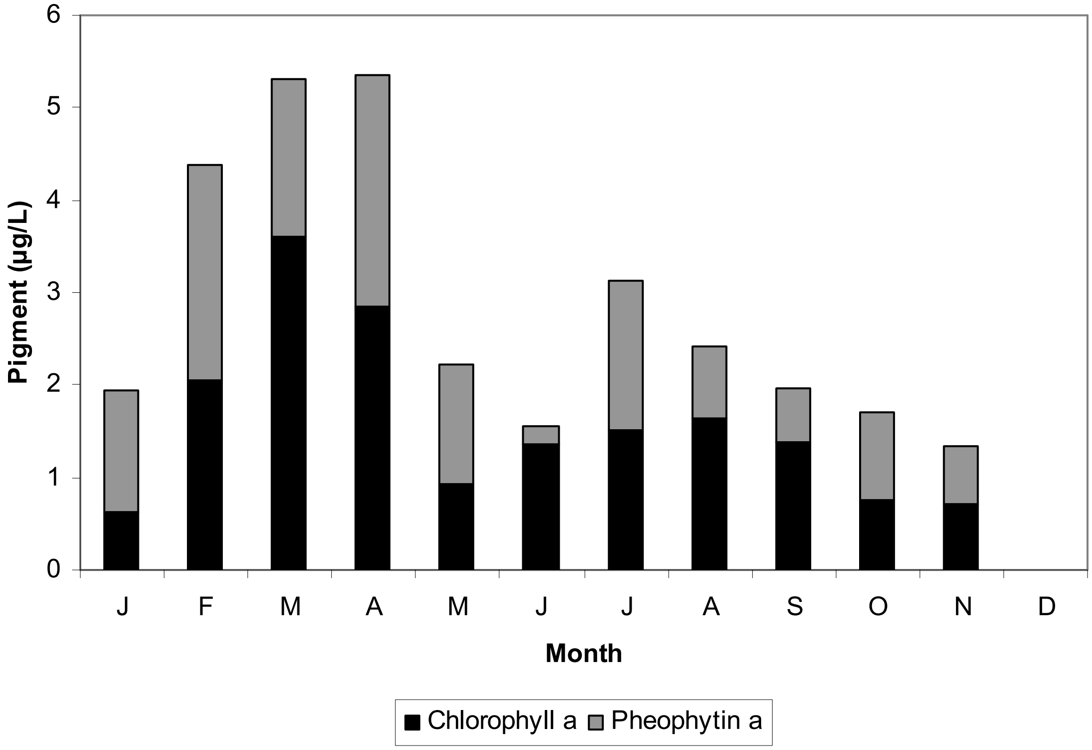


Figure 4-26 Chlorophyll *a* and Pheophytin *a* concentrations at station D6, 2004

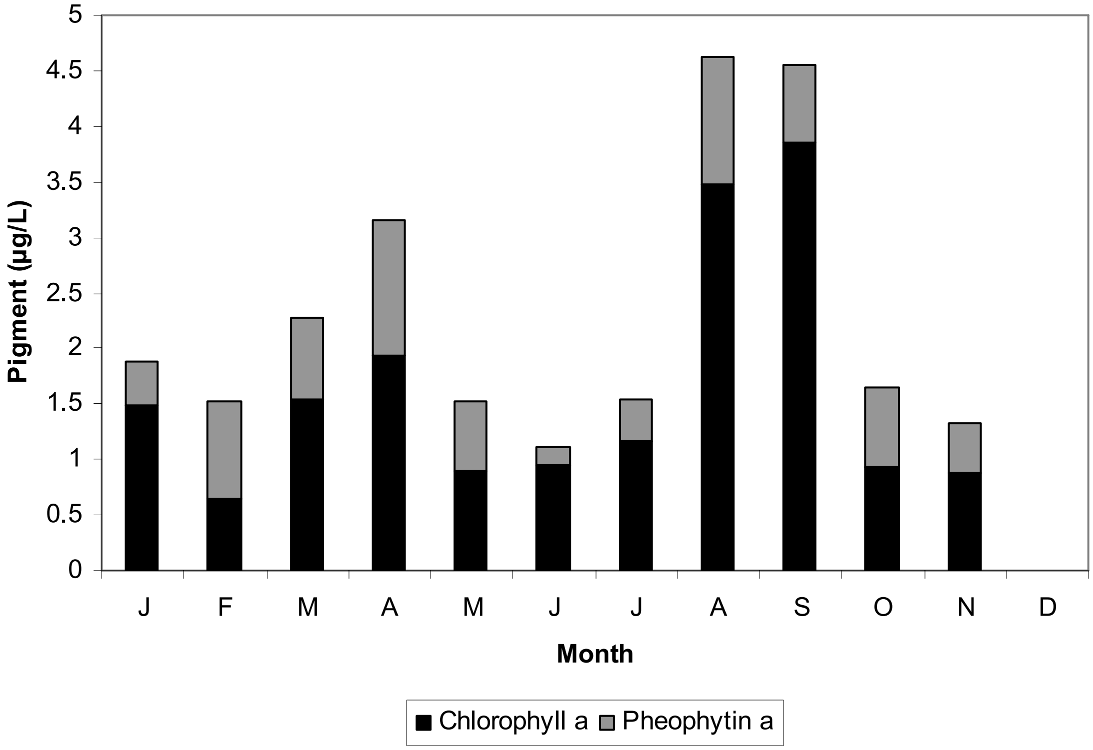


Figure 4-27 Chlorophyll *a* and Pheophytin *a* concentrations at station D41, 2004

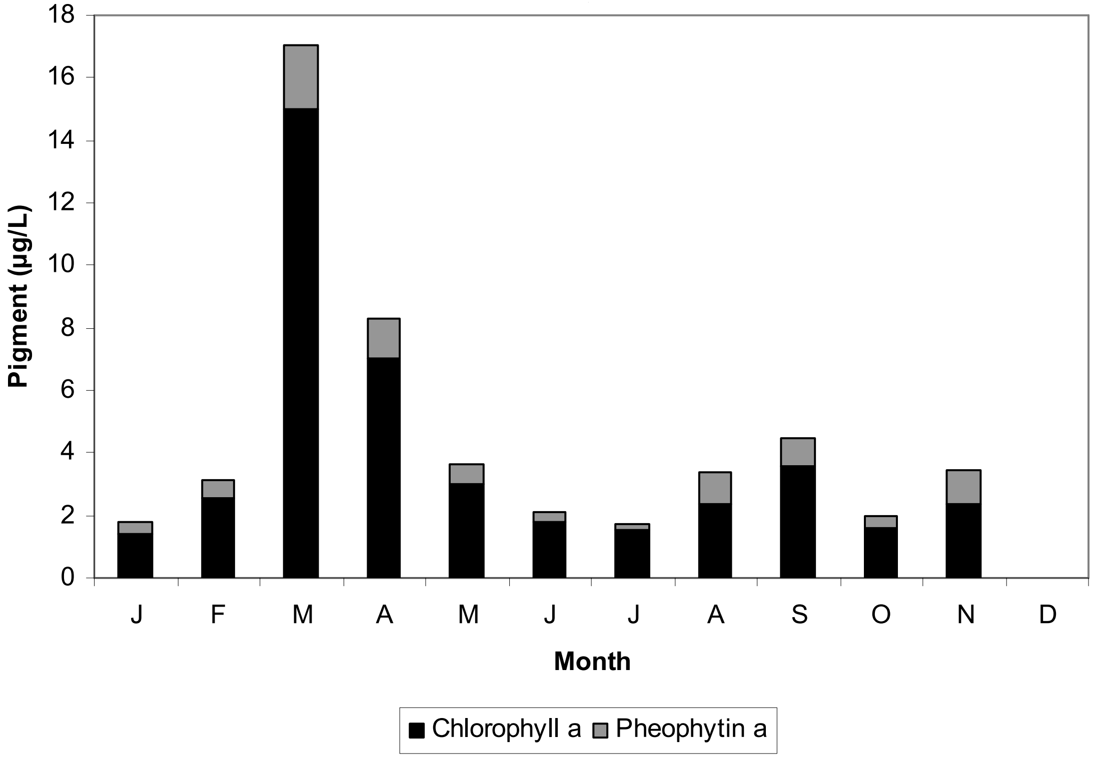


Figure 4-28 Chlorophyll *a* and Pheophytin *a* concentrations at station D41A, 2004

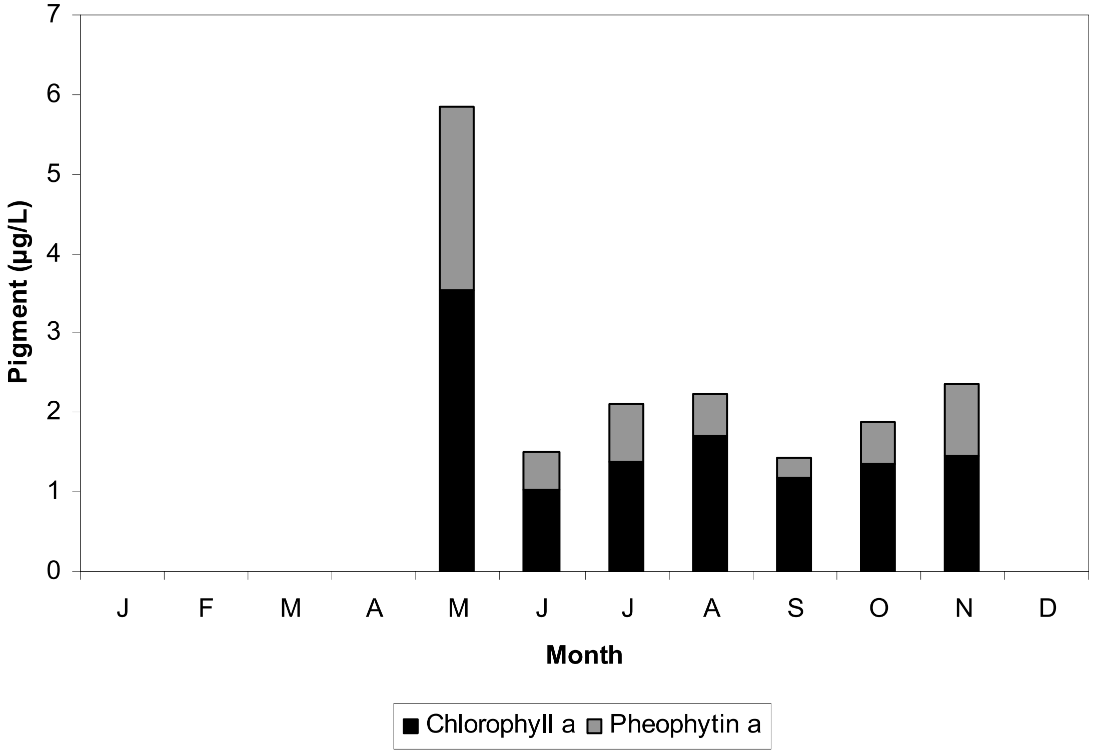
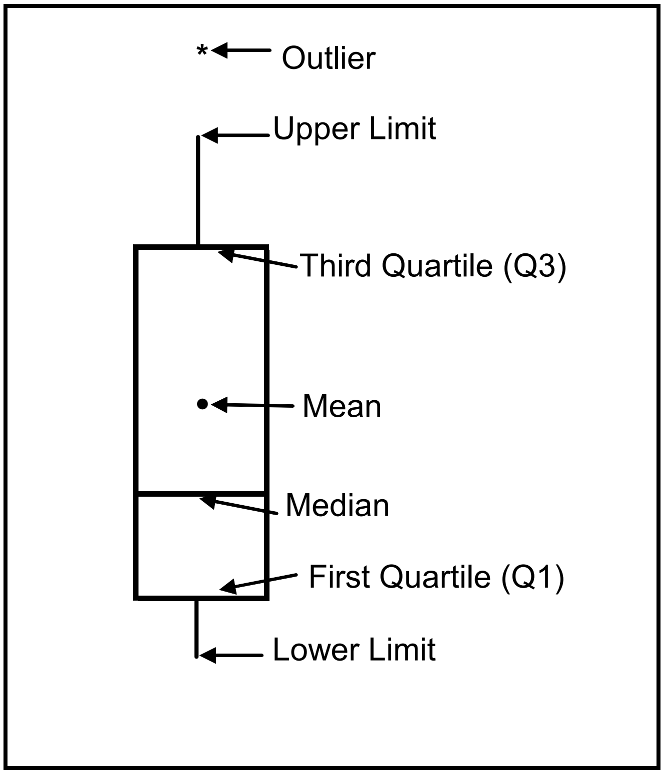


Figure 4-29 Boxplot legend



1. Outliers are data points that fall outside the upper or lower limit.
2. Upper Limit: Q1 – 1.5 (Q3 - Q1)
3. Third quartile (Q3) or the 75th percentile: 75% of the data falls below this line and 25% above it.
4. The mean is the sum of chlorophyll *a* measurements divided by the total number of measurements.
5. The median is the measurement that falls in the middle of the ordered sample. When the sample size *n* is odd, a single measurement occurs in the middle. When the sample size is even, two middle measurements occur, and the median is the midpoint between the two.
6. First quartile (Q1) or the 25th percentile: 25% of the data falls below this line and 75% above it.
7. Lower Limit: Q3 + 1.5 (Q3 – Q1)

Figure 4-30 Chlorophyll *a* boxplot for station C10, 2004

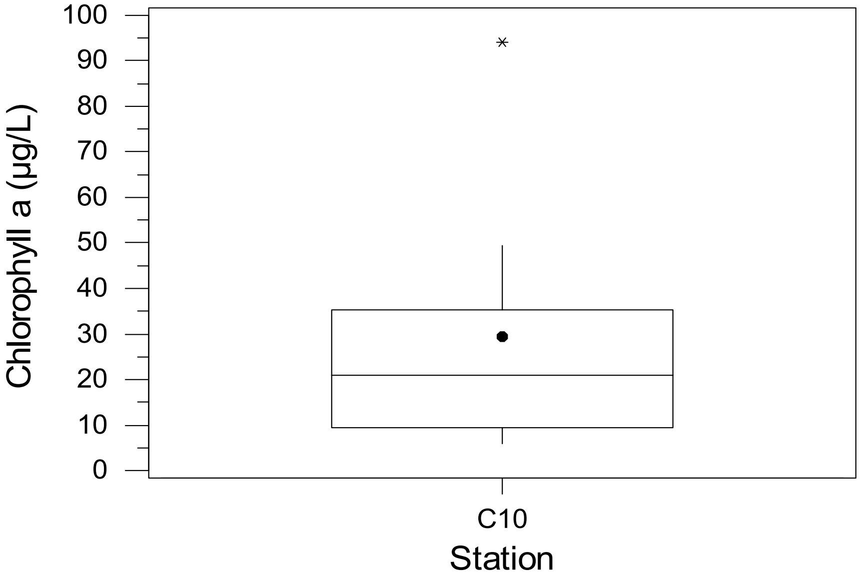


Figure 4-31 Chlorophyll *a* boxplots for stations P8 and MD10A, 2004

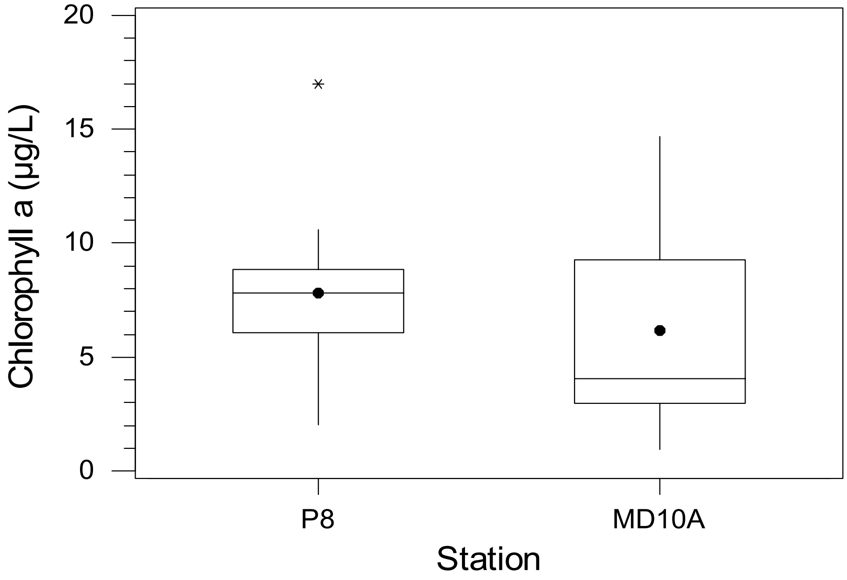


Figure 4-32 Chlorophyll *a* boxplots for stations C3/C3A, D26, D28A, D19 and D4, 2004

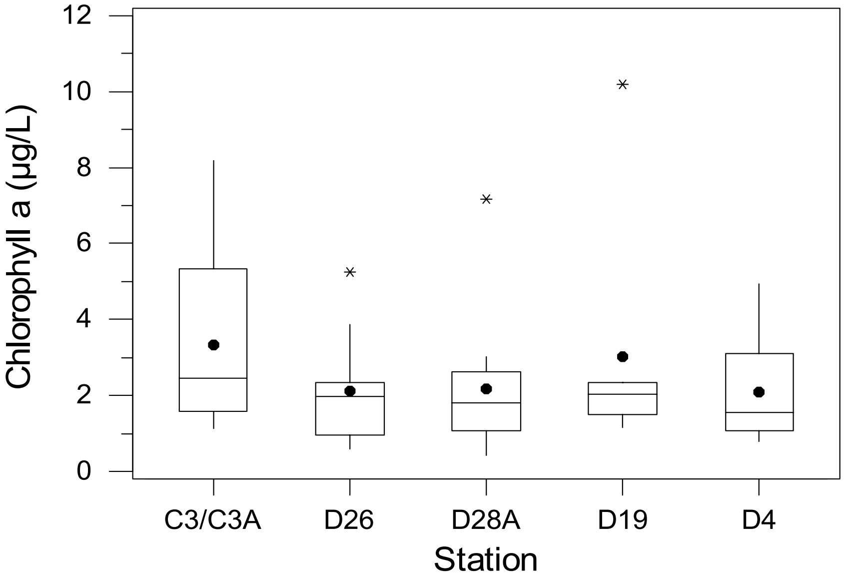


Figure 4-33 Chlorophyll *a* boxplots for stations D8, D7, D6, D41 and D41A, 2004

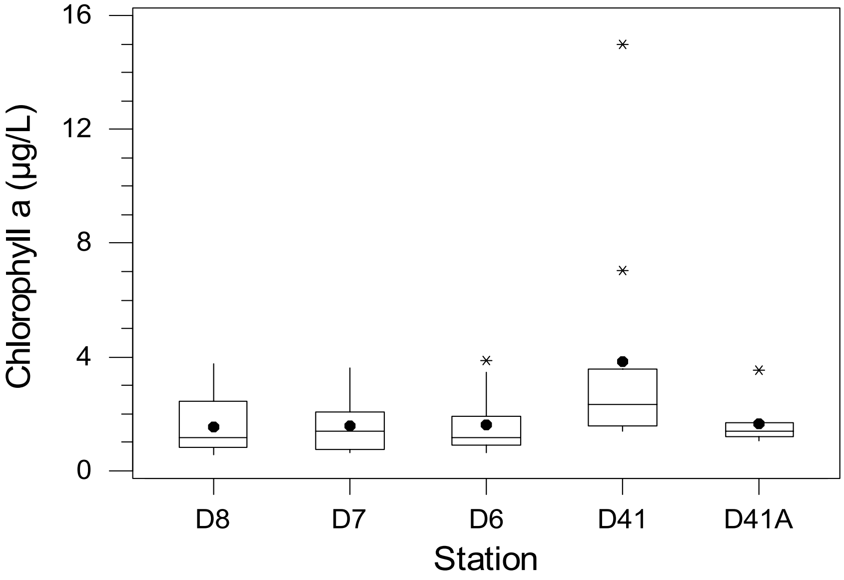


Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2004

Family	Genus	Family	Genus
BACILLARIOPHYCEAE	• *Achnanthes* • *Amphiprora* • *Asterionella* • *Aulacoseira* • *Bacillaria* • *Cocconeis* • *Cosinodiscus* • *Cyclotella* • *Cymbella* • *Diatoma* • *Diploneis* • *Fragilaria* • *Gomphonema* • *Gyrosigma* • *Mastogloia* • *Melosira* • *Navicula* • *Neidium* • *Nitzschia* • *Pennate Diatom* • *Rhoicoshpenia* • *Rhopalodia* • *Skeletonema* • *Synedra* • *Thalassiosira*	**CHLOROPHYCEAE**	• *Actinastrum* • *Ankistrodesmus* • *Carteria* • *Chlamydomonas* • *Chlorella* • *Closteriopsis* • *Closterium* • *Coelastrum* • *Crucigenia* • *Dispora* • *Kirchneriella* • *Mougeotia* • *Nephrocytium* • *Oocystis* • *Scenedesmus* • *Schroederia* • *Selenastrum* • *Stichococcus* • *Tetraedron* • *Tetrastrum*
CHRYSOPHYCEAE	• *Synura*	**CRYPTOPHYCEAE**	• *Cryptomonas* • *Rhodomonas*
CYANOPHYCEAE	• *Anabaena* • *Aphanizomenon* • *Aphanothece* • *Chroococcus* • *Dactylococcopsis* • *Merismopedia* • *Microcystis* • *Pseudanabaena* • *Synechocystis*	**DINOPHYCEAE**	• *Glenodinium* • *Gymnodinium*
		EUGLENOPHYCEAE	• *Euglena* • *Lepocinclis* • *Trachelomonas*
		UNIDENTIFIED	• Unidentified Flagellates
		XANTHOPHYCEAE	• *Ophiocytium*

Chapter 5. Zooplankton and Mysid Shrimp

Introduction

Zooplankton are an important food source for larval and juvenile salmon, striped bass, and splittail, and for planktivorous[1] fishes (such as delta smelt) throughout their lives. The Department of Fish and Game's Neomysis-Zooplankton Study monitors the annual and seasonal abundance and distribution of the major zooplankton taxa (usually genus or species level) to assess the size and location of the fish food resources in the San Francisco Estuary (Estuary). This study also seeks to detect the presence of introduced species recently established in the Estuary, to monitor their distribution and abundance, and to determine their impacts on native species. The study began in June 1968 to monitor the native mysid *Neomysis mercedis* and was expanded in January 1972 to monitor copepods, cladocerans, and rotifers. Other mysid species were consistently identified and enumerated as of 1998, while newly introduced copepods, cladocerans, and rotifers were identified and enumerated as they were detected.

Methods

Zooplankton were sampled monthly at 17 to 22 stations in the Delta and Suisun Bay (Figure 5-1), with stations at Franks Tract (D19) and in northern San Pablo Bay (D41A) added in May 2004. Twenty of these stations were at fixed geographic locations. Two stations were "floating" stations located where bottom electrical conductance (EC) was 2,000 µS/cm and 6,000 µS/cm, +/-10%. Because they are not geographically fixed, the floating stations are not shown in Figure 5-1. One station in San Pablo Bay and two stations in Carquinez Strait were sampled only when their surface EC was less than 20 µS/cm. Monthly sampling was scheduled such that each station was sampled at high slack tide.

Figure 5-1 Zooplankton monitoring stations

At each station three types of gear were deployed: 1) a mysid net, 2) a Clarke-Bumpus (CB) net for meso-zooplankton, and 3) a pump sampler for micro-zooplankton. The mysid net was 1.48 m long with a 28 cm interior mouth diameter and a mesh size of 505 µm. It was attached to a ski-mounted towing frame made of steel tubing, with a General Oceanics model 2030 flowmeter mounted at the center of the mouth. The CB net was 75 cm long with an interior mouth diameter of 12.4 cm and a mesh size of 154 µm. It was attached to a 19.7 cm long stainless steel tube with an integrated flowmeter, which was mounted on top of the mysid frame. In November 2004, a failure of the last remaining original-style flowmeter resulted in a change to a new-style CB frame and flowmeter. This new CB frame used a 19.1 cm long clear acrylic pipe with an inside diameter of 12.0 cm and had a General Oceanics flowmeter suspended in the center of the pipe. The pump sampler consisted of a 15-liter/minute-capacity pump connected to a 15 m intake hose that was discharged into a 19-L carboy. The subsample returned

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[1] Planktivorous fish, such as most fish larvae and many pelagic fishes, feed on plankton.

to the laboratory was filtered through several sieves and the zooplankton retained by the 43 μm mesh sieve were identified.

Gear deployment occurred simultaneously for the mysid and CB nets while the vessel was underway, whereas the vessel was stopped or moving with the prevailing current during pump deployment. At each station a towing frame holding the mysid and CB nets was lowered to the bottom and retrieved obliquely in several steps over a 10-minute period. Flowmeter readings from both nets were recorded before and after each tow to calculate the volume of water filtered. At the end of this tow and after forward momentum had ceased, the pump was turned on and the intake was lowered to the bottom and raised slowly to the surface twice, while pumped water was discharged into the carboy. When the sampling was completed, the carboy was shaken and a 1.5 to 1.9 liter sample decanted into a jar. All samples were fixed in buffered 10% formalin and returned to the laboratory for processing.

Before and after each mysid-CB tow, water temperature (± 0.1 °C) and specific electrical conductance (EC, μS/cm) measurements were taken from the top (1 meter below the surface) and bottom (1 meter above the substrate) of the water column using a Seabird 911*plus* CTD.

In past reports the abundance of copepods, rotifers, and cladocerans was the sum of a taxon's CB and pump sample abundance (number per m^3). In this report abundance is reported only for the gear that collects the taxon most efficiently: the CB net for all the calanoid copepods, the cyclopoid copepod *Acanthocyclops vernalis*, and all the cladocerans; the pump for all the rotifers; and both the CB and pump for the cyclopoid copepods *Limnoithona tetraspina* and *Oithona davisae*. We report abundance for both gears for these last two species because larger adults are retained by the CB mesh and smaller adults are more effectively sampled by the pump.

Zooplankton distribution within the Estuary is determined more by salinity than geography. To account for this, the stations were categorized into three EC zones: 1) upstream of the entrapment zone (bottom EC < 1,800 μS/cm); 2) the entrapment zone (bottom EC range is 1,800 μS/cm to 6,600 μS/cm); and 3) downstream of the entrapment zone (bottom EC > 6,600 μS/cm). Monthly and annual abundance for each taxon was calculated as the mean number per m^3 for each type of gear and each EC zone. The number of stations in each zone varied by month based on upstream and downstream shifts in the salinity gradient. Although none of the species were present at all stations in every month, averaging the abundance for each zone provided a common basis for comparisons.

To depict the seasonal changes in abundance, data were log transformed ($\log_{10}$ (abundance+1)) before plotting. Log transformation smoothed trend lines and allowed low abundance to be discerned when abundance ranged across several orders magnitude.

For brevity, trends from only a subset of the taxa collected are discussed. Taxa were ranked based on mean annual abundance for all stations sampled. Monthly abundance trends are presented for the top three or four top ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Results

Mysids

	Upstream	Entrapment Zone	Downstream	All Areas
Mysids				
Acanthomysis bowmani	**3.10**	**16.01**	**4.20**	6.01
Neomysis kadiakensis	**0.00**	**0.10**	**0.26**	0.12
Neomysis mercedis	**0.07**	**0.03**	**0.00**	0.04
Alienacanthomysis macropsis	**0.00**	**0.00**	**0.06**	0.02

Table 5-1 2004 Mysid abundance

First detected in 1993, *Acanthomysis bowmani* was by far the most abundant mysid collected overall and in all regions sampled in 2004 (Table 5-1). Annual abundance was highest in the entrapment zone, with downstream and upstream abundances approximately 20% to 25% of the entrapment zone abundance. Seasonal abundances were similar between zones, with peaks occurring in spring/summer and lasting through late summer/early fall (Figure 5-2).

Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone for 2004

Taxonomists are attempting to determine if the sampling program is collecting the look-alike, introduced, *Neomysis japonica* in addition to the native *N. kadiakensis*. Until any distinction is confirmed, both species will be grouped as *N. kadiakensis/japonica.* This was the second most abundant species in the study area, but was common only in and downstream of the entrapment zone (Table 5-1). Upstream of the entrapment zone, *N. kadiakensis/japonica* was collected only in January, March, and April (Figure 5-3). It was collected in the entrapment zone in most months, with abundance peaks in late spring and early fall. Downstream from the entrapment zone, abundance peaked in spring and summer before declining slightly through winter. Prior to 1996, *N. kadiakensis/japonica* was collected only occasionally in the upper Estuary, but its abundance has been steadily increasing there ever since.

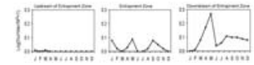


Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone for 2004

Neomysis mercedis, the native mysid that dominated catches until the early 1990s, was the third most abundant mysid in 2004, with most collected upstream of and within the entrapment zone (Table 5-1). Upstream of the entrapment zone it was most abundant from February through July, with a peak in May (Figure 5-4). Abundance within the entrapment zone followed a similar trend, but with a smaller May peak and a shorter period of collection. Downstream of the entrapment zone, *N. mercedis* was collected only in June.

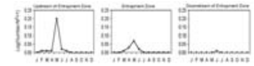


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone for 2004

Preferring high salinity, the native *Alienacanthomysis macropsis* was the fourth most abundant mysid collected in 2004 (Table 5-1). Found only downstream of the entrapment zone, abundance was highest from January through March and in December, but it was undetectable from June through November (Figure 5-5).

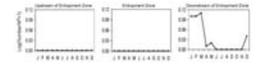


Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone for 2004

Calanoid Copepods

	Upstream	Entrapment Zone	Downstream	All Areas
Calanoid Copepods				
Pseudodiaptomus forbesi	**981.1**	**448.9**	**24.6**	509.5
Acartia *spp.*	**0.3**	**1.3**	**752.0**	287.5
Acartiella sinensis	**27.0**	**440.6**	**166.8**	163.1
Sinocalanus doerrii	**210.4**	**119.4**	**2.5**	112.8

Table 5-2 2004 Calanoid copepod abundance

The introduced *Pseudodiaptomus forbesi* was the most common calanoid copepod collected in the entire study area (Table 5-2). It was very abundant upstream of and within the entrapment zone, where the highest abundance was from May through November (Figure 5-6). Abundance downstream from the entrapment zone was bimodal, with peaks in June and October.

Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone for 2004

The genus *Acartia* is composed of three native brackish water species that are common in the higher salinity areas downstream of the entrapment zone. This was the second most abundant calanoid copepod taxon collected in the study area in 2004 and by far the most common taxon in the downstream area (Table 5-2). In and upstream from the entrapment zone, *Acartia* spp. was rarer, appearing only in winter and spring (Figure 5-7). Downstream from the entrapment zone, abundance peaked in spring and again in fall and winter.

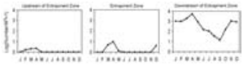


Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

The third most abundant calanoid copepod in 2004 was the introduced *Acartiella sinensis,* with the highest abundance within and downstream of the entrapment zone (Table 5-2). Abundance within the entrapment zone was moderate to high throughout the year (Figure 5-8); upstream and downstream abundance remained relatively low through spring. All zones had similar abundance peaks in late summer/early fall.

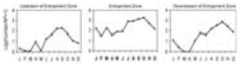


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone for 2004

Sinocalanus doerrii, another introduced species, was the fourth most abundant calanoid copepod in 2004, with relatively high levels both upstream of and within the entrapment zone (Table 5-2). Abundance peaked in May and was lowest in fall and winter in all three zones (Figure 5-9).

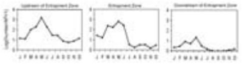


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone for 2004

Cyclopoid Copepods

Limnoithona tetraspina has been the most abundant cyclopoid copepod in the study area since it was first detected in 1993. It was abundant in all three EC zones in 2004, but most common within and downstream of the entrapment zone (Table 5-3). Peak CB abundance in all three zones occurred in spring soon after winter lows, with a second peak in summer or fall (Figure 5-10). Downstream of the entrapment zone CB abundances remained relatively stable throughout the year. Pump abundance in all EC zones was lowest in late winter, followed by a peak in mid-summer to early fall. Greater seasonal variation occurred upstream than within or downstream of the entrapment zone.

	Upstream	Entrapment Zone	Downstream	All Areas
Cyclopoid Copepods				
Clarke-Bumpus Net				
Limnothoina tetraspina	**11.1**	**272.6**	**71.2**	86.4
Oithona davisae	**0.2**	**4.8**	**416.1**	159.9
Acanthocyclops vernalis	**61.5**	**29.3**	**9.9**	35.3
Pump				
Limnothoina tetraspina	**1355**	**15199**	**13073**	8558
Oithona davisae	**66**	**317**	**528**	294

Table 5-3 2004 Cyclopoid copepod abundance

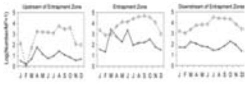


Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of

The introduced *Oithona davisae* was the second most abundant cyclopoid copepod in 2004, but much less common than *L. tetraspina* (Table 5-3). *O. davisae* was abundant only downstream of the entrapment zone in the CB samples, but was abundant both within and downstream of the entrapment zone in the pump samples (Figure 5-11). Seasonal abundance also differed by sampling gear. Upstream of the entrapment zone, the CB net collected *O. davisae* in only winter and spring, while the peak pump abundance was in summer and fall. CB samples within the entrapment zone had relatively low numbers throughout the year, but pump samples showed another summer/fall peak. Conversely, abundance in the CB samples downstream was relatively high throughout the year, with an annual low in April and May. Pump sample abundance downstream of the entrapment zone again peaked in summer and fall, with an additional February peak.

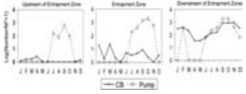


Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone for 2004

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod collected in 2004 and was most abundant upstream of and within the entrapment zone (Table 5-3). Abundance in all EC zones tended to be relatively high from winter through early summer before dropping to annual lows in late summer or fall (Figure 5-12).

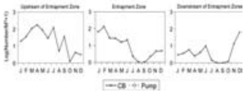


Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone for 2004

Cladocerans

All Cladocera commonly collected by this study are freshwater and usually found upstream of the entrapment zone. *Bosmina* spp. was the most abundant cladoceran genus in the upper Estuary in 2004 (Table 5-4). Densities here were high throughout the year with a broad peak from April through October (Figure 5-13). Within the entrapment zone, *Bosmina* spp. abundance was highest in winter and spring, zero during summer, and increased slightly in fall. Downstream from the entrapment zone, abundance fluctuated at relatively low levels.

Diaphanosoma spp., the second most abundant cladoceran genus in 2004, was collected almost exclusively upstream from the entrapment zone (Table 5-4). Abundance increased rapidly in spring, peaked in July, and then declined slowly until a sharp drop in November (Figure 5-14). In the entrapment zone, low numbers of *Diaphanosoma* spp. were collected from May through August; downstream they were found only in June.

The genus *Daphnia* was the third most abundant cladoceran in 2004 (Table 5-4). Its abundance upstream of the entrapment zone fluctuated at moderate levels through much of the year, peaking slightly in spring and summer (Figure 5-15). Within and downstream of the entrapment zone, *Daphnia* spp. were collected primarily during the first half of the year.

	Upstream	Entrapment Zone	Downstream	All Areas
Cladoceras				
Bosmina *spp.*	**1,742.7**	**13.7**	**5.6**	733.7
Diaphanosoma *spp.*	**508.9**	**0.2**	**0.1**	212.9
Daphnia *spp.*	**367.0**	**4.9**	**0.8**	154.8

Table 5-4 2004 Cladoceran abundance

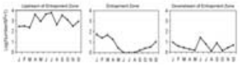


Figure 5-13 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

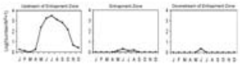


Figure 5-14 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

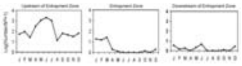


Figure 5-15 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

Rotifers

Rotifers are also primarily freshwater, with most collected upstream of the entrapment zone. In 2004, the genus *Polyarthra* was the most abundant rotifer taxon collected (Table 5-5). Upstream from the entrapment zone, its abundance remained relatively high throughout the year, showing little seasonal variation (Figure 5-16). Within the entrapment zone, abundance was less stable, with a decline early in the year, no catch for several months (except July), and an increase to a second peak in December. Downstream from the entrapment zone, *Polyarthra* spp. abundance was also variable, with no catch in March and peaks in July and December.

The genus *Synchaeta* was the second most abundant rotifer taxon collected in 2004 (Table 5-5). Upstream of the entrapment zone, *Synchaeta* abundance declined steadily before peaking in October (Figure 5-17). In the entrapment zone, *Synchaeta* spp. abundance was bimodal, with peaks in March and August. Downstream of the entrapment zone, abundance was also bimodal, with peaks in March and September.

The third most abundant rotifer taxon was the genus *Keratella* (Table 5-5). *Keratella* spp. abundance was highest upstream of the entrapment zone, where it fluctuated moderately throughout the year (Figure 5-18). *Keratella* spp. abundance was much less stable in the entrapment zone, with peaks in early spring, fall, and winter, punctuated by zero catches in late spring and summer. Downstream of the entrapment zone, abundance fluctuated at relatively low levels until peaking in December.

	Upstream	Entrapment Zone	Downstream	All Areas
Rotifers				
Polyarthra *spp.*	**13,888**	**592**	**2,131**	6,775
Synchaeta *spp.*	**5,815**	**2,603**	**7,152**	5,718
Keratella *spp.*	**8,995**	**324**	**1,038**	4,244

Table 5-5 2004 Rotifer abundance

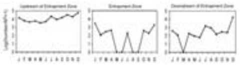


Figure 5-16 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

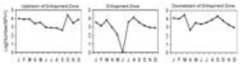


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

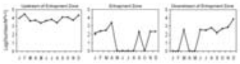


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

Summary

The 2004 annual rankings of the most common zooplankton taxa changed somewhat from 2003, while the monthly abundance patterns were typical of recent years. The introduced *Acanthomysis bowmani* and the *Neomysis kadiakensis/japonica* complex remained the two most abundant mysids, followed by the native *Neomysis mercedis*, which had ranked fourth in 2003. The most common calanoid copepod in 2004 was the introduced *Pseudodiaptomus forbesi*, which had ranked second in 2003, followed by the native *Acartia* spp. and the introduced *Acartiella sinensis*. The three most common cyclopoid copepods remained the introduced *Limnothoina tetraspina* and *Oithona davisae*, followed by the native *Acanthocyclops vernalis.* The top three cladocera also did not change from 2004, with *Bosmina* spp., *Diaphanosoma* spp., and *Daphnia* spp. most commonly collected. The top two rotifer taxa switched ranks in 2004, with *Polyarthra* spp. the most common, followed by *Synchaeta* spp. and *Keratella* spp.

Figure 5-1 Zooplankton monitoring stations

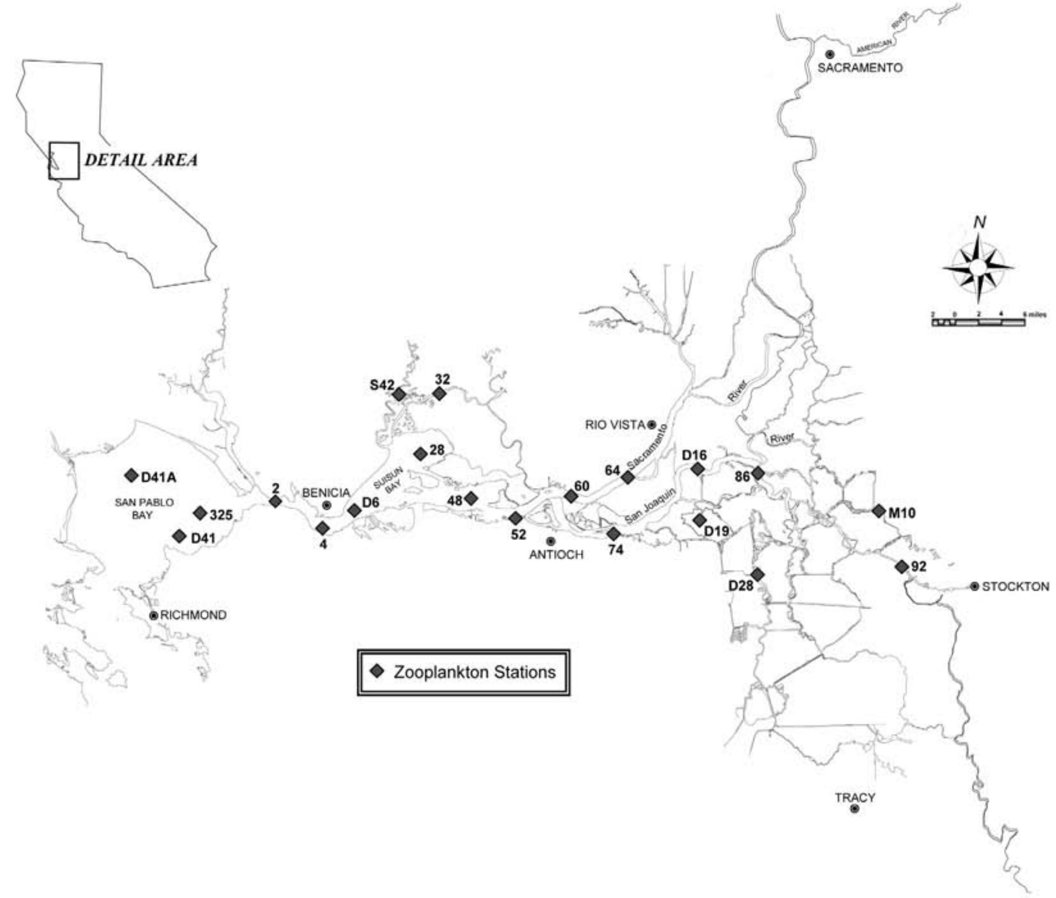


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone for 2004

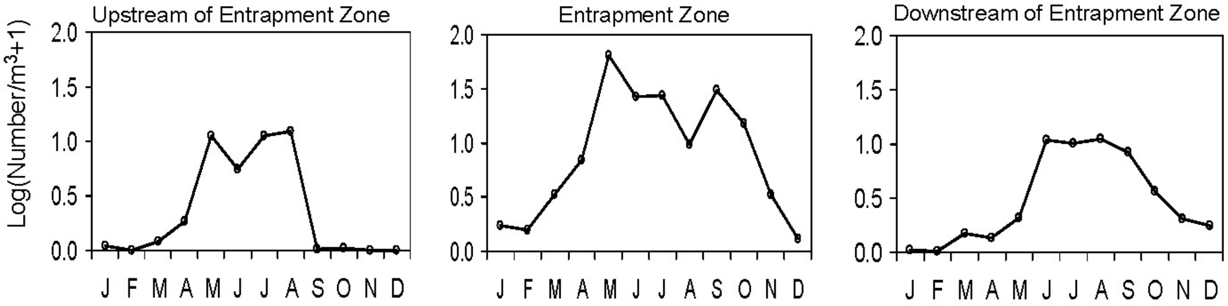


Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone for 2004

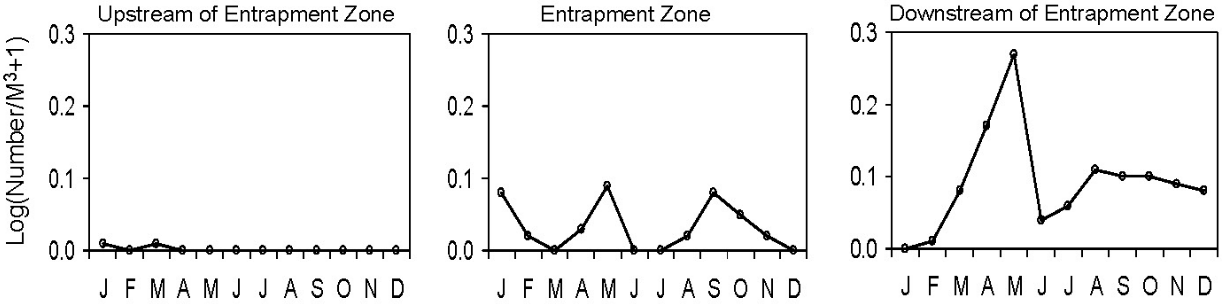


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone for 2004

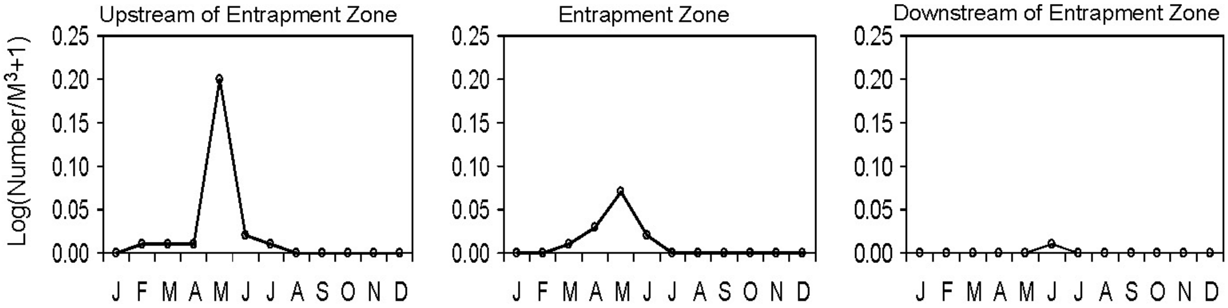


Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone for 2004

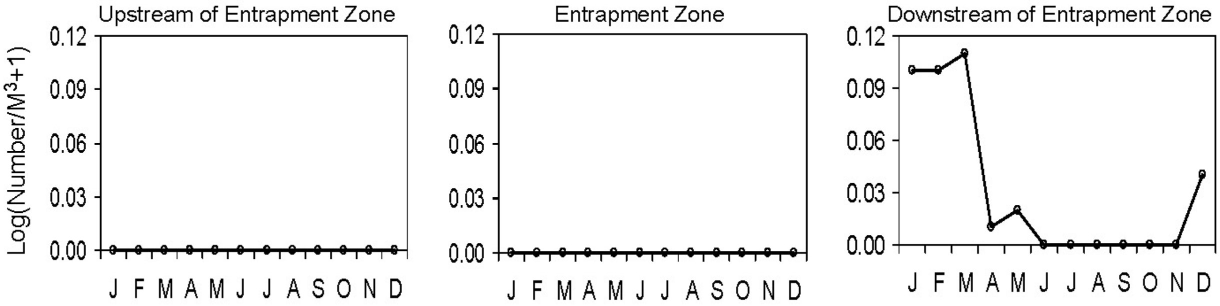


Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

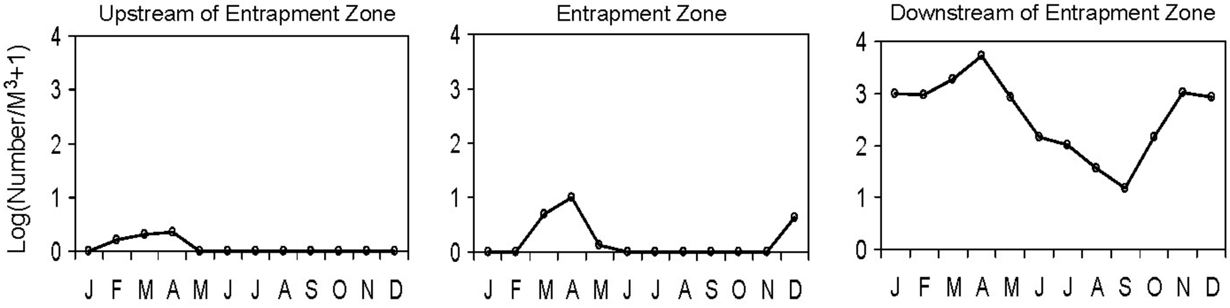


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone for 2004

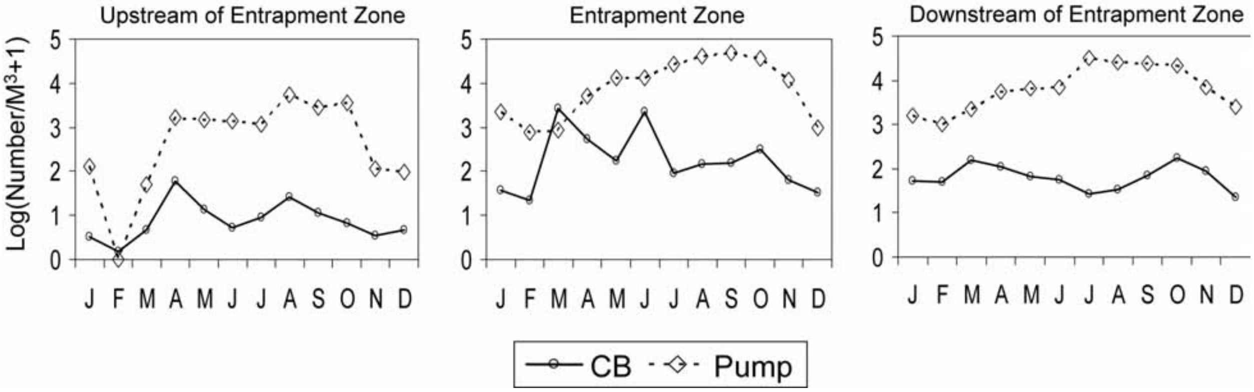


Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone for 2004

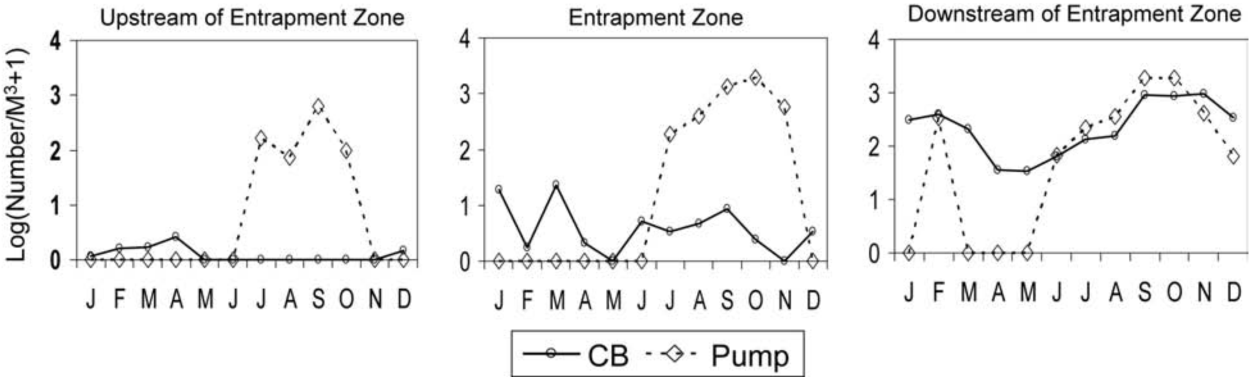


Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone for 2004

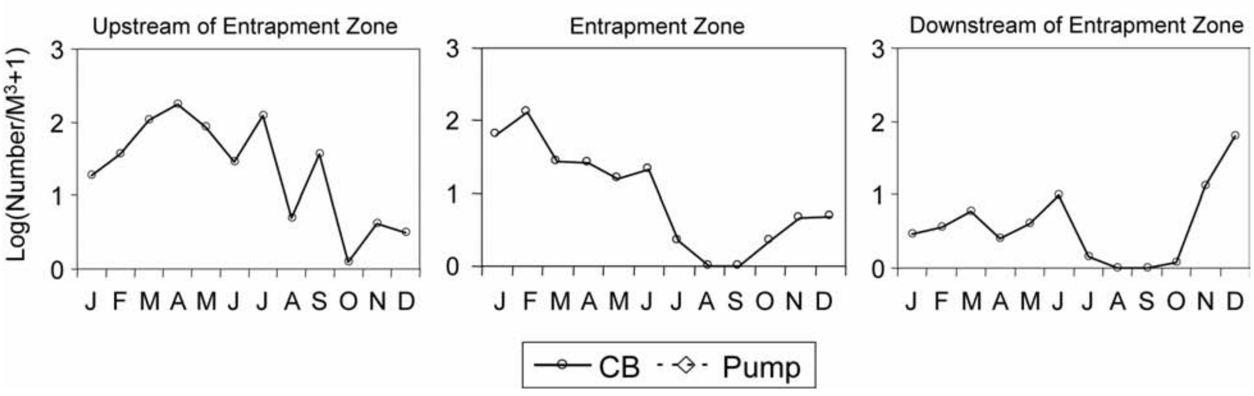


Figure 5-13 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-14 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

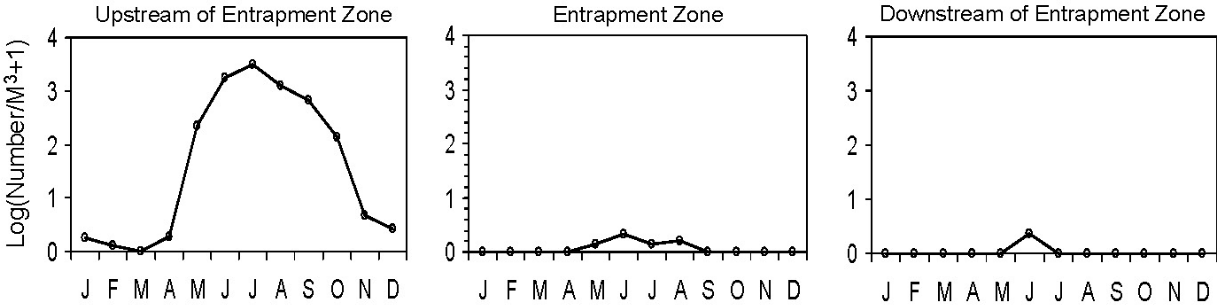


Figure 5-15 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-16 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

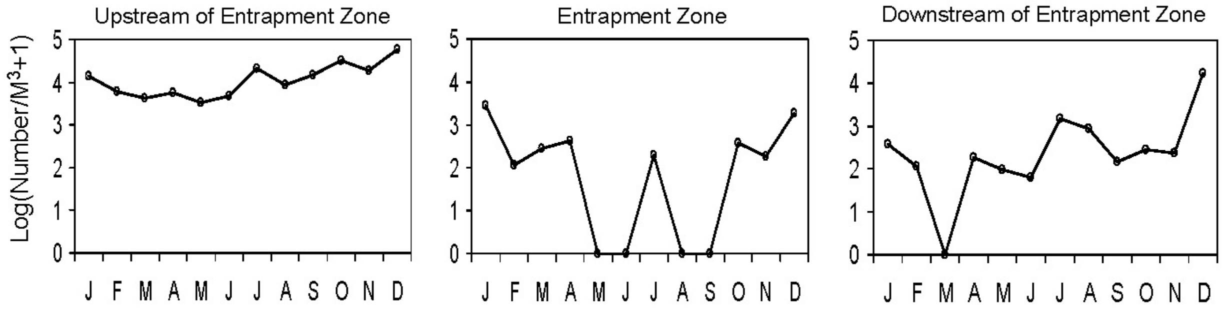


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone for 2004

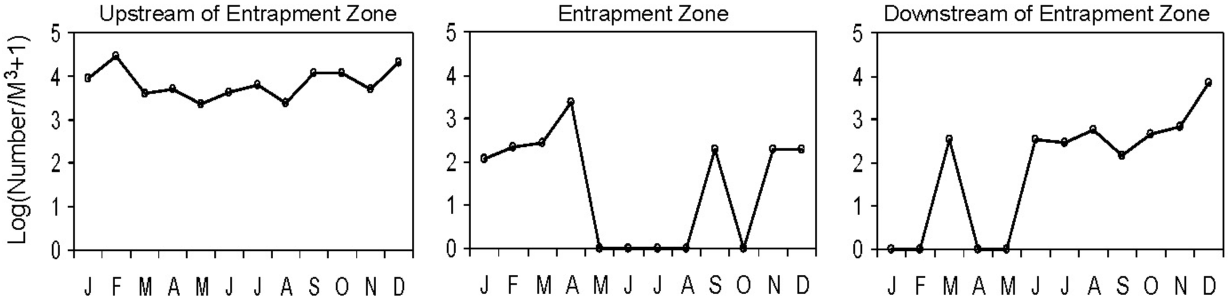


Table 5-1 Mysids: Catch per unit effort

	Upstream	Entrapment Zone	Downstream	All Areas
Mysids				
Acanthomysis bowmani	3.10	16.01	4.20	**6.01**
Neomysis kadiakensis	0.00	0.10	0.26	**0.12**
Neomysis mercedis	0.07	0.03	0.00	**0.04**
Alienacanthomysis macropsis	0.00	0.00	0.06	**0.02**

Table 5-2 Calanoid copepods: Catch per unit effort

	Upstream	Entrapment Zone	Downstream	All Areas
Calanoid Copepods				
Pseudodiaptomus forbesi	981.1	448.9	24.6	**509.5**
Acartia spp.	0.3	1.3	752.0	**287.5**
Acartiella sinensis	27.0	440.6	166.8	**163.1**
Sinocalanus doerrii	210.4	119.4	2.5	**112.8**

Table 5-3 Cyclopoid copepods: Catch per unit effort

	Upstream	Entrapment Zone	Downstream	All Areas
Cyclopoid Copepods				
Clarke-Bumpus Net				
Limnothoina tetraspina	11.1	272.6	71.2	**86.4**
Oithona davisae	0.2	4.8	416.1	**159.9**
Acanthocyclops vernalis	61.5	29.3	9.9	**35.3**
Pump				
Limnothoina tetraspina	1355	15199	13073	**8558**
Oithona davisae	66	317	528	**294**

Table 5-4 Cladocerans: Catch per unit effort

	Upstream	Entrapment Zone	Downstream	All Areas
Cladoceras				
Bosmina spp.	1,742.7	13.7	5.6	**733.7**
Diaphanosoma spp.	508.9	0.2	0.1	**212.9**
Daphnia spp.	367.0	4.9	0.8	**154.8**

Table 5-5 Rotifers: Catch per unit effort

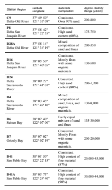
	Upstream	Entrapment Zone	Downstream	All Areas
Rotifers				
Polyarthra spp.	13,888	592	2,131	**6,775**
Synchaeta spp.	5,815	2,603	7,152	**5,718**
Keratella spp.	8,995	324	1,038	**4,244**

Chapter 6. Benthic Monitoring

Introduction

The benthic monitoring program is designed to document the distribution, diversity, and abundance of benthic (bottom dwelling) organisms in the upper San Francisco Estuary (Estuary). Geographic coverage of the sampling sites ranges from San Pablo Bay east through the Sacramento-San Joaquin Delta to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. The benthic community of the upper Estuary is a diverse assemblage of organisms, which includes worms, crustaceans, insects, and molluscs. This program monitors both benthic macrofauna (organisms larger than 0.5 mm) (DWR 2001) and sediment composition. General trends in sediment composition are documented at the same sites where benthic samples are collected.

The benthic monitoring program began in 1975. From 1975 through 1979 the program collected samples biannually from 11 to 16 sites. In 1980, DWR revised the benthic monitoring program and began monthly sampling at five sites. In 1995, major programmatic revisions were implemented to form the current program. Since 1996, monitoring has been conducted at ten sites that are sampled monthly. The current sites represent a wide variety of habitats that vary in size and physical characteristics. Table 6-1 has site-specific information. More detailed information about the location, number, and physical characteristics of the historical sites can be found in Interagency Ecological Program (IEP) Technical Report 12 (Markmann 1986) and IEP Technical Report 38 (Hymanson et al. 1994). The Environmental Monitoring Program (EMP) periodically undergoes programmatic review. As part of that assessment, and with SWRCB approval, the EMP carried out special studies to determine how to improve the benthic monitoring program. In an effort to release the necessary resources to conduct the recommended special studies, the benthic monitoring program switched to quarterly sampling for two years. This change coincided with the beginning of the 2003-2004 water year.



Station Region	Latitude Longitude	Substrate Composition	Approx. Salinity Range (µS/cm)
C9 Delta-Old River	37° 49' 50" 121° 33' 09"	Consistent. Over 90% sand.	200-800
P8 Delta San Joaquin River	37° 58' 42" 121° 22' 55"	Consistent. High sand content (60%).	175-750
D28A Delta Old River	37° 58' 14" 121° 34' 19"	Mixed composition of sand and fines	200-350
D16 Delta San Joaquin River	38° 05' 50" 121° 40' 05"	Consistent. Mostly fines with some organic materials	130-500
D24 Delta Sacramento River	38° 09' 27" 121° 41' 01"	Consistent. High sand content (80%).	200-1,200
D4 Delta Sacramento River	38° 03' 45" 121° 49' 10"	Mixed composition of sand, fines, and organic materials.	130-8,000
D6 Suisun Bay	38° 02' 40" 122° 07' 00"	Fairly equal mixture of sand and fines	135-30,000
D7 Grizzly Bay	38° 07' 02" 122° 02' 19"	Consistent. Mostly Fines with some organic materials.	200-20,000
D41 San Pablo Bay	38° 01' 50" 122° 22' 15"	Consistent. High content of fine material (87%)	20,000-45,000
D41A San Pablo Bay	38° 03' 75" 122° 24' 40"	Consistent. High content of fine material (90%)	30,000-44,000

Table 6-1 Macrobenthic monitoring station characteristics

Methods

Benthic Organisms

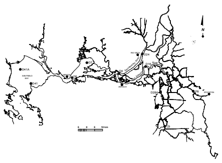


Figure 6-1 2004 Benthic monitoring stations

Field sampling was conducted at ten sites monthly until October 2003, when the sampling regime changed to quarterly. Figure 6-1 shows the location of each site and Table 6-1 summarizes latitude and longitude, salinity range, and substrate composition for each site. The research vessel *Endeavor,* equipped with a hydraulic winch and a Ponar dredge, was used in conducting this sampling. The Ponar dredge samples a bottom area of 0.053 m^2. The contents of the dredge were washed over a Standard No. 30 stainless steel mesh screen (0.595 mm openings) to remove as much of the substrate as possible. All material remaining on the screen was preserved in approximately 20% buffered formalin containing Rose Bengal dye and transported to the laboratory for analysis. The benthic macroinvertebrate sampling methodology used in this program is described in *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

In the laboratory, the field preservative was decanted and the sample was washed with deionized water over a Standard No. 30 stainless steel mesh screen. Organisms were then placed in 70% ethyl alcohol for identification and enumeration. Hydrozoology[1], a private laboratory under contract with DWR, identified and enumerated organisms in the macrofaunal samples. A stereoscopic dissecting microscope (70-120X) was used to identify most organisms. When taxonomic features were too small for identification under the dissecting scope, the organism was mounted permanently on a slide and examined under a compound microscope. If more than four hours of sorting were required and a sample contained many organisms but few species, a one-fourth volume subsample was chosen at random from the sample. The subsample was sorted and the results were multiplied by four to represent the total sample. The remainder of the sample was inspected to make sure no taxa were overlooked. Individual species counts were multiplied by 19 to convert the number of organisms per grab sample to organisms per square meter (where $19 = 1.0\ m^2 / 0.053\ m^2$ and $0.053\ m^2$ = sample area of the Ponar).

All organisms identified and enumerated were recorded on datasheets by Hydrozoology staff. These datasheets were returned to DWR staff for entry into the benthic monitoring program's database.

Sediment

Sediment composition samples were collected monthly in the field from the *Endeavor* using the same hydraulic winch and Ponar dredge used in the benthic sampling. A random subsample of the sediment was placed into a 1-liter plastic jar for storage and transported to DWR's Soils and Concrete Laboratory for analysis.

Particle size analysis and dry weight measurements were performed for each sediment sample. Sediment was analyzed for particle size according to the American Society of Testing and Materials Protocol D422 (ASTMa 2000). Particles were sorted into the following categories: sand (>75 µm) and fine (<75 µm). Organic content of the sediment was determined using the American Society of Testing and Materials Protocol D2974, Method C (ASTMb 2000). For this method, the ash-free dry weight of the sample was used to determine the organic content of the sediment.

Results

Benthic Composition and Abundance

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 178 species, ten species represented 93% of all organisms collected. These species were also the ten

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[1] Hydrozoology. P.O. Box 682, Newcastle, CA 95658

numerically dominant species during the 2004 reporting period. These species are listed below.

Numerically Dominant Species

- Amphipods
    - *Americorophium spinicorne*
    - *Corophium alienense*
    - *Ampelisca abdita*
    - *Gammarus daiberi*
- Cumacean Crustacean
    - *Nippoleucon hinumensis*
- Cytheride Crustacean
    - *Cyprideis sp. A*
- Aquatic Oligochaete
    - V*arichaetadrilus angustipenis*
- Sabellide Polychaete
    - *Laonome sp. A*
- Asian Clams
    - *Corbula amurensis*
    - *Corbicula fluminea*

Of the 10 dominant species, three species—*Ampelisca abdita*, *Nippoleucon hinumensis,* and *Corbula amurensis*—represent macrofauna that inhabit a typically high saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *Corophium alienense, Americorophium spinicorne,* and *Laonome sp. A* tolerate a wider range of salinity. They were collected both in the higher saline western sites and the more brackish to freshwater eastern sites, such as the San Joaquin River at Twitchell Island and the Sacramento River above Point Sacramento. The remaining four species—*Gammarus daiberi*, *Varichaetadrilus angustipenis, Cyprideis* sp. *A*, and *Corbicula fluminea*—are predominantly freshwater species and were collected at sites east of Suisun Bay.

Data Management and Summarization

The EMP maintains a database containing all information on benthic organisms identified within the upper Estuary. This database continuously undergoes peer review and updating. When a new organism is found at any of the sampling sites, the organism is identified to the lowest possible taxonomic level and added to the database. Taxonomic designations are also continuosly updated; for example, the Asian clam *Potamocorbula amurensis* should now be refered to as *Corbula amurensis* (Thompson 2005). All data is available at http://www.baydelta.ca.gov.

All organisms collected during 2004 fell into seven phyla:

- Cnidaria (hydras, sea anemones)
- Platyhelminthes (flatworms)
- Nemertea (ribbon worms)
- Nematoda (roundworms)

- Annelida (segmented worms)
- Arthropoda (aquatic insects, amphipods, isopods, shrimp, crabs, mites, etc.)
- Mollusca (clams, snails)

Of the seven phyla identified, Annelida, Arthropoda, and Mollusca constituted 99.3% of the organisms collected during the study period. Figure 6-2 shows the total percent contribution by phylum for all sites. Figures 6-3 through 6-7 show the total contribution by phylum for each site and organism abundance for each site.

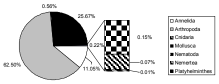


Figure 6-2 Total contribution by phyla for all stations during 2004

Organism abundance (organism per meter squared or org/m^2) and dominant phyla varied between sites. Temporal changes in organism abundance (for example, intra- and interannual) also varied greatly between sites. These variations and trends (for example, maximum/minimum abundance and dominant species) will be discussed for each individual site (Figures 6-3 through 6-7). Sediment composition is also discussed for each site (Figures 6-8 through 6-17).

Site C9: Benthic Abundance

Maximum abundance in 2004 occurred in July with a total of 5,719 organisms per meter squared (Figure 6-3). *Corbicula fluminea* (1,877 org/m^2) and *Americorophium stimpsoni* (1,373 org/m^2) were the dominant species. The minimum abundance in 2004 occurred in April with a total of 385 organisms per meter squared. *Corbicula fluminea* (219 org/m^2) was the dominant species.

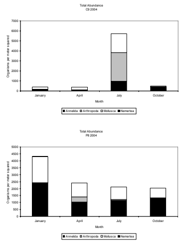


Figure 6-3 Benthic abundance at stations C9 and P8, 2004

Site P8: Benthic Abundance

Maximum abundance in 2004 occurred in January with a total of 4,319 organisms per meter squared (Figure 6-3). The dominant species were *Corbicula fluminea* (1,425 org/m^2), and *Varichaetadrilus angustipenis* (1,107 org/m^2). The minimum abundance in 2004 occurred in October with a total of 2,028 organisms per meter squared. The dominant species were *Laonome species A* (802 org/m^2) and *Corbicula fluminea* (665 org/m^2).

Site D28A: Benthic Abundance

Maximum abundance in 2004 occurred in July with a total of 3,482 organisms per meter squared (Figure 6-4). *Gammarus daiberi* (1,093 org/m^2) and *Varichaetadrilus angustipenis* (784 org/m^2) were the dominant species. The minimum abundance in 2004 occurred in January with a total of 1,872 organisms per meter squared. *Varichaetadrilus angustipenis* (233 org/m^2) was the dominant species.

Site D16: Benthic Abundance

Maximum abundance in 2004 occurred in April with a total of 4,308 organisms per meter squared (Figure 6-4). *Corbicula fluminea* (1,781 org/m^2) and *Americorophium spinicorne* (1,268 org/m^2) were the dominant species.

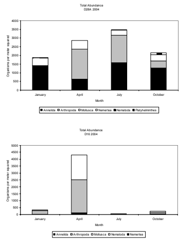


Figure 6-4 Benthic abundance at stations D28A and D16, 2004

The minimum abundance in 2004 occurred in July with a total of 61 organisms per meter squared. *Corbicula fluminea* (24 org/m^2) and *Americorophium stimpsoni* (19 org/m^2) were the dominant species.

Site D24: Benthic Abundance

Maximum abundance in 2004 occurred in January with a total of 13,822 organisms per meter squared (Figure 6-5). *Americorophium stimpsoni* (5,957 org/m^2) and *Varichaetadrilus angustipenis* (3,373 org/m^2) were the dominant species. The minimum abundance in 2004 occurred in October with a total of 6,113 organisms per meter squared. *Americorophium stimpsoni* (3,415 org/m^2) and *Corbicula fluminea* (1,202 org/m^2) were the dominant species.

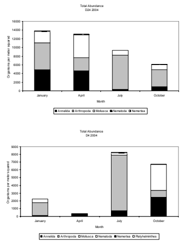


Figure 6-5 Benthic abundance at stations D24 and D4, 2004

Site D4: Benthic Abundance

Maximum abundance in 2004 occurred in July with a total of 8,246 organisms per meter squared (Figure 6-5). *Americorophium spinicorne* (5,520 org/m^2) was the dominant species. The minimum abundance in 2004 occurred in April with a total of 358 organisms per meter squared. *Varichaetadrilus angustipenis* (157 org/m^2) was the dominant species.

Site D6: Benthic Abundance

Maximum abundance in 2004 occurred in January with a total of 16,231 organisms per meter squared (Figure 6-6). *Corbula amurensis* (15,571 org/m^2) was the dominant species. The minimum abundance in 2004 occurred in April with a total of 6,797 organisms per meter squared. C*orbula amurensis* (4,299 org/m^2) and *Nippoleucon hinumensis* (2,432 org/m^2) were the dominant species.

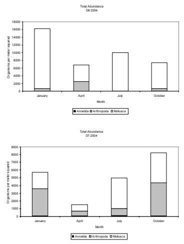


Figure 6-6 Benthic abundance at stations D6 and D7, 2004

Site D7: Benthic Abundance

Maximum abundance in 2004 occurred in October with a total of 8,222 organisms per meter squared (Figure 6-6). *Corbula amurensis* (3,862 org/m^2) and *Corophium alienense* (4,090 org/m^2) were the dominant species. The minimum abundance in 2004 occurred in April with a total of 1,515 organisms per meter squared. C*orbula amurensis* (650 org/m^2) was the dominant species.

Site D41: Benthic Abundance

Maximum abundance in 2004 occurred in October with a total of 39,116 organisms per meter squared (Figure 6-7). *Ampelisca abdita* (36,290 org/m^2) was the dominant species. The minimum abundance in 2004 occurred in July with a total of 5,672 organisms per meter squared. *Ampelisca lobata* (5,140 org/m^2) was the dominant species.

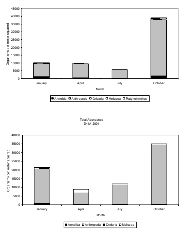


Figure 6-7 Benthic abundance at stations D41 and D41A, 2004

Site D41A: Benthic Abundance

Maximum abundance in 2004 occurred in October with a total of 34,856 organisms per meter squared (Figure 6-7). *Ampelisca abdita* (32,219 org/m^2) was the dominant species. The minimum abundance in 2004 occurred in

April with a total of 8,811 organisms per meter squared. *Ampelisca abdita* (3,520 org/m^2) and *Nippoleucon hinumensis* (2,603 org/m^2) were the dominant species.

Sediment Composition

Site C9: Sediment Composition

Sand was the dominant sediment type at site C9 for 2004 (Figure 6-8). The percentage of organic content was relatively low (< 1.4%) and ranged from 0.4% to 1.4%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

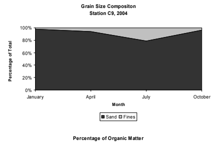


Figure 6-8 Sediment organic content and grain size at station C9 during 2004

Site P8: Sediment Composition

Sand dominated the sediment at site P8 for most of 2004 (Figure 6-9). The organic matter ranged from 0.7% to 2.7%, with the higher values coinciding with an influx of finer sediments.

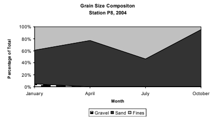


Figure 6-9 Sediment organic content and grain size at station P8 during 2004

Site D28A: Sediment Composition

Finer sediment usually dominated sediment at D28A (Figure 6-10). The organic matter ranged from 3.7% to 13.0%. Higher percentages of organic matter occurred during the months with the highest percentages of fines.

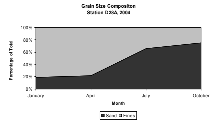


Figure 6-10 Sediment organic content and grain size at station D28A during 2004

Site D16: Sediment Composition

Sand was the dominate sediment type during 2004 (Figure 6-11). The organic matter ranged from 0.6% to 3.3%

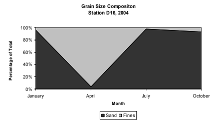


Figure 6-11 Sediment organic content and grain size at station D16 during 2004

Site D24: Sediment Composition

Sand usually dominated the sediment at D24 (Figure 6-12). The percent of organic matter at this site remained fairly stable during 2004 (ranging between 1.3% and 2.0%).

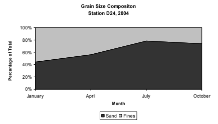


Figure 6-12 Sediment organic content and grain size at station D24 during 2004

Site D4: Sediment Composition

Sand dominated the sediment at D4 during 2004, with the exception of the April sampling event during which fines dominated (Figure 6-13). The percent of organic matter at this site was relatively high for most of the year, except in cases where the percentage of fines increased (ranged from 5.4% to 60.3%).

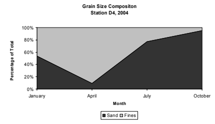


Figure 6-13 Sediment organic content and grain size at station D4 during 2004

Site D6: Sediment Composition

Finer sediments were the dominant sediment at D6 (Figure 6-14). Organic matter at this site was stable during 2003 (ranged from 3.8% to 5.3%).

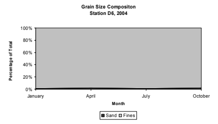


Figure 6-14 Sediment organic content and grain size at station D6 during 2004

Site D7: Sediment Composition

Finer sediments were the dominant type at D7 (Figure 6-15). The organic matter at this site was stable throughout the study period (ranged from 3.6 to 4.6%).

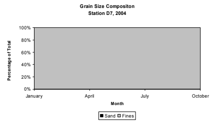


Figure 6-15 Sediment organic content and grain size at station D7 during 2004

Site D41: Sediment Composition

Finer sediments dominated the sediment at D41 (Figure 6-16). The organic matter at this site was relatively stable (ranged from 2.6% to 4.7%).

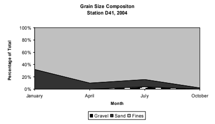


Figure 6-16 Sediment organic content and grain size at station D41 during 2004

Site D41A: Sediment Composition

Finer sediments dominated the sediment at D41A (Figure 6-17). The percentage of organic matter at this site was stable (ranged from 2.9% to 4.6%).

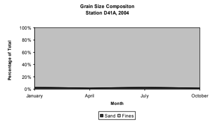


Figure 6-17 Sediment organic content and grain size at station D41A during 2004

Summary

The benthic monitoring program is designed to document the distribution, diversity, and abundance of benthic organisms in the upper San Francisco Estuary. The monitoring program collects a large number of organisms, but a relatively small number of species. All organisms collected during 2004 fell into seven phyla: Annelida, Arthropoda, Cnidaria, Mollusca, Nemertea, Nematoda, and Platyhelminthes. Of these seven phyla, Annelida, Arthropoda and Mollusca constituted 99.3% of the organisms collected during the study period. Ten species represent 93% of all organisms collected during this period. These species are: (1) the amphipods, *Americorophium spinicorne, Corophium alienense*, *Gammarus daiberi* and *Ampelisca abdita*; (2) the cumacean, *Nippoleucon hinumensis*; (3) the cytheride crustacean, *Cyprideis* sp. *A*; (4) the aquatic oligochaete, *Varichaetadrilus angustipenis*; (5) the Sabellide Polychaete, *Laonome* sp. *A*; and (6) the asian clams, *Corbula amurensis* and *Corbicula fluminea*.

References

[APHA] American Public Health Association, American Waterworks, and Water Environmental Federation. 1998. *Standard Methods for the Examination of Water and Wastewater.* 20th ed. Washington, D.C.: American Public Health Association, 10.60-10.74.

[ASTMa] American Society of Testing and Materials, 2000. *Soil and Rock (I): D420 - D5779,* Vol. 04.08: protocol D422

[ASTMb] American Society of Testing and Materials, 2000. *Soil and Rock (I): D420 - D5779,* Vol. 04.08: ASTM protocol D2974 method C.

[DWR] Department of Water Resources, 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta During 1996*. A report to the State Water Resources Control Board in Accordance with Water Right Decision 1485, Order 4(f). Department of Water Resources, Sacramento, California.

Hymanson, Z., D. Mayer, J. Steinbeck, 1994. *Long-Term Trends in Benthos Abundance and Persistence in the Upper Sacramento-San Joaquin Estuary. Summary Report: 1980-1990.* Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 38. Department of Water Resources.

Markmann, C, 1986. *Benthic Monitoring in the Sacramento-San Joaquin Delta. Results from 1975 through 1981.* Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Technical Report 12. Department of Water Resources.

Thompson, J, 2005. "*Potamocorbula amurensis* Is, For Now, *Corbula amurensis"*. *Interagency Ecological Program Newsletter.* Volume 18; Number 2. Spring 2005. Department of Water Resources.

Figure 6-1 Benthic monitoring stations, 2004

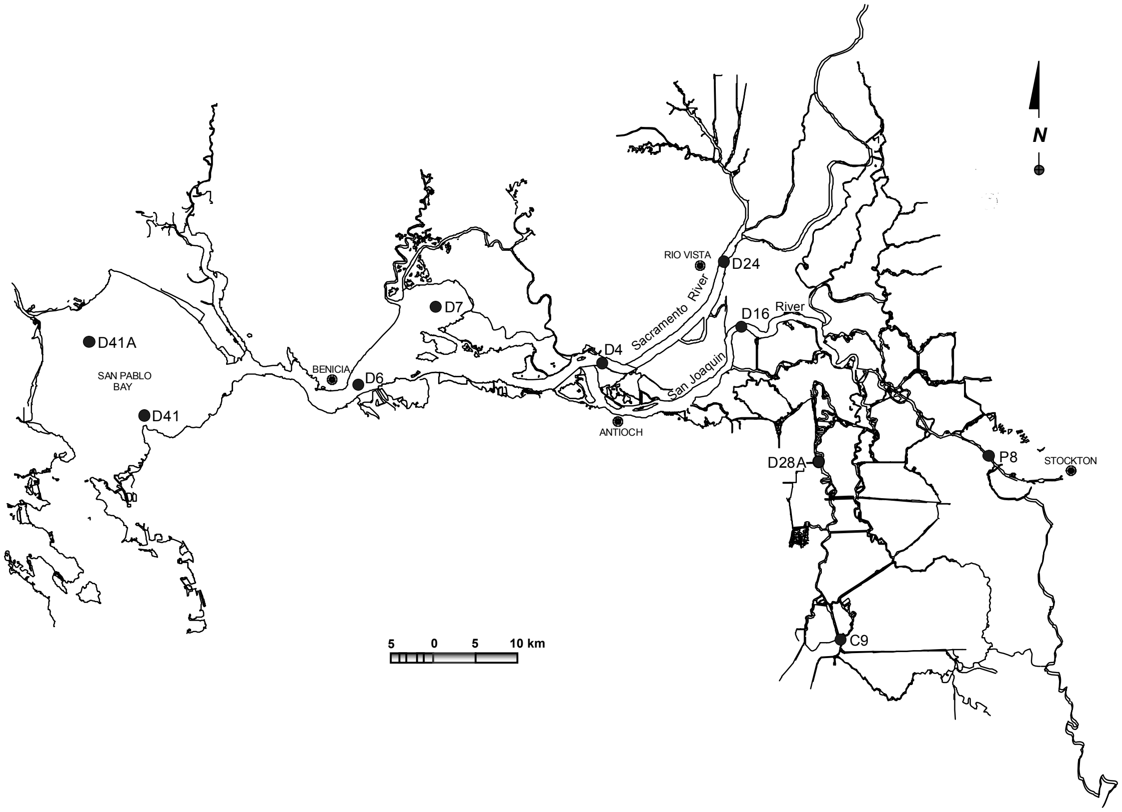


Figure 6-2 Total contribution by phyla for all stations during 2004

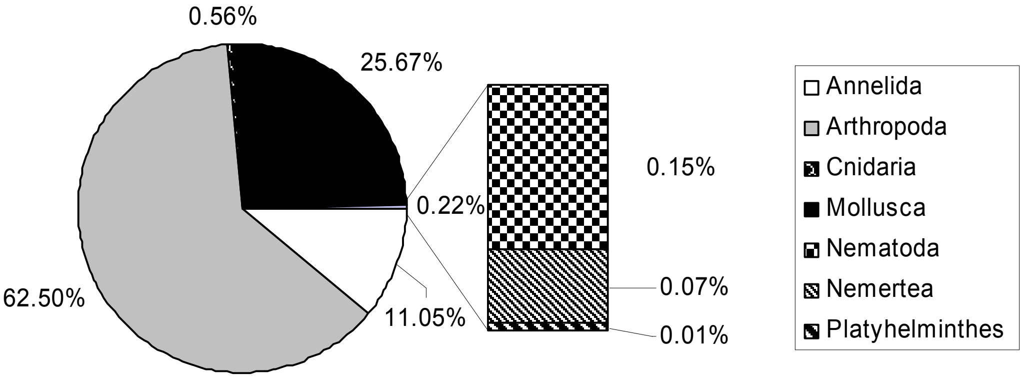
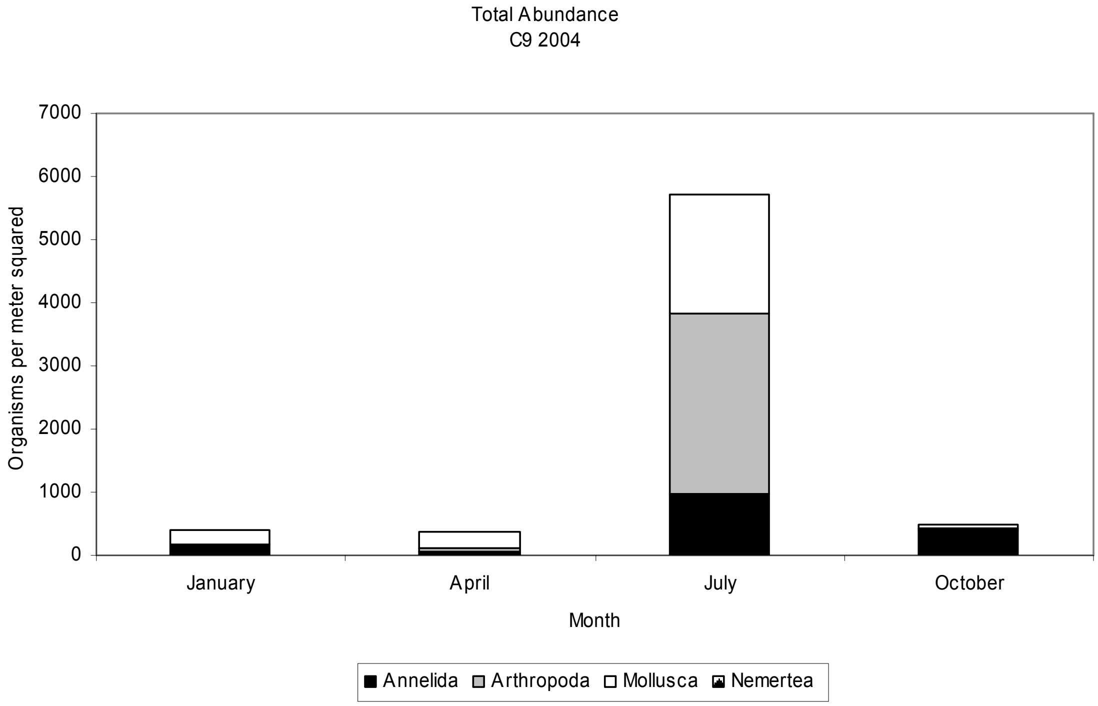


Figure 6-3 Benthic abundance at stations C9 and P8, 2004



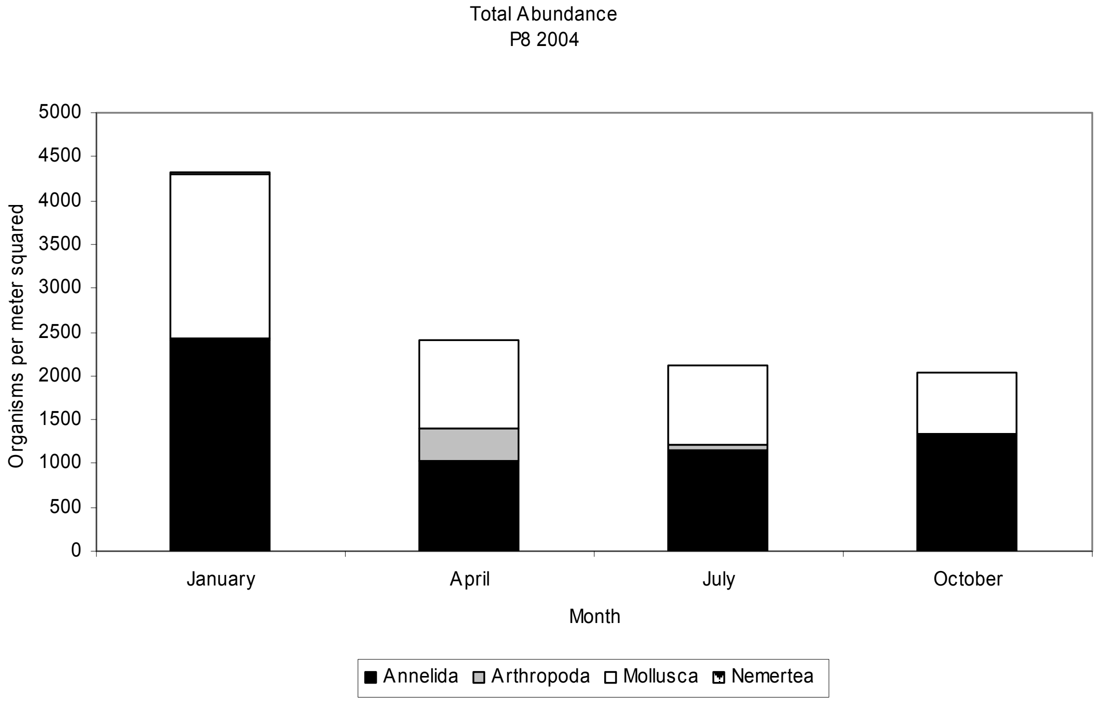
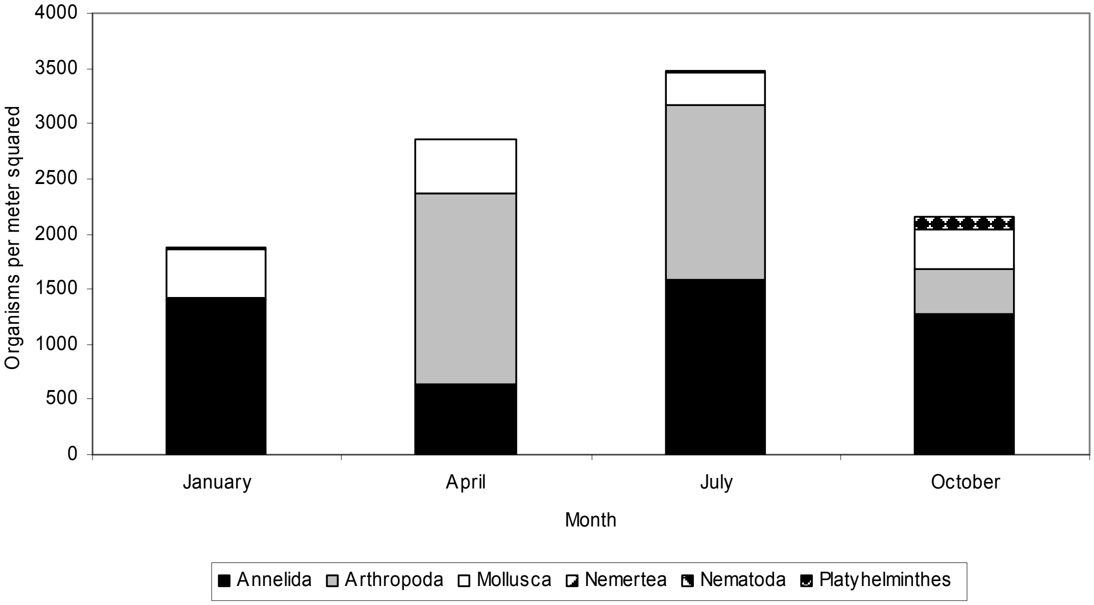


Figure 6-4 Benthic abundance at stations D28A and D16, 2004

Total Abundance
D28A 2004



Total Abundance
D16 2004

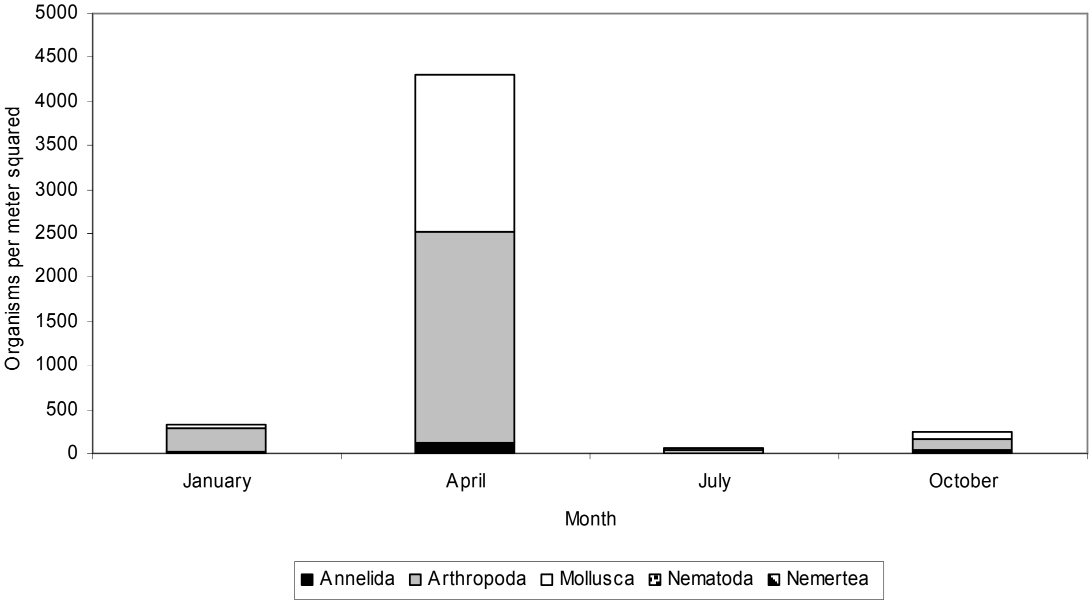
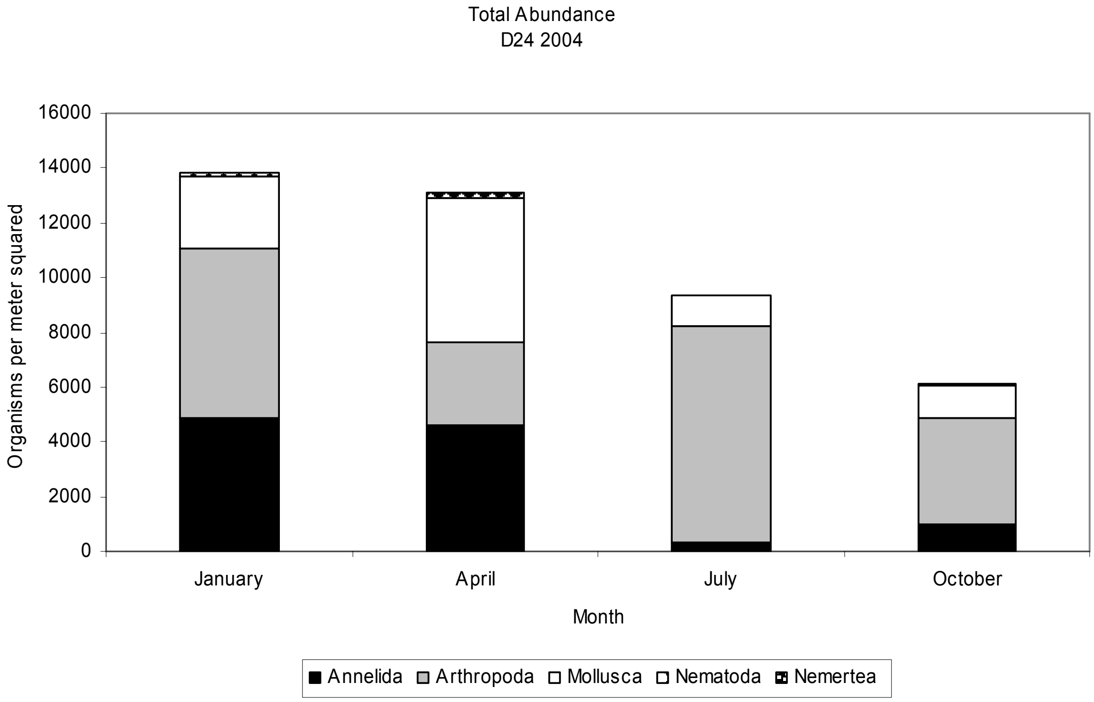


Figure 6-5 Benthic abundance at stations D24 and D4, 2004



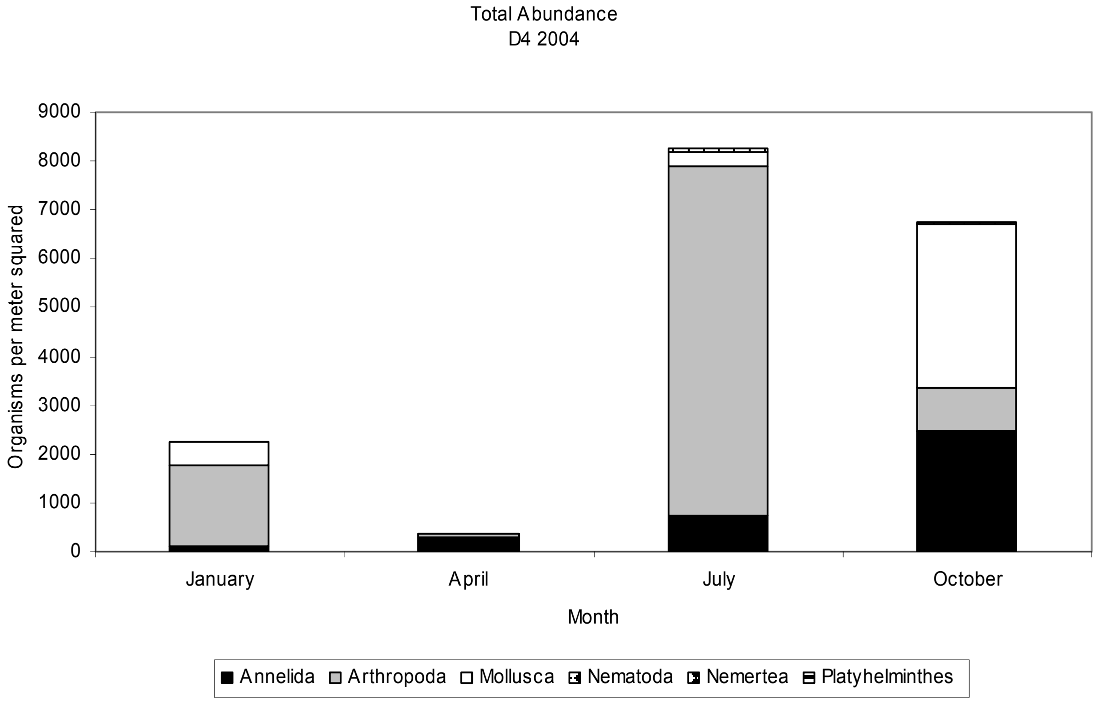


Figure 6-6 Benthic abundance at stations D6 and D7, 2004

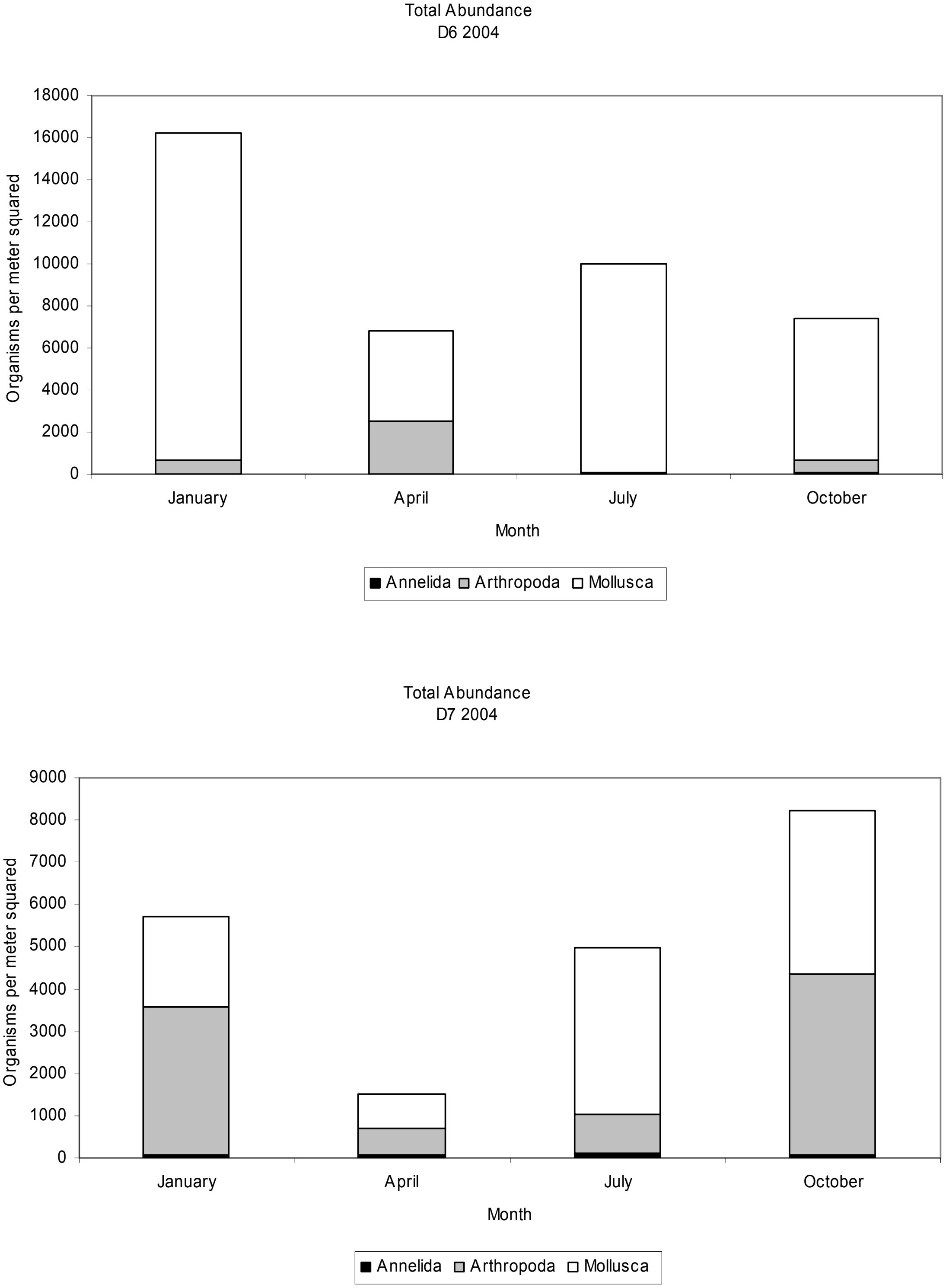
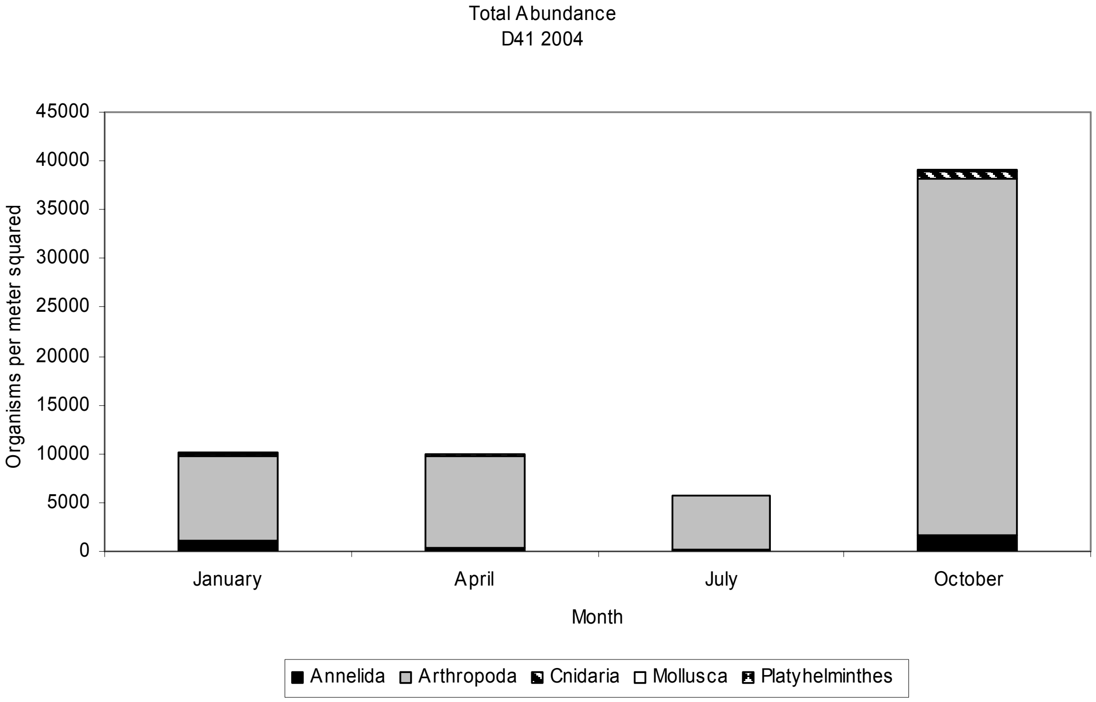


Figure 6-7 Benthic abundance at stations D41 and D41A, 2004



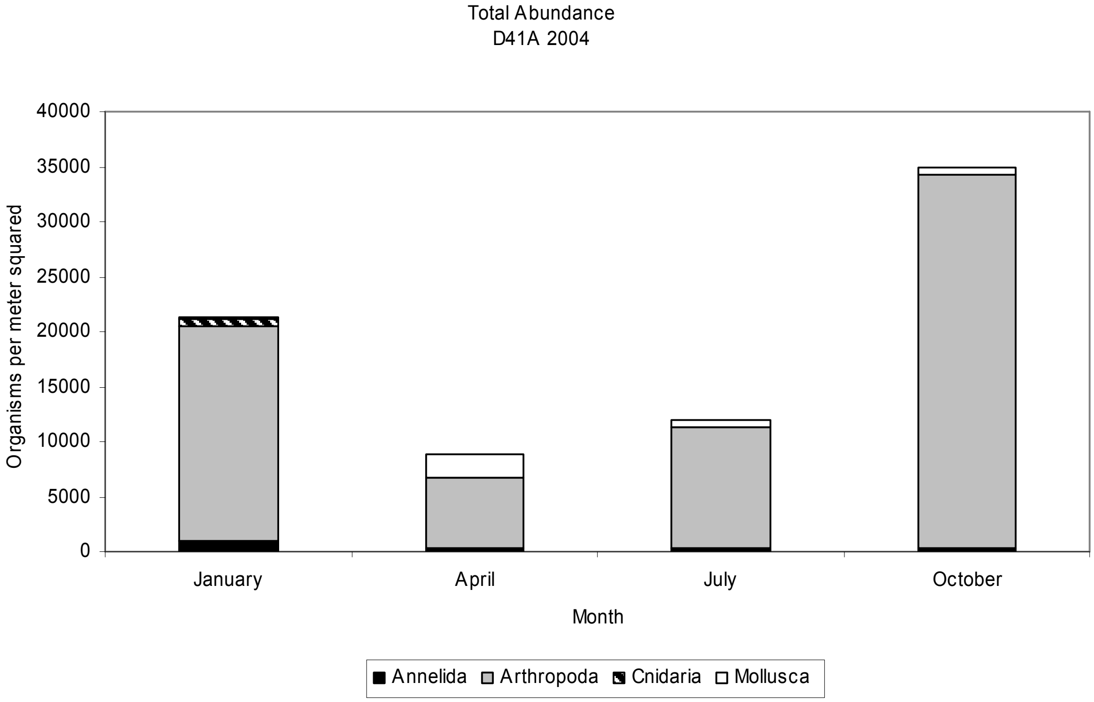
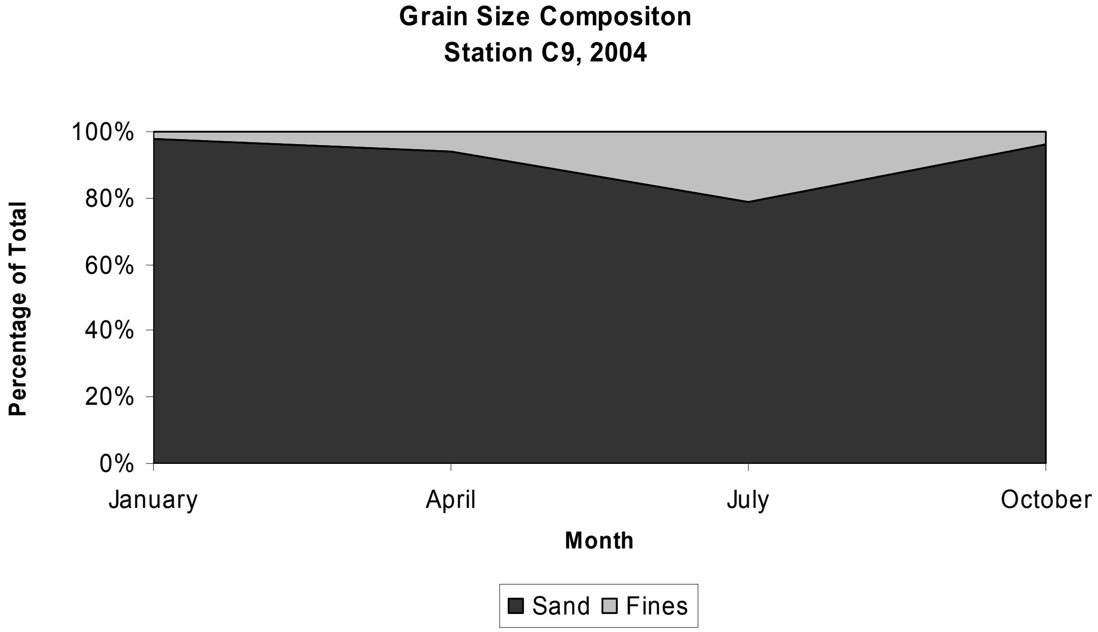


Figure 6-8 Sediment organic content and grain size at station C9 during 2004



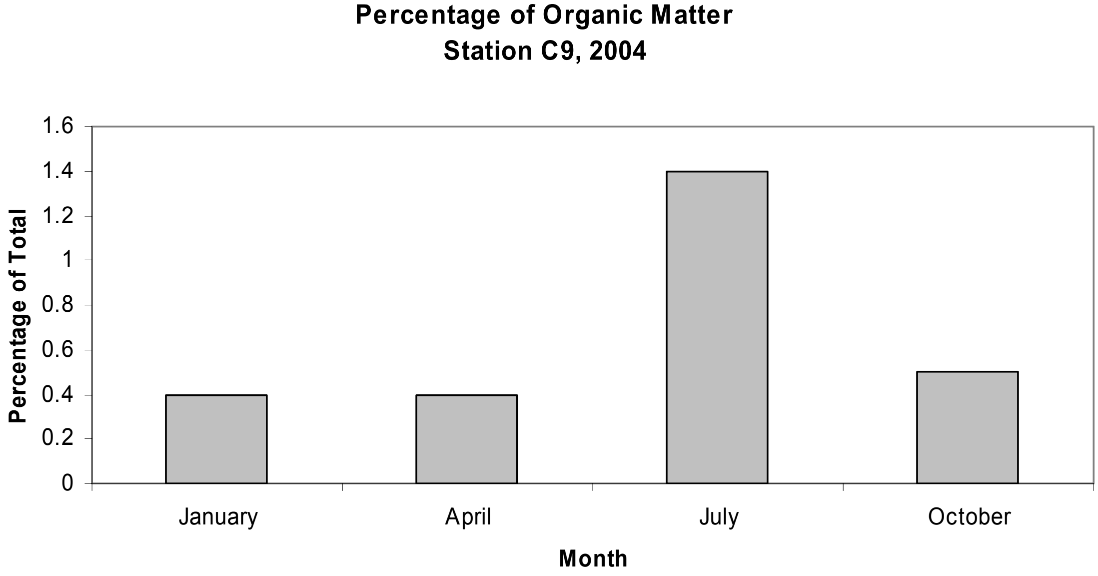
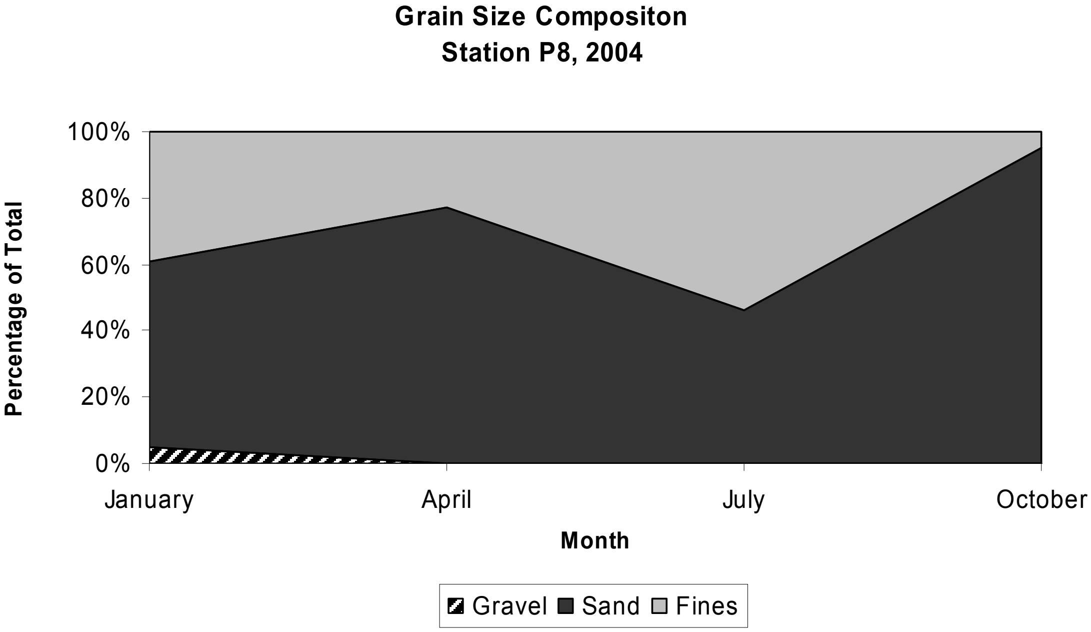


Figure 6-9 Sediment organic content and grain size at station P8 during 2004



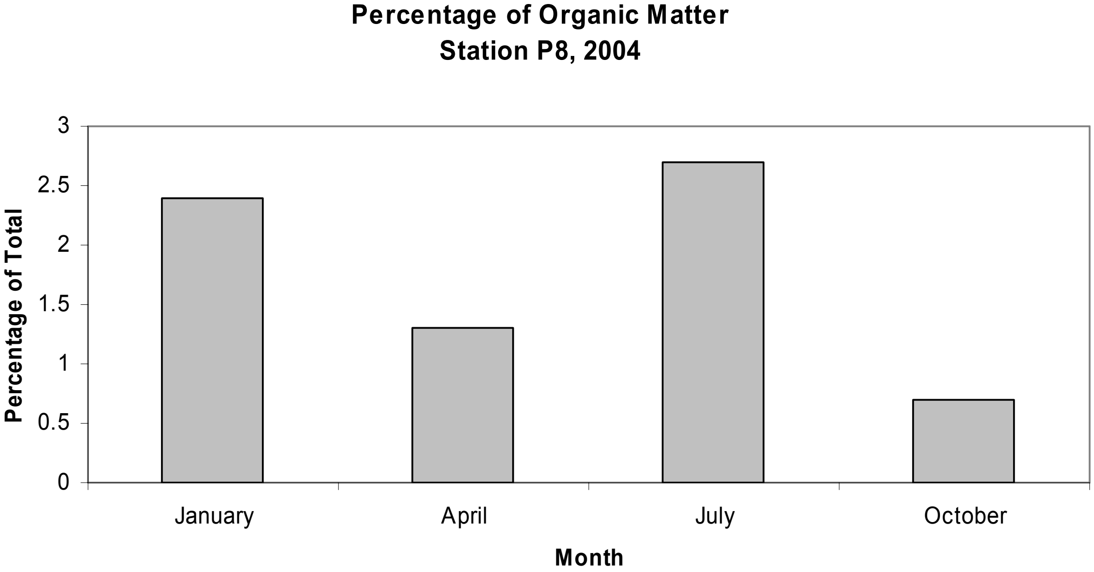
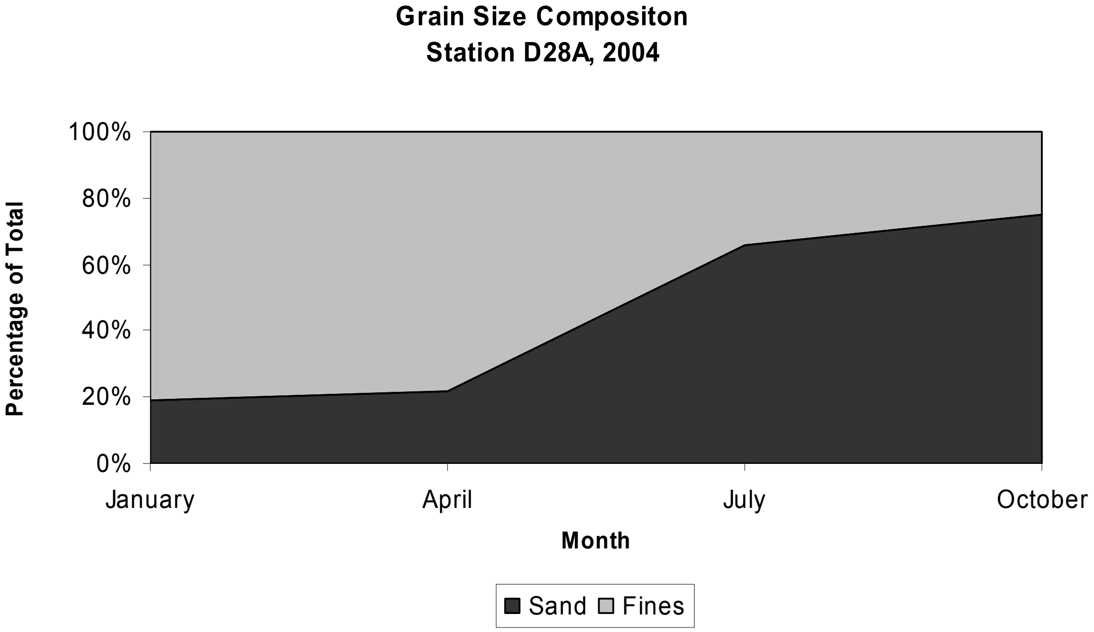


Figure 6-10 Sediment organic content and grain size at station D28A during 2004



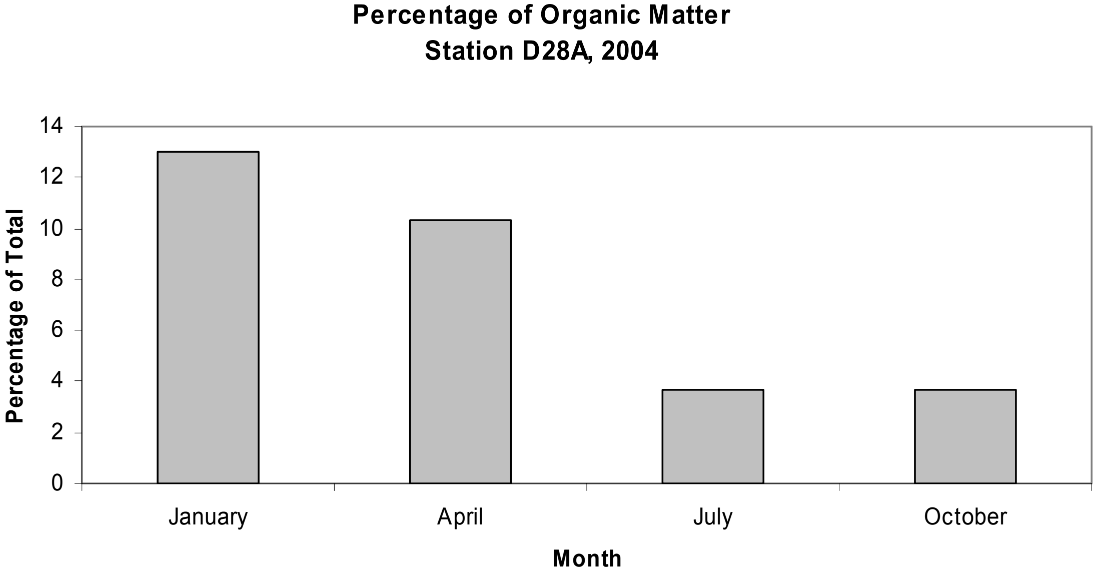
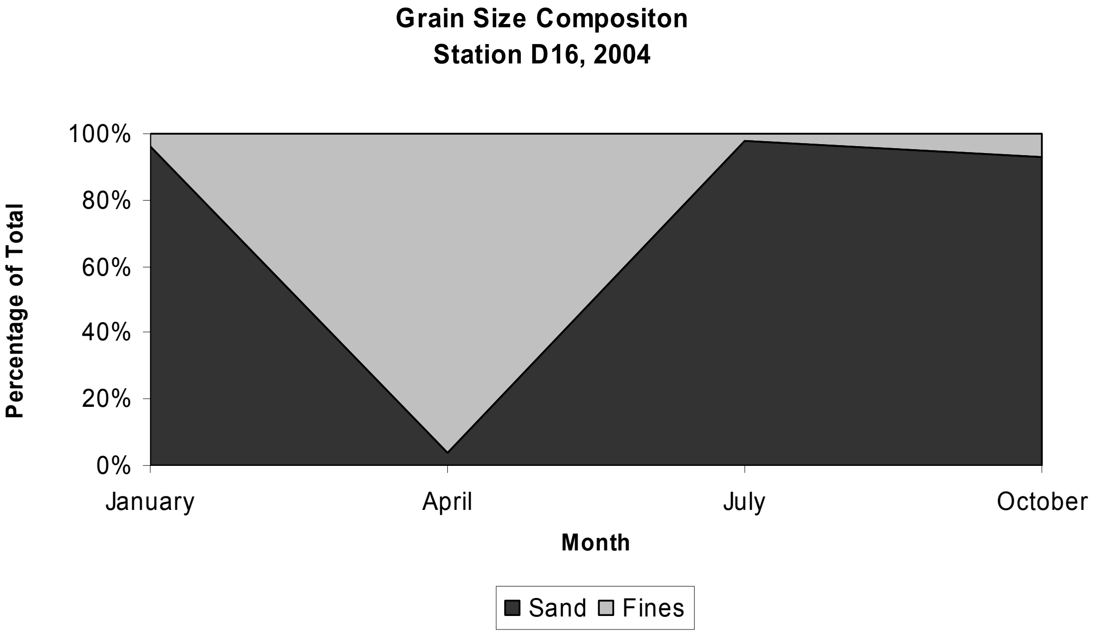


Figure 6-11 Sediment organic content and grain size at station D16 during 2004



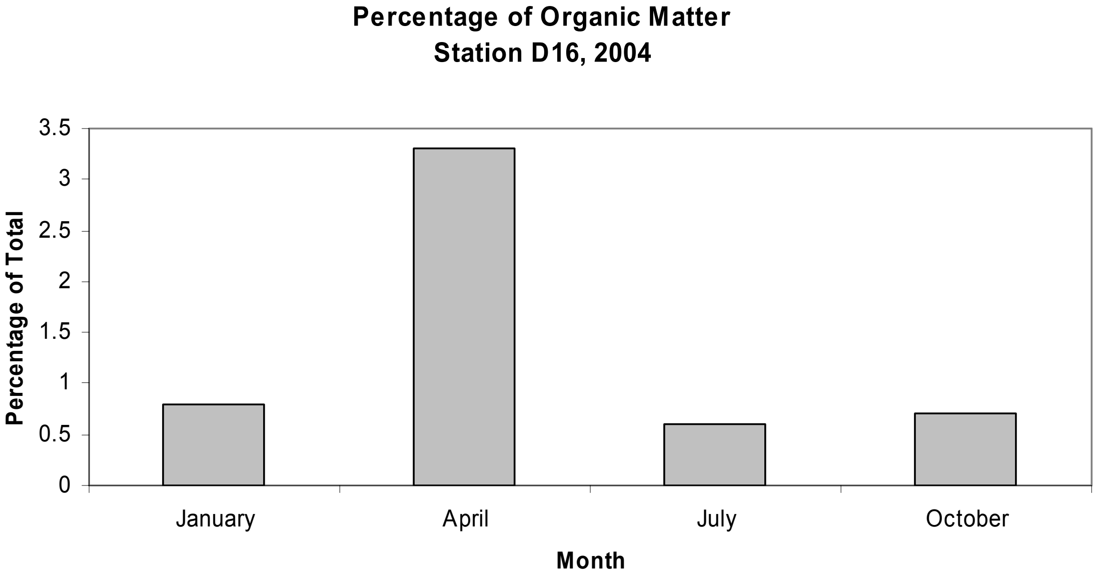
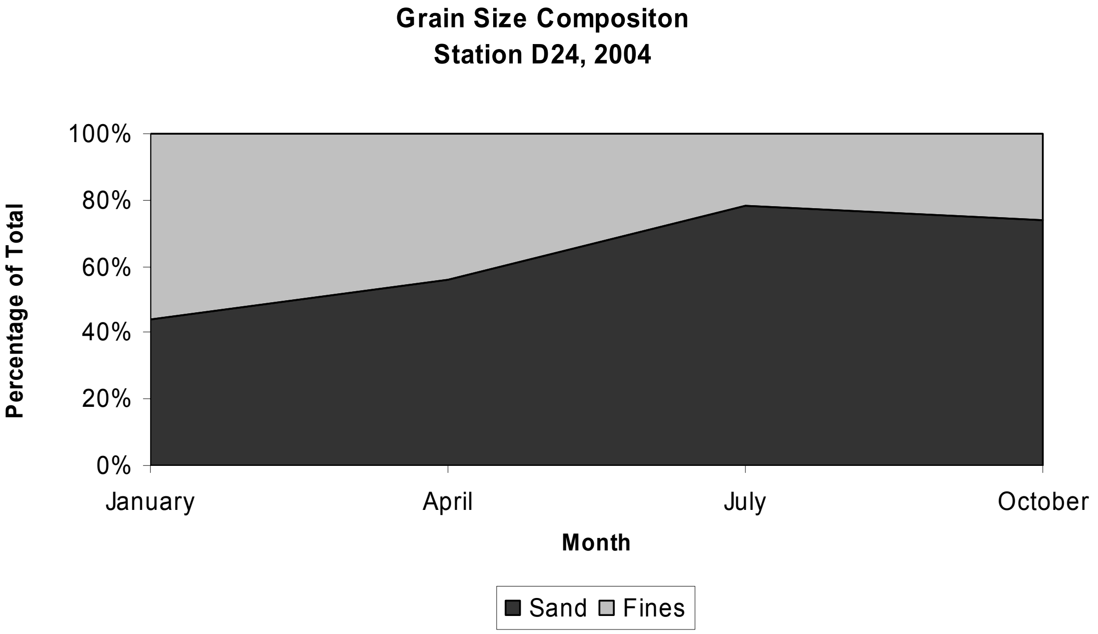


Figure 6-12 Sediment organic content and grain size at station D24 during 2004



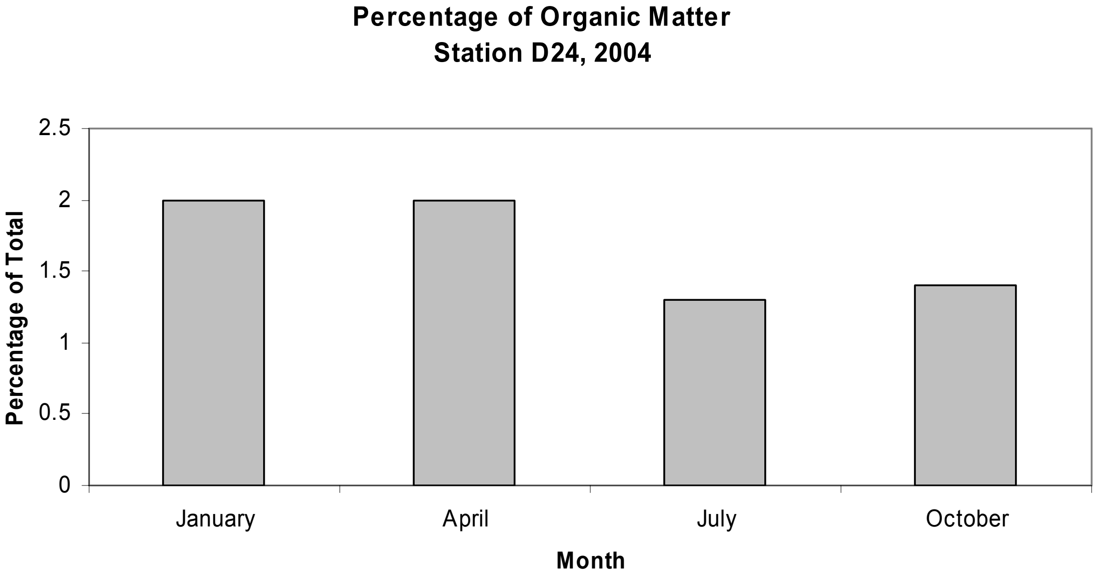
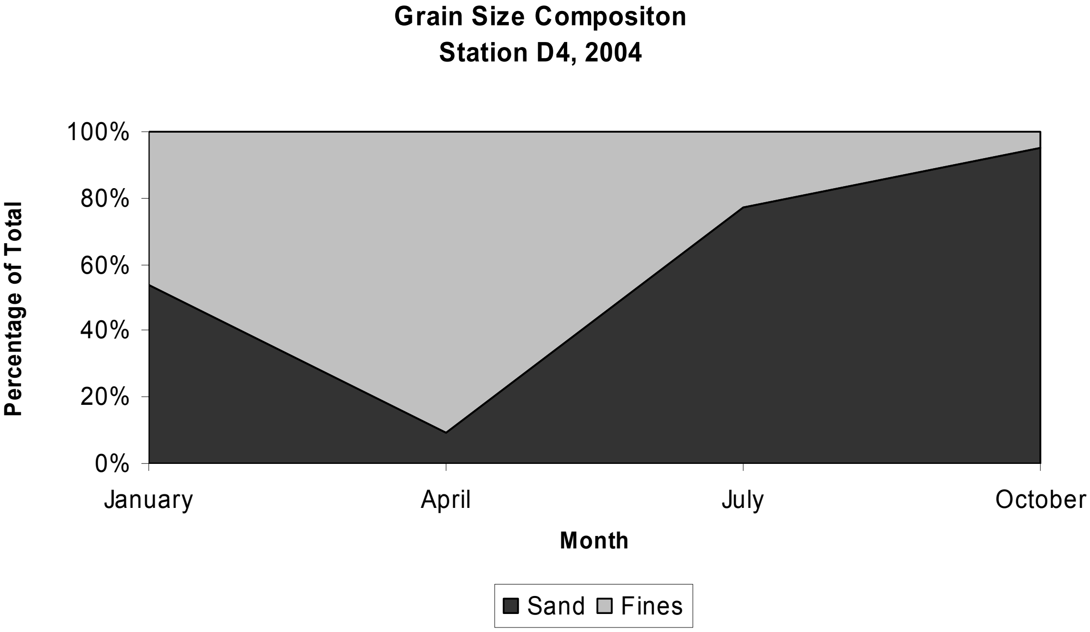
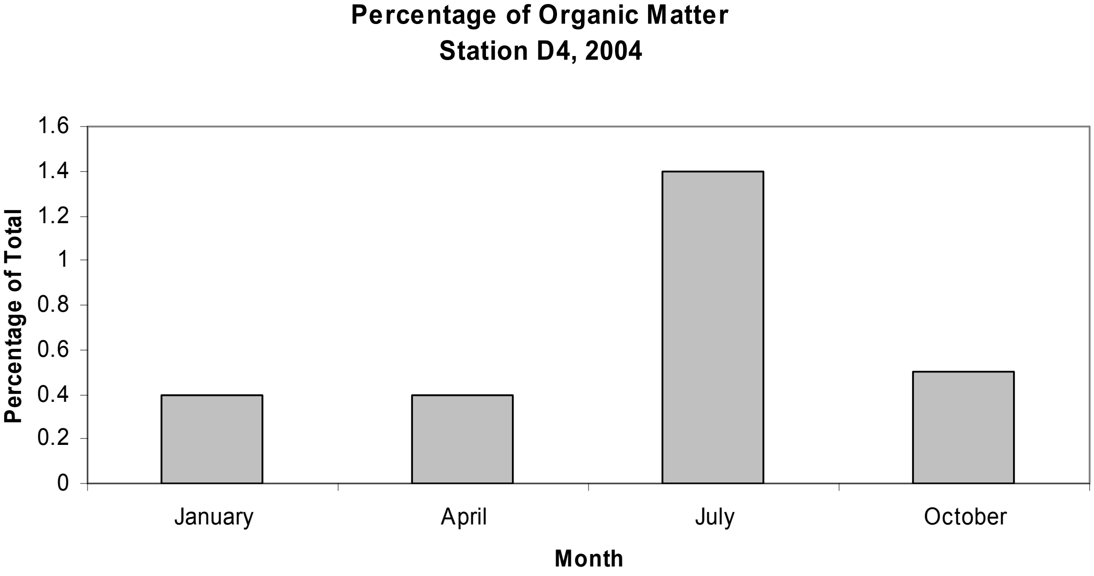


Figure 6-13 Sediment organic content and grain size at station D4 during 2004

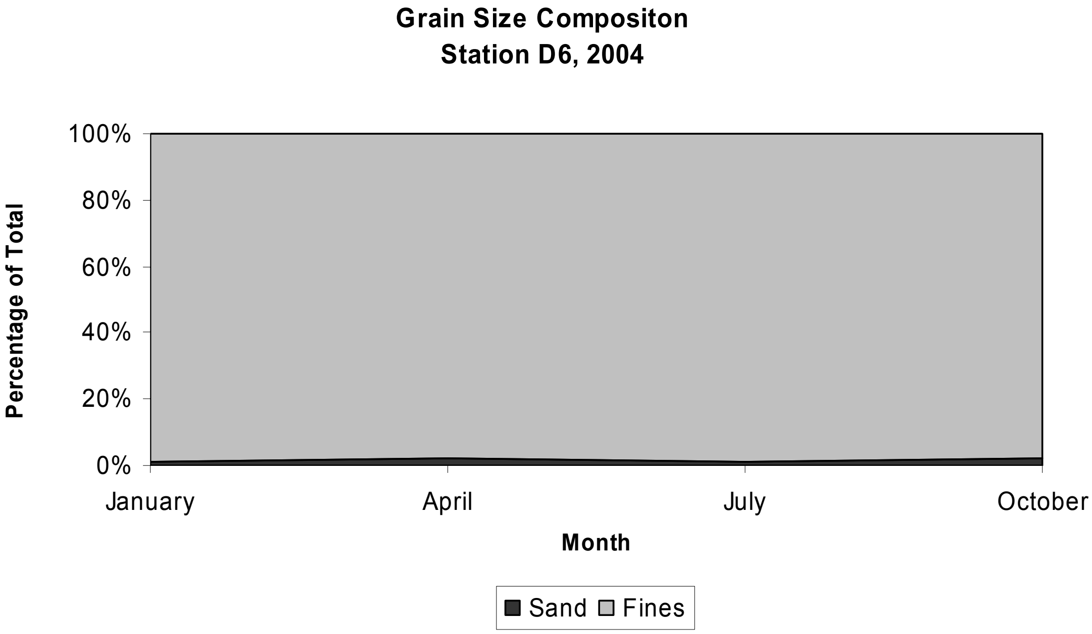


Grain Size Compositon
Station D4, 2004



Percentage of Organic Matter
Station D4, 2004

Figure 6-14 Sediment organic content and grain size at station D6 during 2004



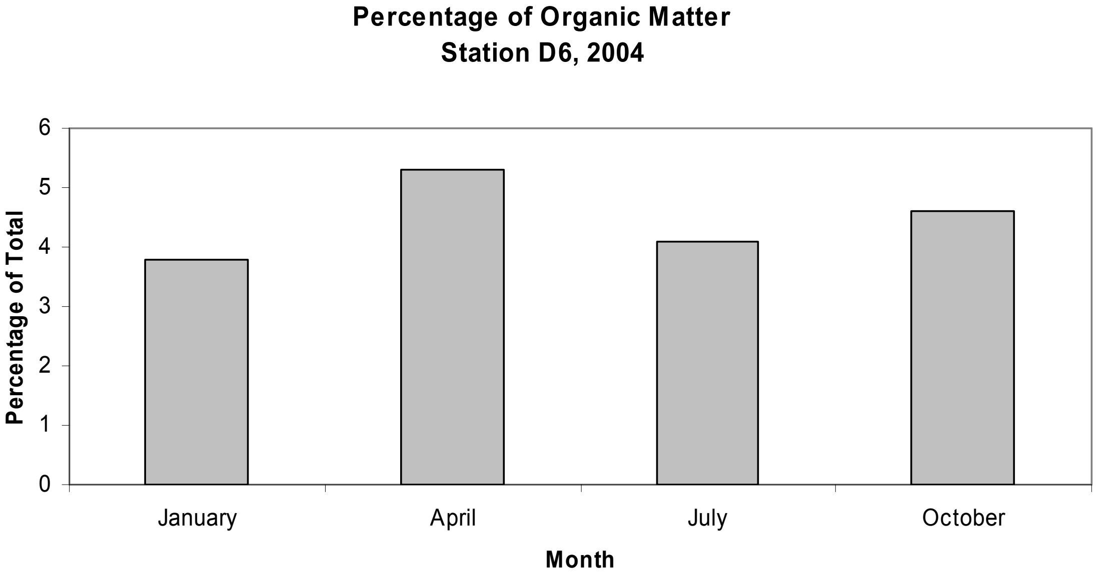
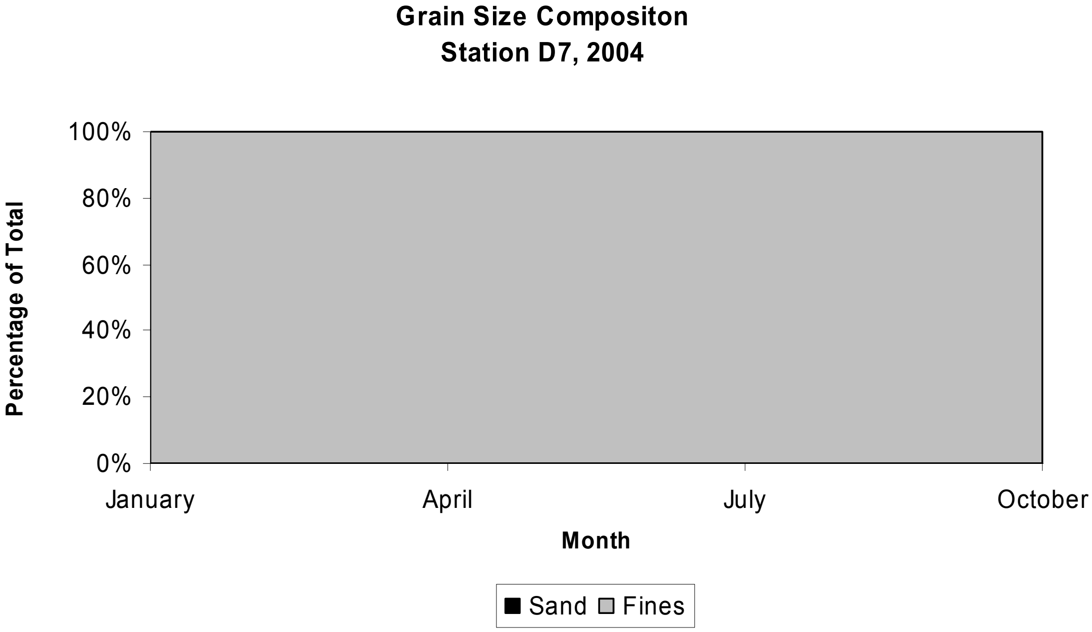


Figure 6-15 Sediment organic content and grain size at station D7 during 2004



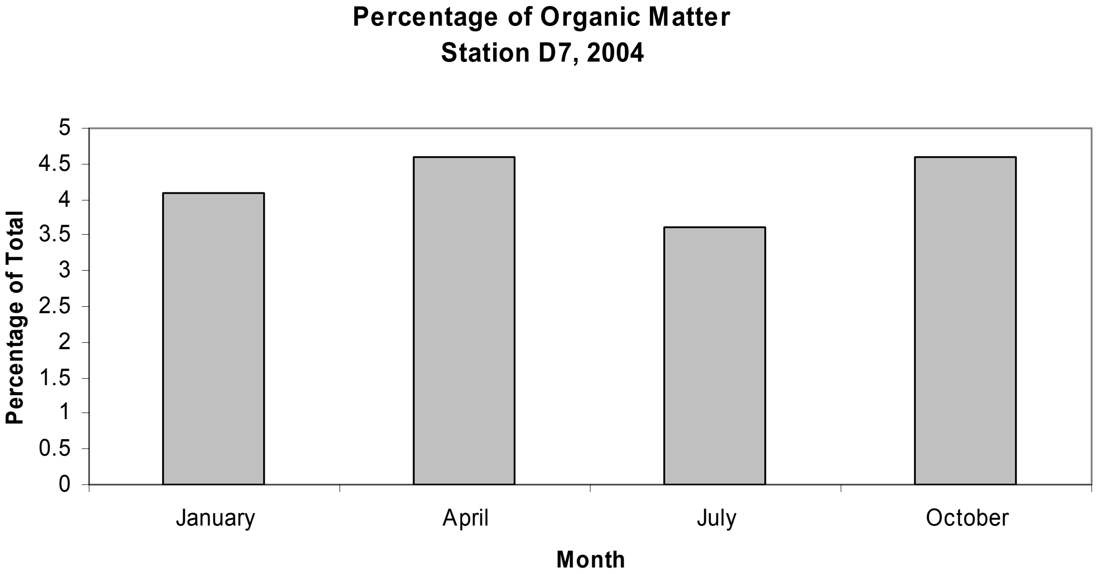
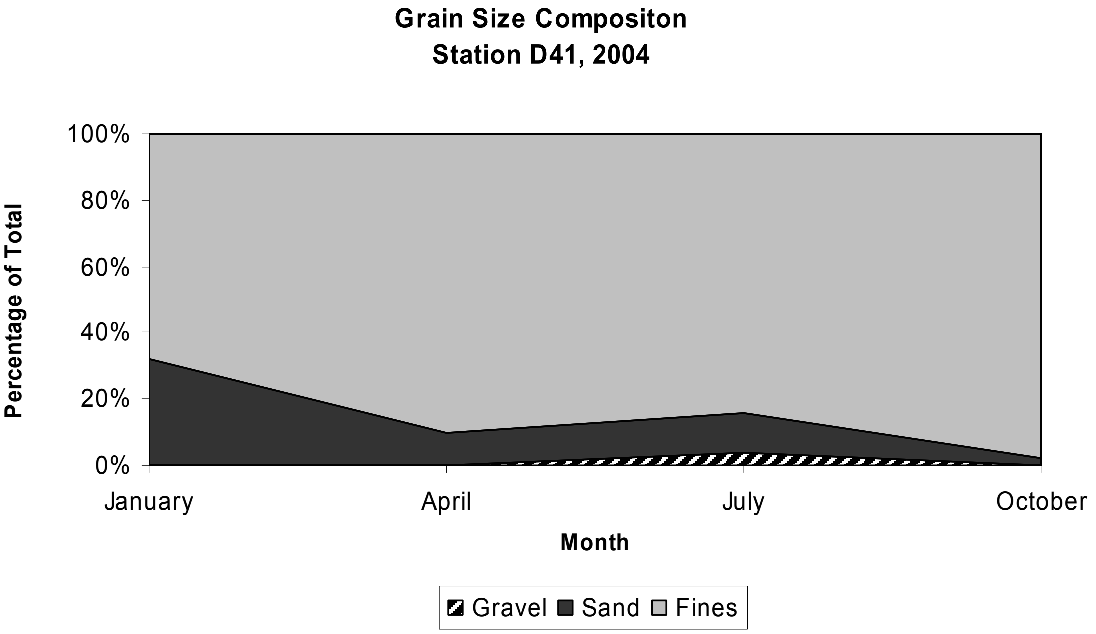


Figure 6-16 Sediment organic content and grain size at station D41 during 2004



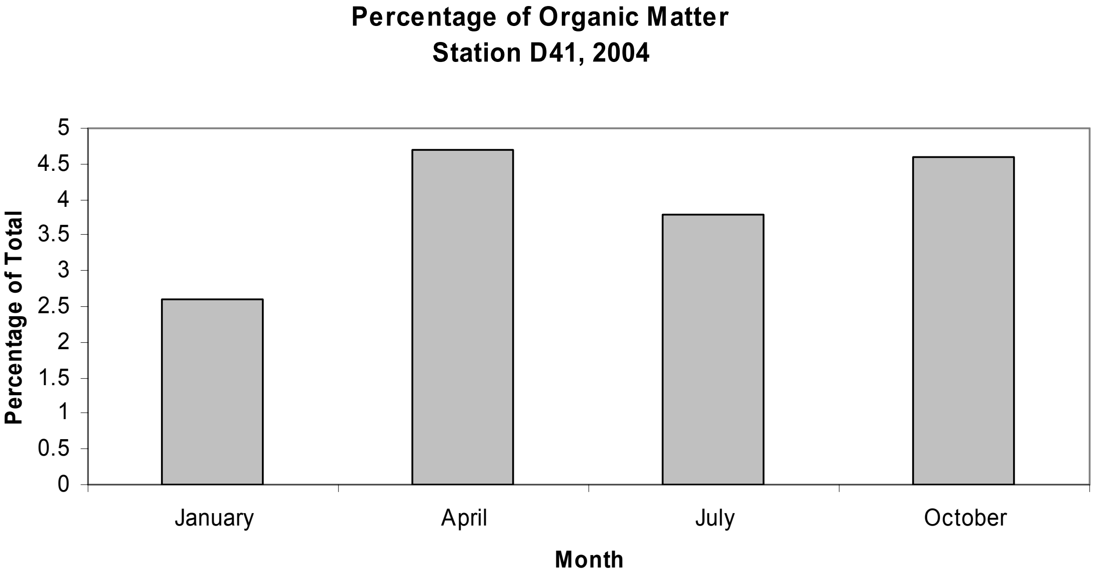
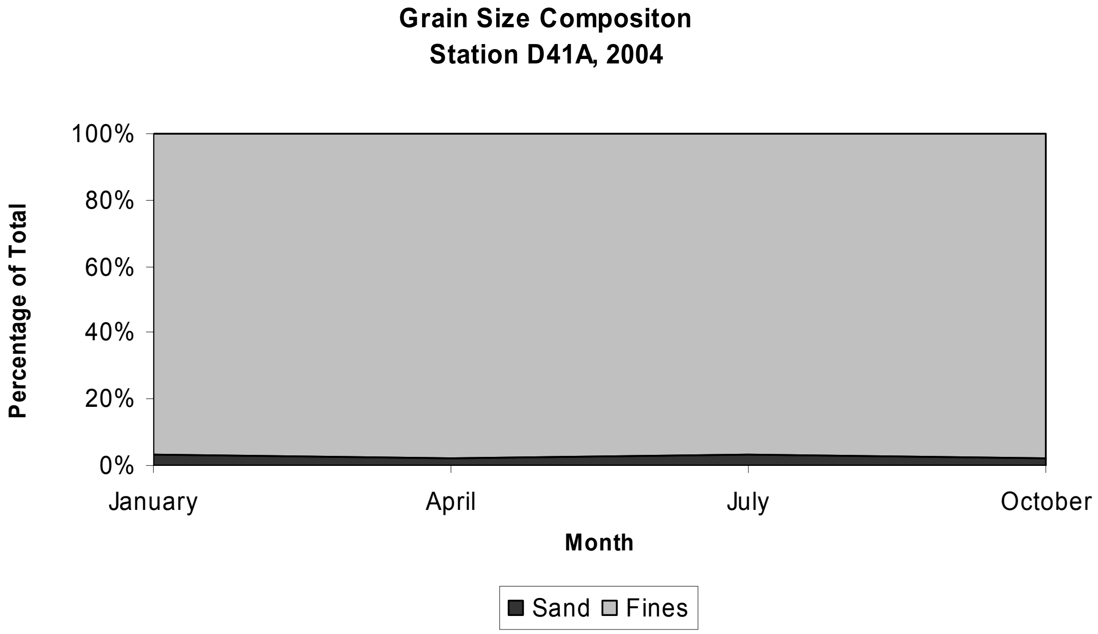


Figure 6-17 Sediment organic content and grain size at station D41A during 2004



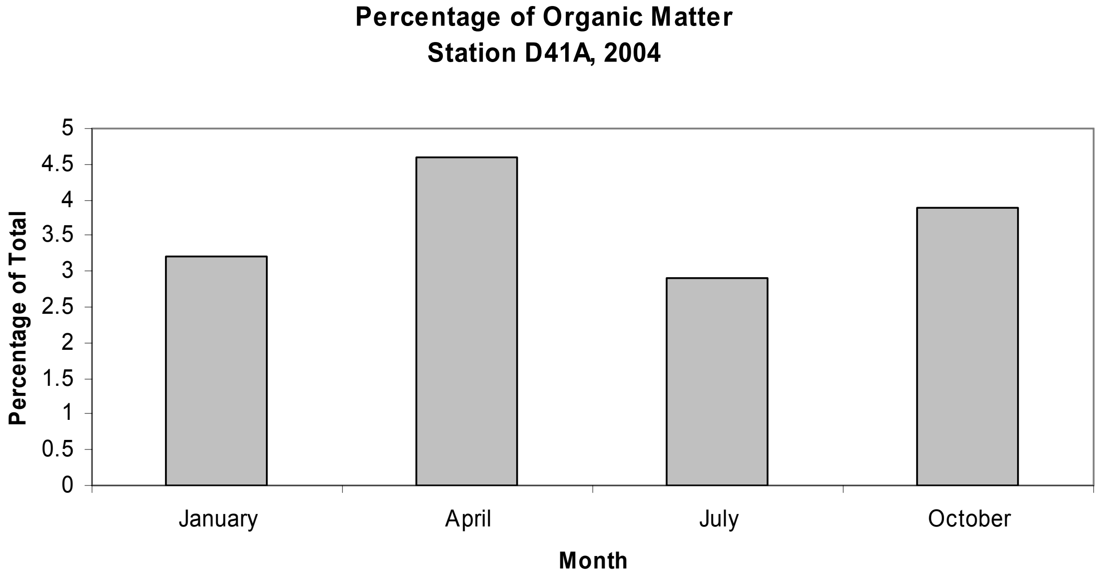


Table 6-1 Macrobenthic monitoring station characteristics

Station Region	Latitude Longitude	Substrate Composition	Approx. Salinity Range (µS/cm)
C9 Delta-Old River	37° 49' 50" 121° 33' 09"	Consistent. Over 90% sand.	200-800
P8 Delta San Joaquin River	37° 58' 42" 121° 22' 55"	Consistent. High sand content (60%).	175-750
D28A Delta Old River	37° 58' 14" 121° 34' 19"	Mixed composition of sand and fines	200-350
D16 Delta San Joaquin River	38° 05' 50" 121° 40' 05"	Consistent. Mostly fines with some organic materials	130-500
D24 Delta Sacramento River	38° 09' 27" 121° 41' 01"	Consistent. High sand content (80%).	200-1,200
D4 Delta Sacramento River	38° 03' 45" 121° 49' 10"	Mixed composition of sand, fines, and organic materials.	130-8,000
D6 Suisun Bay	38° 02' 40" 122° 07' 00"	Fairly equal mixture of sand and fines	135-30,000
D7 Grizzly Bay	38° 07' 02" 122° 02' 19"	Consistent. Mostly Fines with some organic materials.	200-20,000
D41 San Pablo Bay	38° 01' 50" 122° 22' 15"	Consistent. High content of fine material (87%)	20,000-45,000
D41A San Pablo Bay	38° 03' 75" 122° 24' 40"	Consistent. High content of fine material (90%)	30,000-44,000

Chapter 7. Dissolved Oxygen Monitoring in the Stockton Ship Channel

Introduction

Dissolved oxygen (DO) levels in the Stockton Ship Channel have been monitored by the staff of the Bay-Delta Monitoring and Analysis Section during the late summer and fall of each year since 1968. Due to a variety of factors, DO levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River at Stockton.

Because low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the State has established specific water quality objectives to protect these uses. Within the channel, two separate DO objectives have been established. The Central Valley Regional Water Quality Control Board has adopted a dissolved oxygen standard of 5.0 mg/L for the entire Delta throughout the year to protect all beneficial uses (CVRWQCB 1998). The State Water Resources Control Board (SWRCB) has an objective of 6.0 mg/L in the lower San Joaquin River between Stockton and Turner Cut (which includes the eastern portion of the Stockton Ship Channel). The SWRCB's objective applies from September through November to protect migrating fall-run Chinook salmon (SWRCB 1995).

As part of a 1969 Memorandum of Understanding between DWR, the US Fish and Wildlife Service, USBR, and the Department of Fish and Game, DWR has installed a rock barrier across the head of Old River during periods of projected low fall San Joaquin River outflow. This Head of Old River barrier (barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving DO levels. The barrier is usually installed in the fall and spring when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

Because late summer San Joaquin River flows past Vernalis in 2004 were low and early fall flows were not projected to be sufficient to alleviate DO concerns in the eastern channel, DWR began in-water construction of the barrier on approximately September 23. The barrier was in place and fully operational on September 29. Removal of the barrier began on November 1 and was completed by November 12.

Methods

Monitoring of DO concentrations in the Stockton Ship Channel was conducted by vessel on seven monitoring runs from August 11 to November 24, 2004[1]. During each of the monitoring runs, fourteen sites were

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[1] Funding for these special studies was provided by the DWR Division of Operations and Maintenance.

sampled at low water slack, beginning at Prisoner's Point (Station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the ship channel (Station 14). For geographic reference and simplicity of reporting, the sampling stations are keyed to Channel Light Markers[2] as shown in Figure 7-1.

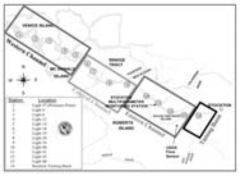

Figure 7-1 Monitoring sites in the Stockton Ship Channel

Because monitoring results differ along the channel[3], sampling stations are grouped into western, central, and eastern regions within the channel. These regions are highlighted in Figure 7-1. The western channel begins at Prisoner's Point (Station 1) and ends at Light 14 (Station 5). The central channel begins at Light 18 (Station 6) and ends at Light 34 (Station 9). Finally, the eastern channel begins at Light 40 (Station 10) and ends at Light 48 (Station 13). The turning basin (Station 14) is unique within the channel because it is east of the entry point of the San Joaquin River into the channel and isolated from down-channel flow. Because of the unique hydromorphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at low water slack, and analyzed for DO concentrations and temperature. Top DO samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were obtained using a Seabird submersible sampler and measured using a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger. Surface and bottom water temperatures were measured using a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe or a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data at Vernalis and were compiled by DWR[4]. Average daily flows past Vernalis were obtained by averaging 15-minute data for a daily average flow rate. Tidal cycles of ebb and flood are not seen in flows at Vernalis and the flow proceeds downstream (positive flow) throughout the year.

Flow measurements for the San Joaquin River past Stockton used in this report were obtained from data recorded by the US Geological Survey flow monitoring station southeast of Rough and Ready Island[5]. Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter[6] to yield net daily flow. Due to

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[2] Channel Light Markers are ship navigational aides placed in navigable waters. Although they are not spaced at fixed intervals, they provide convenient landmarks for identifying sample locations.

[3] The findings of previous fall studies have shown that fall DO levels are typically: robust and high (7.0-9.0 mg/L) in the western channel; transitional, variable (4.0-7.0 mg/L), and stratified in the central channel; and low (3.0-5.0 mg/L) and stratified in the eastern channel.

[4] Station information: DWR Station SJR at Vernalis, RSAN112

[5] Station information: USGS 304810 SJR at Stockton, RSAN063.

[6] The USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15 minute flow data, that occur on less than a 30 hour period. The resulting 15-minute time-series is then averaged to provide a single daily value which represents net river flow exclusive of tidal cycles.

low inflows, upstream agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse direction. During the period from July through December 2004 net flows at Stockton frequently approached zero, and net reverse flows were recorded during several days.

Results

During the August 11 to November 24 study period, DO levels varied considerably between regions within the channel (not including the turning basin) from 2.1 to 8.8 mg/L. In the western channel DO concentrations were relatively high and stable, ranging from 7.0 to 8.8 mg/L. The robustness of DO concentrations in this portion of the channel, in comparison with the central and eastern portions of the channel, is apparently due to greater tidal mixing, less biochemical oxygen demand from sources in the water, and shorter hydrological residence time. In the central portion of the channel, DO concentrations were more variable than the concentrations observed in the western channel, ranging from 2.7 to 8.4 mg/L. In the eastern channel, the DO levels were the most variable and stratified, ranging from 2.1 to 7.8 mg/L.

Inflows from the San Joaquin River past Stockton were variable during the period. Net daily flow, exclusive of tidal pulses, ranged from +2,371 to -188 cfs from June through December 2004. The positive flow indicates net downstream flow, while negative flows indicate net upstream flow.

The findings for the late summer and fall of 2004 are briefly summarized by month as follows.

August

Monitoring during cruises on August 11 and 30 showed surface DO levels ranging from 3.2 mg/L at Station 13 in the east channel to 7.6 mg/L at Station 1 in the west channel (Figure 7-2). Bottom DO levels ranged from 2.7 mg/L at Station 12 in the east channel to 7.7 mg/L at Station 1. (Note: No bottom DO measurements were collected on August 11 due to calibration problems with the measurement probe.)

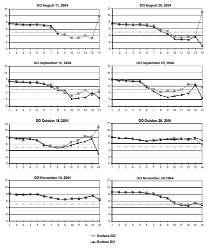

Figure 7-2 Fall 2004 dissolved oxygen concentrations at 14 stations in the Stockton Ship Channel

A DO sag[7] (<6.0 mg/L) was observed at the surface and bottom at both the central and eastern stations. On August 11, the DO sag extended from stations 8 to 13. On August 30 DO conditions improved slightly in the central channel; however, the extent of the DO sag remained unchanged. DO conditions in the western channel remained relatively high throughout August and all stations reported DO levels well above the state's objective.

August water temperature values ranged from surface values of 22.5 °C in the west channel to 26.3 °C in the east channel, and from bottom values of 22.5 °C in the west to 25.9 °C in the east channel (Figure 7-3). An almost linear temperature gradient of approximately 4 °C existed from Station 13 in the west to Station 1 in the east channel.

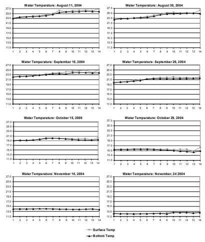

Figure 7-3 Fall 2004 water temperatures at 14 stations in the Stockton Ship Channel

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[7] In this report, we define a DO "sag" as a region within the channel where DO levels do not meet the SWRCB objective of 6.0 mg/L.

Average daily flows in the San Joaquin River past Vernalis in August ranged from 1,354 to 950 cfs. Net flow in the San Joaquin River past Stockton ranged from 576 to 114 cfs (Figure 7-4). Despite daily flow variations, overall flow rates at both Vernalis and Stockton remained virtually flat for the month.

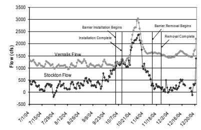


Figure 7-4 San Joaquin River average net daily flow: Fall 2004

September

Monitoring during cruises on September 11 and 29 showed surface DO levels ranging from 3.2 mg/L at Station 10 in the east channel to 8.0 mg/L at Station 1 in the west channel (Figure 7-2). Bottom DO levels ranged from 2.1 mg/L at Station 10 to 7.9 mg/L at Station 1. The western channel exhibited the highest DO and all stations in the channel maintained surface DO levels above the state's objective.

The DO sag observed in August appeared to move westward during September. Monitoring on September 15 showed the extent of the sag from Station 7 (bottom DO) and Station 8 (surface DO) to Station 13. On September 29, surface DO levels in the far eastern channel had improved to above the 6.0 mg/L state objective; however, the sag had moved further into the central channel. The DO sag on September 29 reached from Station 6 to stations 11 and 12 (for surface DO and bottom DO respectively).

September surface water temperatures ranged from 19.4 °C at Station 1 in the west channel to 24.8 °C at Station 12 in the east channel. Bottom temperatures ranged from 19.8 °C at Station 1 to 23.9 °C at Station 9 (Figure 7-3). Similar to the pattern observed in August, September water temperatures declined in a roughly linear gradient from east to west across the channel.

Major in-water work for the barrier installation at the head of Old River began on September 23 and was completed on the September 29. Flow rates past Vernalis were steady during the month, averaging 1,125 cfs. Flows at Stockton increased from levels generally well below 500 cfs prior to barrier construction to 907 cfs at month's end (Figure7-4).

October

Surface DO levels measured in October ranged from 6.75 mg/L at Station 6 in the central channel to 7.9 mg/L at Station 1 in the west channel. Bottom DO levels ranged from 6.7 mg/L at Station 6 to 7.9 mg/L at Station 1. A DO sag was not observed within the channel during the October sampling cruise, and all stations had DO levels well above the state's objective.

Surface water temperatures on October 8 ranged from 14.8 °C at Station 13 in the east channel to 15.6 °C at Station 5 in the west channel (Figure 7-3). Bottom water temperatures were similar, ranging from 14.3 °C at Station 13 to 15.5 °C at Station 5. Surface water temperatures were fairly uniform across the channel; however, in contrast to previous months, bottom temperatures were lower in the east channel than in the west.

Average daily flows of the San Joaquin River at Vernalis ranged from 1,055 to 3,034 cfs during October (Figure 7-4). Net daily flows at Stockton were similar, ranging from 923 to 2,371 cfs. Flow rates at both locations increased dramatically during the second half of the month, before falling markedly in the last three days of the month. Flows recorded at Stockton were very similar to those measured at Vernalis for much of the month, indicating that little upstream diversion was occurring. The barrier at the head of Old River was in place with all culverts closed for the entire month of October.

November

Due to acceptable DO concentrations throughout October, efforts to begin the removal of the barrier at Old River began on November 1, and barrier removal was effectively completed by November 12. DWR conducted monitoring cruises on November 10, which was prior to removal of the barrier, and on November 24, almost two weeks after barrier removal. Surface DO levels for the month ranged from 4.9 to 8.8 mg/L. Bottom DO levels were similar, ranging from 4.6 to 8.7 mg/L. All DO levels measured on the November 10 were well above the state's objective; however, immediately after the barrier was removed, DO levels began to fall in the east channel. A DO sag developed again in the east channel, extending from Station 10 to 13.

Surface and bottom water temperatures on November 10 were uniform throughout the channel, with a difference of only 0.2 °C. Both surface and bottom temperatures were similar, ranging from 13.9 to 14.1 °C (Figure 7-3). Monitoring on November 24 showed water temperatures had cooled further, although a temperature gradient developed with the warmer temperatures in the east channel. Surface temperatures ranged from 12.1 °C in the west channel to 12.8 °C in the east channel. Similarly, bottom water temperatures ranged from 12.0 °C in the west channel to 12.6 °C in the east channel.

Flow rates past Vernalis continued to decline during the first week of November before stabilizing mostly above 1,500 cfs for the remainder of the month. November flows at Vernalis ranged from 2,108 to 1,436 cfs. Net daily flows past Stockton also fell markedly from 1,752 cfs on November 1 to -9 cfs by the November 30 (Figure 7-4). The reduced flows seen at Stockton coincided with the removal of the barrier, which allowed a significant diversion of flow from the San Joaquin River to the Old River.

Stockton Turning Basin

DO levels in the Stockton turning basin were below the state's objective at either the surface or bottom for every monitoring cruise, except for November 10. Surface DO levels in August were supersaturated, while bottom levels were 0.9 mg/L (Figure 7-2). September DO levels at surface and bottom ranged from 5.6 to 2.5 mg/L. October DO levels showed improvement, with surface levels at 6.9 mg/L; however, bottom levels dipped below the state's objective to 5.7 mg/L. Early November DO readings were above the state's objective (the surfacing reading was 6.5 mg/L and the bottom reading was 6.2 mg/L); however by November 24, DO levels had fallen to 5.1 mg/L at the surface and 4.8 mg/L at the bottom.

Summary

DO concentrations in the Stockton Ship Channel fell below both the CVRWQCB's 5.0 mg/L and the SWRCB's 6.0 mg/L objectives in August, September, October, and November 2004, a period which coincided with generally low net flows in the San Joaquin River past Stockton. A temporary barrier across the head of Old River was installed and fully operational on September 28, 2004, which increased flows down the San Joaquin River into the Stockton Ship Channel. The installation of the barrier coincided with increased net flows at Vernalis and Stockton. Subsequent sampling after the barrier installation, occurring during high inflows in October, showed a marked improvement of DO conditions with all stations showing levels above the 6.0 mg/L state objective, except bottom DO levels in the turning basin that were only slightly below the objective.

DO levels remained high through the first half of November, and the barrier was removed on November 12. The removal of the barrier coincided with a sharp reduction in net flows at Vernalis. Significant upstream diversions and exports resulted in net inflows at Stockton falling below zero. Subsequent monitoring showed DO levels declining again in the east channel and a DO sag developed again despite cool water temperatures.

Monitoring operations for the 2004 Dissolved Oxygen Study were suspended after the November 24, 2004, monitoring run.

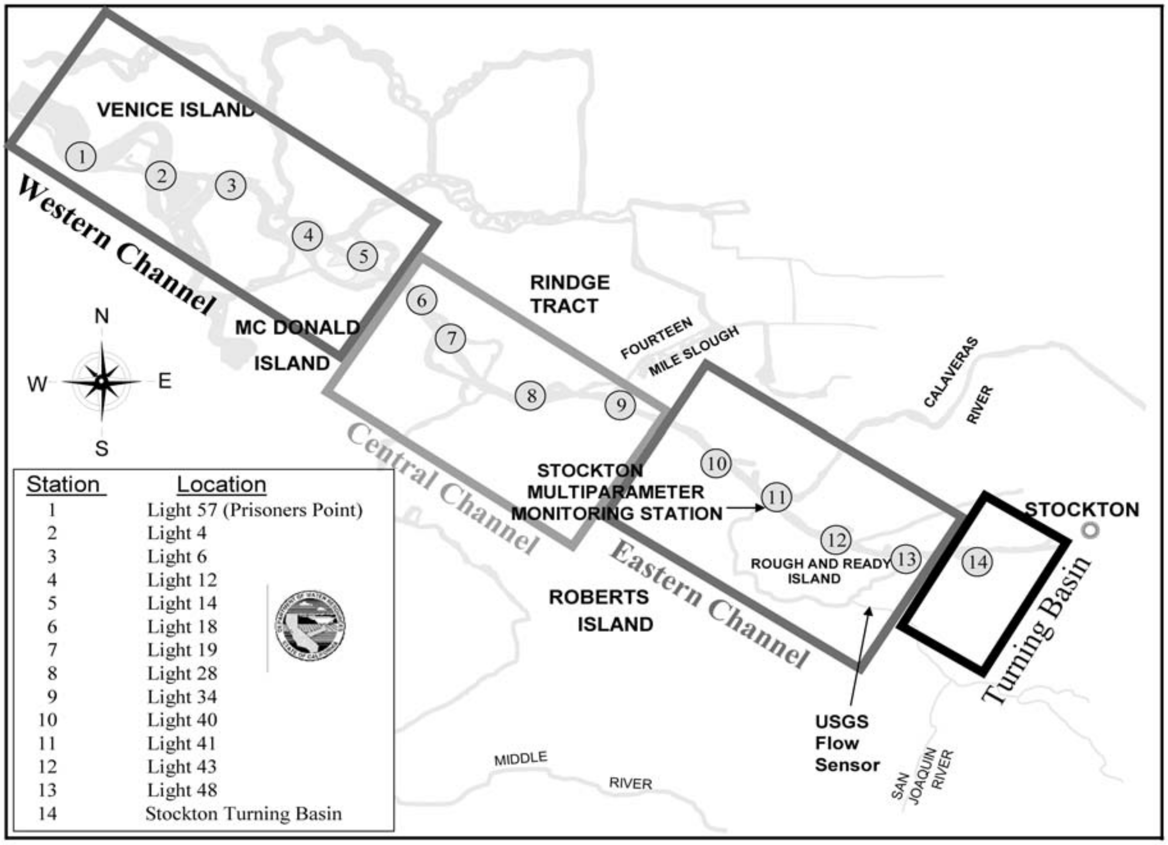
References

[APHA] American Public Health Association. 1998. *Standard Methods for the Examination of Water and Wastewater.* 20th Edition. Washington, D.C.

[CVRWQCB] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin.* Fourth Edition.

[SWRCB] State Water Resources Control Board. 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary.* Adopted May 22, 1995, pursuant to Water Right Order 95-1. Sacramento, CA. 44pp.

Figure 7-1 Monitoring sites in the Stockton Ship Channel



Station	Location
1	Light 57 (Prisoners Point)
2	Light 4
3	Light 6
4	Light 12
5	Light 14
6	Light 18
7	Light 19
8	Light 28
9	Light 34
10	Light 40
11	Light 41
12	Light 43
13	Light 48
14	Stockton Turning Basin

Figure 7-2 Fall 2004 dissolved oxygen concentrations at 14 stations in the Stockton Ship Channel (mg/L)

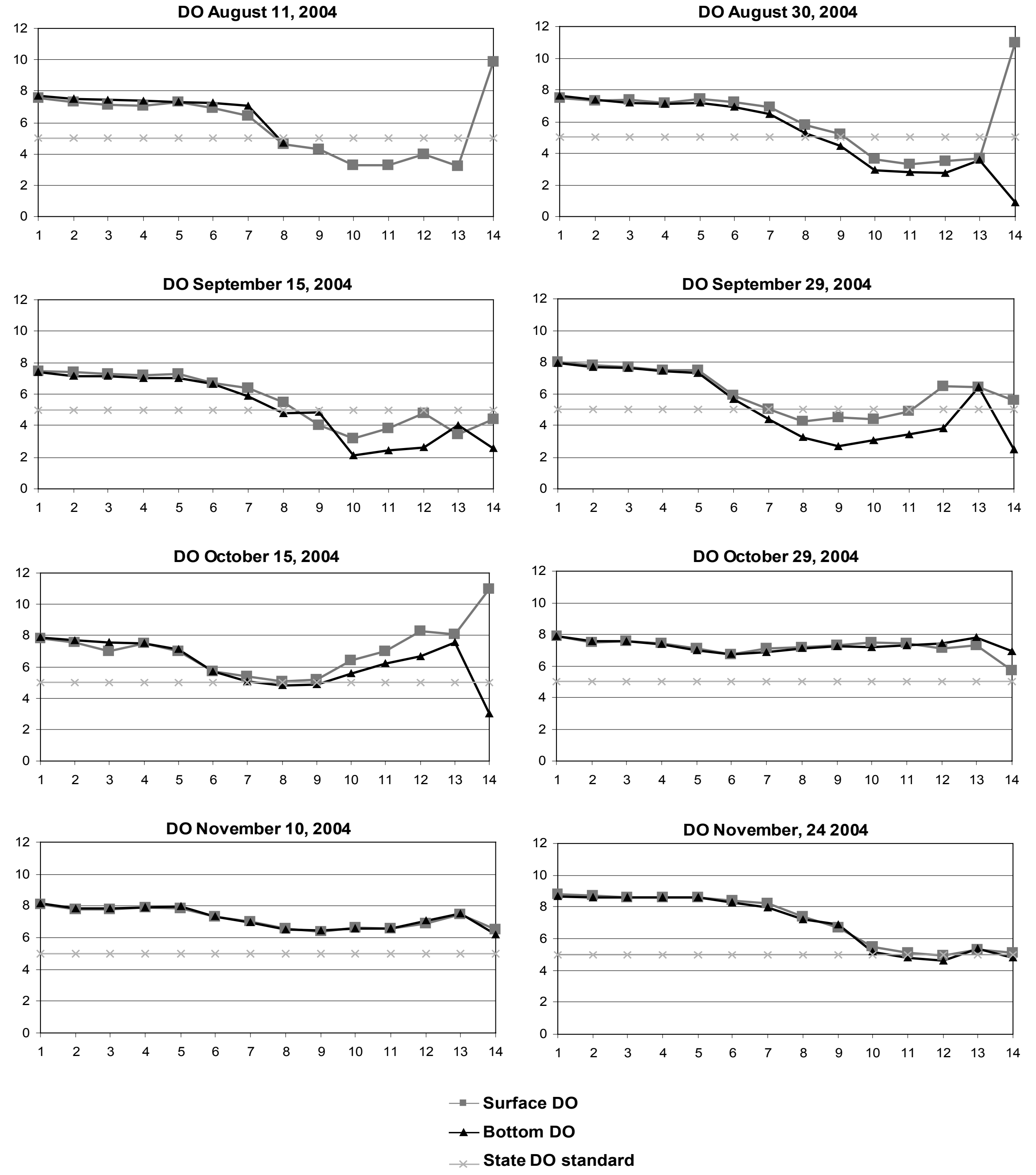
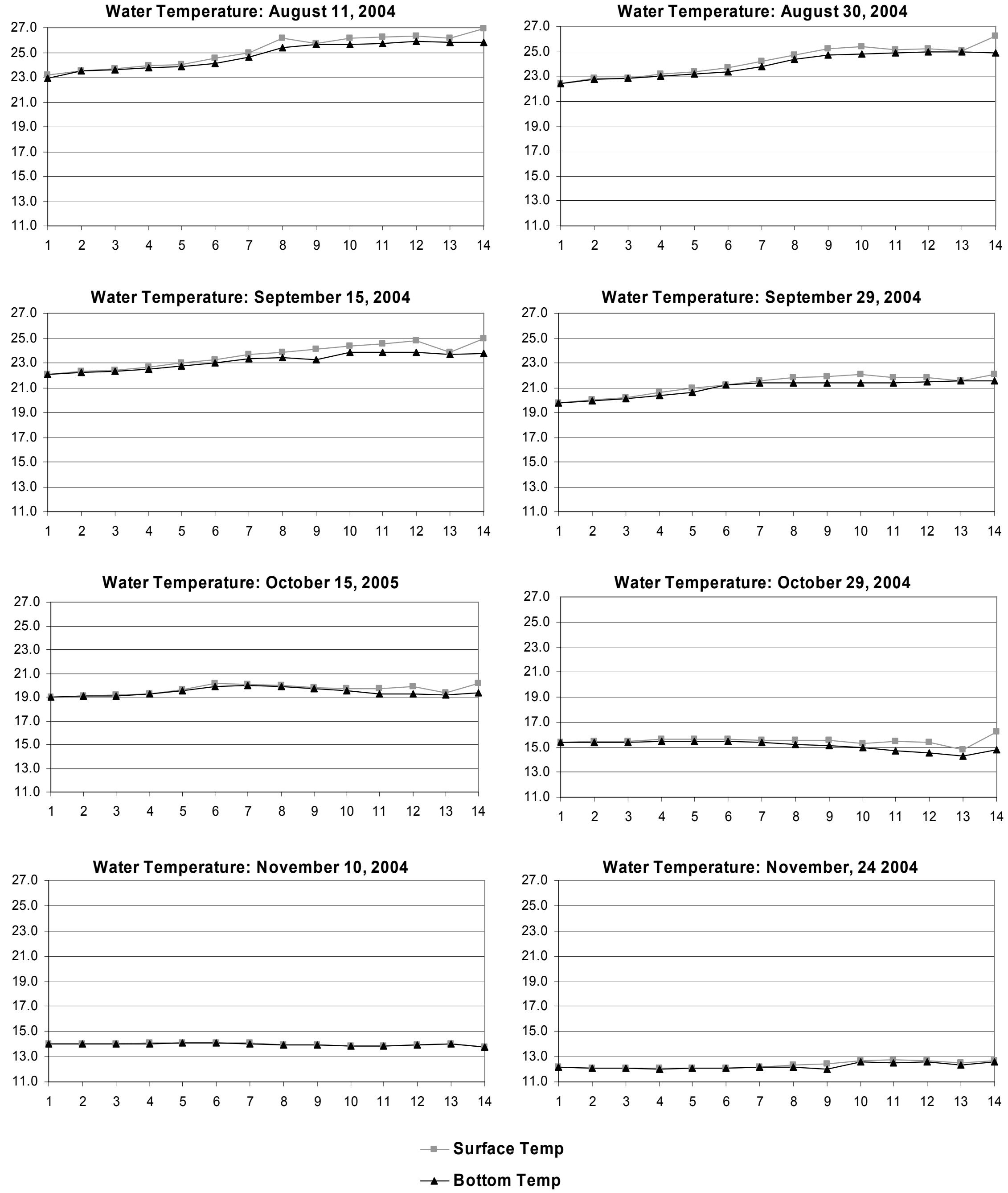


Figure 7-3 Fall 2004 water temperatures at 14 stations in the Stockton Ship Channel (°C)



Water Temperature: August 11, 2004

Water Temperature: August 30, 2004

Water Temperature: September 15, 2004

Water Temperature: September 29, 2004

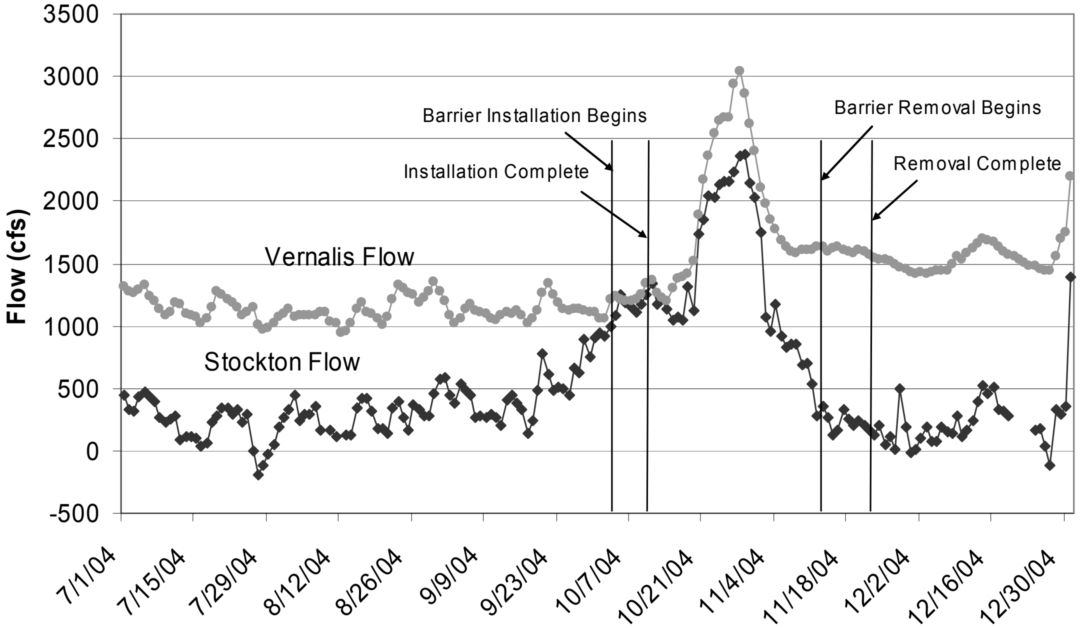
Water Temperature: October 15, 2005

Water Temperature: October 29, 2004

Water Temperature: November 10, 2004

Water Temperature: November, 24 2004

Figure 7-4 San Joaquin River average net daily flow: Fall 2004



Chapter 8. Data Management

Introduction

All data collected by the Environmental Monitoring Program (EMP) are stored in digital format for data management and dissemination. Each monitoring element (discrete and continuous water quality, benthic, phytoplankton, and zooplankton) has a particular process for data entry, quality control, management, and dissemination. All data, except zooplankton and sediment composition, can be downloaded via the Internet from the Bay Delta and Tributaries database (BDAT). Links to EMP's data on BDAT can be found at: http://www.iep.water.ca.gov/emp/data_index.html

BDAT consolidates and provides public access to environmental data contributed by more than fifty organizations. The database includes water quality, biological, and meteorological data from throughout the Sacramento-San Joaquin Estuary's watershed. The EMP water quality, benthic, and phytoplankton data stored in this database are available over the Internet at: http://baydelta.water.ca.gov.

Information about the various EMP monitoring elements and detailed information about the EMP can be found at: http://www.iep.water.ca.gov/emp/.

Metadata information describing sampling site locations, sampling methodology, and field and laboratory processing for all the data variables is available on the IEP website at: http://www.iep.water.ca.gov/emp/metadata_index.html

Complete metadata files are available for the benthic, phytoplankton, and discrete water quality monitoring elements of this program. Metadata files are currently being developed for the continuous water quality monitoring elements and the zooplankton element. These files also provide contact information for the staff member responsible for each monitoring element.

Data Management Procedures

The procedures for handling each type of EMP data are described below. The description includes: where the data are stored, how the data are checked for quality, what data are available, how to obtain these data, and who is responsible for managing the data for each monitoring element. Water quality is monitored with both discrete and continuous sampling. The discrete monitoring sites are surveyed monthly, primarily by vessel. The continuous monitoring stations are equipped with automated probes and data recorders that log data every 10 minutes to 1 hour depending on the water quality variable.

Discrete Water Quality Data

During monthly sampling runs, field measurements are recorded on paper datasheets and entered into the field module of the DWR Field and Laboratory Information Management System (FLIMS) using a portable computer. Later, laboratory analyses are performed at DWR's Bryte Laboratory and the results are entered by laboratory staff into the lab module of the FLIMS database. Data are then loaded electronically into the EMP's Discrete Water Quality database (a Microsoft Access database). This database is the reference database for this program element. The EMP staff periodically reviews the data for accuracy, completeness and consistency against the paper datasheet records. Data are then exported electronically to BDAT.

Discrete water quality data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding management and access to discrete water quality data, contact Scott Waller at swaller@water.ca.gov.

Continuous Water Quality Data

Data from automated continuous water quality monitoring stations are retrieved by downloading the data from each station's recorders onto a handheld "pocket PC". Upon return to the office, data are loaded into the EMP's Continuous Water Quality database, which is an IBM/Informix database. This database is the reference database for this program element. The EMP staff reviews these data for accuracy, completeness, and consistency using probe verification and calibration records. Data that are determined to be the result of a measuring instrument that was operating out of proper calibration are flagged as "bad" and are retained in the database. The values of data flagged as "bad" are not available on the BDAT web site, but may be obtained from EMP staff upon request.

Continuous water quality data from 1983 to present are available from download through the BDAT interface at: http://baydelta.water.ca.gov/index.html.

A subset of the data from automated continuous water quality monitoring stations is sent by telemetry in near real time to DWR's California Data Exchange Center (CDEC). **These real-time data are unchecked and may include data that are the result of malfunctioning instruments.** They are available for viewing and download at: http://cdec.water.ca.gov/

For more information regarding management and access to continuous water quality data, contact Mike Dempsey at mdempsey@water.ca.gov.

Benthic Data

Until October 2003, benthic sampling sites were surveyed monthly by vessel. From October 2003 to October 2005 they were sampled quarterly. After October 2005, monthly sampling resumed. Laboratory identification and enumeration of macrobenthic organisms in each sample is performed by Hydrozoology, a private laboratory under contract with DWR. The results are reported to DWR on standard paper datasheets. Laboratory analysis of sediment samples is performed by the DWR's Soils and Concrete

Laboratory. The results of the sediment analyses are provided to EMP staff in a written report.

Both sediment and benthic organism data are entered into the EMP Benthic database, which is a Microsoft Access database. This is the reference database for the benthic program element. The EMP staff periodically reviews the data for accuracy, completeness, and consistency. Data are exported electronically to BDAT on a quarterly basis.

Benthic data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

Sediment composition data gathered by the benthic monitoring element are exported to BDAT but not yet available for download via the Internet.

For more information regarding benthic or sediment data, contact Karen Gehrts at kagehrts@water.ca.gov.

Phytoplankton Data

Phytoplankton sampling sites are surveyed monthly, primarily by vessel. Bryte Laboratory identifies, enumerates, and measures the size of phytoplankton from these samples. These data are entered into the EMP phytoplankton database using Microsoft Access software. This is the reference database for the phytoplankton monitoring element. The EMP staff periodically reviews the data for accuracy, completeness, and consistency. Data are then exported electronically to BDAT.

Phytoplankton data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding phytoplankton data, contact Tiffany Brown at tbrown@water.ca.gov.

Zooplankton Data

Zooplankton sampling sites are surveyed monthly by vessel. Laboratory identification and enumeration of zooplankton and mysid organisms is performed by the Department of Fish and Game’s Central Valley Bay-Delta Branch Laboratory. The results are entered into a computer and stored electronically in a SAS statistical package format. Data are periodically reviewed for accuracy and completeness by DFG staff. Currently zooplankton data are only available through DFG; however, construction of a zooplankton database able to export data to BDAT is underway.

Data are available upon request from Randy Baxter at rbaxter@delta.dfg.ca.gov.

Chapter 9. Continuous Monitoring

Introduction

The Continuous Monitoring Program at the Department of Water Resources supplements the monthly discrete Compliance Monitoring Program by providing real-time hourly and quarter-hourly water quality and environmental data from seven shore-based automated sampling stations located in the upper San Francisco Estuary (Figure 9-1). These stations provide continuous measurements of seven water quality parameters and four environmental parameters. These are used by operators of the State Water Project and the Central Valley Project to assess the impacts of the project operations and to adjust project operations to comply with mandated water quality standards. The Continuous Monitoring Program has been in operation since 1983. This chapter summarizes the results of continuous water quality monitoring at seven sites for calendar year 2004. The stations were divided into three regions for the purposes of detail in the plots:

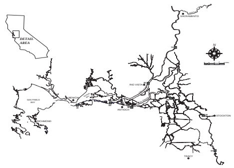


Figure 9-1 Station locations

Sacramento River stations:	Hood and Rio Vista
San Joaquin River stations:	Mossdale, Prisoner's Point, and Stockton
Tidally influenced stations:	Antioch, Mallard Island, and Martinez

Methods

Continuous data are collected for the water quality and environmental parameters shown in Table 9-1. At seven of the monitoring stations, continuous data are collected for water temperature, pH, dissolved oxygen, surface specific conductance, chlorophyll fluorescence, and turbidity. Additional sensors are installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom specific conductance, 1.5 meters above the channel bottom. These measurements, along with river stage data measured at the Mallard and Martinez stations, are needed to determine compliance with the salinity standard (also known as X2) mandated by Water Right Decision 1641 (SWRCB 1999). Environmental measurements of air temperature—such as solar radiation, wind speed, and direction—are taken at all stations except the Mossdale (only air temperature) and Hood stations (none). The Prisoner's Point station also monitors only water temperature and specific conductance to meet SWRCB Water Right Decision 1641 requirements (SWRCB 1999).

Parameter	Units	Frequency
Water Temperature	*°C*	*Hourly average*
Air Temperature	*°C*	*Hourly average*
Dissolved Oxygen	*mg/L*	*Hourly average*
pH	*unitless*	*Hourly average*
Chlorophyll Fluorescence	*fluorescence units*	*10 minute instantaneous*
Turbidity	*NTU*	*10 minute instantaneous*
Surface Specific Conductance	*µS/cm*	*Hourly average*
Bottom Specific Conductance	*µS/cm*	*15 minute instantaneous*
River Stage	*feet (from mean sea level) (NGVD 1929)*	*15 minute instantaneous*

Table 9-1 Parameters measured by the Continuous Monitoring Program

Except for bottom specific conductance and data collected at Prisoner's Point station, all water samples are collected at 1 meter below the water surface using a float-mounted pump and distributed to the water quality sensors. An Ocean Data Equipment model DACTS-80-26 Data Acquisition, Control and Telemetry System scans the output from the sensors once per second and records the hourly average of these approximately 3,600 readings on the hour. Bottom specific conductance, Prisoner's Point data, and environmental data—such as solar radiation, wind speed, and wind direction data—are recorded at 15-minute intervals.

Complete hourly or quarter-hourly data for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, chlorophyll fluorescence, turbidity, wind velocity, wind direction, solar radiation intensity, and river stage are available on the Bay Delta and Tributaries (BDAT) Project database http://bdat/index.html unless otherwise noted. All other inquiries are available by request to the Chief of the Real Time Monitoring and Support Section[1].

Results

The monthly averages of the continuous 15-minute or hourly data collected for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, chlorophyll fluorescence, and turbidity for calendar year 2004 are shown in Figures 9-2 to 9-10.

Water Temperature

Water temperature was measured in degrees Celsius (°C) using a Schneider Instruments RM25C-031 Temperature Parametric System.

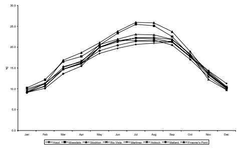


Figure 9-2 Average monthly water temperature at eight stations, 2004

Average monthly water temperatures in the upper San Francisco Estuary ranged from 9.1 °C in January 2004 at the Mallard Island and Hood stations on the Sacramento River to 25.9 °C in July 2004 at the Stockton station on the San Joaquin River (Figure 9-2). These values are lower than the same time period in 2003.

Average monthly water temperatures at the Sacramento River stations were lower in comparison to the San Joaquin River stations, with the greatest divergence occurring from June through September at the San Joaquin River stations of Stockton and Mossdale.

Dissolved Oxygen

Dissolved oxygen was measured using a Schneider Instruments RM25C-033 measuring circuit with a Clark-polarographic probe.

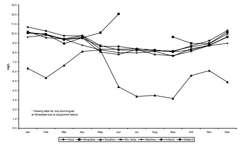


Figure 9-3 Average monthly dissolved oxygen at seven stations, 2004

Average monthly dissolved oxygen values for the seven monitoring stations ranged from 3.1 mg/L to 12.1 mg/L (Figure 9-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton and Mossdale. A monthly average of 3.1 mg/L was calculated for the Stockton station in September 2004, and a value of 12.1 mg/L was calculated for the Mossdale station for June 2004. All other stations showed monthly averages between 7.8 mg/L and 10.7 mg/L. All compliance monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the Central Valley Regional Water Quality Control Board in the Basin Plan (CVRWQCB 1998). Monthly average dissolved oxygen values at the Stockton station were highly variable and ranged from 3.1 mg/L to 8.3 mg/L. The Stockton station, in the Stockton Deep Water Ship Channel, showed a

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[1] Darrell Kaff, Chief, Real-Time Monitoring and Support Section, Division of Environmental Services, Office of Water Quality, Environmental Water Quality and Estuarine Studies Branch, 901 P Street, Sacramento CA 95814

small DO sag of 5.3 mg/L in February 2004. This pattern of winter sag was first identified in 2000. The sag in 2004 was significantly less than the same time period in 2003.

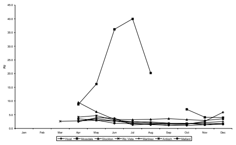

Figure 9-9 Average monthly chlorophyll at seven stations, 2004

During summer and fall 2004, monthly average dissolved oxygen values at the Mossdale station showed the familiar pattern of increase, but due to equipment malfunctions no reliable data was collected for July and August. Monthly average dissolved oxygen values in 2002 and 2003 showed a similar pattern from June to September, ranging from 11.4 mg/L to 13.6 mg/L. The high average summer DO levels seen at the Mossdale station coincided with high chlorophyll fluorescence during the same period (Figure 9-9).

Specific Conductance

Specific conductance was measured using a Schneider Instruments RM25C-032 system.

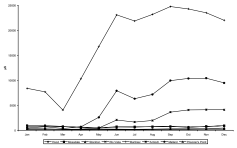

Figure 9-4 Average monthly specific conductance at eight stations, 2004

Monthly average surface specific conductance for the upper San Francisco Estuary ranged from 127 µS/cm to 24,753 µS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 9-4). Data gathered upstream from the Mossdale and Stockton stations on the San Joaquin River showed a higher average specific conductance than the data upstream from Hood and Rio Vista stations on the Sacramento River (Figure 9-4a).

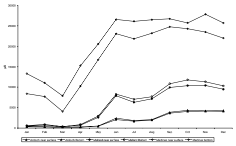

Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2004

Bottom specific conductance measured at the Antioch, Mallard Island, and Martinez stations exhibited seasonal patterns and ranges similar to the surface specific conductance (Figure 9-5).

pH

pH was measured using a Schneider Instruments RM25C-035 system.

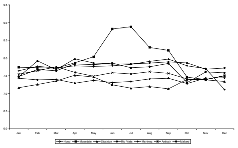

Figure 9-6 Average monthly pH at seven stations, 2004

Monthly average pH levels for the upper San Francisco Estuary for all stations ranged from 7.1 to 8.0 pH units, with the exception of Mossdale where pH values in June, July, August, and September ranged from 8.2 to 8.9 pH units (Figure 9-6). This increased pH coincided with high chlorophyll fluorescence observed at Mossdale during the same period (Figure 9-9b).

Air Temperature

Air temperature was measured using a Schneider Instruments RM25C-036 system.

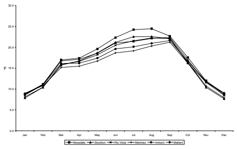

Figure 9-7 Monthly average air temperature at six stations, 2004

Monthly average air temperatures in the San Francisco Estuary ranged from 7.7 °C in December 2004 at the Stockton station on the San Joaquin River to 24.5 °C August 2004 at the Mossdale station on the San Joaquin River (Figure 9-7).

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured using a Turner Designs SCUFA® Fluorometer set-up with a continuous flow system using chlorophyll *a* filters.

Monthly average chlorophyll fluorescence was recorded at the stations in the upper San Francisco Estuary from the installation in April 2004 to December 2004 after a factory upgrade (Figure 9-9a-c). The recorded values ranged from minima of 1.1 fluorescence units (FU) in October 2004 at the Mallard station on the Sacramento River to maxima of 40 FU on July 2004 at the Mossdale station on the San Joaquin River.

Turbidity

Turbidity was measured using a Turner Designs SCUFA® Fluorometer.

Monthly average turbidity was recorded at the stations in the upper San Francisco Estuary from the installation in April 2004 to December 2004 after a factory upgrade (Figure 9-10a-c). The recorded values ranged from a minimum of 4 Nephelometric Turbidity Units (NTU) at the Stockton station on the San Joaquin River in September 2004 to a maximum of 37 NTU at the Hood station on the Sacramento River in December 2004.

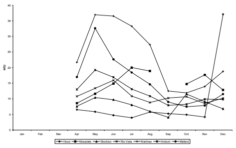

Figure 9-10 Average monthly turbidity at stations, 2004

Stockton Ship Channel Dissolved Oxygen

As part of DWR's mandate to monitor water quality in the Delta, a special monitoring study is focused on dissolved oxygen (DO) conditions in the Stockton Ship Channel from Prisoner's Point to the Stockton Turning Basin (see Chapter 7). Continuous data from a monitoring station in the ship channel (Stockton Station #20) supplements monthly discrete sampling and alerts DWR personnel when DO levels become critical.

The Central Valley Regional Water Quality Control Board has established a baseline objective of 5.0 mg/L for the entire Delta (CVRWQCB 1998). Due to the special concerns in the Stockton Ship Channel to protect fall-run Chinook salmon, a DO objective of 6.0 mg/L has also been established for September through November by the SWRCB (1995).

For 2004, average monthly DO values at the Stockton station fell below the 6.0 mg/L standard during September, October, and November, and showed a drop in December 2004 after a recovery in November 2004 (Figure 9-8).

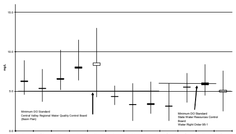

Figure 9-8 San Joaquin River at Rough and Ready Island: Range of monthly dissolved oxygen values, 2004

Monthly average DO values in 2004 ranged from 3.1 mg/L to 8.3 mg/L. The lowest DO value occurred in February 2004, while the highest value of 10.2 mg/L occurred in May 2004. Monthly average DO values dropped well below the state-mandated standards from June through September. In 2004, hourly values ranged from 1.3 mg/L to 13.0 mg/L. The minimum value of 1.3 mg/L was recorded in July and September 2004. As seen in previous years, the DO levels dropped during the summer months of July, August, and September; however, low monthly and hourly DO levels occurred in winter months as well. The pattern of falling DO levels in the winter, first observed in 2000, was again observed in 2004 but remained above the 5.0 mg/L standard (CVRWQCB 1998).

The box plots (Figure 9-8) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal “whiskers” indicate the range of hourly DO values for each month. Boxes represent monthly medians and means. Open boxes indicate that the monthly median is greater than the monthly mean, with the top of the box indicating the median, and the bottom of the box indicating the mean. Filled boxes indicate that the monthly mean is greater than the median, with the top of the box indicating the mean and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the mean are equal.

Summary

Water quality conditions in the upper San Francisco Estuary for calendar year 2004 were in the expected range of values for water temperature, dissolved oxygen, specific conductance, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. The exceptions continue to be found on the San Joaquin River.

The San Joaquin River station at Mossdale showed higher dissolved oxygen, pH, and chlorophyll *a* fluorescence values in June, July August, and September than any other station in the Estuary. The dissolved oxygen ranged from 9.6 mg/L to 12.1 mg/L. The pH values ranged from 8.2 pH to 8.9 pH units. The chlorophyll *a* fluorescence values ranged from 16 FU to 40 FU.

The San Joaquin River station at Stockton, unlike any other station in the Estuary, showed a dissolved oxygen sag below the 5.0 mg/L standard set in CVRWQCB 1998 for June, July, and August 2004, as well as a second sag below 5.0 mg/L in December 2004. The winter dissolved oxygen sag was first noticed in 2000. The dissolved oxygen levels were below the 6.0 mg/L standard set by SWRCB (1995) for the passage of fall-run Chinook salmon through the Stockton Deep Water Channel for September, October, and November 2004.

References

[CVRWQCB] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. Fourth Edition.

[SWRCB] State Water Resources Control Board. 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary*. Adopted May 22, 1995, pursuant to Water Right Order 95-1. Sacramento, CA. 44pp.

[SWRCB] State Water Resources Control Board. 1999. *Water Right Decision 1641*. Adopted December 29, 1999, Revised in Accordance with order WR2000-02 March 15, 2000, Sacramento, CA. 211pp.

Figure 9-1 Station locations

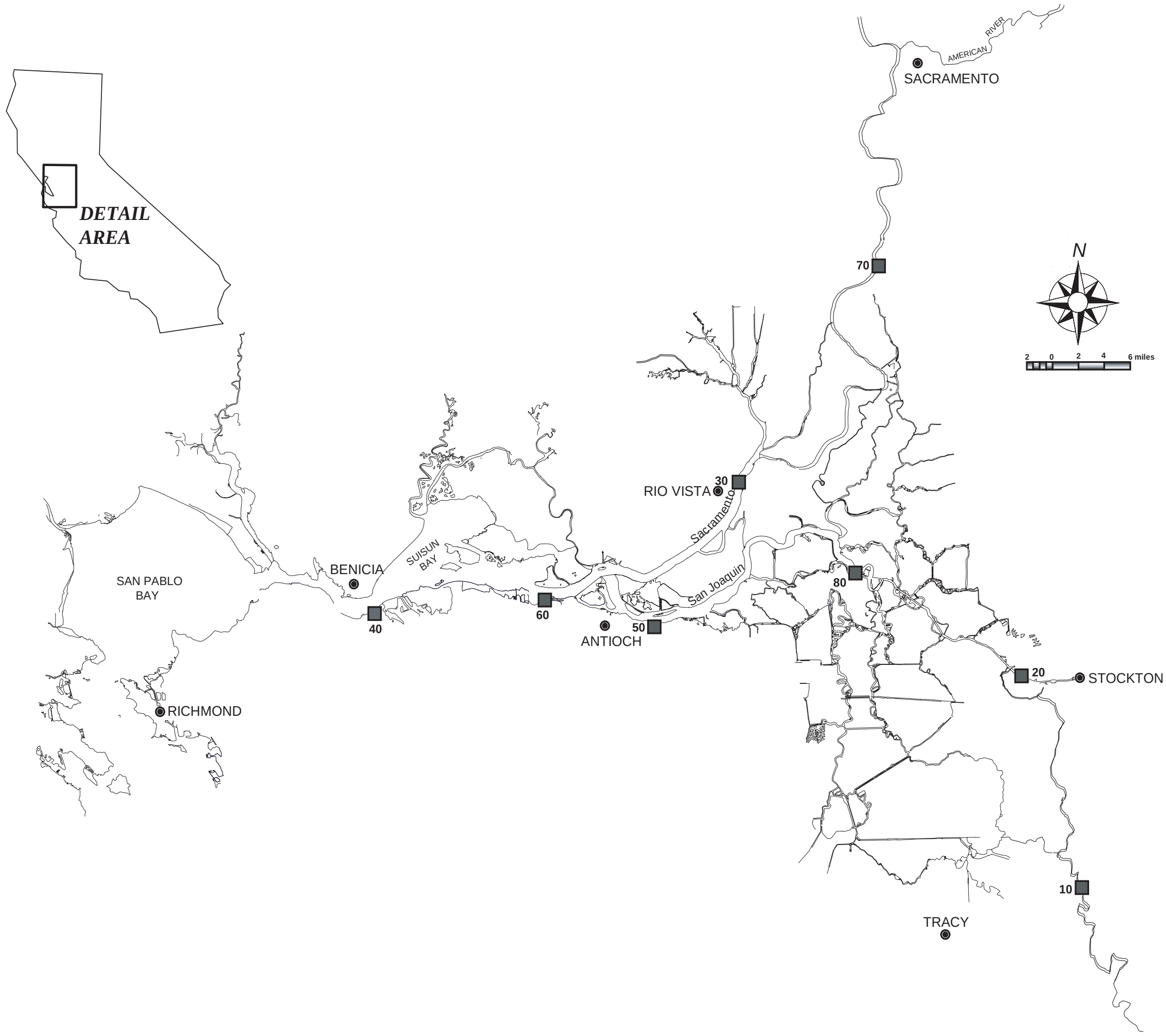

Figure 9-2 Average monthly water temperature at eight stations, 2004

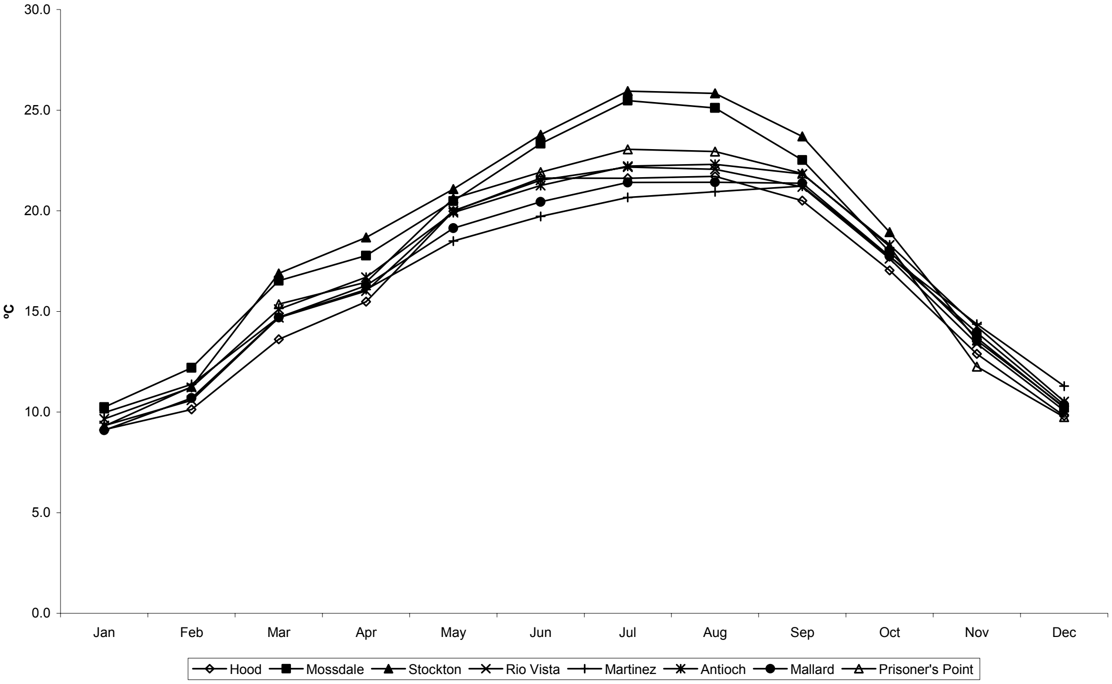

Figure 9-3 Average monthly dissolved oxygen at seven stations, 2004

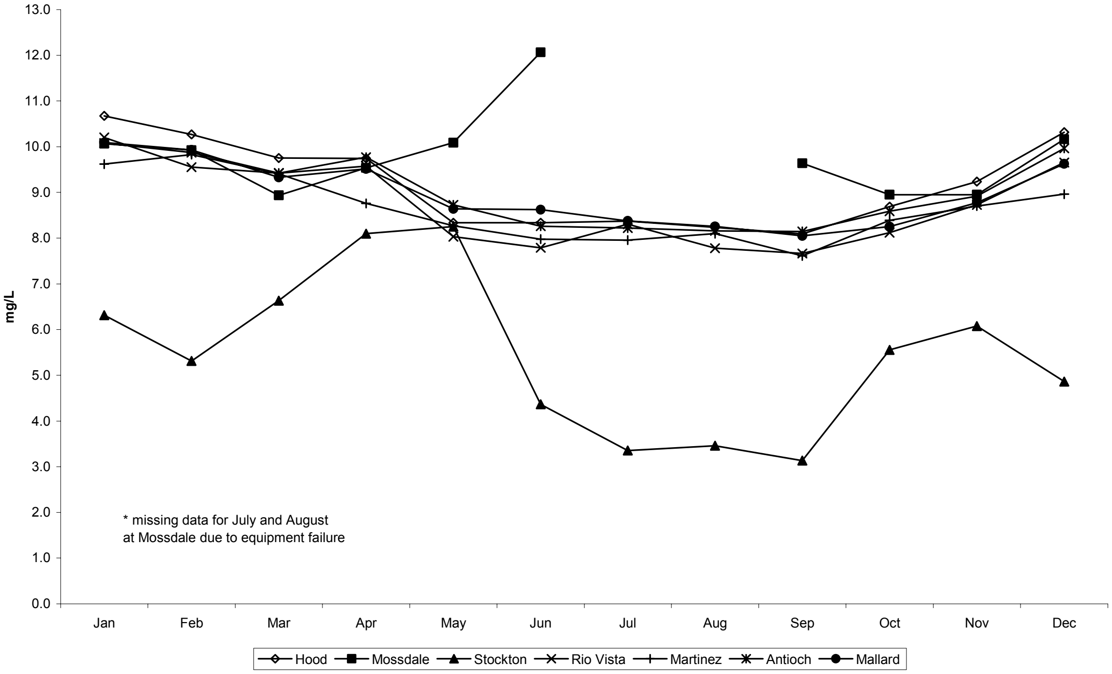

Figure 9-4 Average monthly specific conductance at eight stations, 2004

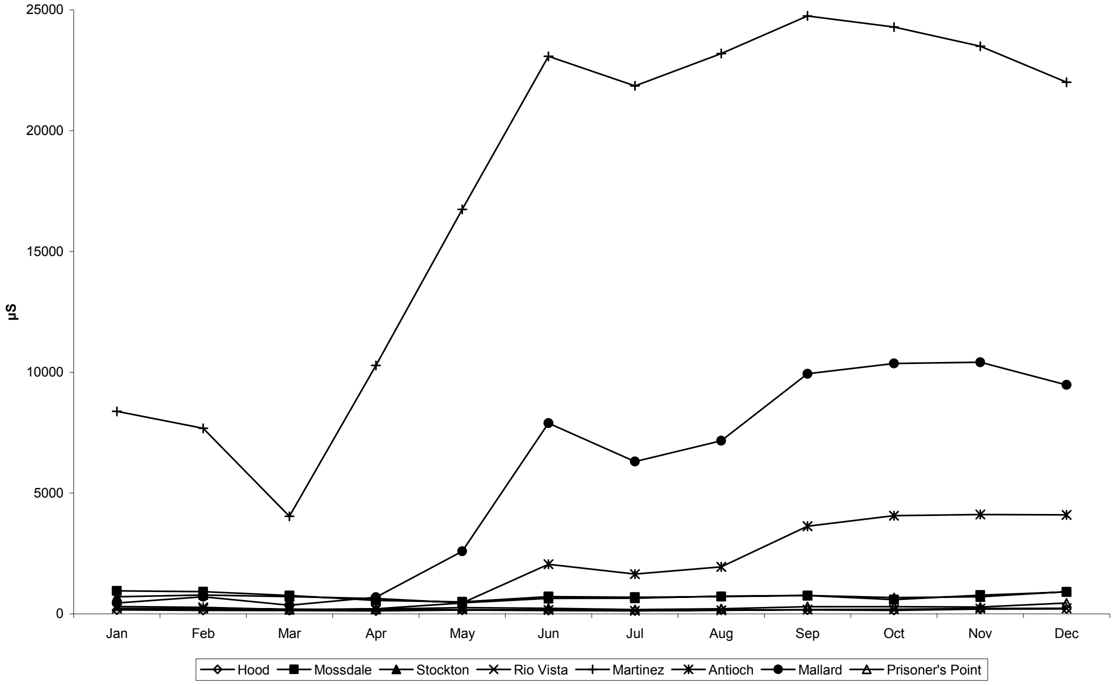

Figure 9-4a Average monthly specific conductance at five stations, 2004

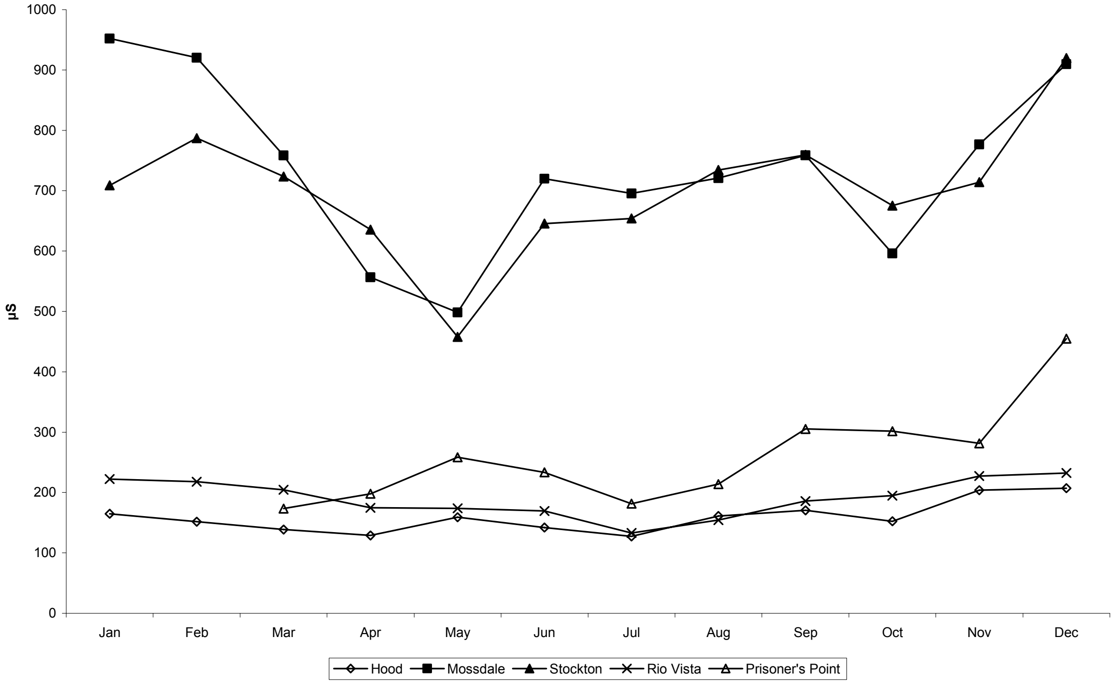

Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2004

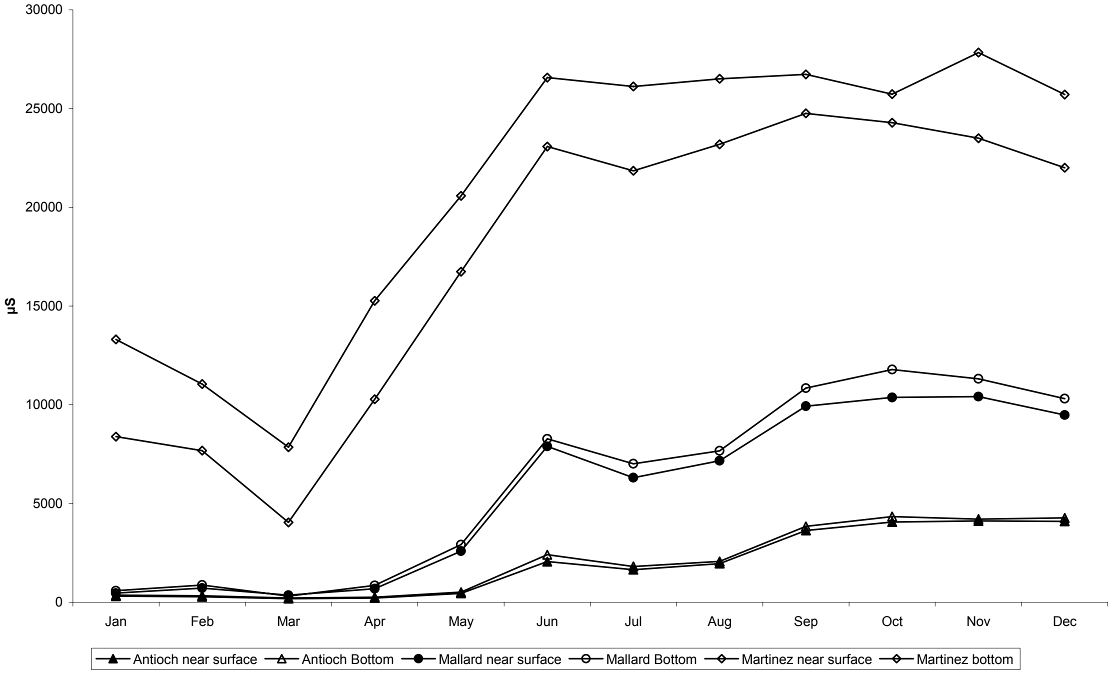

Figure 9-6 Average monthly pH at seven stations, 2004

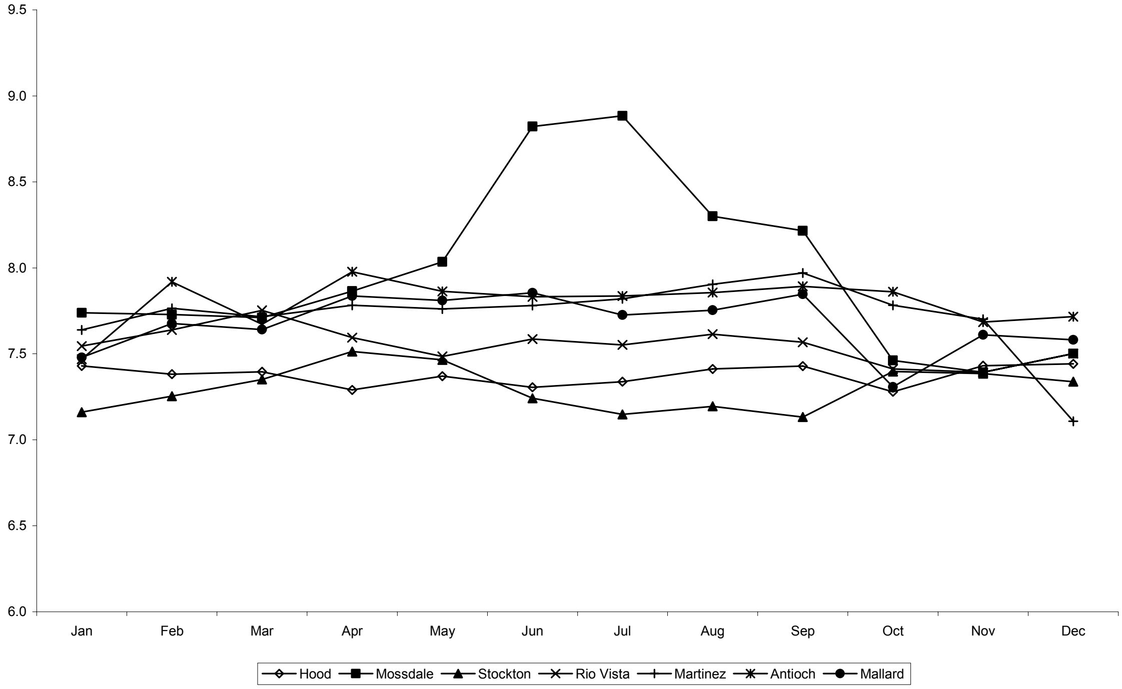

Figure 9-7 Monthly average air temperature at six stations, 2004

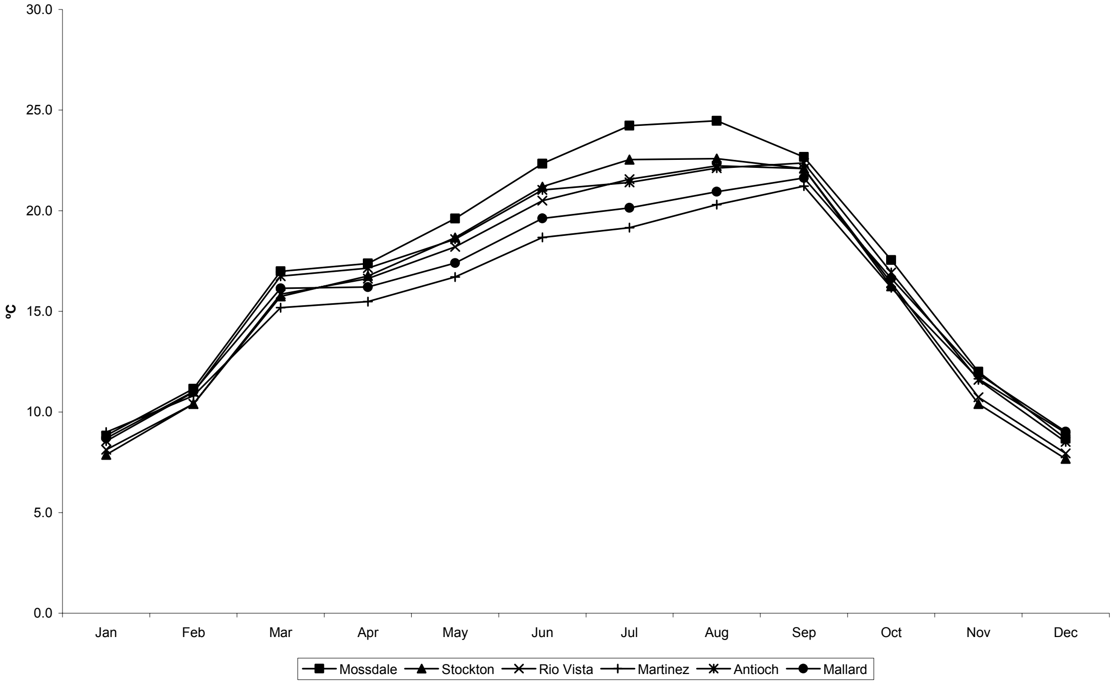

Figure 9-8 San Joaquin River at Rough and Ready Island: Range of monthly dissolved oxygen values, 2004

* Solid Boxes when Monthly average higher than Monthly median

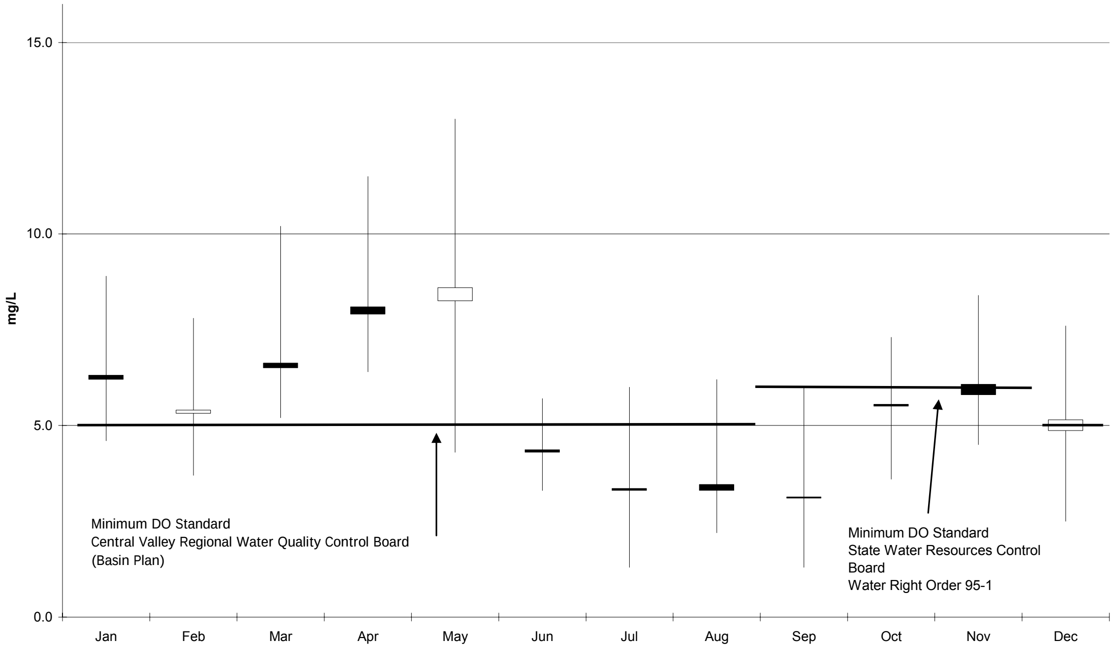

Figure 9-9 Average monthly chlorophyll at seven stations, 2004

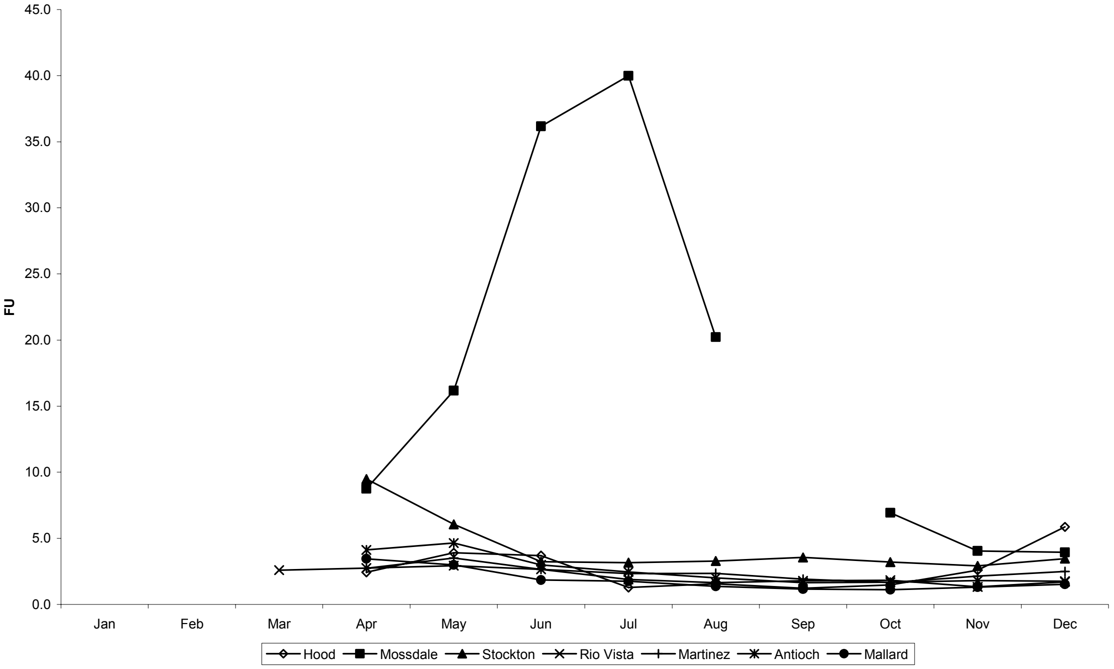

Figure 9-9a Average monthly chlorophyll at two Sacramento River stations, 2004

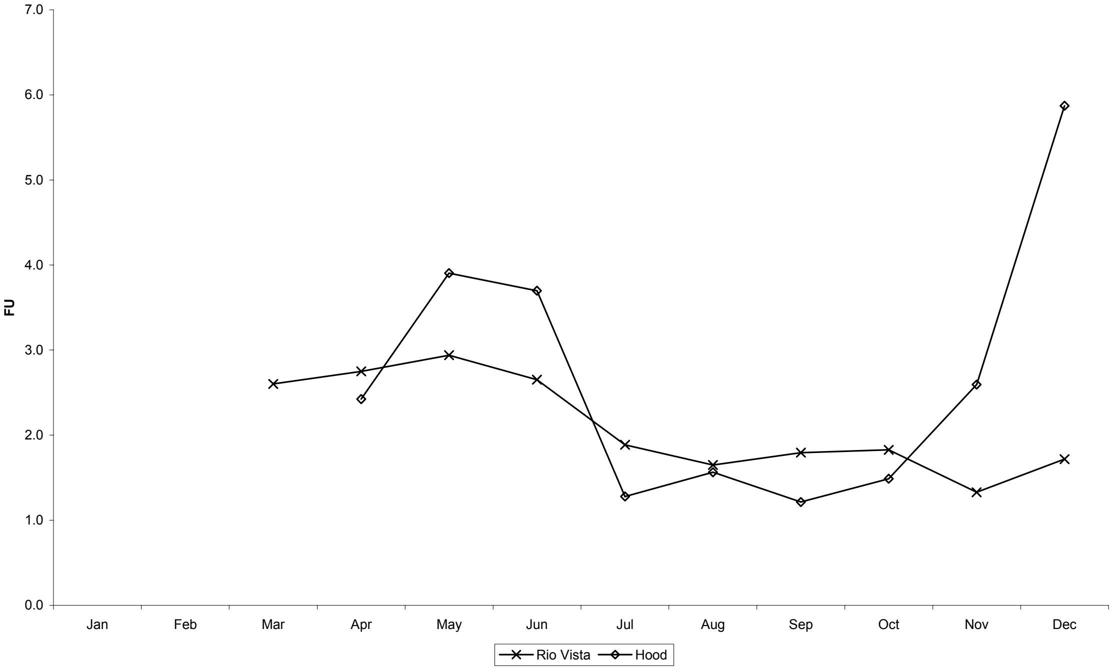

Figure 9-9b Average monthly chlorophyll at two San Joaquin River stations, 2004

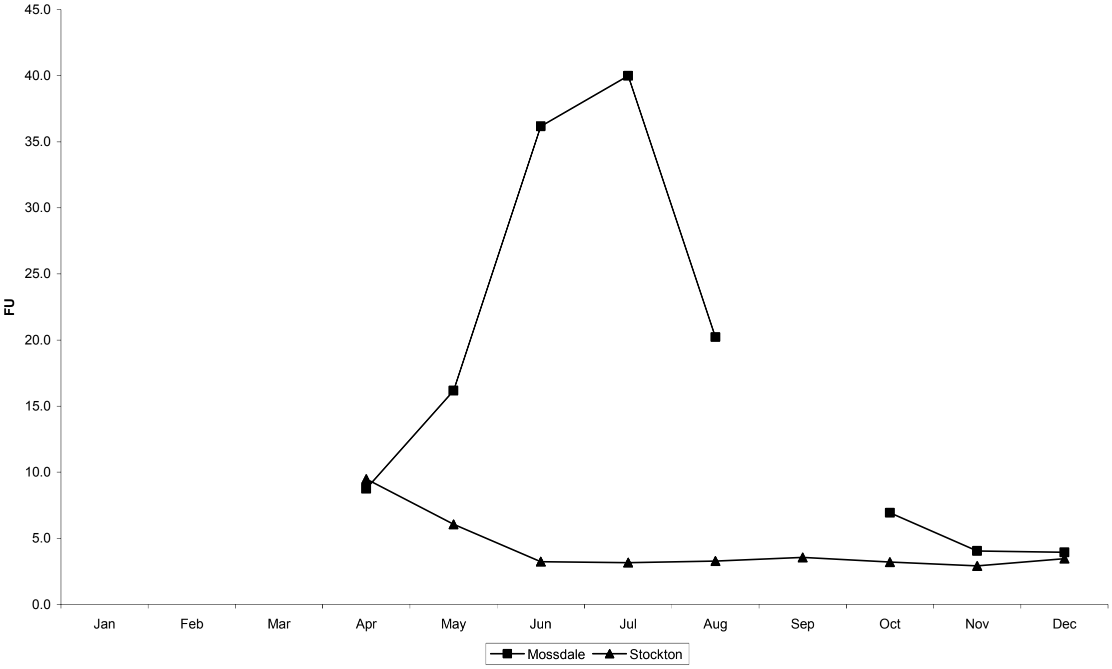

Figure 9-9c Average Monthly chlorophyll at three tidally influenced stations, 2004

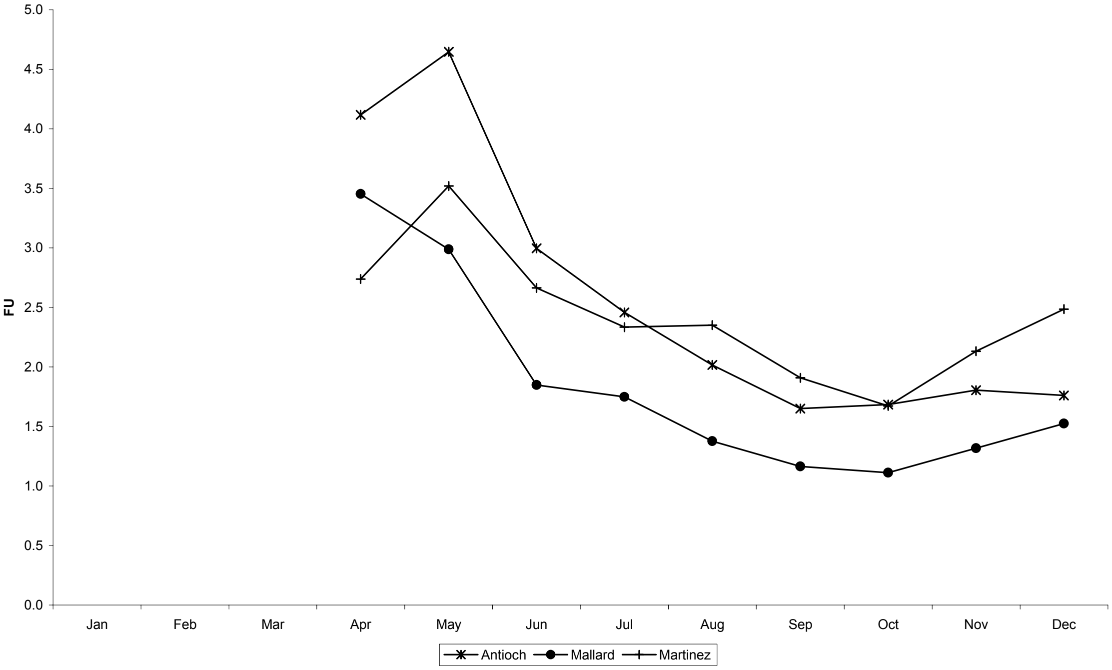

Figure 9-10a Average monthly turbidity at seven stations, 2004

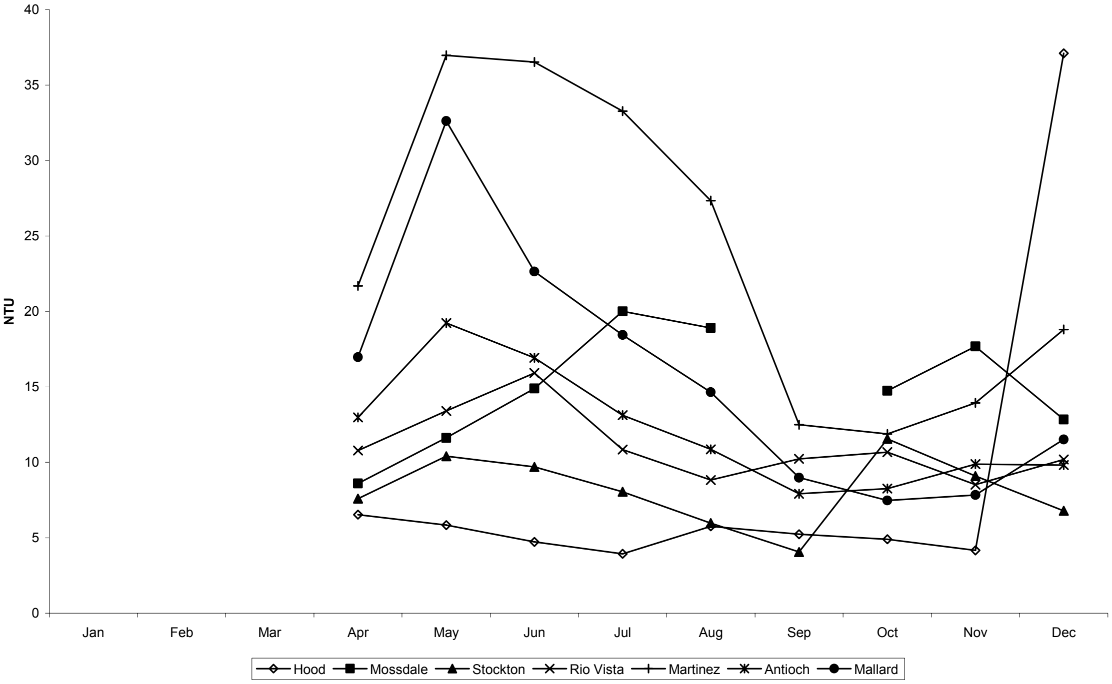

Figure 9-10a Average monthly turbidity at two Sacramento River stations, 2004

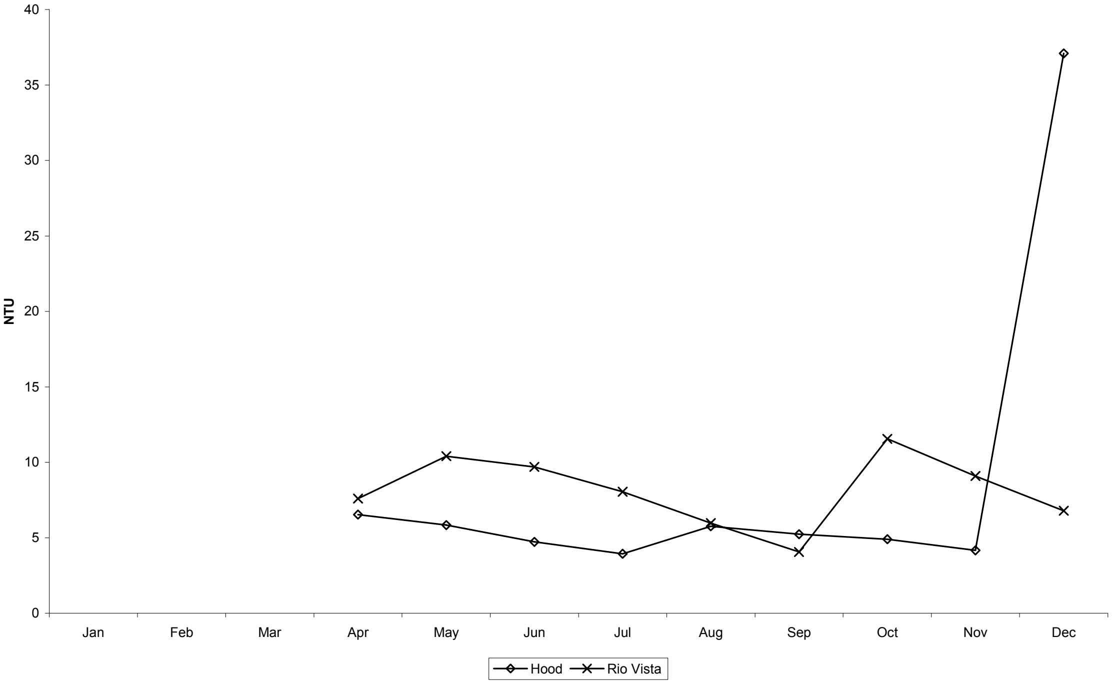

Figure 9-10b Average monthly turbidity at two San Joaquin River stations, 2004

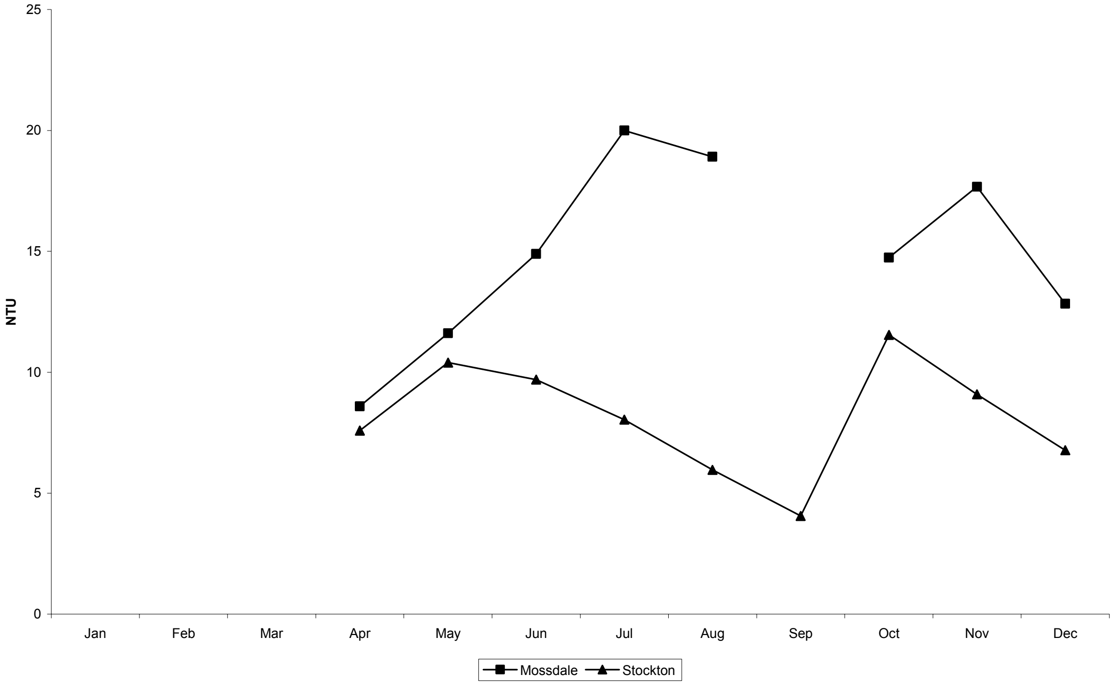

Figure 9-10c Average monthly turbidity at three tidally influenced stations, 2004

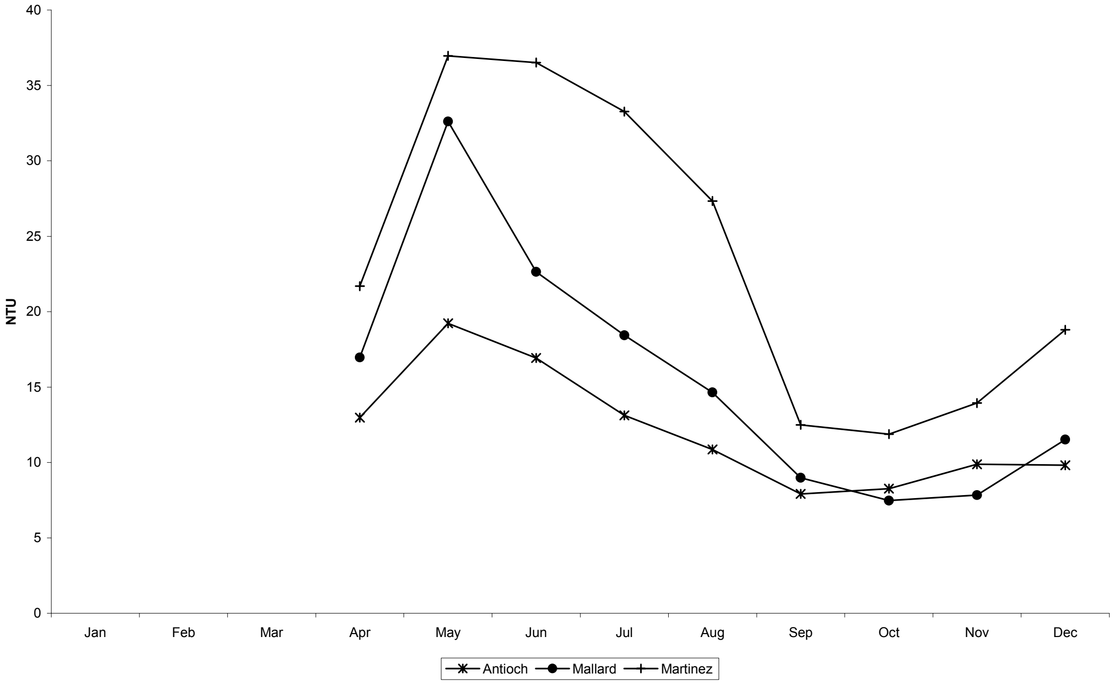

Table 9-1 Parameters measured by the Continuous Monitoring Program

Parameter	Units	Frequency
Water temperature	°C	Hourly average
Air temperature	°C	Hourly average
Dissolved oxygen	mg/L	Hourly average
pH	unitless	Hourly average
Chlorophyll fluorescence	fluorescence units	10 minute instantaneous
Turbidity	NTU	10 minute instantaneous
Surface specific conductance	µS/cm	Hourly average
Bottom specific conductance	µS/cm	15 minute instantaneous
River stage	feet (from mean sea level) (NGVD 1929)	15 minute instantaneous