IV. Load of oxygen demand substances

Community growth rate studies and continuous fluorometry were used to estimate the relative amount of algal biomass in the DWC produced by new growth in the DWC and transported into the DWC the upper San Joaquin River. This information addressed the question:

Question: What is the relative contribution of algal biomass from new growth in the DWC and upstream algal load to oxygen demand in the Stockton Deep Water Channel (DWC)?
Answer: The maximum potential net daily load of algal biomass from new growth in the DWC and transport from upstream were similar in magnitude.

Historical perspective

Chlorophyll *a* concentration, a measure of algal biomass, in the San Joaquin River has measured by the Department of Water Resources and U. S. Bureau of Reclamation on a monthly or semi-monthly basis at 1 m depth since 1970 (iep.water.ca.gov). These data indicate that chlorophyll *a* concentration is currently four times lower in the DWC than in the 1970s and suggests algal biomass may be less important to the dissolved oxygen deficit now than historically (Fig. IV-1). A reduced role of algal biomass to the oxygen deficit in the San Joaquin River was supported by at least a factor of 2 decrease in the algal load at Vernalis, the tidal head of the estuary (Fig. IV-2).

Fig. IV-1. Chlorophyll *a* concentration measured at Rough and Ready Island between 1970 and 2000.

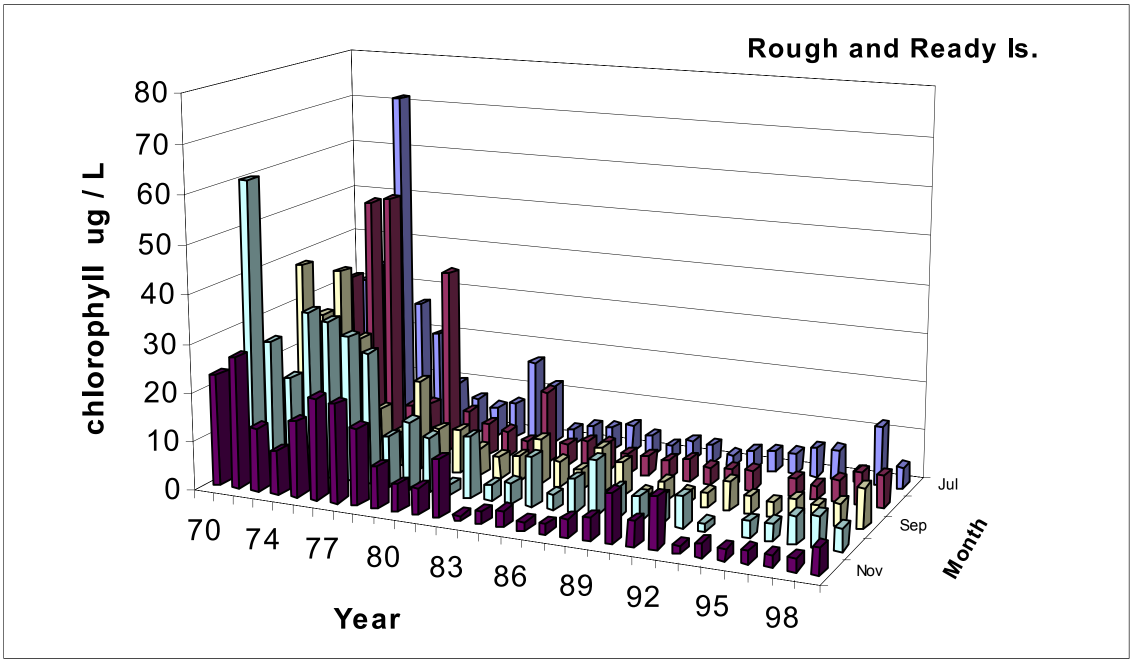
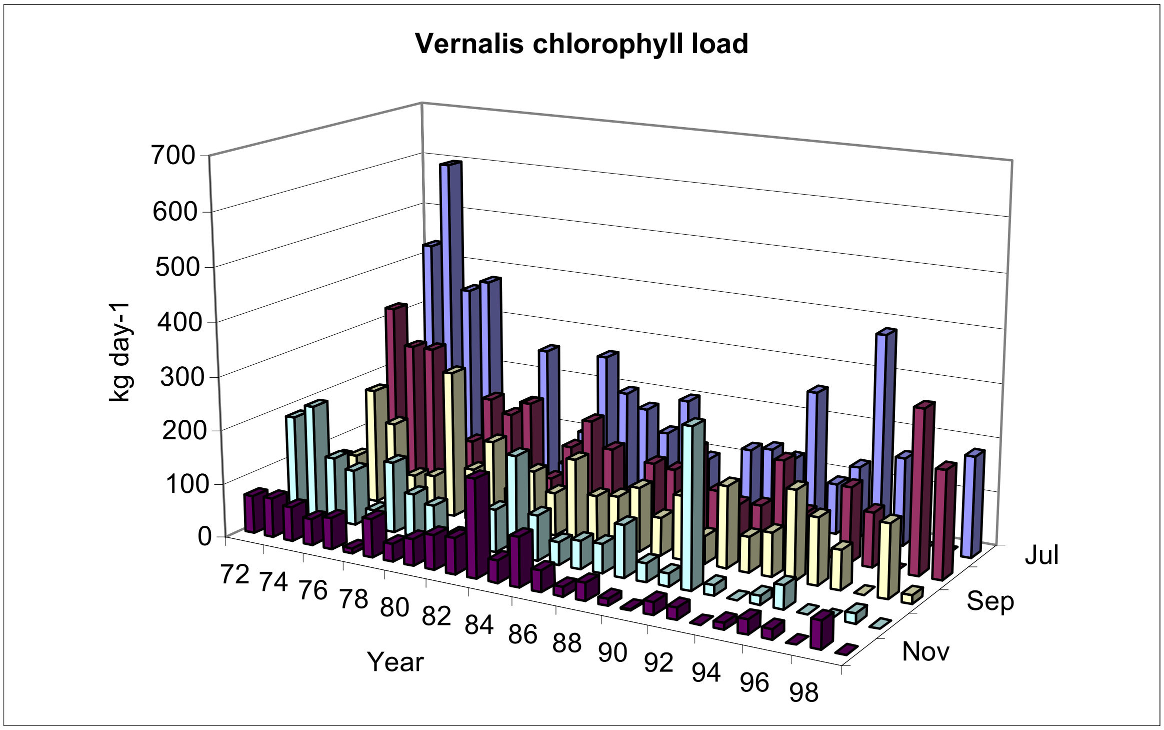


Fig. IV-2. Chlorophyll *a* load calculated for Vernalis between 1970 and 2000.



Growth in the channel

Methods - Community production and respiration rate was measured by dissolved oxygen light and dark bottle in situ incubation. Natural water samples were placed in replicate light and dark bottle glass-stoppered 300 ml B.O.D. borosilicate bottles and incubated in the water column at 1 m and 5 m depth in the DWC for 24 hr (Vollenweider 1972). Sample bottles were maintained at the specified depth in the water column using an incubation rack attached to a buoy that allowed the bottles to stay at constant depth during the daily 1.3 m tide.

The change in dissolved oxygen concentration over the incubation period was determined using Winkler titration. Incubations were stopped in the field by addition of magnanous sulfate and bottles were kept cool and in the dark until titration within 24 hr. Alkaline azide and sulfamic acid were added just before titration with sodium thiosulfate (APHA 1998). Addition of the azide and sulfamic acid just before titration reduced the interference of high organic carbon on the analysis (APHA 1989).

Ancillary water quality measurements included ammonia, nitrate and nitrite, total phosphorus, dissolved orthophosphate, chlorophyll *a*, phaeophytin, total and dissolved organic carbon, total Kjeldahl nitrogen, biochemical oxygen demand (BOD), carbonaceous oxygen demand (CBOD) and phytoplankton species composition. Methods for water quality variables are described in Appendix A. Phytoplankton species were identified using an inverted microscope following settling using the Utermohl method (1958).

Field measurements included vertical profiles of light attenuance using a LiCor quantum sensor and specific conductance, chlorophyll *a* fluorescence, water temperature and turbidity using a YSI 6600 water quality monitor. In addition, continuous solar irradiance (g cal cm2 min) was measured by an Eppley pyroheliometer at station 43.

Specific community production and respiration rates (ug oxygen / ug chlorophyll *a* / hr) estimated the minimum net daily algal production rate (kg oxygen / day) in the photic zone and maximum net daily algal respiration rate (kg oxygen / day) in the aphotic zone. The net algal production rate in the photic zone was estimated as the total mass of chl *a* in the photic zone of the study reach between station 24 and station 48 multiplied by the specific community production rate adjusted to 24 hr. The algal respiration rate in the aphotic zone was calculated in the same fashion as the production rate but specific community respiration rate was used instead of the production rate. The net water column community production (kg oxygen / day) was the sum of the photic and aphotic zone daily production and respiration (negative value). Oxygen demand (mg/L) in the study reach was calculated as the net water column community production divided by the total volume. Chlorophyll a biomass was estimated from horizontal profiles of chlorophyll *a* concentration and assumed a uniform distribution with depth.

The daily load of chlorophyll *a* (kg chlorophyll *a* / day) into the DWC from growth in the photic zone was estimated by conversion of the net community production rate (kg oxygen / day) to carbon using the conversion factor of 0.312 and then to chlorophyll *a* using a carbon: chlorophyll *a* ratio of 40 (Vollenweider 1972).

It is difficult to accurately quantify algal production rate in the DWC because the light/dark bottle technique measures community production and respiration rates that include both phytoplankton and bacterial respiration. This is particularly important in the DWC where high ammonia concentration exerts an oxygen demand from nitrifying bacteria late in the season. The separate contribution of algal growth and respiration to the community production rate was evaluated by comparison of the net daily water column community production rate measured in the DWC with calculated values determined from empirical models using chlorophyll *a* concentration, solar irradiance and light attenuation. Net productivity in the photic zone was calculated from the Cole and Cloern (1987) empirical model for San Francisco Bay algae as follows: $P = (4.6\Psi I_o B)/k$ where P is net primary productivity ($mgC/m^2/day$); I_o is the surface flux of photosynthetically active radiation ($E/m^2/day$); B is phytoplankton biomass as chlorophyll *a* (mg chlorophyll a/m^3); k is the attenuation coefficient (1/m); and Ψ is a constant of 0.69 mg C/mg chlorophyll a/Em^{-2}.

Respiration in the aphotic zone was calculated from the Rudek and Cloern (1996) equation for San Francisco algae when chlorophyll *a* concentration was greater than 9 ug/L as follows: $R = 217.1 + 18.5\ B$ where R is respiration (nmol oxygen/l/hr), B is chlorophyll *a* concentration (ug/L), and 217.1 is a constant.

Results **-** Measured specific production and respiration rates were high and variable at station 24 and 43 in the DWC (Fig. IV-3). Net community production rates represented a minimum load from algal production that reached at least 35 kg/day to 194 kg/day and was often highest at station 34 and station 40 in the middle of the reach. Oxygen demand from these community production rate measurements reached 1 mg/L at individual stations and totaled 4 mg/L in the reach (Table IV-4).

Average measured net water column production rates were far lower than those calculated from empirical equations and reflected the large respiration rate in natural water samples (Table IV-5). However, higher measured net photic zone production rate suggested algal growth rate was also higher than suggested by modeled values. This difference probably increased seasonally because modeled values were strongly influenced by the seasonal decrease in chlorophyll *a* concentration. Nitrification probably accounted for the high respiration rates in measured values, particularly after August, when ammonia concentration reached over 1 mg/L in the DWC and the ultimate demand was near 7 mg/L (Fig. IV-6). Nitrification resulted in the measured production and respiration rates being close to the minimum and maximum values respectively.

Table IV-3. Net production rate, respiration rate, oxygen demand and chlorophyll load from algal growth in the DWC between station 24 at Turner Cut and station 48 at Light 48 measured from light/dark bottle incubation measurements of community production rate.

Date	net photic zone production rate	aphotic zone respiration rate	net water column production rate	oxygen demand	load chla
	kg O2/ day	kg O2/ day	kg O2/ day	mg O2 / L	kg / day
27-Jul	12051	-18342	-6291	-2.83	94
14-Aug	8930	-10110	-1180	-0.53	70
23-Aug	14140	-22307	-8167	-3.67	110
6-Sep	4900	-14497	-9598	-4.32	38
12-Sep	3416	-16455	-13039	-5.82	27
14-Sep	2384	-11395	-9011	-4.05	19
12-Oct	2758	-8899	-6141	-2.76	22
16-Oct	3462	-5708	-2247	-1.01	27
25-Oct	9872	-7598	2274	1.02	77
26-Oct	2986	-4535	-1549	-0.69	23
7-Nov	1276	-1621	-344	-0.15	10
14-Nov	4462	-4431	31	0.01	35
mean	5886	-10492	-4605	-2	46

Fig. IV-4. Measured oxygen demand in the study reach.

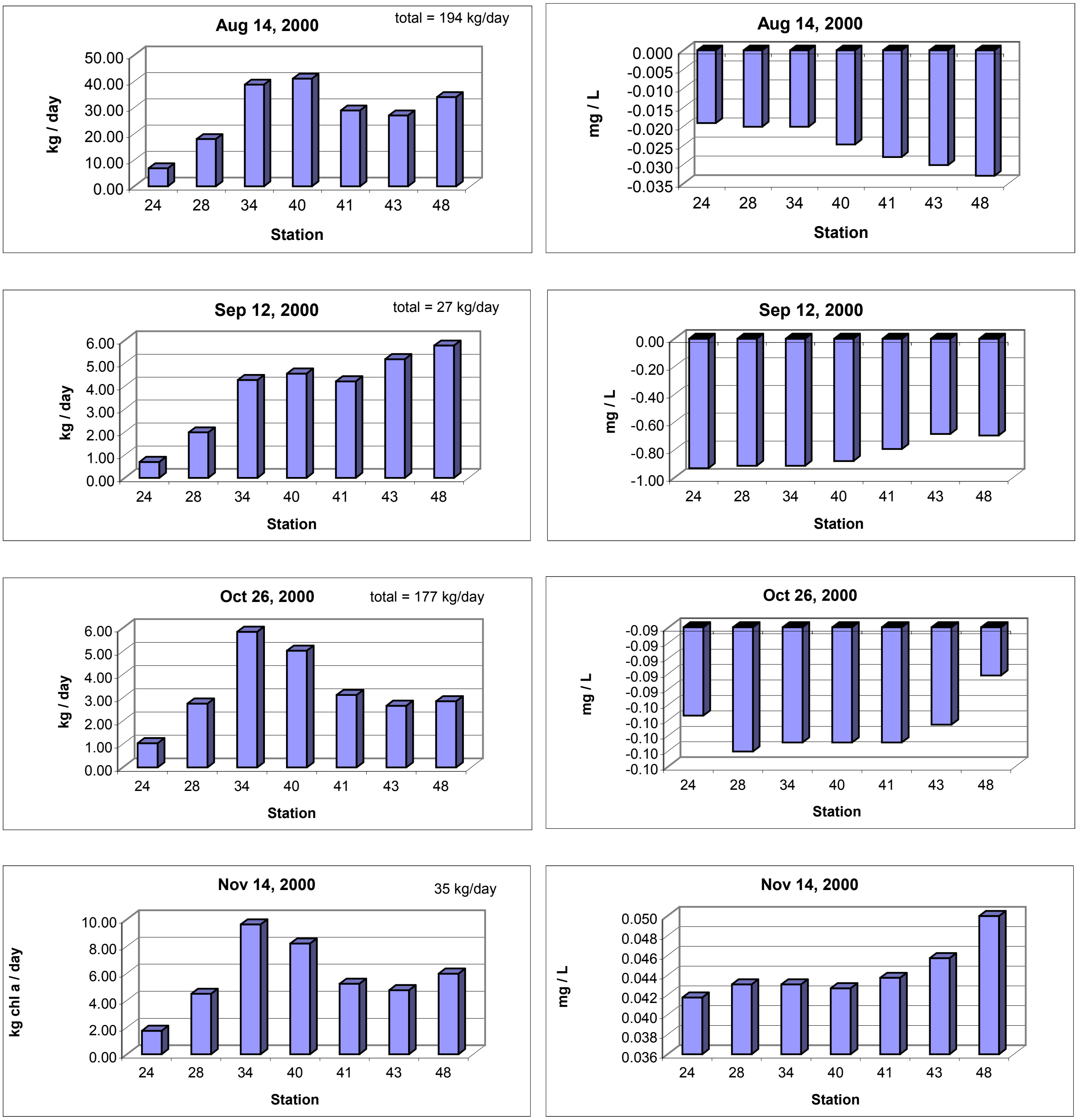
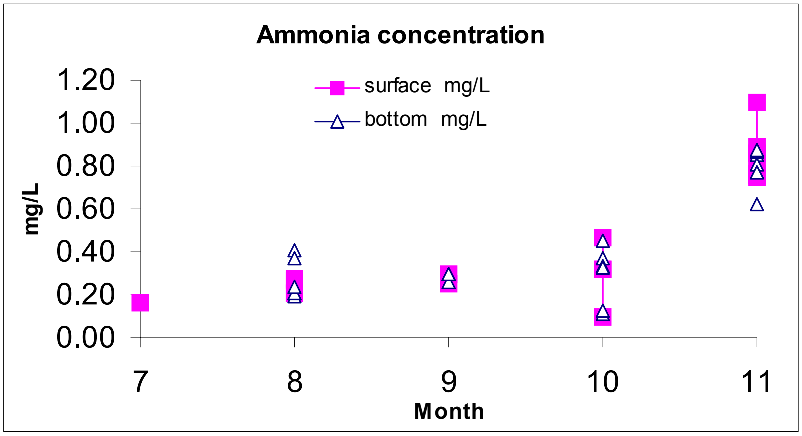
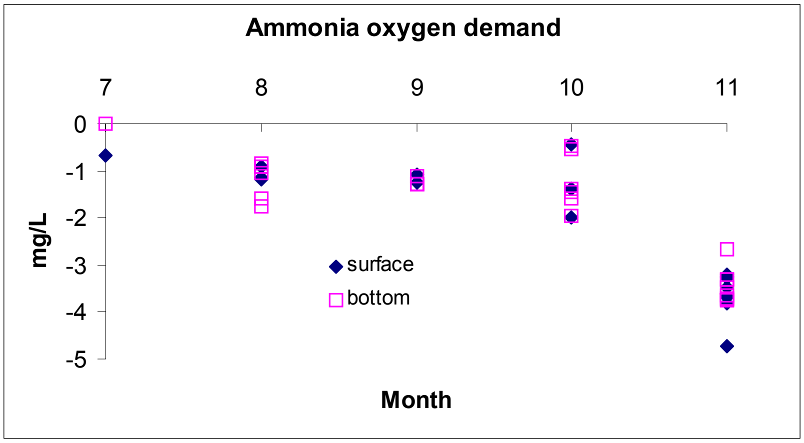


Table IV-5. Daily net production rate, respiration rate, oxygen demand and chlorophyll *a* load from algal growth in the DWC between station 24 at Turner Cut and station 48 at Light 48 calculated by equations using chlorophyll *a* concentration, surface irradiance and extinction coefficient.

Date	net photic zone production rate	aphotic zone respiration rate	net water column production rate	oxygen demand	load chla
	kg O2/ day	kg O2/ day	kg O2/ day	mg O2 / L	kg / day
27-Jul	7272	-3751	3521	0.00	57
14-Aug	12451	-7784	4667	2.11	97
23-Aug	10921	-6224	4697	2.11	85
6-Sep	3756	-5530	-1774	-0.80	29
12-Sep	3896	-7978	-4082	-1.86	30
14-Sep	6797	-4746	2051	0.92	53
12-Oct	2469	-4306	-1836	-0.83	19
16-Oct	1870	-3486	-1616	-0.73	15
25-Oct	1231	-3910	-2679	-1.20	10
26-Oct	2829	-5180	-2351	-1.06	22
7-Nov	923	-3168	-2245	-1.01	7
14-Nov	2450	-4998	-2548	-1.15	19
mean	4739	-5088	-350	-0.29	37

Fig. IV-6. Ammonia concentration and the ultimate oxygen demand from ammonia between July and November in the deep water channel at station 43, Rough and Ready Island.





Tidal load

Tidal loads into the DWC from upstream and downstream were measured in order to access the relative contribution of algal load from growth in the DWC and upstream and downstream sources.

These measurements addressed the following questions:
Question: What is the relative contribution of algal biomass from in situ growth and upstream load to the Stockton Deep Water Channel (DWC) ?
Answer: Algal biomass load from growth in the channel and net tidal transport from the upper San Joaquin River can be similar in magnitude, but varied monthly.

Question: What is the oxygen demand from algal biomass compared with other oxygen demanding substances in the DWC and upstream?
Answer: The potential oxygen demand from carbonaceous BOD and algal respiration in the DWC was smaller than the potential oxygen demand from nitrogenous BOD in the DWC and upstream.

Question: Are the loads of oxygen demanding substances from Vernalis and Mossdale representative of the load that actually enters the DWC ?
Answer: The load of organic oxygen demanding substances including algal biomass, total organic carbon, volatile suspended solids and non-ammonia total Kjeldahl nitrogen into the DWC at Channel Point was lower than expected from measurements at Vernalis and Mossdale. The load of inorganic oxygen demanding substances at Channel Point was higher than expected from Vernalis and Mossdale measurements and was primarily a function of ammonia discharge at the Stockton RWCF.

Methods

The upstream and downstream net transport of algal biomass and associated inorganic and organic materials was estimated by continuous and discrete tidal day measurements. Chlorophyll *a* concentration was estimated from 15 min chlorophyll *a* fluorescence measured with a YSI 6600 water quality meter at station 51 and a Turner fluorometer at station 43 and station 55 (Fig. Map II-1). Chlorophyll *a* concentration (ug/L) was converted to 15 min or hourly load by multiplication with streamflow (L/15 min or L/hour) and daily load was the sum of the 15 min or hourly loads over 25 hr. Streamflow at station 51 was estimated from 15 min flow measured by UVM station and operated by the U. S. Geological Survey just upstream of the Stockton RWCF discharge. Streamflow at station 55 was assumed to be similar to those at station 60 that are estimated from hourly stage data by the CA Department of Water Resources. Streamflow at station 43 was measured by 15 min ADCP measurements.

Tidal day load of nonalgal biomass was estimated from four discrete water samples collected on ebb and flood tide during both spring and neap tide using an ISCO automatic sampler and flow estimates described above. A single discrete water sample was used to estimate load at station 55 and station 60 where tidal exchange is small. Water samples were analyzed for a suite of water quality and biological variables including ammonia, nitrate plus nitrite, orthophosphate, total phosphorus, total and dissolved organic carbon, total and volatile suspended solids, chlorophyll *a*, phaeophytin concentration, BOD and CBOD and phytoplankton species composition and density. Methods for these analyses are listed in Appendix A.

Results

Upstream algal load – Upstream algal load into the DWC was similar in magnitude to the load from algal growth in the DWC (compare Table IV-3 and Fig. IV-7). The net tidal day load of algal biomass into the DWC from station 51 ranged from 10 kg/day to 160 kg/day and was highest between late August and early October.

Fig. IV-7. Net daily chlorophyll *a* load at Channel Point.

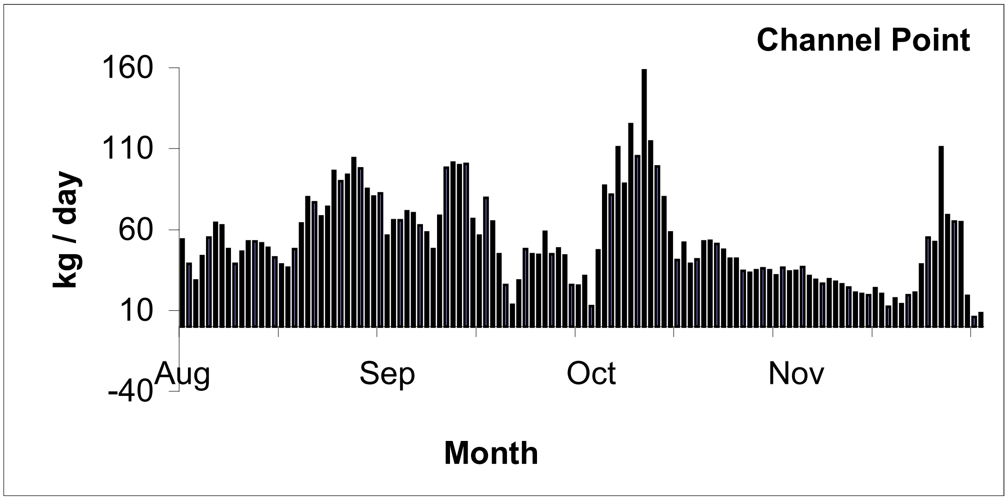
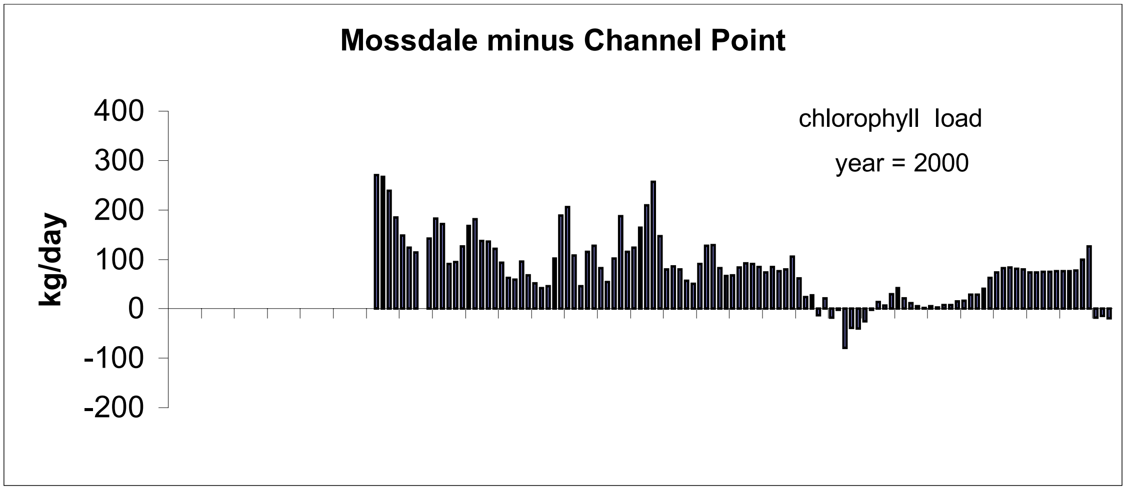
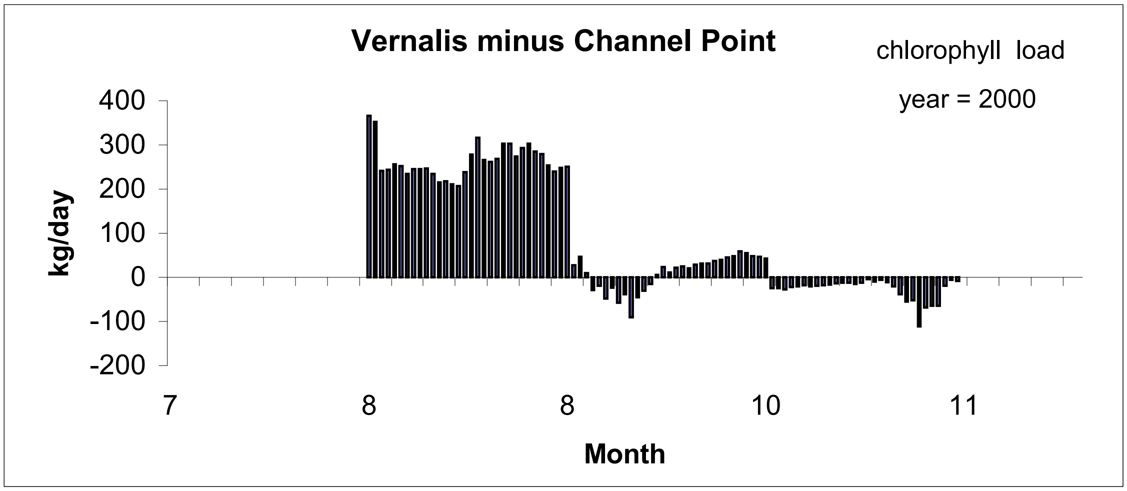
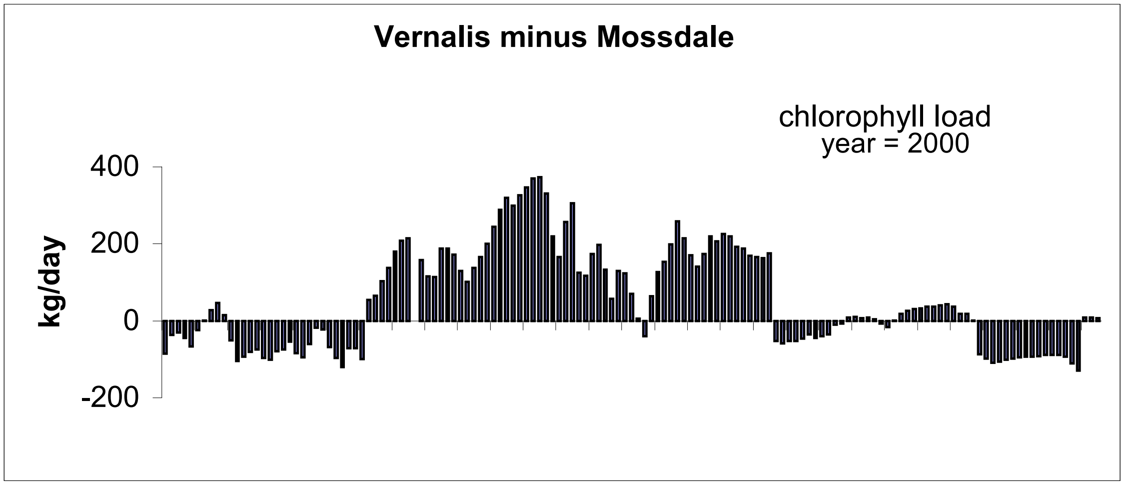


Fig. IV-8. Load difference for upstream stations at Vernalis or Mossdale and Channel Point at the entrance of the DWC.







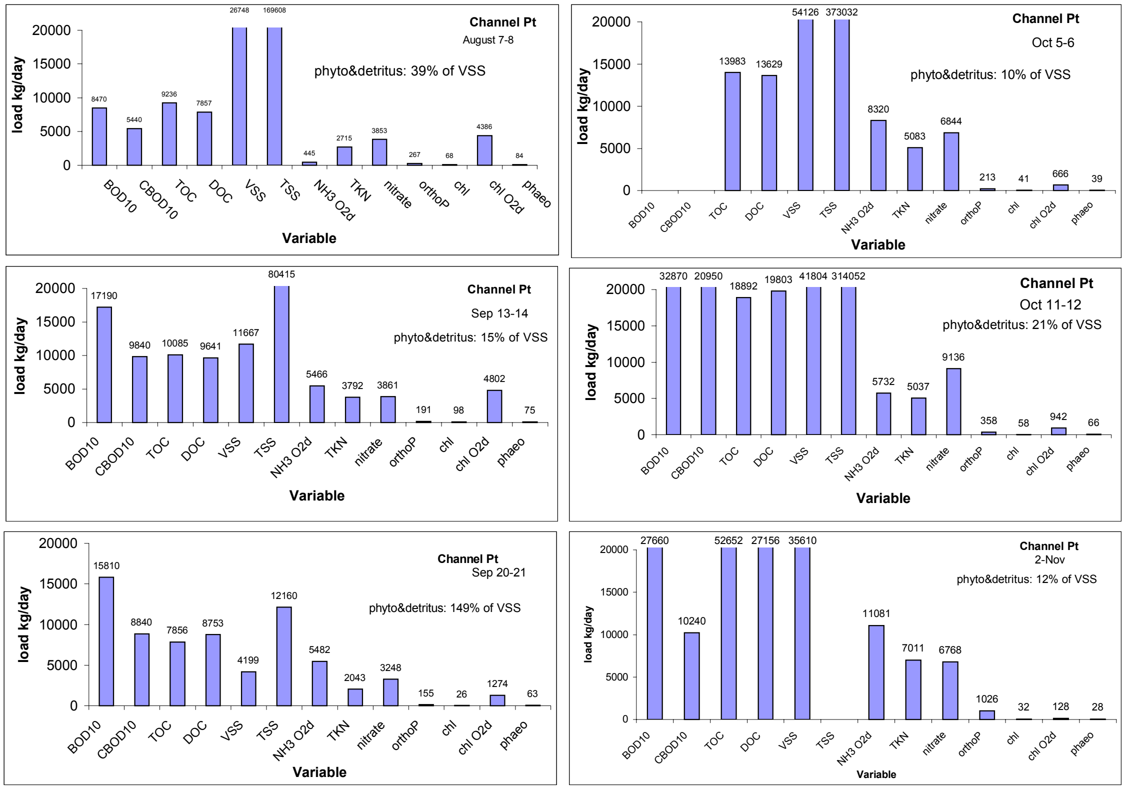
Net tidal day load from Mossdale or Vernlis was a poor estimate of the material load into the DWC from upstream. Net tidal day load from upstream into the DWC was 100-300 kg/day lower when calculated from measurements at station 51 near Channel Point at the entrance of the DWC than from station 55 near Mossdale or station 60 near Vernalis further upstream during August and September (Fig. IV-8). This suggests the upper San Joaquin River was a sink for algal biomass early in the season when most of the algal biomass was lost between station 60 and station 55. Algal load was more similar among upstream stations in October, but was characterized by an increased load between station 60 and station 55 in November.

Non-algal tidal load - The load of algal biomass into the DWC was small compared with the volatile suspended solid load. Chlorophyll *a* and phaeophytin dry weight equivalents were at most 40% of the volatile suspended solids (Fig. IV-9) and most of this algal material was phaeophytin, a surrogate for algal detritus. Chlorophyll *a* derived oxygen demand calculated from measured respiration rate (chl O2d) could have accounted from only a small portion of the total oxygen demand. In addition, most of the organic load into the DWC was dissolved. Nearly 80% of the total organic carbon load was dissolved.

The majority of the upstream oxygen demand was derived from nitrogenous sources. The 10-day carbonaceous BOD load at station 51 was small compared to the total BOD (Fig. IV-9). In contrast, the nitrogenous BOD load or difference between the total BOD and carbonaceous BOD comprised between 50% and 80% of the total and increased seasonally at Channel Point. Nitrification of ammonia from the Stockton RCF contributed to the nitrogenous BOD and may have accounted for a late season increase in total BOD load at Channel Point. Ammonia discharge from the Stockton RWCF increases sharply between September and November (Chen and Tsai 2001). Daily ammonia load increased to over 5,000 kg/day and was associated with ammonia concentrations near 1 mg/L at station 51. Complete conversion of this ammonia to nitrate would require up to 8,000 mg of oxygen at 20 ^{o}C.

The majority of the upstream nitrogenous load was from non-ammonia TKN, assuming ammonia attached to the suspended matter was small. Non-ammonia TKN consists of inorganic and organic material that can be converted to ammonia and does not include nitrate or nitrite. The non-ammonia TKN load at Mossdale was often many times higher than dissolved ammonia and was a fairly constant load over the season. Whether the non-ammonia TKN was particulate or dissolved is unknown. However, total organic carbon: TKN ratios are lower than the value of about 5 that would occur for material of only algal origin.

Fig. IV-9. Net tidal day load measured at Channel Point from tidal water quality measurements.

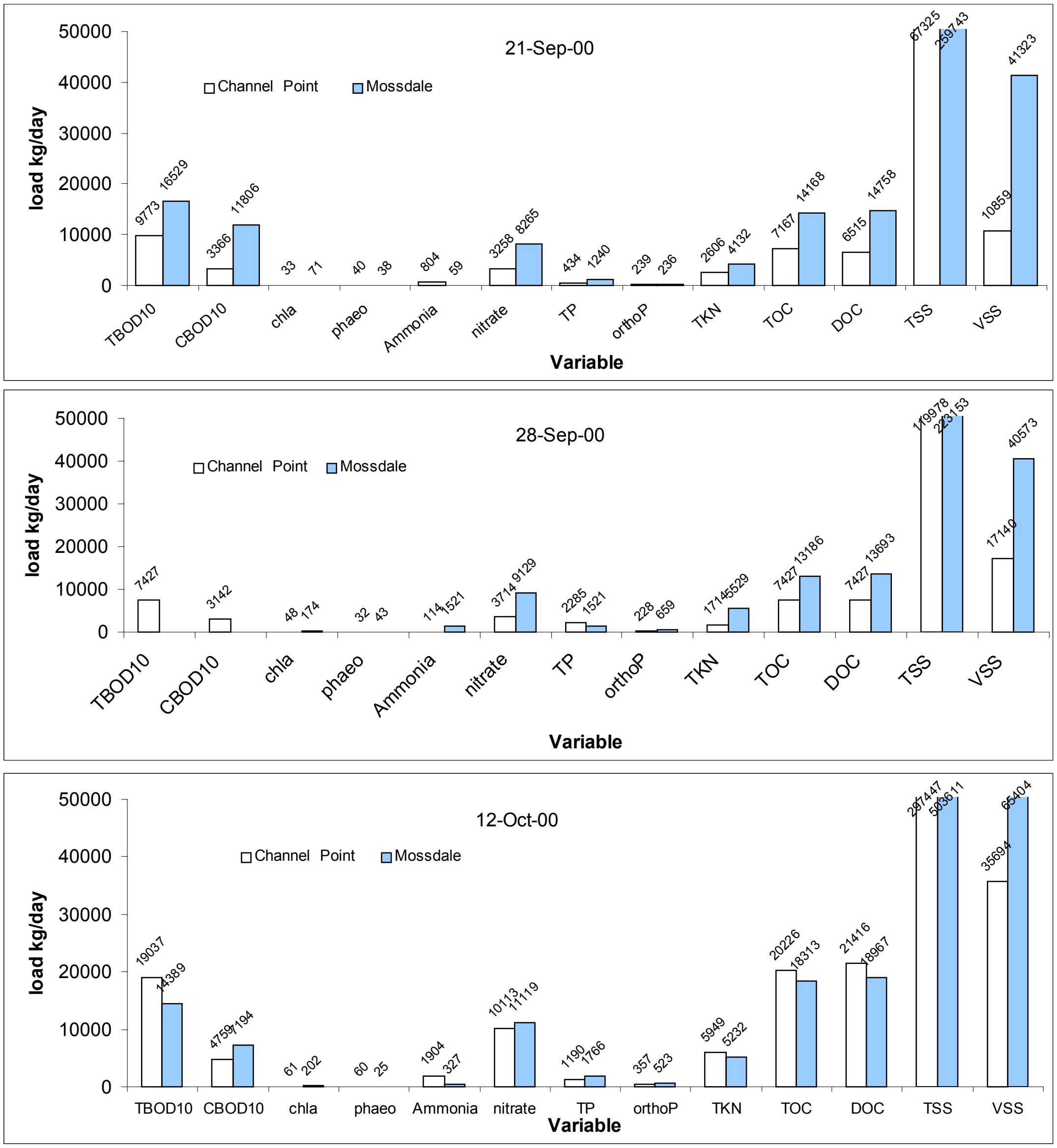


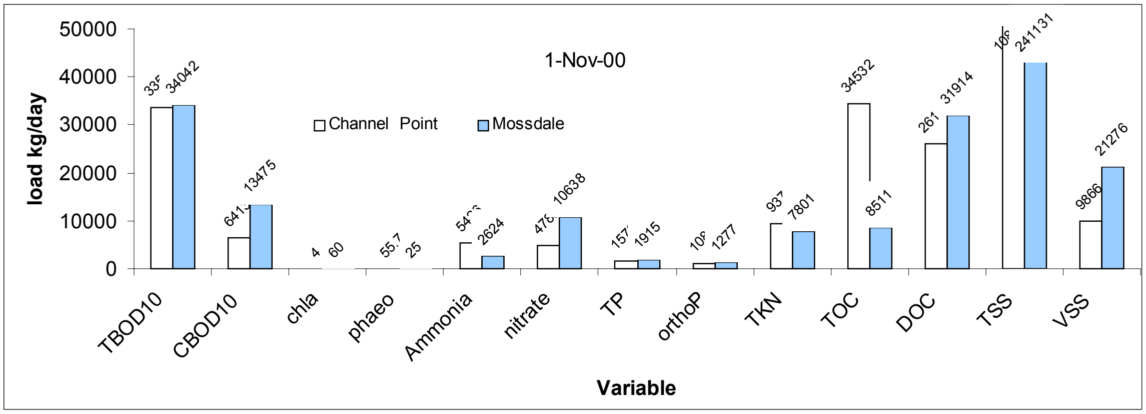
Comparisons of net tidal day load measurements confirmed the loss of organic and inorganic material between station 55 and station 51 suggested by continuous fluorometry data (Fig. IV-10). Total and volatile suspended solids, nitrate, total phosphorus and carbonaceous BOD loads were consistently lower at station 51 than station 55. The cause of this material loss is unknown.

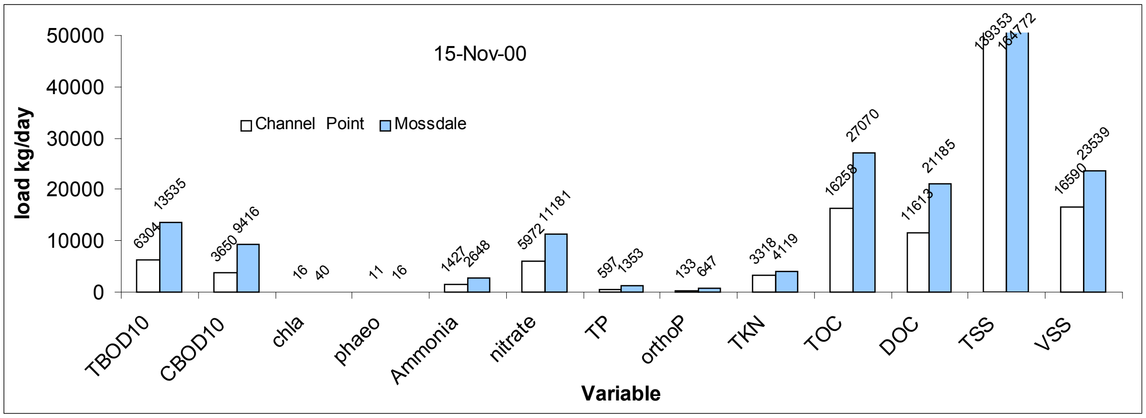
In contrast, total 10 day BOD was higher at station 51 than station 55 in October and November when both ammonia concentration, total Kjeldahl nitrogen and total and dissolved organic carbon were higher at station 51 (Fig. IV-10). The source of this additional oxygen demand was probably the Stockton RWCF that discharges both high loads of ammonia and some organic matter, including chlorophyll a downstream of station 55 late in the fall.

That the San Joaquin River above the DWC was often a sink for algal biomass was supported by comparison of net tidal day loads at station 51, station 55 and station 60 at Vernalis (Fig. IV-11) further upstream.

Fig. IV-10. Comparison of tidal day load at Channel Point station 51 and Mossdale station 55.




1-Nov-00
load kg/day
50000
40000
30000
20000
10000
0
☐ Channel Point
🟦 Mossdale
33
34042
641
13475
4
60
55.7
25
54
2624
47
10638
15
1915
10
1277
93
7801
34532
8511
261
31914
10
241131
9866
21276
TBOD10
CBOD10
chla
phaeo
Ammonia
nitrate
TP
orthoP
TKN
TOC
DOC
TSS
VSS
Variable


15-Nov-00
load kg/day
50000
40000
30000
20000
10000
0
☐ Channel Point
🟦 Mossdale
6304
13535
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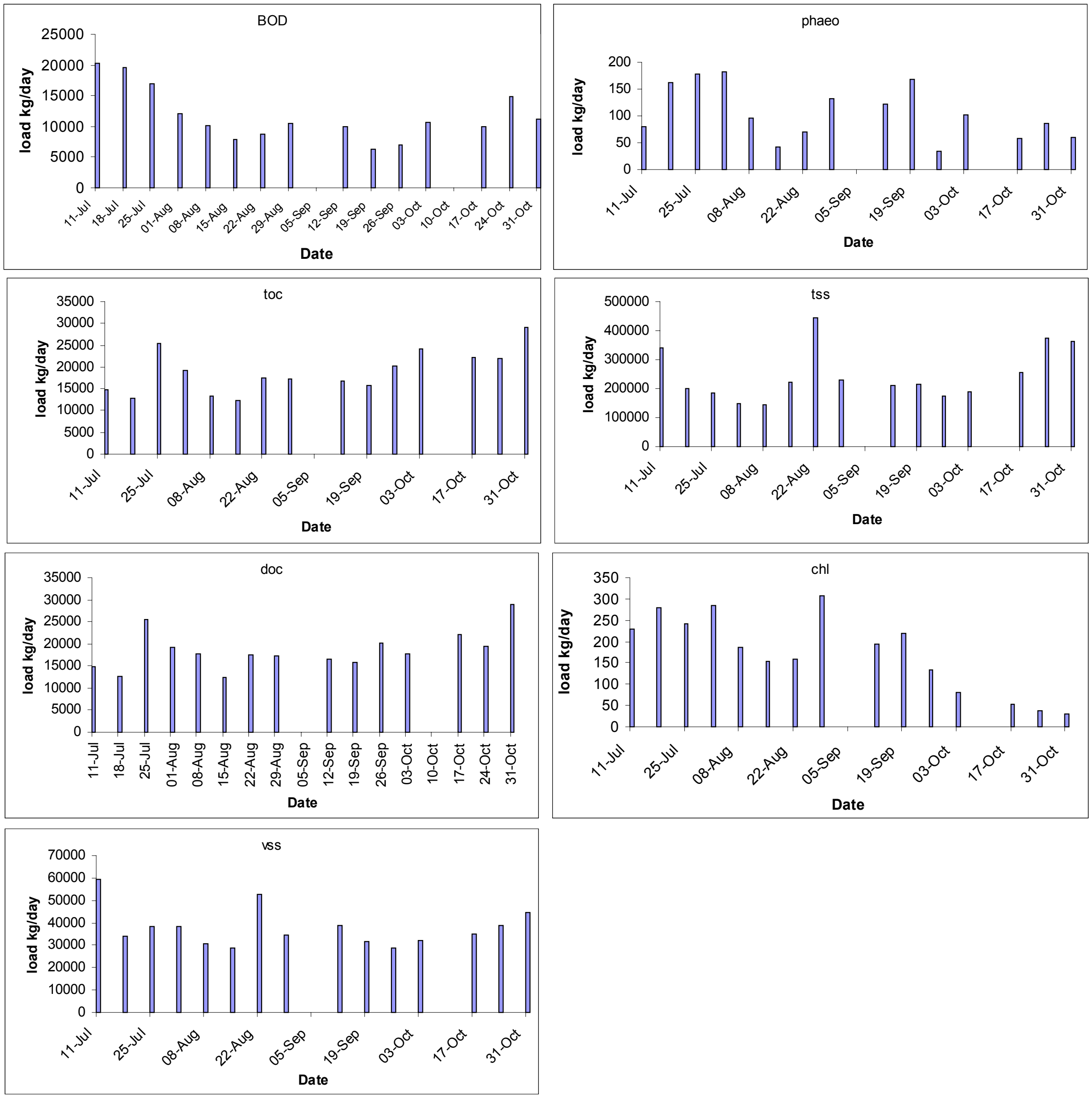
16
40
11
16
1427
2648
5972
11181
597
1353
133
647
3318
4119
16258
27070
11613
21185
139353
164772
16590
23539
TBOD10
CBOD10
chla
phaeo
Ammonia
nitrate
TP
orthoP
TKN
TOC
DOC
TSS
VSS
Variable

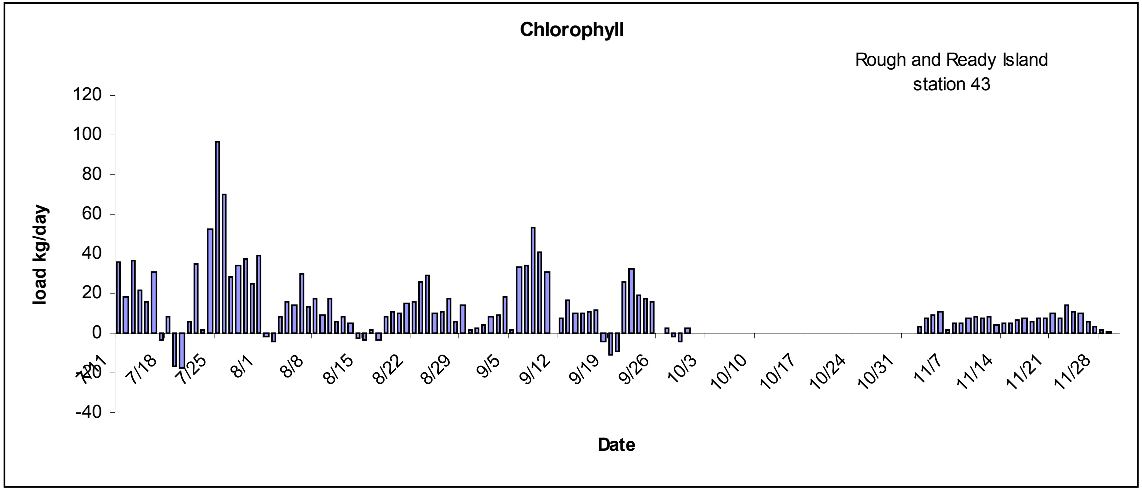
Fig. IV-11. Vernalis tidal day load. Data were collected by the City of Stockton.



Downstream algal load - Net daily downstream export of algal biomass decreased seasonally from near 100 kg/day to 20 kd/day at station 43 (Fig. IV-12). This downstream export was similar in magnitude to load at station 51 upstream and load from algal growth in the DWC (Fig. IV-3 and IV-8). However, unlike upstream, the net export of live algal biomass was usually higher than detrital biomass.

Chlorophyll *a* load was independent of the total suspended solids load that often reached near 200,000 kg/day even though both surface total suspended solids and chlorophyll *a* decreased seasonally (Fig. IV-13). Chlorophyll *a* concentration was also poorly correlated with volatile suspended solids. Volatile suspended solid load was fairly stable throughout the season at 20,000 kg/day, but the percent chlorophyll and phaeophytin was 40% or less and decreased seasonally.

Fig. IV-12. Net daily chlorophyll *a* load calculated from continuous fluorometry and flow data.



Downstream non-algal load - Total BOD10 export at station 43 increased over the season and contrasted with carbonaceous BOD10 that did the reverse (Fig. IV-13). The seasonal increase in total BOD10 was accompanied by a factor of 4 increase in ammonia load. In contrast, the seasonal decrease in carbonaceous BOD10 was accompanied by an increase in total and dissolved organic carbon that suggested carbon was a reduced source of oxygen demand.

DRAFT

Fig. IV-13. Tidal day load calculated for station 43 at Rough and Ready Island based on tidal water quality measurements.