City of Stockton Year 2001 Field Sampling Program

Data Summary Report for
San Joaquin River Dissolved Oxygen TMDL
CALFED 2001 Grant

Submitted by
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Executive Summary

This report was prepared to summarize and evaluate data collected by City of Stockton (COS) staff for the TMDL special river surveys conducted as part of the CALFED 2001 directed action grant during the summer and fall of 2001. The study reach includes the river monitoring stations established for NPDES sampling in the Stockton Deep Water Ship Channel (DWSC). An additional river station in the turning basin and upstream river stations at Mossdale and Vernalis were sampled weekly during the TMDL study period.

The purpose of the monitoring program was to provide a framework of weekly samples to characterize the water quality patterns within the DWSC and to evaluate the potential relationships between regional wastewater control facility (RWCF) effluent loads and San Joaquin River (SJR) loads. Available flow data from Vernalis and from the Stockton tidal UVM flow station were obtained for the year. The hourly water quality monitoring conducted by DWR at the Rough & Ready Island and Mossdale stations were obtained and compared with COS data. The RWCF effluent flows and concentrations for the year were also compared with the concentrations in the DWSC. Vertical and longitudinal water quality patterns within the DWSC were evaluated. An overall description of water quality and dissolved oxygen (DO) concentrations within the DWSC is presented for 2001. The CALFED grant covered 50% of the costs for COS sampling and laboratory analyses. This summary report also describes other available data for the DWSC that was not directly required by the CALFED grant, to provide a more integrated evaluation of the 2001 TMDL data.

Several major hypotheses can be partially tested and evaluated with this basic DWSC water quality data collected by the COS. Framed as general questions with brief results from the 2001 samples, some of the major hypotheses are:

1) How important are seasonal patterns of water quality in the DWSC?

There are strong seasonal changes in some RWCF concentrations (i.e., increasing ammonia) and SJR concentrations (i.e., declining VSS and chlorophyll). DO concentrations were very uniform from June through August at 3-5 mg/l. DO Concentrations increased to 4-6 mg/l in September and to 6-8 mg/l in October.

2) How similar were water quality and DO conditions observed in 2001 to previous years?

The pattern of nutrients, VSS, and chlorophyll were similar to the summer and fall values measured in previous years by DWR at Vernalis, Mossdale, Buckley Cove, and the DWSC. The diurnal DO measured at Mossdale and the DO fluctuations recorded at the Rough & Ready Island station were also similar to the patterns observed in previous years.

3) How strongly mixed is the DWSC? Is temperature or DO stratification (layering) observed?

The DWSC is generally well-mixed vertically. The COS vertical temperature profiles (generally increased in the morning) often showed a near-surface layer with a slightly higher temperature, but the DO gradient was more often declining throughout the depth. However, there are no measurements of afternoon stratification. There may be periods of temporary stratification that persists for a few days during warming trends. More detailed vertical temperature measurements are recommended.

4) How much settling of particulates is observed in the DWSC?

The COS data indicates that the average bottom concentrations for TSS and VSS are about 2.3 and 1.6 times greater than the surface concentrations. On average TSS concentrations decline by 20% between R3 and R7.

5) How variable are light conditions in the DWSC?

Turbidity and secchi depth measurements suggest that light conditions were remarkably steady throughout the survey period of June through October. The average 1% light depth (I.e., zone for algae photosynthesis) is almost always less than 6 feet.

6) How much of a longitudinal DO decline (sag) is observed in the DWSC?

The observed decline in the mid-depth DO concentrations between R3 and R7 was always less than 2 mg/l in year 2001. The lowest COS mid-depth DO concentrations of about 3 mg/l are less than the Basin Plan DO objective of 5 mg/l. The Rough & Ready Island station (R5) is not always the location of the lowest DO concentration in the DWSC. Sometimes the R6 station has the lowest mid-depth DO concentration.

7) How high and variable are the nutrient concentrations in the DWSC?

The nitrogen and phosphorus concentrations are generally very high and steady throughout the summer and fall seasons. Nitrite + Nitrate concentrations averaged about 1.5 - 2.0 mg/l and total Phosphorus averaged about 0.25 - 0.35 mg/l. Changes in measured river chlorophyll are apparently independent of these steady nutrient concentrations during 2001.

8) How variable is the RWCF loading of BOD, VSS, and ammonia?

The COS data indicate that the RWCF loads of BOD and VSS are relatively constant. The ammonia load was lower in the summer (i.e., May through August) than in the fall and winter. Maximum BOD_5 loads were about 5,000 lbs/day. Summer ammonia loads were higher than in previous years, with 2,000 to 4,000 lbs/day from June though September. The nitrification equivalent BOD would therefore be about 10,000 to 20,000 lb/day.

9) How variable is the SJR loading of BOD, VSS, and chlorophyll?

The river concentrations of BOD, VSS, and chlorophyll declined substantially between June and October at Vernalis and Mossdale. -The river loads of VSS were at least 10 times the RWCF loads of VSS during June-October of year 2001. Assuming an ultimate BOD/VSS ration of 1.0, the river BOD load ranged from 20,000 to 50,000 lbs/day.

10) How much effect does SJR flow have on water quality and DO in the DWSC?

The year 2001 survey period included a limited range of flows from about 600-700 cfs in June-August to about 1,600 cfs in October. Flows were relatively steady during 2001 so direct observations of water quality caused by flow changes were not possible. DWSC water quality may be influenced by changes in SJR flow, but there are several other factors that interact to make it difficult to observe any direct effects of flow on DO concentrations in the DWSC.

Introduction

This report was prepared to summarize and evaluate data collected by City of Stockton (COS) Department of Municipal Utilities Regional Water Control Facility (RWCF) for the TMDL special river surveys conducted as part of the CALFED 2001 directed action grant during the summer and fall of 2001. The study reach includes the river monitoring stations established in the RWCF NPDES permit. An additional river station in the turning basin was sampled during the TMDL study period. Upstream river stations at Mossdale and Vernalis were also sampled weekly during the TMDL study period. Although the NPDES monitoring requires mid-depth samples, surface and bottom samples were collected for the special TMDL surveys. Figure 1 graphically locates sampling stations as they are referred to in this report, in addition to referencing navigation lights as used in other sampling programs.

Hypotheses about DWSC Water Quality and DO Concentrations

Several major hypotheses can be partially tested and evaluated with these basic measurements of DWSC water quality data collected by COS in their year 2000 sampling programs for NPDES and for the special TMDL studies. Framed as general questions, some of the major hypotheses are:

1) How important are seasonal patterns of water quality in the DWSC?
2) How similar were water quality and DO conditions observed in 2001 to previous years?
3) How strongly mixed is the DWSC? Is temperature or DO stratification (layering) observed?
4) How much settling of particulates is observed in the DWSC?
5) How variable are light conditions in the DWSC?
6) How much of a longitudinal DO decline (sag) is observed in the DWSC?
7) How high and variable are the nutrient concentrations in the DWSC?
8) How variable is the RWCF loading of BOD, VSS, and ammonia?
9) How variable is the SJR loading of BOD, VSS, and chlorophyll?
10) How much effect does SJR flow have on water quality and DO in the DWSC?

Sampling Methods

The weekly sampling program that was conducted by COS for the TMDL special river and RWCF effluent study followed normal field and laboratory procedures. The City of Stockton RWCF laboratory is certified by the California Environmental Laboratory Accreditation Program (CELAP). The established QA/QC methods include field equipment calibration and laboratory batch procedures for blanks, spike recoveries, and split sample comparisons. Table 1 indicates the laboratory methods (EPA or Standard Methods) and the reporting limits used during the 2001 special TMDL river sampling. Some of the parameters were analyzed by a contract laboratory using the same QA/QC procedures and operating under the same CELAP certification. Duplicate analyses and spike recovery determinations are performed on a minimum of 5% of the samples for those analyses that are appropriate. Generally the acceptance range for replicate analyses is within 20%, and for spike recoveries is 80-120%. Filter blanks are run for dissolved parameters where appropriate. One field duplicate sample is collected on each sampling trip. The necessary detection limits shown in Table 1 are based on the expected river concentrations as well as laboratory procedures. Lower than standard detection limits are specified for BOD and suspended solids measurements to obtain positive readings from all river samples (i.e., low values anticipated).

The field measurements included vertical profiles of temperature and DO at each DWSC station. These vertical profiles were measured at 2 feet intervals with a YSI meter. The DO probe was calibrated with moist-air saturation procedures and a titration verification of the DO membrane each week prior to the survey. Special TMDL surveys were conducted for 17 weeks during 2001, beginning on June 5 and ending on October 23.

Table 1. Sampling and Laboratory Methods for COS TMDL Monitoring Program

Parameter	Method	Laboratory	Preservative	Handling	Reporting Limit, mg/l
PH	SM 4500-H B	COS		Field	0.1
Dissolved Oxygen	SM 4500-O G	COS		Field	0.1
Biochemical Oxygen Demand	SM 5210B	COS		Ice, 4° C	0.1
Total Suspended Solids	SM 2540 D	COS		Ice, 4° C	1
Volatile Suspended Solids	SM 2540 E	COS		Ice, 4° C	1
Electrical Conductivity	SM 2510 B	COS		Ice, 4° C	1
Turbidity	SM 2130 B	COS		Ice, 4° C	1
Total Organic Carbon	EPA 415.1	COS	H_2SO_4, pH <2	Ice, 4° C	0.1
Chlorophyll a and Phaeophytin a	SM 10200 H	COS		Ice; filter then freeze in lab	0.001
Ammonia	EPA 350.1	COS	H_2SO_4, pH <2	Ice, 4° C	0.1
$NO_2 + NO_3$-N	EPA 353.3	COS		Ice, 4° C	0.1
Total Kjeldahl Nitrogen	EPA 351.1	COS	H_2SO_4, pH <2	Ice, 4° C	0.5
Total Phosphorus	EPA 365.4	COS	H_2SO_4, pH <2	Ice, 4° C	0.01

1. Dissolved Oxygen meter performance checked by Winkler weekly. Calibration in air checked at each monitoring location.
2. Laboratory analyses
   a. One field duplicate collected each monitoring event
   b. Minimum 5% samples analyzed with duplicate analyses and spikes.
   c. Filter blanks are run for dissolved parameters.
3. Bulk samples are returned to the laboratory for sub-sampling/filtering/preservation as necessary.
   a. Samples for dissolved parameters, including chlorophyll/phaeophytin, are filtered the same day.
   b. Samples for Geo Analytical picked up the next day.
   c. Sample filtrates for SCL shipped iced Federal Express Overnight the next day.

San Joaquin River and RWCF Effluent Flows

The net daily San Joaquin River flow past Stockton and the RWCF effluent flows are important factors controlling water quality in the DWSC. The RWCF and SJR loads of nutrients, BOD, VSS, and other materials are estimated as the concentration times the flow. The City cooperatively funds the USGS Stockton tidal flow station to allow the RWCF daily discharge flows to be reported as part of their NPDES permit.

San Joaquin River Flow

An ultrasonic velocity meter (UVM) operated and maintained by the United States Geological Survey (USGS) continuously monitors river stage and tidal flows at a location upstream of the submerged pipe outfall at the RWCF. The UVM station was not functioning properly during several other periods from May to September. New instrumentation has been installed by USGS. Figure 2 displays net daily flow at the UVM station for calendar year 2001 period, and includes the daily records of San Joaquin River at Vernalis flow, combined CVP and SWP export pumping flow, and south Delta temporary barrier placement periods. The UVM station flow is generally less than 50% of the flow at Vernalis, unless the Head of Old River (HOR) barrier is installed for fish protection. High Delta export pumping relative to the Vernalis flow will reduce the fraction of the Vernalis flow that reaches Stockton. A special report documenting these observations during the 1996-2000 UVM measurement period has been prepared as part of the NPDES permit renewal process for the City of Stockton (Jones & Stokes, 2001a).

During these periods without UVM measurements, flow in the DWSC was estimated from other available data. When tidal flow records were available from the DWR Head of Old River station, Stockton flow was estimated as Vernalis flow minus Old River flow. From late April through September, missing Stockton flows were estimated by averaging the high and low Stockton flow estimate based on the Vernalis flows. The estimates were derived as follows:

	Low Estimate	**High Estimate**
No Barriers Installed	(0.5-0.075*(P/V))*V	(0.5-0.05*(P/V))*V
Head of Old River Spring Barrier Installed	0.75*V	0.95*V
Grant Line Canal, Old River, Middle River Barriers Installed	0.30*V	0.60*V
Head of Old River Fall Barrier Installed	0.75*V	0.90*V

Where P = Delta Export Pumping, V = Vernalis Flow

Figure 3 shows these various estimates and measured data. Net river flow at the Stockton UVM station during the TMDL sampling period of June through October varied from less than 750 cfs in June to more than 2,500 cfs at the end of October. Monthly average flows are given in Table 2. The estimated UVM values generally followed the measured UVM data.

Figure 4 shows the estimated Stockton (DWSC) flows and the corresponding travel time (i.e., volume/daily flow) for water moving through the DWSC, calculated for an assumed DWSC volume of about 16,000 acre-feet (AF) that corresponds to the volume between Turner Cut and including the turning basin. The travel time was longest (i.e., 10-15 days) from June through August when the net flow at the Stockton UVM station was less than 750 cfs. Travel time was estimated to decrease from 15 days to 10 days during September when the UVM flow was increasing from 750 cfs to 1,000 cfs. The estimated DWSC travel time was less than 5 days in October when the UVM flow increased to over 2,000 cfs. The travel time for water between Mossdale and the DWSC corresponds to an estimated volume of about 3,000 AF.

Source of Water in the Stockton Deep Water Ship Channel

During the TMDL study period of June-October 2001, the tidal mixing of Sacramento River water from the downstream boundary near Turner Cut was less than in other years with lower SJR flows. Figure 5 presents mid-depth EC data from the DWSC stations for the period of June to October 2001. Figure 5 suggests that the majority of water in the DWSC was from the San Joaquin River. Only river station R8 had a generally lower EC value than the other stations, because of the Sacramento River water moving across the Delta towards the export pumping facilities as indicated by the EC at San Andreas Landing located near the mouth of the Mokelumne River. EC at station R7 was only sometimes lower than the other DWSC stations, perhaps caused by sampling at higher tides. Stations R3 to R7 are therefore used to characterize water quality within the Stockton DWSC.

Stockton RWCF Discharge Flow

Stockton RWCF discharge flows to the San Joaquin River are reported as daily averages. Figure 6 shows the daily RWCF effluent flows during 2001. There were about 40 days with zero discharge. The RWCF has sufficient storage volume in the treatment ponds to hold water for several days. Discharge flows during the June-October TMDL study period were about 45 cfs (29 mgd). Table 2 provides monthly average flows at Vernalis, at the Stockton UVM station, and for the Stockton RWCF discharge during 2001.

The daily effluent load and tidal mixing patterns of the RWCF effluent in the San Joaquin River are relatively complex because of the variations in tidal flows, net river flows, and effluent flows. River stations R2, located about 1 mile upstream, and R3, located about 1.5 miles downstream from the RWCF discharge, provide the most direct indication of the tidal dilution of the RWCF effluent concentration. A special report describing these tidal mixing and dilution patterns has been prepared for the City of Stockton to support the NPDES permit renewal process (Jones & Stokes, 2001b)

Table 2. Monthly Average Flows for 2001

Month	Vernalis Flow cfs	Stockton UVM cfs	Estimated Stockton UVM cfs	RWCF mgd	RWCF cfs
January	2,458	570	570	30	51
February	3,192	1,001	1,001	28	43
March	3,559	1,246	1,246	26	43
April	3,079	1,215	1,384	23	44
May	3,643	1,695	2,926	26	45
June	1,623	673	691	26	42
July	1,401	--	631	20	42
August	1,340	--	603	30	52
September	1,380	885	797	26	46
October	1,891	1,712	1,712	24	44
November	2,063	1,331	1,331	28	44
December	2,101	526	526	29	44

Stockton RWCF Concentrations and Discharge Loads

Stockton RWCF monthly concentrations are summarized in Table 3. Some variables are measured daily, and some are measured weekly. Monthly RWCF discharge loads were calculated as the monthly average concentration times the monthly average discharge flow:

Load (lbs/day) = 5.4 * Flow (cfs) * Concentration (mg/l)

TSS, total BOD_5, $CBOD_5$, ammonia-nitrogen, and DO were collected every day there was RWCF discharge. VSS, chlorophyll, and phaeophytin measurements were gathered only during the TMDL study period. Table 4 provides the average monthly effluent loads for these parameters.

Figures 7 and 8 depict the trend in total $CBOD_5$ and ammonia concentrations (mg/l) and loads (1,000 lbs/day) over the 2001 calendar year. $CBOD_5$ and ammonia concentrations are measured each day with RWCF discharge. Figure 7 shows that total $CBOD_5$ concentration remained fairly constant throughout the TMDL study period, with total $CBOD_5$ concentration ranging from 2-8 mg/l. The corresponding $CBOD_5$ load varied with RWCF discharge flow between about 500 lbs/day and 2,500 lbs/day, with an average of about 800 lbs/day from June through October. The summer ammonia concentrations remained higher than previous years, remaining between 5 mg/l and 10 mg/l most of the summer months. Figure 8 shows that the ammonia-nitrogen concentrations steadily increased in September and October, reaching a maximum of about 24 mg/l at the end of October. As a consequence, ammonia-nitrogen load increased from about 2,100 lbs/day in June through August to about - 3,800 lbs/day in October.

Some but not all ammonia will be oxidized in the normal 5-day BOD test. To calculate ultimate oxygen demand of the Stockton RWCF effluent, ultimate CBOD was estimated from the 5-day CBOD value, and the ultimate ammonia oxidation was estimated from the ammonia value. The

CBOD is measured after a nitrifying-bacteria inhibitor is added to eliminate any ammonia oxidation. Biological oxygen demand decomposition kinetics measured in the 30-day BOD tests conducted in 1999 and 2001 (Litton, 2002) provided estimates of daily BOD decay rate (*k*) values for Stockton RWCF effluent. The long-term BOD measurements indicated a decay value of about 0.1 per day for CBOD. This *k* value corresponds to a 5-day to 30-day (ultimate) conversion coefficient of about 2.5 for CBOD. For ammonia, a conversion coefficient of 4.57 was used, assuming complete conversion of ammonia to nitrate (i.e., $NH_4 + 2O_2 = NO_3 + 2H + H_2O$ with 4*16/14 = 4.57).

The load of organic nitrogen will ultimately contribute to the maximum BOD load during the summer. TKN measures both ammonia and organic-N. Table 5 summarizes the estimated RWCF monthly average ultimate DO demands for 2001. During the winter months when river temperatures approach 10ºC, biologically mediated oxidation of ammonia (i.e., nitrification) is reduced considerably. The values in Table 4, therefore, likely overestimate ultimate DO demands during November, December and January.

Figure 9 compares the effluent ammonia to the river concentrations in the DWSC. River concentrations (right scale, 0 to 3 mg/l) are less than 10% of effluent concentrations (left scale, 0 to 30 mg/l). A river concentration shown equal to effluent concentration on this figure indicates a dilution of 10:1. The river data suggest that river dilution was always greater than 10:1 (often greater than 20:1) during the TMDL study period, as well as other times during 2001 when ammonia samples are collected for NPDES monitoring.

Stockton RWCF BOD and Volatile Suspended Solids

In addition to BOD, total suspended solids (TSS) and volatile suspended solids (VSS) were measured. Only the organic fraction of TSS (i.e., VSS) is expected to exert an appreciable oxygen demand. Of particular interest is the particulate fraction of effluent BOD, because particulate BOD may contribute to sediment oxygen demand (SOD) in the Deep Water Ship Channel whereas dissolved BOD is expected to largely remain in the water column and be transported downstream with the net flow.

Figure 10 illustrates the conceptual components of BOD measurements. Table 6 summarizes RWCF effluent total BOD and the organic fraction of total solids (i.e., VSS/TSS) for the year 2001 TMDL study period. During the study period, 88% of the total solids discharged were organic materials that would contribute to either BOD or SOD in the DWSC. The TSS values averaged 1.2 times the BOD_5. The $CBOD_5$ was about 50% of the BOD_5. The organic nitrogen is also about 40% of the BOD_5. On average, the VSS concentrations are slightly less than the TSS, and about 90% of the BOD.

The TSS/BOD_5 was calculated from the daily values. The average TSS/BOD_5 ratio is 1.01. The VSS/BOD_5 is calculated from the weekly values. The average VSS/BOD_5 is 96%. The VSS (particulates) may represent about half of the ultimate BOD which is expected to be about 2 times the BOD_5 value.

Table 3. Stockton RWCF Monthly Average Concentrations for 2001 (mg/l)

Month	TSS	VSS	Total BOD 5-Day	CBOD 5-Day	Ammonia Nitrogen	Organic Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	DO	Chl a	Chl a + Pha
January	10	--	10.5	5.6	24.8	4.5	0.3	0.1	9.1	--	--
February	15	--	11.4	6.3	24.3	5.6	0.6	0.1	9.8	--	--
March	15	--	12.4	5.7	14.7	4.8	5.8	0.7	7.5	--	--
April	9	--	7.1	3.4	4.3	3.4	14.9	0.2	10.0	--	--
May	5	--	6.9	2.7	7.9	2.8	7.3	0.4	7.4	--	--
June	5	6	8.4	3.7	7.2	2.7	5.9	0.7	6.2	12.2	2.3
July	6	5	6.4	2.7	10.8	2.8	1.7	0.6	8.3	8.1	1.3
August	11	11	10.1	4.8	12.1	3.7	0.8	0.3	7.7	36.3	5.9
September	10	9	8.1	4.0	9.4	2.8	1.2	0.3	8.0	28.0	5.2
October	9	9	10.2	4.5	19.1	4.1	0.2	0.2	8.0	18.3	3.7
November	13	--	9.9	6.0	16.1	3.0	3.5	0.9	8.9	--	--
December	15	--	5.6	3.4	11.5	3.2	7.5	0.2	10.0	--	--

Table 4. Stockton RWCF Monthly Average Loading for 2001 (lbs/Day)

Month	TSS	VSS	Total BOD 5-Day	CBOD 5-Day	Ammonia Nitrogen	Organic Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	DO	Chl a	Chl a + Pha
January	2,539	--	2,632	1,396	6,214	1,122	83	13	2,277	--	--
February	3,369	--	2,650	1,454	5,639	1,292	144	23	2,271	--	--
March	3,252	--	2,704	1,238	3,201	1,048	1,268	151	1,634	--	--
April	1,752	--	1,385	669	833	665	2,923	46	1,952	--	--
May	988	--	1,513	597	1,722	617	1,598	98	1,620	--	--
June	1,160	1,323	1,830	797	1,552	593	1,273	154	1,347	2640	497
July	1,008	834	1,059	449	1,806	472	289	96	1,379	1350	219
August	2,740	2,704	2,559	1,214	3,056	938	193	77	1,946	9210	1504
September	2,200	2,007	1,745	864	2,027	602	251	65	1,719	6022	1111
October	1,801	1,808	2,046	895	3,829	831	32	33	1,610	3684	745
November	3,135	--	2,331	1,400	3,779	696	810	210	2,098	--	--
December	3,601	--	1,330	806	2,738	764	1,799	42	2,399	--	--

Table 5. Calculated Stockton RWCF Daily Average DO Demand For Calendar Year 2001 (lbs/day)

Month	Ultimate CBOD DO Demand	Ultimate Nitrogenous DO Demand	Ultimate TKN DO Demand	Ultimate CBOD + Ultimate TKN DO Demand
January	3,490	28,397	33,523	37,012
February	3,636	25,769	31,673	35,309
March	3,094	14,627	19,416	22,511
April	1,672	3,805	6,846	8,518
May	1,494	7,870	10,691	12,185
June	1,991	7,093	9,803	11,794
July	1,122	8,252	10,411	11,532
August	3,035	13,964	18,250	21,285
September	2,161	9,262	12,014	14,175
October	2,237	17,500	21,295	23,533
November	3,501	17,270	20,452	23,953
December	2,014	12,512	16,004	18,018

Table 6. Stockton RWCF Effluent Particulate BOD_5 and Organic Suspended Solids Fractions

Date	Total BOD_5	Total BOD_{10}	TSS	VSS	Volatile Fraction	BOD_5/ VSS	BOD_{10}/ BOD_5
June 12	7.8	21	4.4	4.3	0.98	1.81	2.69
June 19	6.6	22	10	9	0.90	0.73	3.33
June 26	14	56	7	5	0.71	2.80	4.00
July 3	--	--	--	--	--	--	--
July 10	--	--	--	--	--	--	--
July 17	6.3	63	6	5	0.83	1.26	10.00
July 24	27	41	7	5	0.71	5.40	1.52
July 31	--	--	--	--	--	--	--
August 7	--	--	--	--	--	--	--
August 14	9.7	46	11	10	0.91	0.97	4.74
August 21	11	34	13	12	0.92	0.92	3.09
August 28	8.5	12	10	10	1.00	0.85	1.41
September 4	--	--	--	--	--	--	--
September 11	8.2	19	10	9	0.90	0.91	2.32
September 18	8.8	30	12	11	0.92	0.80	3.41
September 25	7.7	12	9	8	0.89	0.96	1.56
October 2	11	22	9	8	0.89	1.38	2.00
October 9	--	--	--	--	--	--	--
October 16	9.7	26	12	10	0.83	0.97	2.68
October 23	9	18	10	9	0.90	1.00	2.00
Mean	10.38	30.14	9.31	8.24	0.88	1.48	3.20
Standard Deviation	5.177	15.922	2.462	2.479	0.083	1.251	2.188

San Joaquin River Concentrations and Loads

Two river stations were sampled each week during the TMDL study period from June 12 through October 23, 2001. Vernalis is located about 15 miles upstream of Mossdale, and Mossdale is located about 15 miles upstream from the DWSC. Mossdale is about 2.5 miles upstream from the Head of Old River, and is slightly influenced by tidal currents during high tide. Vernalis is upstream of any tidal influence. The travel time between Vernalis and Mossdale is estimated to be less than 12 hours at a flow of 2,000 cfs. The Mossdale to DWSC travel time is about 1.5 days, assuming a flow of 1,000 cfs at the Stockton UVM station.

Both Mossdale and Vernalis have been routinely sampled (i.e., monthly) for water quality parameters by DWR since about 1972 but Mossdale was discontinued in 1995. DWR also operates an hourly water quality monitoring station at Mossdale (i.e., temperature, EC, pH, and DO). The COS staff collected samples at both stations during the TMDL study period to allow a comparison with the historical DWR data and provide replicate samples for evaluating the river concentrations and loads entering the DWSC. Sample locations downstream from Mossdale, such as river station R1, are influenced by RWCF effluent that is tidally mixed both upstream and downstream of the discharge location. The river concentrations and loads are most accurately evaluated at stations upstream from Mossdale (to eliminate RWCF influence), although the potential settling and decay of river concentrations of algae and organic materials between Mossdale and DWSC cannot be determined directly.

Salinity

San Joaquin River salinity (measured as EC) at Vernalis is a complex interaction between runoff and drainage salinity (salt loads), upstream irrigation diversions, and tributary flows that may provide substantial dilution in the SJR. Figure 11 shows the daily salinity recorded at Vernalis, Mossdale, in the DWSC at the Rough and Ready Island station and San Andreas Landing located near the mouth of the Mokelumne River. Salinity fluctuated in response to major storm events, as indicated by the inverse relationship between flow and salinity. The Vernalis EC values increased from less than 300 uS/cm to 700 uS/cm in May and June as Vernalis flow declined from 4,500 cfs to 1,200 cfs. EC remained at these levels through summer and fall. The 1995 Water Quality Control Plan salinity objective at Vernalis is 700 uS/cm from May through August. The EC at Mossdale was generally a little higher than at Vernalis. The Vernalis and Mossdale EC declined to less than 400 uS/cm during the pulse flow in October. The Rough & Ready EC also decreased to less than 500 uS/cm with a travel time of about 3-4 days. This was generally the opposite trend from what has been observed in many other summer periods, but the trends in 2001 were the same as those observed in 2000.

The differences between the three EC monitoring stations were relatively small during the summer and fall. Although the RWCF effluent has an EC of about 1,200 uS/cm, the effects of the effluent on EC cannot easily be detected from the difference between the Rough and Ready Island and Mossdale stations. This is because of the relatively strong dilution of RWCF effluent when the UVM flows are greater than 500 cfs (i.e., dilution of 10 when RWCF discharge of 50 cfs and river flow is 450 cfs). The difference of 500 uS/cm between the RWCF and the SJR salinity in July would be expected to be about 50 uS/cm at the Rough and Ready station. This can be seen in June and July, although there is also a 10-15 day delay between a change in salinity at Mossdale and a corresponding change at the Rough and Ready station. The minimum San Andreas Landing EC is always about 250 uS/cm. The average San Andreas Landing EC increases during periods of low Delta outflow (August-November for 2001).

Nutrient Concentrations

Table 7 gives the weekly nutrient concentrations at Vernalis and Mossdale. The river nutrient concentrations were generally high and relatively constant during the June-October TMDL study period. Nitrate concentrations averaged 1.5 to 2.0 mg/l. RWCF effluent nitrate concentrations were generally less than 1 mg/l but were about 10 mg/l during the spring. Total phosphorus concentrations were about 0.25 to 0.35 mg/l. The RWCF effluent total phosphorus is about 1-3 mg/l. These nutrient concentrations were generally much higher than values that would limit the algae growth and uptake processes.

Particulate Parameters

Table 7 indicates that the river TSS concentrations declined from about 50 mg/l in June to about 35 mg/l in October. Turbidity values also decreased during the summer from 25 to 20 NTU. The corresponding light penetration measurements (i.e., secchi depth) increased from about 15 inches to 20 inches. One of the major river hypotheses is that algal growth and biomass (i.e., chlorophyll *a*) are strongly influenced by light conditions. These nearly constant secchi depths suggest that the seasonal pattern of solar radiation is the dominant factor controlling light and algae concentrations. Figure 12 shows daily TSS measured by USGS at Vernalis and the weekly grab measurements from the TMDL sampling.

Algae and Organic Parameters

Table 7 indicates that the river organic parameters all generally decreased from June through October. Figure 13 shows that the BOD_5 values decreased from about 5 mg/l to about 2 mg/l at both Vernalis and Mossdale between June and October. The VSS concentrations decreased from about 11 mg/l to 6 mg/l at both Vernalis and Mossdale. The chlorophyll *a* concentrations decreased from about 50 ug/l to 10 ug/l, and the pheophytin decreased from about 20 ug/l to 10 ug/l between June and October. This seasonal decline in VSS and chlorophyll was very similar to the average monthly pattern from the historical DWR samples from Mossdale and Vernalis (Jones & Stokes 1998). The mean concentrations of the TMDL data are shown on the right-hand side of the figure.

Figure 14 shows the relationship between the chlorophyll *a* concentrations at Mossdale and Vernalis and the diurnal DO variations measured at Mossdale by the DWR hourly monitor station. The maximum diurnal DO of about 5 mg/l seems to correlate with the highest chlorophyll concentrations at Mossdale and Vernalis of about 60-75 ug/l. Additional evaluation of the correlations between diurnal DO and algae biomass (chlorophyll) should be conducted because the diurnal DO measurements may provide a method for monitoring the river algae and organic concentrations (i.e., VSS and BOD_5 estimates).

Because the San Joaquin River algal productivity cannot be simulated, measurements of the algae and organic concentrations at Mossdale are necessary to estimate the river loads entering the DWSC. The development of a San Joaquin River model for algal productivity is being supported by another CALFED grant.

San Joaquin River Loads

The San Joaquin River loads entering the DWSC are estimated by the UVM flow measurements and the concentrations measured at Vernalis and Mossdale. The amount of decay and settling between Mossdale and DWSC is an important factor that may reduce the fraction of these estimated river loads that reach the DWSC. The change in concentrations between Mossdale and R3 indicates that the reduction in river load is not substantial, although this reach is also influenced by the RWCF discharge. Figures 15 and 16 show the daily estimates of river loads of VSS and BOD_5 entering the DWSC, with both Mossdale and Vernalis concentration values. The RWCF discharge loads are shown for comparison. The river loads of VSS ranged from 20,000 to 50,000 lbs/day, with an average of about 40,000 lbs/day. The river loads of BOD_5 ranged from 5,000 to 25,000 lbs/day, with an average of about 15,000 lbs/day. The BOD_5 loads should be multiplied by 2.5 to estimate ultimate BOD loads. These are the best estimates of the river organic loads that cause a DO demand in the DWSC.

The river BOD_5 measurements are considerably less than the VSS concentrations. If the VSS is assumed to be composed of algae biomass (i.e., $C_{106}H_{263}O_{110}N_{16}P$), the ultimate BOD is expected to be 1.25 mg/l from the oxidation of 1 mg/l of VSS. Organic-N in the VSS (assumed to be 6.5% of VSS) would account for 30% of the oxygen demand as it is oxidated to nitrate. The ultimate BOD estimate for these river loads would therefore range from 30,000 lbs/day if the BOD_5 loads are used (i.e., 2.5 times BOD_5 load) to 50,000 lbs/day if the VSS loads are used (i.e., 1.25 times VSS load). These river loads to the DWSC were generally much higher than the Stockton RWCF discharge loads during the TMDL study period of June through October of 2001.

Table 7. Water Quality in the San Joaquin River at Vernalis and Mossdale

Location	June 12	June 19	June 26	July 10	July 17	July 24	July 31	August 10	August 17	August 24	August 31	Sept 11	Sept 18	Sept 25	October 2	October 16	October 23	Mean
Vernalis																		
DO	11.2	11.0	10.8	11.2	9.9	9.6	12.2	11.9	12.4	10.6	12.2	10.5	10.0	8.7	9.1	8.8	8.6	10.5
Temp	23.4	25.3	23.3	25.0	23.5	25.7	25.6	25.6	24.2	24.1	25.3	23.2	22.9	21.0	22.6	19.9	16.6	23.4
PH	8.4	8.5	8.4	8.9	8.3	8.3	8.7	8.7	8.8	8.4	8.6	8.5	8.2	7.9	7.8	7.8	7.6	8.3
BOD5	6.7	4.2	1.9	5.1	3.2	1.5	4.9	3.6	5.4	3.2	3.5	3.9	4.7	1.9	4.5	1.7	1.5	3.6
TOC	4.5	5.0	6.5	4.9	6.0	6.1	5.3	3.3	4.8	4.0	3.6	4.1	3.3	3.2	3.7	3.7	3.3	4.4
TSS	37	49	56	67	47	57	49	48	61	62	27	34	37	35	36	33	41	46
VSS	9	10	11	13	9	10	11	11	13	11	10	8	7	7	6	6	6	9
NH3-N	<0.1	<0.1	0.1	0.5	0.2	0.3	0.3	0.5	0.1	0.1	<0.1	0.9	<0.1	0.2	<0.1	0.3	<0.1	0.2
Kjeldahl-N	1.1	0.9	0.9	0.9	0.8	1.1	1.0	1.0	1.2	1.2	0.7	1.0	1.0	0.6	1.1	0.6	0.4	0.9
NO_2+NO_3-N	1.6	1.8	1.9	1.8	1.8	2.5	1.9	1.7	1.9	2.0	2.2	2.2	2.4	2.1	2.2	2.2	1.1	2
Total Phosphorus	0.27	0.28	0.24	0.29	0.23	0.25	0.27	0.25	0.27	0.27	0.26	0.21	0.21	0.18	0.23	0.23	0.16	0.24
Turbidity	22	24	30	38	27	34	27	27	30	32	15	19	19	19	18	18	23	25
EC	747	730	654	691	644	808	734	713	756	730	756	759	751	744	714	755	422	712
Chlorophyll a	64	23	36	37	55	52	43	26	72	46	40	44	16	28	0	14	8	36
Phaeophytin a	41	3	14	30	18	10	66	75	21	23	23	20	33	21	13	6	14	25

Table 7 (Cont.) Water Quality in the San Joaquin River at Vernalis and Mossdale

Location	June 12	June 19	June 26	July 10	July 17	July 24	July 31	August 10	August 17	August 24	August 31	Sept 11	Sept 18	Sept 25	October 2	October 16	October 23	Mean
Mossdale																		
DO	11.4	11.8	10.6	11.5	9.6	12.2	9.7	8.3	9.3	7.9	7.9	8.3	8.6	7.8	7.6	8.1	8.3	9.3
Temp	23.0	26.0	22.8	25.1	23.4	26.1	24.9	26.4	23.9	23.5	25.6	22.5	23.0	21.0	21.9	20.0	16.9	23.3
PH	8.5	8.8	8.8	8.9	8.5	8.8	8.5	8.4	8.7	8.2	8.2	8.2	7.8	7.9	7.6	7.5	7.6	8.3
BOD5	5.2	5.8	4.6	6.3	4.2	4.0	3.8	2.6	4.3	2.3	1.8	3.7	3.7	2.7	3.5	1.7	1.3	3.6
TOC	4.4	5.0	7.0	4.9	5.5	6.4	6.0	3.3	4.2	3.7	3.0	3.7	3.3	2.9	3.5	3.4	3.0	4.3
TSS	31	36	42	50	46	25	40	42	41	43	31	33	33	28	30	24	32	36
VSS	10	11	12	13	10	9	9	8	10	8	8	8	7	6	6	5	5	9
NH3-N	<0.1	0.9	0.1	0.4	0.1	0.2	0.8	0.6	0.8	0.1	<0.1	1.0	0.6	0.6	0.6	0.7	<0.1	0.4
Kjeldahl-N	0.6	2.3	1.4	1.2	0.9	1.4	1.5	1.3	1.6	1.0	0.8	1.5	1.7	1.4	1.5	1.2	0.4	1.3
NO_2+NO_3-N	2.0	1.4	1.5	1.5	1.5	2.0	1.6	1.7	1.5	0.2	2.2	1.9	2.0	2.2	2.1	2.1	1.3	1.7
Total Phosphorus	0.21	0.39	0.23	0.29	0.25	0.22	0.37	0.31	0.33	0.23	0.22	0.18	0.32	0.28	0.35	0.29	0.16	0.27
Turbidity	20	19	24	31	28	16	25	28	26	27	23	21	20	19	18	15	21	22
EC	812	724	716	738	663	768	720	763	771	744	716	747	729	740	701	786	415	721
Chlorophyll a	51	58	78	80	58	69	49	20	58	24	28	44	33	25	23	15	11	43
Phaeophytin a	18	37	15	28	55	22	55	47	25	30	24	29	30	29	16	15	12	29

Stockton Deep Water Ship Channel Concentration Gradients

Nutrient Concentrations

Figure 17 shows the measured nitrate-N concentrations in the DWSC, along with the river concentrations at Mossdale and Vernalis. Because nitrate is dissolved, there is not much of a gradient within the DWSC (i.e., 10% decline between R3 and R7). There is very little change in nitrate concentration during the June-October period, although river flow changed somewhat. The seasonal averages at each station are shown at the right-hand side of the figure.

Figure 18 shows the total phosphorus concentrations in the DWSC and in the river samples. Some of the total phosphorus may be attached to particles, and may be reduced somewhat by settling in the DWSC. Overall, the total phosphorus declined by about 20% between R3 and R7. These nitrate and phosphorus concentrations are very high relative to levels that limit algae growth rates. Because there is not substantial variation in nutrient concentrations during the summer, the changes in observed chlorophyll concentrations are not likely to have been caused by changes in nutrients.

Dissolved Oxygen Concentrations

Dissolved oxygen (DO) concentrations are measured in the DWSC hourly by DWR's surface (i.e., 3-feet depth float within a perforated stilling well pipe) monitoring station at the downstream end of Rough and Ready Island, and were sampled weekly by City of Stockton at mid-depth for the NPDES stations from June through November. Mid-depth and bottom DO samples as well as the vertical DO profiles were collected at each of the DWSC stations during the TMDL study period. Figure 19 displays the daily minimum and maximum DO concentrations for the DWR surface measurements and the mid-depth weekly samples from R3, R4, R5, and R6 for year 2001. The diurnal variation of 2 to 4 mg/l during the summer at the DWR station was similar to other years of data (Jones and Stokes, 1998), suggesting diurnal stratification and growth of algae in the surface layer. Excursions below the DO objective of 5 mg/l occurred in June through August. The DO measurements indicate that some excursions below the DO objective of 6 mg/l were observed in September and early October.

The DO measurements suggest that the organic decay and respiration processes are relatively strong in the DWSC throughout the summer and fall. The minimum DO concentrations are generally 4-5 mg/l below saturation. This is similar to the DO deficit observed in other years (Jones & Stokes, 1998).

The overall balance between oxygen demands and oxygen production from aeration and photosynthesis is reflected in the DO deficit below saturation concentration. The re-aeration of atmospheric oxygen into the DWSC can be estimated from the average DO deficit below DO saturation, although the coefficient is uncertain and may depend on water velocity and wind. Although the RWCF loads and the measured river loads of organic materials into the DWSC were relatively constant during the TMDL study period in 2001, something in addition to these organic loads must control the episodes of DO depletion below the DO objectives that were observed in the DWSC. It might be variations in the RWCF and river loads that are amplified in the DWSC, or it might be characteristics of the DWSC mixing, algae dynamics, and settling processes that account for the measured variations in DO concentrations.

Because the SJR flows were relatively high (greater than 500 cfs) during the June-October period, the observed excursions below the DO objectives are somewhat unexpected. The Stockton RWCF effluent load was diluted to a relatively low river concentration (10:1 to 20:1) by the flows observed during 2001. The river load of algae and other organic materials entering the DWSC was increased by the higher than average river flows. Understanding this balance between river dilution and river load is an important goal of the TMDL study, but this balance cannot be directly determined from the weekly routine river and DWSC monitoring.

Temperature and DO Profiles

The COS staff measured temperature and DO vertical profiles every 2 feet at the DWSC stations for the TMDL surveys. The lowest DO concentrations are generally observed near the bottom in the DWSC. The tidal flows in the DWSC are generally quite strong, with an average tidal flow of more than 5,000 cfs. The tidal velocities in the DWSC therefore average about 0.25 ft/sec, because the typical cross-section of the DWSC is about 25 feet deep and 750 feet wide. These tidal flows generally maintain strong vertical mixing, although there is some temperature and DO stratification (i.e., vertical gradient) observed on several of the sampling dates. The greatest vertical differences are often observed at the Turning Basin station (i.e., lowest tidal flows).

Figure 20 shows the vertical temperature and DO gradients measured on June 12 and June 19. On June 12 the temperature gradient was less than 0.5 C and the DO gradient was less than 1 mg/l. On June 19, relatively strong stratification was observed, with a 1 C temperature gradient and a 3 mg/l DO gradient. The turning basin (i.e., less tidal mixing) generally has stronger vertical temperature and DO gradients.

Table 8 gives the average difference between the surface and bottom temperature and DO for stations R3 to R7 and the Turning Basin for each survey date. The vertical temperature and DO gradient fluctuates from week to week, as meteorology and daytime tidal flows change. The magnitude of the vertical temperature gradient, and the possible effects of this temperature (i.e. density) stratification on mixing and decay processes in the DWSC cannot be identified from the vertical profiles themselves. DWR has installed a bottom temperature and DO monitor at the Rough and Ready Island station. This hourly data may allow the interactions between tidal flows and solar heating and wind to be better understood. CALFED is supporting the development of a 2-D model of the DWSC to allow the effects of this diurnal stratification on DO concentrations to be further evaluated.

Table 8. Difference between Surface and Bottom Profiles for Temperature and Dissolved Oxygen in the Stockton Deep Water Ship Channel

Location	June 12	June 19	June 26	July 10	July 17	July 24	July 31	August 10	August 17	August 24	August 31	Sept 11	Sept 18	Sept 25	October 2	October 16	October 23	Mean
Water Temperature (C)																		
R3	0.0	1.0	1.0	0.0	1.0	0.5	0.0	0.0	0.5	0.0	0.5	1.0	0.0	0.5	0.0	0.0	0.5	0.38
R4	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.5	0.5	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.26
R5	0.5	1.0	0.5	0.0	1.0	0.5	0.0	0.5	1.0	1.0	0.0	0.5	0.0	0.0	0.5	0.5	0.0	0.44
R6	-1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.18
R7	0.0	0.0	1.0	0.0	0.5	0.5	0.0	1.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.26
TB	0.0	2.0	0.5	0.0	0.5	1.0	0.0	0.5	0.5	0.0	1.0	0.0	0.0	0.5	0.5	0.5	0.5	0.47
Dissolved Oxygen (mg/l)																		
R3	0.1	3.9	0.0	0.5	-2.0	0.1	0.2	1.2	-1.1	0.1	2.7	0.3	0.3	-1.3	0.2	0.4	-0.1	0.32
R4	0.2	3.4	0.3	1.2	0.7	1.3	0.8	1.0	1.8	0.7	3.0	0.7	0.5	0.0	1.1	1.3	0.3	1.08
R5	0.4	2.9	0.7	0.9	0.6	1.2	0.3	1.3	1.3	0.5	1.2	0.8	0.5	0.4	0.6	2.4	0.7	0.98
R6	0.1	0.6	0.4	0.9	0.5	2.2	0.6	0.8	0.9	0.6	0.6	0.6	0.5	0.2	0.2	0.9	0.0	0.62
R7	0.3	0.3	1.0	0.8	0.9	1.0	0.4	0.9	1.2	0.5	0.7	0.5	0.8	0.1	0.8	0.6	0.2	0.65
TB	-0.1	8.9	0.6	0.9	-0.9	5.7	0.5	4.7	1.6	0.1	7.6	0.1	1.2	0.0	4.4	3.1	0.5	2.29

Downstream Water Quality Gradients

Table 9 provides a summary of the downstream gradients for water quality parameters measured during the TMDL study period. Downstream gradient ratios were calculated as the mid-depth values at R7 (downstream) compared with the mid-depth values at R3 (upstream) and represent the proportional increase or decrease in the parameter within the Stockton Deep Water Ship Channel. For example, on June 12 the BOD_5 decreased between R3 and R7 (i.e., downstream gradient ratio of 0.80). The average downstream BOD_5 gradient was 0.59, indicating that the BOD_5 values at R7 values averaged 59% of the BOD_5 at R3. The mechanism for the downstream decrease cannot be directly determined, but may have been decay of the BOD or settling of the BOD particulate materials. There may also have been some production of BOD materials within the DWSC. Because the travel time between R3 and R7 is about 10 days (at a flow of 750 cfs), a much larger decrease in BOD_5 was anticipated.

Table 9 indicates that the downstream gradient in the DWSC was generally uniform for dissolved chemical parameters (TOC, NO3, and EC) showing little variation between upstream and downstream boundaries and little variation between sampling events. Suspended and volatile solids are seen to generally decrease over the length of the DWSC, suggesting a settling of suspended matter. Settling of suspended matter is further indicated by a corresponding decrease in turbidity and BOD5 (since at least half of BOD_5 is particulate). Chlorophyll *a* and phaeophytin *a* concentrations are generally lower at the downstream end of the DWSC, although there is significant variation between sampling events.

Figure 21a shows that the BOD_5 concentrations generally decrease with longitudinal distance in the DWSC. This trend in BOD_5 suggests settling as well as decay of particulate BOD_5. Figure 21b depicts a similar trend in VSS that indicates settling of VSS in the DWSC. Substantial settling (and re-suspension) of particulate parameters suggests that these materials would move through the DWSC at a slower rate than the water. The residence time for particulate materials may be longer, so the decay of the organic materials may be greater than the water residence time indicates. Settling and re-suspension of particulate parameters is being investigated by another CALFED direct action study (i.e., sediment trap experiments).

Vertical Water Quality Gradients

The COS staff collected water samples at mid-depth and 2 feet from the channel bottom for laboratory analysis during the June to October TMDL study period. R3-R7 surface samples were also collected for particulate parameters. Table 10 presents the average of the vertical gradients for stations R3 to R7, calculated as the average bottom to mid-depth ratio for these 5 stations (bottom/surface ratio for particulates). Table 10 values indicate the amount of settling at the DWSC monitoring stations R3 to R7. A value greater than 1 indicates greater concentration of the associated parameter 2 feet from the bottom relative to the same parameter at mid depth or at surface. A significant settling of TSS, VSS, turbidity was measured. Mean vertical gradient values for chlorophyll *a* and phaeophytin *a* also suggest settling, although there was significant variation in measurements between sampling events. The remainder of the parameters showed little difference in concentration between the bottom and mid-depth samples.

Figure 22 shows the DWSC surface and bottom BOD_5 and VSS concentrations for June 12 and June 19. The concentrations at the four river stations are shown for comparison. The DWSC stations generally have higher bottom concentrations and concentrations decrease downstream. The mid-depth samples are required for the NPDES river monitoring. Surface samples were generally similar to the mid-depth samples for these particulate parameters.

Turbidity and Light Conditions in the DWSC

Algal growth in the DWSC is potentially controlled by the much greater water depth and the correspondingly lower average light levels than are calculated in the San Joaquin River at Vernalis and Mossdale. Figure 23 shows the turbidity values that were measured during 2001 at all of the sampling locations. Turbidity values were between about 15 and 30 NTU in June, and decreased to between about 10 and 25 NTU in October. The turbidity in the river samples was not much higher than in the DWSC stations. Although there is some settling of turbidity in the DWSC, re-suspension apparently maintains the turbidity and other particulate parameters at about the same concentration in the DWSC as in the San Joaquin River throughout the summer and fall. The mean turbidity values are shown at the right-hand side of the figure.

Figure 24 shows the secchi disk depth, which is a good index of light penetration distance. The secchi depths were generally between 12 and 36 inches during the TMDL study period. Light penetration was somewhat greater in the turning basin, and secchi depths were often considerably greater at station R8. A secchi depth of 24 inches will allow light penetration (1% of surface) to reach about 4-6 feet, suggesting that algae will be growing only in the top several feet of the DWSC. This limited light conditions appears to be normal in the DWSC, because variations in turbidity and secchi depth were not large between weekly measurements. The expected algal growth in the DWSC will therefore depend on the vertical stratification that may develop during the daylight hours when solar heating warms the surface layers and supplies the light necessary for photosynthesis.

Table 9. Stockton Deep Water Ship Channel Downstream Gradient Ratios for R3 to R7, Fall 2001

Parameter	Average R3 Mid-Depth	June 12	June 19	June 26	July 10	July 17	July 24	July 31	August 10	August 17	August 24	August 31	Sept 11	Sept 18	Sept 25	October 2	October 16	October 23	Mean
DO	5.3	1.15	0.84	1.37	1.36	0.87	1.40	1.14	1.10	0.87	1.08	0.93	1.02	0.81	0.70	0.72	0.88	0.94	1.01
Temp	23.8	1.00	0.99	0.97	0.96	1.03	1.00	1.00	1.01	1.02	0.99	1.01	1.00	1.02	0.98	1.01	1.02	1.07	1.00
PH	7.48	0.99	0.98	0.92	0.96	0.93	0.99	1.64	0.99	0.95	0.95	0.96	0.99	1.00	0.96	0.93	1.02	1.01	1.01
BOD5	3.1	0.81	0.25	0.12	0.35	0.32	0.63	0.33	0.00	0.39	0.32	0.43	0.38	2.11	0.66	0.94	0.97	1.00	0.59
TOC	4.6	1.00	0.95	1.00	1.04	1.00	0.89	1.15	0.93	1.00	0.90	1.06	0.94	0.95	1.09	0.95	0.84	1.06	0.99
TSS	30.8	0.63	0.75	1.05	0.78	0.69	1.40	0.53	0.89	0.23	1.57	0.72	1.74	0.38	0.23	1.04	0.57	0.83	0.83
VSS	6.1	0.60	0.67	0.80	0.75	0.67	1.00	0.71	0.60	0.23	1.20	1.00	1.20	0.38	0.33	0.57	0.80	0.75	0.72
NH3-N	0.6	0.41	0.49	0.15	0.61	0.21	0.24	0.43	0.28	0.18	0.13	0.00	0.00	0.00	0.65	0.22	0.32	0.72	0.30
Kjeldahl-N	1.3	3.82	0.42	0.39	0.44	0.42	0.31	0.67	0.48	0.61	0.49	0.66	0.60	0.42	0.77	0.59	0.47	0.51	0.71
NO_2+NO_3-N	1.7	0.72	0.94	0.80	0.93	0.88	0.71	0.94	0.12	1.13	0.94	0.95	0.88	1.00	1.00	1.12	1.10	1.20	0.90
Total P	0.31	0.65	0.71	0.42	0.90	0.75	0.56	0.73	0.61	0.62	0.71	1.00	1.16	0.80	0.95	0.92	0.53	0.90	0.76
Turbidity	19	0.75	0.90	1.06	0.84	0.87	1.21	0.75	1.00	0.34	1.31	0.80	1.67	0.60	0.33	1.13	0.75	0.85	0.89
EC	706	0.84	0.91	0.74	0.90	0.96	0.69	1.00	0.88	0.96	0.92	0.94	0.86	0.96	1.14	0.90	0.96	1.34	0.94
Chlorophyll a	15.1	0.34	0.12	0.28	0.18	2.56	5.82	0.69	0.58	0.25	0.32	0.55	0.41	0.23	0.24	0.08	0.47	1.33	0.85
Phaeophytin a	22.3	0.17	0.18	0.54	0.45	0.24	0.67	0.05	0.53	0.41	0.39	0.39	0.63	0.31	0.50	0.82	0.68	0.71	0.45

Table 10. Stockton Deep Water Ship Channel Average of Vertical Gradient Ratios for R3 to R7, Fall 2001

Parameter	Average R3 Mid-Depth	June 12	June 19	June 26	July 10	July 17	July 24	July 31	August 10	August 17	August 24	August 31	Sept 11	Sept 18	Sept 25	October 2	October 16	October 23	Mean
DO(1)	5.3	0.95	0.66	0.89	0.82	0.99	0.78	0.90	0.80	0.86	0.89	0.69	0.90	0.90	1.01	0.90	0.86	0.97	0.87
Temp(1)	23.8	1.00	0.98	0.97	1.00	0.97	0.98	1.00	0.98	0.97	0.99	0.99	0.98	1.00	0.99	1.00	0.99	0.99	0.99
pH(3)	7.5	1.00	1.00	1.01	1.00	1.01	1.00	1.00	1.00	1.01	1.01	0.99	1.01	1.00	1.00	1.00	1.00	1.02	1.00
BOD5(2)	3.1	1.14	1.07	1.14	0.92	1.40	--	0.92	--	0.92	1.04	0.82	0.89	0.97	1.01	1.20	1.02	0.85	0.90
TOC(3)	4.6	0.99	0.99	1.03	1.02	1.00	1.00	1.02	0.97	1.02	1.00	1.03	1.02	0.99	1.01	1.00	1.01	0.98	1.00
TSS(2)	30.8	1.29	2.16	3.16	1.91	3.60	1.83	1.88	1.97	2.14	2.47	2.33	1.84	1.72	2.41	4.48	2.27	1.72	2.30
VSS(2)	6.1	1.37	1.61	2.09	1.52	2.40	1.47	1.58	1.26	1.43	1.94	1.34	1.39	1.42	1.75	1.96	1.22	1.55	1.60
NH3-N(3)	0.6	1.10	1.28	1.10	1.18	1.03	1.06	0.88	1.05	0.93	1.04	--	--	--	1.46	1.25	1.18	1.05	0.92
Kjeldahl-N(3)	1.3	2.36	1.01	1.06	0.80	1.28	1.09	1.02	1.10	0.95	1.02	1.05	1.04	1.02	1.07	1.14	1.21	1.08	1.14
NO_2+NO_3-N(3)	1.7	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.10	0.97	1.01	1.00	1.03	1.05	1.08	1.01	0.99	0.98	1.01
Total P(2)	0.31	1.06	1.07	1.15	1.08	1.20	1.09	1.06	1.02	1.10	1.11	1.14	1.38	1.02	1.07	1.17	1.12	1.09	1.11
Turbidity(2)	19.1	1.30	1.84	2.24	1.59	2.54	1.54	1.60	1.80	1.88	1.97	2.01	1.58	1.48	1.93	3.51	2.12	1.62	1.91
EC(3)	706	1.00	1.00	1.01	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.01	1.02	1.00	0.99	1.00
Chl a(2)	15.1	1.47	1.19	1.35	1.69	1.59	1.09	1.01	0.61	1.84	0.87	0.66	0.76	0.47	0.75	0.76	0.75	1.87	1.10
Pha a(2)	22.3	1.83	2.43	1.22	1.86	2.31	1.15	1.78	2.62	0.92	1.36	3.29	1.26	1.41	1.36	2.70	1.22	0.97	1.75

Notes:
(1) Taken from vertical profiles
(2) [(R3bottom/R3surface) + (R4bottom/R4surface) + (R5bottom/R5surface) + (R6bottom/R6surface) + (R7bottom/R7surface)] / 5
(3) [(R3bottom/R3mid-depth) + (R4bottom/R4mid-depth) + (R5bottom/R5mid-depth) + (R6bottom/R6mid-depth) + (R7bottom/R7mid-depth)] / 5

It is likely that all of these physical factors interact to produce slightly stratified conditions that are optimum for algal growth within a surface layer, and subsequently produce periods of increased mixing that may lead to less growth and more decay and re-suspension of organic materials from the bottom. A more detailed monitoring of these conditions within the DWSC together with modeling of the anticipated settling, re-suspension, algal growth, respiration, and subsequent vertical temperature, DO, and pH profiles will be necessary to adequately understand water quality in the DWSC. The vertical temperature gradient may be the best indicator of the balance between these physical processes in the DWSC. It is possible that a vertical string of temperature sensors, with 2 or 3 feet spacing, could be added to the DWR Rough & Ready monitoring station to better identify these diurnal and tidal dynamics within the DWSC.

Decay Rates for Organic-N and Chlorophyll a

There are two important water quality parameters that decay within the DWSC in a two-step process (i.e., organic nitrogen and chlorophyll *a*). The relative decay rates for these two-step decay processes can be examined by calculating the ratios of one parameter to the sum of the two parameters. Organic-N in algae and other organic materials decays to ammonia, which subsequently is oxidized (i.e., nitrifies) to nitrate, consuming DO. Figure 25 shows the ratio of organic-N to the sum of organic-N and ammonia (i.e., TKN) and indicates that organic-N is usually 20% to 60% of the TKN values. This suggests that the decay rate for organic-N to ammonia is similar to the decay rate for ammonia to nitrate. Otherwise, the organic-N would become a very high or very low fraction of TKN.

Figure 26 shows the ratio of chlorophyll *a* to the total pigments (i.e., chlorophyll *a* and phaeophytin). Because chlorophyll *a* decays rapidly to phaeophytin and phaeophytin decays more slowly than chlorophyll *a*, the ratio of chlorophyll *a* to total pigment is expected to decrease with time once algal productivity is limited by light in the DWSC (Litton 2002). Vernalis and Mossdale ratios are generally higher than 0.5. The ratio of chlorophyll *a* to total pigment is generally less than 0.5 and consistently declines within the DWSC from R3 to R7. There is an indication that substantial algal productivity does occur within the DWSC, because the ratio of chlorophyll *a* to pigment does not decline as rapidly as fresh alage held in the dark.

Longitudinal Temperature and Dissolved Oxygen Patterns

The portion of the DWSC with the potential for low DO concentrations extends from the turning basin, located at SJR mile 40, to Turner Cut located at SJR mile 33. The DWR uses their boat to measure the surface and bottom temperature and DO concentrations at a series of navigation light stations along the DWSC from Prisoners Point at SJR mile 25 upstream to the Turning Basin. The purpose of the DWR surveys is to investigate the response of DO in the DWSC as the fall HOR barrier is installed to increase flows and DO for upstream migrating chinook salmon.

Figure 27 shows the DWR temperature and DO data for August 1 and August 20, 2001 along with the COS mid-depth measurements from the same date. The 7-day average Stockton UVM flows were about 600 cfs for both days. The lowest DO concentrations were about 4 mg/l and were observed at R5 and R6. The DO concentrations were about 2 mg/l higher at the R3 (light

48 station) indicating that the DO decline (i.e. "sag") was moderate on these days. The DO concentrations were substantially higher (i.e., 8 mg/l) at the stations downstream of R8. There is some indication of a vertical DO gradient in these DWR measurements upstream of R7. The DWR measurements confirm the COS mid-depth measurements, but provide a longer longitudinal profile.

Figure 28 shows the same longitudinal temperature and DO data for September 17 and October 16, 2001. Stockton flows were higher on these days than on the August survey dates. Minimum DO was still about 4 mg/l on September 17 at station R5. The minimum DO on October 16 had increased to 6 mg/l and was located at station R7. This longitudinal DO pattern suggests that the DO "sag" location may be moved further downstream by the higher flows. The cooler water temperatures on the October 16 survey increased the DO saturation concentration and the magnitude of the sag appears to be less. Because the DWR surveys have generally been made in the fall when temperatures and river algae concentrations are declining, the direct effects of the HOR barrier on DO concentrations in the DWSC has been difficult to identify.

Diurnal Temperature and Dissolved Oxygen Patterns

Figure 29 shows the hourly temperature and DO concentrations from the DWR monitoring stations at Mossdale and Rough and Ready Island for June 2001. The June temperatures at Mossdale had a diurnal fluctuation of about 2 F and indicated a rapid response to meteorological conditions with a 10 F swing within the month. The DO concentrations at Mossdale in June were always greater than saturation, with many afternoon values greater than 15 mg/l (e.g., maximum for the DO probe). The COS weekly DO measurements generally confirm the DO monitoring records. This suggests significant algal productivity of DO, with a diurnal variation of 5-6 mg/l for this river location that has an average depth of 6 feet (determined from diurnal temperature range). The Mossdale chlorophyll *a* concentrations were about 60-75 ug/l during June. A similar DO diurnal variation in the surface of the DWSC might be observed if the chlorophyll *a* concentrations were the same. This suggests an algae biomass (i.e. VSS) production of about 5 g/m^2/day.

The June 2001 Rough & Ready near-surface temperatures show a slower response to meteorology, although a similar diurnal variation of 2 F was measured. The depth of the stratified surface layer that must be forming to allow this diurnal temperature variation cannot be accurately determined from these data, however. The DO concentrations are always below saturation at the Rough & Ready near surface station. The largest diurnal DO variation occurred on days with surface warming between June 15 and June 20. This suggests that near surface growth conditions were enhanced by the more stable temperature stratification that apparently developed on these days (e.g., the maximum temperatures were sustained for more hours on these days). The surface, mid-depth, and bottom DO measurements at the R5 station are plotted to indicate the vertical DO gradient on these weekly surveys (generally mid-morning measurements). The COS measurements are generally similar to the Rough & Ready Island monitor values.

Figure 30 shows the hourly temperature and DO concentrations from the DWR monitoring stations at Mossdale and Rough and Ready Island for July 2001. Mossdale DO was above saturation the entire month with a diurnal variation of about 3-5 mg/l. Temperatures were slightly cooler during the middle of the month. The Rough & Ready Island temperatures again indicate that periods of warming allowed the maximum temperatures to be sustained for longer during the day, with correspondingly greater DO variations. The near-surface diurnal DO variations ranged from about 2 mg/l to 5 mg/l during the month of July.

Figure 31 shows the hourly temperature and DO concentrations from the DWR monitoring stations at Mossdale and Rough and Ready Island for August 2001. The DO concentrations were still above saturation, but the diurnal DO variations at Mossdale were much less than during the previous months. Conditions were very uniform at the Rough & Ready Island station in August. The near-surface diurnal DO variations ranged from about 2 mg/l to 5 mg/l during August.

Conclusions from Year 2001 City RWCF and River Sampling

Based on this review of the 2001 COS data, as well as comparison with other available DWSC data, several general conclusions about the 10 major hypotheses can be made.

1) How important are seasonal patterns of water quality in the DWSC?

   There are strong seasonal changes in some RWCF concentrations (i.e., increasing ammonia) and SJR concentrations (i.e., declining VSS and chlorophyll) that may be a dominant factor in the DWSC water quality. DWSC water quality and DO concentrations were relatively steady throughout the study period. For example, DO concentrations averaged about 5 mg/l, with a range between about 3 mg/l and 8 mg/l. Many other parameters showed a similar range of variation without a strong seasonal trend.

2) How similar were water quality and DO conditions observed in 2000 to previous years?

   Although the SJR flows were higher than average, the pattern of nutrients, VSS, and chlorophyll were similar to the historical summer and fall values measured by DWR at Vernalis, Mossdale, and Buckley Cove (opposite Rough & Ready Island station). The diurnal DO measured at Mossdale and the fluctuations recorded at the Rough & Ready Island station were also similar to the patterns observed in previous years (Jones & Stokes, 1998).

3) How strongly mixed is the DWSC? Is temperature or DO stratification (layering) observed?

   The DWSC is generally well-mixed vertically. The measured surface temperature and DO at the Rough & Ready Island station is sometimes elevated during the day, but is apparently almost always well-mixed during the night, as indicated by a slowly decreasing temperature and DO in the early morning hours each day. The COS vertical profiles of temperature often showed only a near-surface layer with a slightly higher temperature (i.e., 1-2 F), but the DO gradient was more often declining throughout the depth. The temperature and DO stratification is more pronounced at the turning basin station. Tidal mixing is less in the turning basin because most of the tidal flow moves up the SJR towards Mossdale. This suggests that the vertical mixing was fast relative to surface heating (mixing at least each night), but slow relative to DO decay processes. However, there are no measurements of daily stratification to verify that temperatures are always mixed each night. There may be periods of temporary stratification that persists for a few days during warming trends.

4) How much settling of particulates is observed in the DWSC?

   The COS data indicates that the average bottom concentrations for TSS and VSS are about 2.3 and 1.6 times greater than the surface concentrations. The data indicates that the R7 mid-depth concentrations are about 70-80% of the R3 mid-depth concentrations of TSS and VSS. These data suggest that the vertical gradient is relatively strong, but that re-suspension is strong enough to maintain relatively high particulate concentrations within the DWSC.

5) How variable are light conditions in the DWSC?

Turbidity and secchi depth measurements suggest that light conditions were remarkably steady throughout the survey period of June through October. Average turbidity was reduced from about 19 NTU at R3 to about 15 NTU at R7. The secchi depth only increased from 23 inches at R3 to 24 inches at R7. Figures 23 and 24 indicate that there was a slight general decline in turbidity from June through October (i.e., from 25 NTU to 15 NTU) with a corresponding increase in secchi depth (i.e., from 15 inches to 25 inches). However, the 1% light depth (generally estimated as 3 times the secchi depth) is almost always less than 6 feet.

6) How much of a longitudinal DO decline (sag) is observed in the DWSC?

The observed decline in the mid-depth DO concentrations between R3 and R6 (Figure 19) was always less than 2 mg/l in year 2001. The R3 DO concentrations were usually within 2 mg/l of saturation, suggesting that the lowest DO concentrations were about 4 mg/l. The hourly DWR station recorded values that were sometimes less than 4 mg/l. This may be a surprising result, considering the attention that has been placed on the low DO concentrations in the DWSC. This is actually a relatively small DO "sag", relative to other rivers with substantial BOD loadings. However, the lowest mid-depth DO concentrations of 4 mg/l are slightly less than the Basin Plan DO objective of 5 mg/l.

7) How high and variable are the nutrient concentrations in the DWSC?

The nitrogen and phosphorus concentrations are generally very high and steady throughout the summer and fall seasons. Nitrate-N concentrations averaged 1.5 mg/l and total Phosphorus averaged about 0.30 mg/l. There was some evidence of nitrate uptake (i.e., 0.2-0.4 mg/l) between Vernalis and Mossdale during June, July, and August that might have been caused by algae growth. However, these nutrient concentrations are very high relative to most nutrient classification thresholds (i.e., eutrophication), suggesting that there are plenty of nutrients to support maximum algae biomass. However, the COS data cannot be used to indicate the possible reduction in algae biomass (chlorophyll) that might be achieved with a reduction in the river nutrient concentrations.

8) How variable is the RWCF loading of BOD, VSS, and ammonia?

The COS data indicate that the RWCF loads of BOD and VSS are relatively constant (Figures 15 and 16). The ammonia load was lower in the summer (i.e., May through August) than in the fall and winter. Maximum BOD5 loads were about 5,000 lbs/day. Maximum ammonia and organic nitrogen DO loads were about 10,000 lbs/day in June and July, and 20,000 lbs/day from August to December of 2001. However, ammonia nitrification will be very slow during the winter when temperatures are less than 10 C and the ammonia may not cause a substantial DO demand in these cooler months.

Summer ammonia loads were higher than in previous years, with 2,000 to 4,000 lbs/day from June through September. The nitrification equivalent BOD would therefore be about 10,000 to 20,000 lbs/day. Maximum ammonia-N loads were about 10,000 lbs/day in January.

9) How variable is the SJR loading of BOD, VSS, and chlorophyll?

The river concentrations of BOD, VSS, and chlorophyll (plus phaeophytin) declined substantially between June and October (Figure 13) at Vernalis and Mossdale. Chlorophyll + phaeophytin decreased from 100 ug/l to 15 ug/l. VSS concentrations decreased from about 10 mg/l to 5 mg/l. BOD_5 decreased from about 5 mg/l in June and July to about 2 mg/l in September and October. The VSS river loads past Stockton (i.e., UVM flows) averaged about 40,000 lbs/day. The RWCF VSS loads were less than 4,000 lbs/day. The river loads were therefore about 10 times the RWCF load during June-October of year 2001.

10) How much effect does SJR flow have on water quality and DO in the DWSC?

The year 2001 survey period included a range of flows from less than 750 cfs in June and July to more than 2,000 cfs in October. The DWSC residence time changed from more than 5 days in June and July to less than 5 days in October. The effects of flow changes on DO concentrations in the DWSC are apparently more complex than a simple dilution of RWCF and a reduction in residence time. The river load to the DWSC increases with flow if the flow change is the result of the Head of Old River barrier. The river concentrations may be reduced if the flow change is from upstream reservoir releases. DWSC water quality may be influenced by changes in SJR flow, but there are several other factors that interact to make it difficult to clearly observe the effects of flow on DO concentrations in the DWSC.

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