City of Stockton Year 2000 Field Sampling Program
Data Summary Report for
San Joaquin River Dissolved Oxygen TMDL
CALFED 2000 Grant

First Draft for
CALFED Grant PI Review

Submitted by
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Introduction

This report was prepared to summarize and evaluate data collected by City of Stockton Department of Municipal Utilities Regional Water Control Facility (RWCF) staff during year 2000 NPDES sampling program and for the TMDL special river surveys conducted as part of the CALFED 2000 grant during the summer and fall. 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. Figure 1 graphically locates sampling locations as they are referred to in this report, in addition to referencing navigation lights as used in other sampling programs.

San Joaquin River and RWCF Effluent Flows

Net San Joaquin River flow past Stockton and the RWCF effluent flows are important basic factors controlling water quality in the DWSC. The City cooperatively funds the USGS Stockton tidal flow station and reports the RWCF daily discharge flows 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 just upstream of the submerged pipe outfall at the RWCF. Figure 2 displays net daily flow at the UVM station for calendar year 2000 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 export pumping relative to the Vernalis flow will also 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).

Net river flow at the Stockton UVM station during the TMDL sampling period of June through October varied from less than 1000 cfs in June and July to as much as 2,500 cfs in October. Flows at Stockton dropped to less than 500 cfs in December when the Head of Old River barrier was removed.

Figure 3 shows the estimated travel time (i.e., volume/daily flow) for water moving through the Deep Water Ship Channel (DWSC), calculated for an assumed DWSC volume of 17,500 acre-feet (AF). The travel time was longest (i.e., 10-15 days) during June and July when the net flow was less than 1,000 cfs. The estimated DWSC travel time was only about 5 days from mid-August through mid-November. The travel time from Mossdale to the DWSC is about 1/7 of the DWSC travel time because the river volume is estimated to be 2,500 acre-feet (i.e., 2,500 af/17,500 af).

Source of Water in the Stockton Deep Water Ship Channel

During the TMDL study period of June-October 2000, with relatively high San Joaquin River flows entering the DWSC, 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 4 presents mid-depth EC data for the period of June to October 2000. Figure 4 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. 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 5 shows the daily RWCF effluent flows during 2000. There were about 67 days with zero discharge. The RWCF has sufficient storage volume in the treatment ponds to hold water for several days. Table 1 provides monthly average flows at Vernalis, at the Stockton UVM station, and for the Stockton RWCF during 2000. Discharge flows during the June-October TMDL study period were about 50 cfs (32 mgd). 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)

Stockton RWCF Concentrations and Discharge Loads

Stockton RWCF daily concentrations are summarized in Table 2. 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 (Table 3). Several parameters were only collected weekly during the TMDL study period.

Table 1
Monthly Average Flows for 2000

	Vernalis		Stockton UVM		RWCF	
Month	**mgd**	**Cfs**	**Mgd**	**cfs**	**mgd**	**cfs**
January	1,380	2,136	513	794	26	41
February	4,883	7,559	2,430	3,762	37	57
March	7,815	12,098	3,747	5,800	34	53
April	3,238	5,013	2,439	3,775	27	41
May	3,110	4,814	2,238	3,464	16	26
June	1,791	2,772	697	1,079	30	47
July	1,226	1,898	448	693	19	30
August	1,402	2,171	646	1,000	32	49
September	1,505	2,330	834	1,290	27	41
October	1,811	2,804	1,269	1,965	29	46
November	1,560	2,415	904	1,400	23	36
December	1,430	2,213	223	345	29	44

Figures 6 and 7 depict the trend in total BOD_5 and ammonia concentrations and loads over the 2000 calendar year. Concentrations are measured each day with discharge. Figure 6 shows that total BOD_5 load and concentration remains fairly constant throughout the TMDL study period, with total BOD_5 concentration ranging from 8-12 mg/l and the corresponding BOD_5 load varying with RWCF discharge flow between 1,000 lbs/day and 3,000 lbs/day, with an average of about 1,500 lbs/day from June through October. Figure 7 shows that the ammonia-nitrogen concentrations steadily increased in September and October, reaching a maximum of about 25 mg/l in November and December. As a consequence, ammonia-nitrogen load increased substantially from less than 1,000 lbs/day in June through August to about 5,000 lbs/day in October.

TSS, total BOD_5, $CBOD_5$, ammonia-nitrogen, and DO were collected every day there was RWCF discharge. Soluble BOD (SBOD) VSS, chlorophyll, and phaeophytin measurements were gathered during the TMDL study period. Table 3 provides the average monthly effluent loads for these parameters.

A suitable method for estimating the ultimate BOD load is to add the CBOD (ultimate) and ammonia (ultimate) loads, because ammonia is not fully oxidized in the 5-day total 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 (Litton, 2000) provided estimates of daily BOD decay rate (k) values for Stockton RWCF effluent. The long-term BOD measurements indicated a decay value of 0.133 per day for CBOD. This k values resulted in a 5-day to 30-day (ultimate) conversion coefficient of 2.06 for CBOD. For ammonia, a conversion coefficient of 4.57 was used, assuming complete conversion of ammonia to oxidized nitrogen (NO_3).

Table 4 summarizes the estimated RWCF monthly average ultimate DO demands for 2000. 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 and December.

Table 2
Stockton RWCF Monthly Average Concentrations for 2000 (mg/L)

Month	TSS	VSS	Total BOD 5-Day	CBOD 5-Day	Soluble BOD 5-Day	Ammonia Nitrogen	Organic Nitrogen	Nitrite Nitrogen	Nitrate Nitrogen	DO	Chl a	Chl a + Pha
January	9.1	NA	13.4	8.1	NA	25.5	4.7	0.1	0.6	6.1	NA	NA
February	11.6	NA	11.5	6.4	NA	20.9	4.1	0.1	0.4	7.2	NA	NA
March	13.6	NA	12.2	4.7	NA	16.9	5.2	0.2	0.9	8.8	NA	NA
April	17.5	NA	7.7	5.2	NA	6.3	3.8	0.5	6.6	9.9	NA	NA
May	2.7	NA	3.4	2.2	NA	1.2	2.5	0.0	6.8	8.1	NA	NA
June	9.1	11.5	5.6	3.1	4.7	3.0	3.5	0.1	2.6	7.4	0.0175	0.0355
July	10.6	10.5	6.3	3.7	5.5	2.8	3.1	0.0	0.8	7.3	0.0180	0.0250
August	12.1	10.6	7.0	3.9	2.1	3.2	3.2	0.1	0.6	7.5	0.0356	0.0564
September	7.6	5.5	6.4	3.3	2.0	11.9	3.3	0.1	0.0	7.6	0.0210	0.0323
October	11.8	7.8	9.0	4.0	2.5	20.3	3.3	0.1	0.0	7.7	0.0345	0.0505
November	10.0	NA	11.8	6.4	NA	25.3	4.5	0.1	0.1	8.9	NA	NA
December	11.3	NA	11.0	5.0	NA	26.0	4.1	0.2	0.2	6.9	NA	NA

Stockton RWCF BOD and Volatile Suspended Solids

As part of the TMDL sampling program, Stockton RWCF staff measured dissolved BOD_5 in addition to the total BOD_5. 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. In addition, total suspended solids (TSS) and volatile suspended solids (VSS) were measured. Only the organic fraction of TSS is expected to exert an appreciable oxygen demand.

Figure 8 shows the relationship between RWCF BOD_5 and other effluent parameters. The TSS values are 1-2 times the BOD. The CBOD is about 50% of the BOD. The organic nitrogen is also about 50% of the BOD. The VSS concentrations are slightly less than the TSS, and about 1-1.5 times the BOD. Table 5 summarizes RWCF effluent particulate fractions of the total BOD and the organic fraction of total solids for the year 2000 TMDL study period. During the study period, 80% of the total solids discharged were organic materials that would contribute to either BOD or SOD in the DWSC. An average of about 60% of BOD_5 was particulate, which would contribute to SOD in the DWSC.

San Joaquin River Concentrations and Loads

Two river stations were sampled each week during the TMDL study period from June 20 through October 31, 2000. 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 a day, assuming a flow of 1,000 cfs at the Stockton UVM station, because the channel depth is greater and the flow is less between Mossdale and DWSC.

Both Mossdale and Vernalis have been routinely sampled (i.e., monthly) for water quality parameters by DWR since about 1972. Mossdale sampling was discontinued in 1996, although DWR operates an hourly water quality monitoring station at Mossdale (i.e., temperature, pH, and DO). The City 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, although the potential settling and decay of algae and organic materials between Mossdale and DWSC cannot be determined directly.

Table 3
Stockton RWCF Monthly Average Loading for 2000 (lbs/Day)

Month	TSS	VSS	Total BOD 5-Day	CBOD 5-Day	Soluble BOD 5-Day	Ammonia Nitrogen	Organic Nitrogen	Nitrite Nitrogen	Nitrate Nitrogen	DO	Chl a	Chl a + Pha
January	2,009		2,958	1,788		5,629	1,037	22	132	1,346		
February	3,586		3,555	1,978		6,461	1,267	31	124	2,226		
March	3,887		3,487	1,343		4,830	1,486	57	257	2,515		
April	3,885		1,709	1,154		1,399	844	111	1,465	2,198		
May	372		468	303		165	344	0	936	1,115		
June	2,283	2,886	1,405	778	1,179	753	878	25	652	1,857	4.39	8.91
July	1,697	1,681	1,009	592	881	448	496	0	128	1,169	2.88	4.00
August	3,222	2,823	1,864	1,039	559	852	852	27	160	1,997	9.48	15.02
September	1,694	1,226	1,426	735	446	2,652	735	22	0	1,694	4.68	7.20
October	2,908	1,922	2,218	986	616	5,002	813	25	0	1,897	8.50	12.44
November	1,948		2,299	1,247		4,929	877	19	19	1,734		
December	2,706		2,634	1,197		6,225	982	48	48	1,652		

Table 4
Calculated Stockton RWCF Daily Average DO Demand For Calendar Year 2000 (lbs/day)

Month	Ultimate CBOD DO Demand	Ultimate NH_3 DO Demand	Ultimate CBOD + NH_3 DO Demand
January	3,683	25,723	29,406
February	4,076	29,526	33,602
March	2,767	22,072	24,839
April	2,378	6,392	8,770
May	624	755	1,379
June	1,602	3,440	5,043
July	1,220	2,049	3,269
August	2,139	3,894	6,033
September	1,515	12,120	13,635
October	2,030	22,860	24,891
November	2,569	22,525	25,094
December	2,466	28,450	30,916

Table 5
Stockton RWCF Effluent Particulate BOD_5 and Organic Suspended Solids Fractions

Date	Total BOD_5	Soluble BOD_5	BOD_5 Particulate Fraction	TSS	VSS	Volatile Fraction	BOD_5/VSS
June 20	10.30	4.80	0.53	11	9	0.82	1.14
June 27	15.40	4.60	0.70	17	14	0.82	1.10
July 11	11.30	5.90	0.48	12	10	0.83	1.13
July 25	12.00	5.10	0.58	14	11	0.79	1.09
August 1	5.70	1.70	0.70	11	9	0.82	0.63
August 8	5.50	1.50	0.73	13	11	0.85	0.50
August 15	5.90	1.90	0.68	15	13	0.87	0.45
August 22	6.00	2.80	0.53	13	11	0.85	0.55
August 29	7.50	2.80	0.63	11	9	0.82	0.83
Sept 12	6.00	1.70	0.72	6	5	0.83	1.20
Sept 19	7.40	2.60	0.65	8	7	0.88	1.06
Sept 26	5.30	1.80	0.66	5.8	4.5	0.78	1.18
October 3	6.20	2.30	0.63	13	10	0.77	0.62
October 17	7.30	3.10	0.58	12	9	0.75	0.81
October 24	7.60	2.50	0.67	10	7	0.70	1.09
October 31	5.70	1.90	0.67	6	5	0.83	1.14
Mean	7.82	2.94	0.63	11.11	9.03	0.81	0.91
Standard Deviation	2.915	1.391	0.074	3.285	2.772	0.046	0.273

Salinity

San Joaquin River salinity (measured as EC) at Vernalis and Mossdale 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 9 shows the daily salinity recorded at Vernalis, Mossdale, and in the DWSC at the Rough and Ready Island station. Salinity fluctuated in response to major storm events, as indicated by the inverse relationship between flow and salinity. The EC values increased from 400 uS/cm to 600 uS/cm in June as Vernalis flow declined from 6,000 cfs to 4,000 cfs. Changes in EC during the summer and fall were less dramatic, but EC declined slightly from 600 uS/cm in June to about 400 uS/cm in October, which is generally the opposite trend from what has been observed in many other summer periods. The differences between the three EC monitoring stations were relatively small. 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.

Nutrient Concentrations

Table 6 gives the weekly concentrations at Vernalis and Mossdale. The nutrient concentrations were generally high and relatively constant during the June-October TMDL study period. Nitrate concentrations were about 1.5 to 2.0 mg/l. Dissolved reactive phosphorus concentrations were about 0.15 to 0.20 mg/l. These concentrations were generally much higher than values that would limit the algae growth and uptake processes.

Table 6
Water Quality in the San Joaquin River at Vernalis and Mossdale

Location	June 20	June 27	July 11	July 18	July 25	August 1	August 8	August 15	August 22	August 29	September 12	September 19	September 26	October 3	October 17	October 24	October 31	Mean
Vernalis																		
DO	8.5	11.9	10.4	10.3	12.4	10.8	10.2	8.3	9.3	8.8	9.6	9.7	9.7	7.9	8.4	8.6	8.8	9.6
Temp	25.2	26.6	24.4	23.1	25.3	26.2	24.5	23.6	22.6	21.7	22.1	23.4	21.5	21.8	18.4	14.8	14.3	22
pH	7.86	8.09	7.79	8.22	8.45	8.06	8.58	8.10	7.99	8.12	7.93	7.95	7.39	7.42	7.43	7.42	7.53	7.90
BOD5	3.3	3.8	4.1	4.6	4.0	2.5	2.3	1.9	1.5	1.8	1.8	1.2	1.2	2.0	1.7	1.9	1.5	2.4
SBOD5	1.3	<1.0	1.9	2.3	2.1	1.7	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
TOC	3.0	3.0	3.0	3.0	6.0	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	4.5	3.8	2.8	3.9	3.4
DOC	3.0	3.0	3.0	3.0	6.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	3.5	3.3	3.8	2.5	3.9	3.4
TSS	56	87	69	47	44	31	33	54	76	40	38	41	30	35	44	48	49	48
VSS	9	14	12	8	9	8	7	7	9	6	7	6	5	6	6	5	6	7.6
NH3-N	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.0
Kjeldahl-N	0.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.0
NO2+NO3-N	1.7	1.8	2.0	1.9	1.4	1.5	1.7	1.9	1.7	1.2	1.9	1.9	1.6	1.8	1.4	0.8	1.1	1.6
Total Phosphorus	0.15	0.19	0.14	0.15	0.10	0.15	0.13	0.13	0.13	0.25	0.18	0.14	0.12	0.10	0.15	0.10	0.14	0.14
Soluble Phosphorus	0.11	0.11	0.12	0.09	0.12	0.11	0.14	0.11	0.10	0.09	0.11	0.11	0.09	0.14	0.12	0.08	0.13	0.11
Turbidity	35	43	40	27	24	18	19	30	34	19	19	20	15	17	22	25	26	25.5
EC	670	668	686	684	628	578	650	672	446	445	502	552	472	586	550	290	420	559
CL-	78	90	83	81	70	66	76	77	47	48	59	68	55	71	64	32	48	65.5
Chlorophyll a	29	60	46	66	57	59	42	37	27	53	35	42	23	15	9	5	4	35.8
Phaeophytin a	40	49	16	38	42	38	22	10	12	23	22	32	6	19	10	11	8	23.4
Mossdale																		
DO	10.0	12.4	10.7	11.6	9.8	11.0	10.6	11.2	8.9	9.1	10.4	9.8	9.4	8.0	9.2	9.2	8.5	10.0
Temp	24.6	26.4	24.5	23.3	24.6	26.6	24.3	25.1	23.4	21.9	22.2	23.4	21.3	21.3	18.1	14.8	14.3	22.4
pH	8.04	8.00	7.69	8.31	8.10	8.32	8.66	8.68	7.95	8.33	8.16	7.93	7.32	7.60	7.45	7.45	7.47	7.97
BOD5	4.3	3.9	4.8	4.3	4.6	3.4	2.7	3.4	2.0	2.2	1.8	2.2	1.7	2.6	1.5	3.2	2.9	3.0
SBOD5	1.2	1.0	1.6	2.2	1.9	1.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
TOC	3.0	4.0	3.0	3.0	7.0	4.0	3.0	3.0	3.0	3.0	3.0	3.8	3.5	3.9	3.6	3.6	3.6	3.6
DOC	1.2	1.0	1.6	2.2	1.9	1.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	3.4	0.7
TSS	47	39	53	34	38	31	30	29	44	28	23	36	23	22	30	43	32	34
VSS	9	11	11	9	9	9	8	8	7	7	5	6	3	5	4	5	4	7.1
NH3-N	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.3	0.0
Kjeldahl-N	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.0
NO2+NO3-N	1.2	1.5	1.7	1.4	1.4	1.5	1.5	1.7	1.7	1.0	1.6	2.3	1.2	2.4	1.9	3.9	1.1	1.7
Total Phosphorus	0.34	0.35	0.13	0.15	0.11	0.18	0.22	0.13	0.18	0.13	0.16	0.15	0.15	0.10	0.15	0.10	0.15	0.17
Soluble Phosphorus	0.09	0.14	0.11	0.07	0.16	0.09	0.12	0.10	0.17	0.08	0.09	0.10	0.13	0.11	0.10	0.10	0.17	0.11
Turbidity	25	23	30	20	24	19	19	17	26	17	14	21	12	15	17	23	20	20.1
EC	622	666	701	604	590	620	649	672	500	464	494	568	466	571	528	357	436	559
CL-	78	91	87	77	70	74	73	86	58	50	59	68	54	66	61	43	52	67.5
Chlorophyll a	55	81	87	85	55	56	55	59	35	61	43	43	21	20	18	12	8	46.7
Phaeophytin a	29	40	36	43	34	49	10	8	11	26	25	13	14	9	16	10	6	22.3

Particulate Parameters

Table 6 indicates that the TSS concentrations declined from 75 mg/l in June to 50 mg/l in October. Turbidity values also decreased during the summer from 40 to 20 NTU. The corresponding light penetration measurements (i.e., secchi depth) increased from about 12 inches to 24 inches. One of the major river hypotheses is that algal growth and biomass (i.e., chlorophyll a) are strongly influenced by light conditions. Because the light levels in the river are directly related to the secchi depth measurements, the chlorophyll a values would be expected to increase during the summer and fall period.

Algae and Organic Parameters

Table 6 indicates that the organic parameters all generally decreased from June through October. Figure 10 shows that the BOD_5 values decreased from about 4 mg/l to 2 mg/l. Figure 10 shows that the VSS concentrations decreased from 10 mg/l to 5 mg/l. The chlorophyll a concentrations decreased from about 75 ug/l to 25 ug/l, and the pheophytin decreased from about 40 ug/l to 20 ug/l between June and October. This summer decline in VSS and chlorophyll was very similar to the average monthly pattern from the historical DWR samples from Mossdale (Jones & Stokes 1998).

Figure 11 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 ug/l. Additional evaluation of the correlation between diurnal DO and algae biomass (chlorophyll) should be conducted.

The decrease in algal biomass (chlorophyll a) and associated VSS and BOD concentrations cannot be explained directly from the improving light levels observed during the 2000 sampling period. The dynamics of the algal biomass in the SJR is not completely understood at this time. Measurements of the algae and organic concentrations at Mossdale are necessary to estimate the river loads entering the DWSC.

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 uncertainty for estimating these river loads. Figures 12 and 13 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 ranged from 20,000 to 60,000 lbs/day for VSS, with an average of about 40,000 lbs/day. The river loads ranged from 5,000 to 40,000 lbs/day for BOD_5, with an average of about 15,000 lbs/day. These are the best estimates of the organic loads that cause a DO demand in the DWSC. The river BOD5 measurements are considerably less than the VSS concentrations. If the VSS is assumed to be 50% carbon, the ultimate BOD would be 1.6 mg/l from the oxidation of 1 mg/l of VSS. The ultimate DO demand estimate for these river loads would therefore range from 30,000 lbs/day if the BOD loads are used (i.e., 2.06 times BOD5 load) to 60,000 lbs/day if the VSS loads are used (i.e., 1.6 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 2000.

Stockton Deep Water Ship Channel Concentration Gradients

Temperature and DO Profiles

The City measured temperature and DO vertical profiles every 2 feet at the DWSC stations. The lowest DO concentrations are generally observed 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 are therefore about 0.2 ft/sec, because the typical cross-section of the DWSC is about 25 feet deep and 1,000 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.

Figure 14 shows the vertical temperature and DO gradients measured on July 18 and August 1. On July 18 the temperature gradient was less than 0.5 C and the DO gradient was less than 1 mg/l. On August 1, relatively strong stratification was observed, with a 1 C temperature gradient and a 3 mg/l DO gradient

Table 7 gives the average difference between the surface and bottom temperature and DO for stations R3 to R5 and the Turning Basin for each survey date. The vertical temperature and DO gradient fluctuates from week to week, as meteorology and tidal flows change. The magnitude of the vertical gradients, and the possible effects of this stratification on mixing and decay processes in the DWSC cannot be identified from the vertical profiles themselves. DWR 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.

Dissolved Oxygen Concentrations

Dissolved oxygen (DO) concentrations are measured in the DWSC hourly by DWR's surface (i.e., 3-feet depth) 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 15 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 2000. The diurnal variation of 1 to 2 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. As shown in figure 15, excursions below the DO objective of 5 mg/l occurred in June, July, and August. The DO measurements indicate that some excursions below the DO objective of 6 mg/l were observed in September and October.

The DO measurements suggest that the organic decay and respiration processes are relatively strong in the DWSC throughout the summer and fall. The DO concentrations are generally 2-3 mg/l below saturation. Figure 15 indicates that this was true during 2000 as well.

Table 7
Difference between Surface and Bottom Profiles for Temperature and Dissolved Oxygen in the Stockton Deep Water Ship Channel

Location	June 20	June 27	July 11	July 18	July 25	August 1	August 8	August 15	August 22	August 29	September 12	September 19	September 26	October 3	October 17	October 24	October 31	Mean
Temperature																		
R3	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.0	0.31
R4	0.0	0.0	0.0	0.5	0.0	1.0	0.0	0.5	0.5	0.5	0.5	1.0	0.5	0.0	0.0	0.0	0.0	0.31
R5	0.0	0.5	0.0	0.5	0.5	0.5	1.0	1.0	1.0	0.5	0.0	1.0	0.5	0.0	0.0	0.5	0.0	0.47
TB	1.0	0.5	0.5	0.0	0.5	0.5	-0.5	0.5	1.5	0.5	1.0	1.5	1.5	0.0	1.0	1.0	0.0	0.69
Dissolved Oxygen																		
R3	0.1	-0.2	0.7	0.3	0.9	3.2	-1.2	0.8	1.5	-0.2	1.8	0.3	0.4	1.0	0.2	-0.3	0.3	0.58
R4	0.9	1.3	2.3	0.7	3.8	3.9	0.4	1.7	1.1	0.4	3.0	2.2	0.6	0.9	0.4	-0.1	0.4	1.47
R5	0.6	1.2	1.8	0.5	1.7	2.5	1.0	1.1	1.2	0.4	2.7	1.7	0.4	0.8	0.3	-0.1	0.4	1.11
TB	3.5	2.2	5.8	1.8	3.8	4.4	2.1	6.0	4.7	2.4	7.6	10.0	1.3	2.9	3.8	0.0	0.4	3.89

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. Since the RWCF and the river load of organic materials into the DWSC was relatively constant during the TMDL study period in 2000, something in addition to these organic loads must control the episodes of DO depletion below the DO objectives that were observed in the DWSC.

Because the SJR flows were relatively high during the June-October period, these excursions below the DO objectives are somewhat unexpected. The Stockton RWCF effluent load was diluted to a relatively low river concentration by the higher flows observed during 2000. The river load of algae and other organic materials entering the DWSC was increased by the higher river flows. Understanding this balance between river dilution and river load is an important goal of the TMDL study, but this cannot be directly determined from the weekly routine river monitoring.

Downstream Gradients

Table 8 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 compared with the mid-depth values at R3 and represent the proportional increase or decrease in the parameter within the Stockton Deep Water Ship Channel. For example, on June 20 the BOD_5 decreased between R3 and R7 (i.e., downstream gradient ratio of 0.42). For those dates with BOD_5 values above detection level, the average downstream gradient was 0.53, indicating that the R7 values averaged 53% of the BOD_5 at R3. The mechanism for the downstream decrease cannot be directly determined, but may have been oxidation of the BOD materials or settling of the BOD particulate parameters.

Table 8 indicates that the downstream gradient in the DWSC was generally uniform for dissolved chemical parameters (TOC, DOC, NO3, soluble P, EC, and Cl,) 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 Deep Water Ship Channel, suggesting a settling of suspended matter. Settling of suspended matter is further supported through a corresponding decrease in turbidity, and BOD5 (since the majority is particulate). Chlorophyll *a* and phaeophytin *a* concentrations are generally lower at the downstream boundary, although there is significant variation between sampling events

Figure 16 shows that the BOD_5 concentrations generally decrease with longitudinal distance in the DWSC. Both total and soluble BOD_5 were collected, but soluble BOD_5 was almost always below analytical detection limits (i.e., less than 1.0 mg/l), suggesting that the majority of BOD_5 in the Deep Water Ship Channel is particulate. This trend in BOD_5 suggests settling as well as decay of particulate BOD. Figure 17 depicts a similar trend in VSS that indicates settling of VSS in the DWSC. Substantial settling (and resuspension)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 resuspension of particulate parameters (VSS and chlorophyll) is being added to the water quality model for the DWSC, and is being investigated by another study (i.e., sediment trap experiments).

Table 8
Stockton Deep Water Ship Channel Downstream Gradient Ratios for R3 to R7, Fall 2000

Parameter	Avg R3 Mid-Depth	June 20	June 27	July 11	July 18	July 25	August 1	August 8	August 15	August 22	August 29	September 5	September 12	September 19	September 26	October 3	October 17	October 24	Mean
DO	6.72	0.90	0.85	1.12	1.06	0.87	0.75	0.98	0.81	0.87	0.81	0.73	0.86	0.75	0.84	0.89	0.84	0.92	0.87
Temp	22.51	0.97	0.98	1.02	1.00	0.98	0.98	1.03	0.99	1.06	1.00	1.04	0.99	1.04	1.07	1.04	1.00	1.08	1.02
pH	7.56	0.96	0.93	0.99	0.95	0.89	0.95	0.97	1.01	1.01	0.98		0.98	1.03	0.99	0.95	0.99	0.99	0.97
BOD5	2.45	0.42	0.34	0.45	0.53	0.52	0.77	0.63	0.57	0.46				0.59					0.53
SBOD5	0.19																		
TOC	3.99	1.00	0.80	1.33	1.00	1.17	1.00	1.00	1.00	1.00	1.00		1.13	0.78	0.80	0.68	0.95	1.00	0.98
DOC	3.66	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.00		0.94	0.88	0.84	0.64	1.61	1.00	1.00
TSS	33.82	0.60	0.43	0.40	0.54	0.58	0.61	0.58	0.86	0.68	0.81		0.70	0.60	0.50	0.83	0.82	0.54	0.63
VSS	5.71	0.67	0.40	0.43	0.44	0.50	0.57	0.67	0.67	0.60	1.00		0.67	0.75	0.67	0.75	1.00	0.75	0.66
NH3-N	0.10																		
Kjeldahl-N	0.23																		
NO2+NO3-N	1.36	0.75	0.83	0.80	0.69	0.92	1.00	0.85	0.87	0.11	0.79		1.14	1.15	1.45	0.54	1.00	1.20	0.88
Total	0.17	0.78	0.64	0.71	0.75	1.09	0.10	0.86	0.83	0.92	0.88		0.78	0.77	1.00	1.20	0.83	0.60	0.80
Soluble	0.14	0.65	0.76	0.82	0.75	0.73	0.88	0.88	0.81	0.92	1.00		1.00	0.91	1.00	0.57	1.08	1.22	0.87
Turbidity	22.05	0.79	0.73	0.55	0.61	0.76	0.71	0.67	0.94	0.67	0.95		0.78	0.71	0.67	0.88	0.76	0.75	0.75
EC	527	0.86	0.79	1.00	0.95	0.82	0.95	1.00	0.98	1.00	1.15		0.97	1.25	1.06	0.82	0.98	0.96	0.97
CL-	65.12	0.83	0.75	0.92	1.03	0.80	0.89	1.11	0.93	1.05	1.23		0.97	1.27	1.08	0.76	0.96	0.93	0.97
Chlorophyll a	18.88	0.24	0.17	0.30	0.25	0.11	0.26	0.73	0.42	1.12	0.69		0.43	0.78	0.37	0.64	1.75	1.29	0.60
Phaeophytin a	17.88	0.13	0.26	1.13	0.14	0.11	0.33	0.15	0.17	0.53	0.50		0.17	0.39	0.50	0.23	1.29	0.67	0.42

Vertical Profiles

The City 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. Table 9 presents the average of the vertical profile gradients for stations R3 to R7, calculated as the average bottom to mid-depth ratio for these 5 stations. Table 9 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. A significant settling of TSS, VSS, and turbidity was measured. Mean vertical gradients 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 18 shows the DWSC surface and bottom BOD_5 and VSS concentrations for July 18 and August 1. The concentrations at the river stations are shown for comparison. The DWSC stations generally have higher bottom concentrations and decrease downstream. Because a surface sample was not collected, the surface to bottom vertical gradients of TSS, VSS, turbidity and chlorophyll might be greater than indicated in Table 9. The mid-depth samples are required for the NPDES river monitoring of DO and ammonia. Surface samples might be collected, in addition to the bottom and mid-depth samples, to confirm the vertical gradient for particulate parameters and verify the surface chlorophyll a concentrations.

Turbidity and Light Conditions

Algal growth in the DWSC is potentially controlled by the much greater water depth and the correspondingly lower average light levels than are observed in the San Joaquin River at Vernalis and Mossdale. Figure 19 shows the turbidity values that were measured during 2000 at all of the sampling locations. Turbidity values were between 20 and 40 NTU in June, and decreased to between 15 and 25 NTU in October. The river samples were not much higher than the DWSC stations. Although there is some settling of turbidity in the DWSC, resuspension apparently maintains the turbidity and other particulate parameters at about the same concentration as in the San Joaquin River throughout the summer and fall.

Figure 20 shows the secchi disk depth, which is a good index of light penetration distance. The secchi depths were generally between 12 and 24 inches during the TMDL study period. Light penetration was somewhat greater in the turning basin (i.e., secchi depths of 24 to 36 inches), and secchi depths were often considerably greater at station 8. A secchi depth of 24 inches will allow light penetration (1% of surface) to reach about 6 feet, suggesting that algae will be growing only in the top 5 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.

Diurnal Vertical Variations

The vertical stratification and mixing patterns within the DWSC are relatively complex. The hourly surface water quality monitoring station operated by DWR at the downstream end of Rough and Ready Island (near R-5) illustrates the variable nature of the near-surface water quality patterns. Figure 21 shows the hourly temperature, pH, and DO concentrations during September 2000 at the surface (3-feet depth) Rough & Ready Island DWR station. On September 1, the DO concentrations were slightly less than 6 mg/l , which was about 3 mg/l below saturation. Water temperature cooled slightly during the first

5 days of September because of a storm (i.e., low solar and higher wind speeds) and the diurnal variation in DO was relatively low. The DO increased substantially on days 3 and 4,although temperatures were still cooling. This may indicate a strong influence of vertical mixing from cooling on the aeration of the water column. A warming period between September 5 and 10 then allows a stronger diurnal temperature pattern (i.e., surface stratification) to develop, with a subsequent increase in the diurnal pH and DO concentrations. The DO becomes supersaturated with more than 9 mg/l observed for several days (Sept 7-9), before another period with declining DO and pH concentrations, with the DO falling below 6 mg/l on September 22-24. The water temperatures were actually increasing slightly during this period until September 20. The diurnal variations for the remainder of September were relatively small, with slightly cooling temperatures from September 21 to the end of the month.

Figure 22 shows the hourly records of solar radiation, wind speed, and tidal stage for September 2000. Variations in solar radiation were relatively small during the month, indicating clear conditions except on September 1-2, 12-13, and 22. Water temperatures are also influenced by air temperatures, which are not shown on Figure 22. The wind speed patterns are characterized by afternoon "Delta breezes" that generally are parallel to the DWSC from the northwest. There is not an obvious match between days with higher peak wind speeds and correspondingly reduced diurnal variations in temperature and DO, although this is an expected relationship. The other factor that is illustrated in Figure 22 is tidal stage. The possible effects of tidal energy on mixing in the DWSC can be evaluated by considering that periods of slack tide are indicated by the high and low stages.

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 resuspension of organic materials from the bottom. A more detailed monitoring of these conditions within the DWSC together with modeling of the anticipated settling, resuspension, algal growth, respiration, and subsequent vertical temperature, DO, and pH profiles will be necessary to adequately understand water quality in the DWSC.

Table 9
Stockton Deep Water Ship Channel Average of Vertical Gradient Ratios for R3 to R7, Fall 2000

Parameter	Avg R3 Mid-Depth	June 20	June 27	July 11	July 18	July 25	August 1	August 8	August 15	August 22	August 29	September 12	September 19	September 26	October 3	October 17	October 24	Mean
pH	7.56	1.00	1.00	0.80	1.01	0.98	1.00	1.00	1.00	1.00	1.01	1.01	1.02	1.02	1.01	1.00	1.01	0.99
BOD5	2.45	1.08	1.19	1.04	1.06	0.95	1.07	1.18	1.04	0.93			1.01					1.05
TOC	3.99	1.00	0.86	1.07	0.95	1.14	1.09	0.95	1.07	1.00	1.00	1.00	0.97	0.94	1.11	0.99	0.91	1.00
DOC	3.66	1.00	0.95	1.07	0.95	1.00	1.03	0.85	1.07	0.95	1.00	1.03	1.00	1.00	0.98	0.97	0.94	0.99
TSS	33.82	2.15	1.58	1.65	1.47	1.83	2.06	1.93	2.10	1.67	1.93	1.65	2.07	2.16	1.92	1.57	1.30	1.81
VSS	5.71	2.01	1.44	1.49	1.33	1.45	1.77	1.53	1.56	1.42	1.55	1.33	1.79	1.62	1.60	1.45	1.20	1.53
NO2+NO3-N	1.36	0.77	1.04	1.00	0.99	0.95	1.03	1.00	0.98	1.06	1.12	0.95		1.04	1.03	1.46		1.03
Total	0.17	1.17	1.06	1.00	1.15	1.02	2.47	1.13	0.99	1.05	1.13	0.98	1.08	1.13	1.14	1.02	1.02	1.16
Soluble	0.14	0.96	0.99	0.96	0.96	0.99	1.04	1.01	0.99	1.02	1.00	1.00	1.05	1.02	0.96	0.97	1.04	1.00
Turbidity	22.05	1.79	1.24	1.47	1.34	1.83	1.85	1.66	1.91	1.48	1.73	1.40	1.84	1.89	1.71	1.39	1.20	1.61
EC	527	1.01	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.98	1.00	1.00	0.95	0.99	0.99	1.01	0.99	0.99
CL-	65.12	1.02	1.02	1.01	1.01	0.99	1.00	1.00	1.00	0.98	1.02	1.00	0.93	1.00	1.00	1.00	0.99	1.00
Chlorophyll a	18.88	2.74	2.35	1.38	1.19	1.67	1.31	1.41	1.46	1.32	1.65	1.08	1.64	1.16	1.23	1.70	0.86	1.51
Phaeophytin a	17.88	2.93	1.33	1.40	1.38	1.30	1.92	0.89	0.93	0.98	1.29	1.14	1.57	2.54	1.55	0.84	1.56	1.47

Recommendations for Year 2001 City RWCF and River Sampling

The CALFED directed action grant proposal for 2001 will include another year of TMDL study sampling by the City. The sampling stations will remain the same as for 2000. A weekly schedule will again be used, although sampling of the upstream river stations should begin in April to sample the increasing chlorophyll a and VSS concentrations during the spring. Sampling of the DWSC should begin the week of June 4 and continue through October, with a total of 20 weekly surveys (none the week of July 4 and September 3 holidays). The total cost for the sampling and laboratory analyses is estimated to be $150,000. The CALFED grant will provide 50% of these funds (i.e., $75,000) to the City.

Based on this review of the 2000 data, several recommendations for changes can be made.

1) Because the VSS is an easier measurement than particulate BOD (i.e., total BOD - dissolved BOD) and seems to be well-correlated with particulate BOD, daily VSS measurements of the RWCF effluent should be made along with the TSS, ammonia, and BOD from the 24-hour composite samples.

2) Additional samples should be collected at the inflow to the tertiary treatment facility for TSS, VSS, BOD, chlorophyll a and phaeophytin a to document the performance of the air floatation and sand filters during the spring and summer.

3) Because the river concentrations change substantially in the spring, weekly sampling of the Vernalis and Mossdale stations should begin the week of April 2, rather than the week of June 4 when the TMDL study of the DWSC is scheduled to begin. This will add 8 weeks of sampling at these two stations (no sampling week of May 28 holiday). This will provide a more complete spring and summer record of river concentrations and corresponding loads to compare with the RWCF concentrations and loads that usually decline in the spring as the oxidation ponds become more effective.

4) The parameter list can be changed to delete the dissolved BOD, because samples were rarely above the detection limit of 1.0 mg/l. The total Kjeldahl nitrogen detection limit needs to be reduced from 0.5 mg/l to 0.1 mg/l. A single measurement of TOC can be made, because the DOC and TOC values were usually the same. The TOC value should be reported with a 0.1 mg/l precision (rather than 1 mg/l).

5) Surface samples should be collected at station R3 to R7 and the Turning Basin to document the full vertical gradient of particulate parameters (TSS, VSS, turbidity, total P, BOD, chlorophyll a, and phaeophytin a). The surface chlorophyll is important for estimating algae growth and photosynthesis. Light penetration should be measured with the PAR meter at 1-feet intervals to a depth of 10 feet (or 1% of surface light).

6) Because TSS/VSS is the easiest measurement of organic material, and can be concentrated in a settling trap (Litton 2000), daily samples should be obtained to document the variation in river loads and settling rates in the DWSC. One sample should be collected near the mouth of the SJR as in enters the DWSC (i.e., at the bridge to Rough and Ready Island) and another should be collected in the DWSC (i.e., from one of the docks along Rough and Ready Island). The traps could be deployed from a submerged "flagpole" that would slowly be raised to collect the settling trap sample and then lowered to a depth of 5m or mid-depth to begin the next day's sample. The TSS/VSS measurements from these traps should be more accurate because the 24-hour trap samples are concentrated by a factor of about 20 (i.e., settling rate of 0.8 m/hr) compared with the water concentrations.

References

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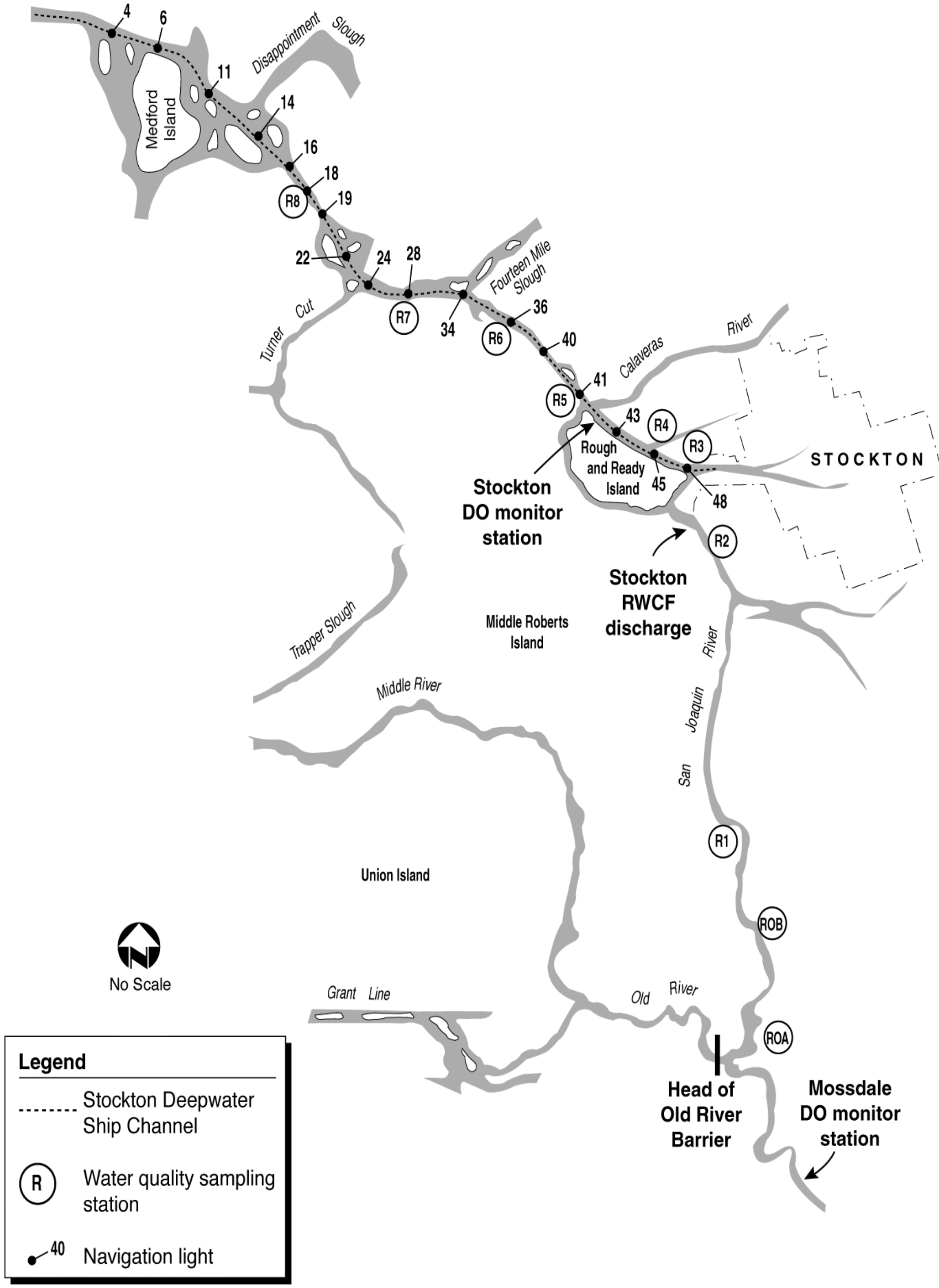
Jones & Stokes Inc. (1998) Potential Solutions for achieving the San Joaquin River Dissolved Oxygen Objectives. Prepared for City of Stockton

Jones & Stokes Inc. (2001a) Evaluation of San Joaquin River Flows at Stockton. Prepared for City of Stockton

Jones & Stokes Inc. (2001b) Tidal Dilution of the Stockton Regional Wastewater Control Facility into the San Joaquin River. Prepared for City of Stockton



Jones & Stokes

Figure 1
Location of Water Quality Stations and Navigation Lights on the San Joaquin River in the Vicinity of Stockton

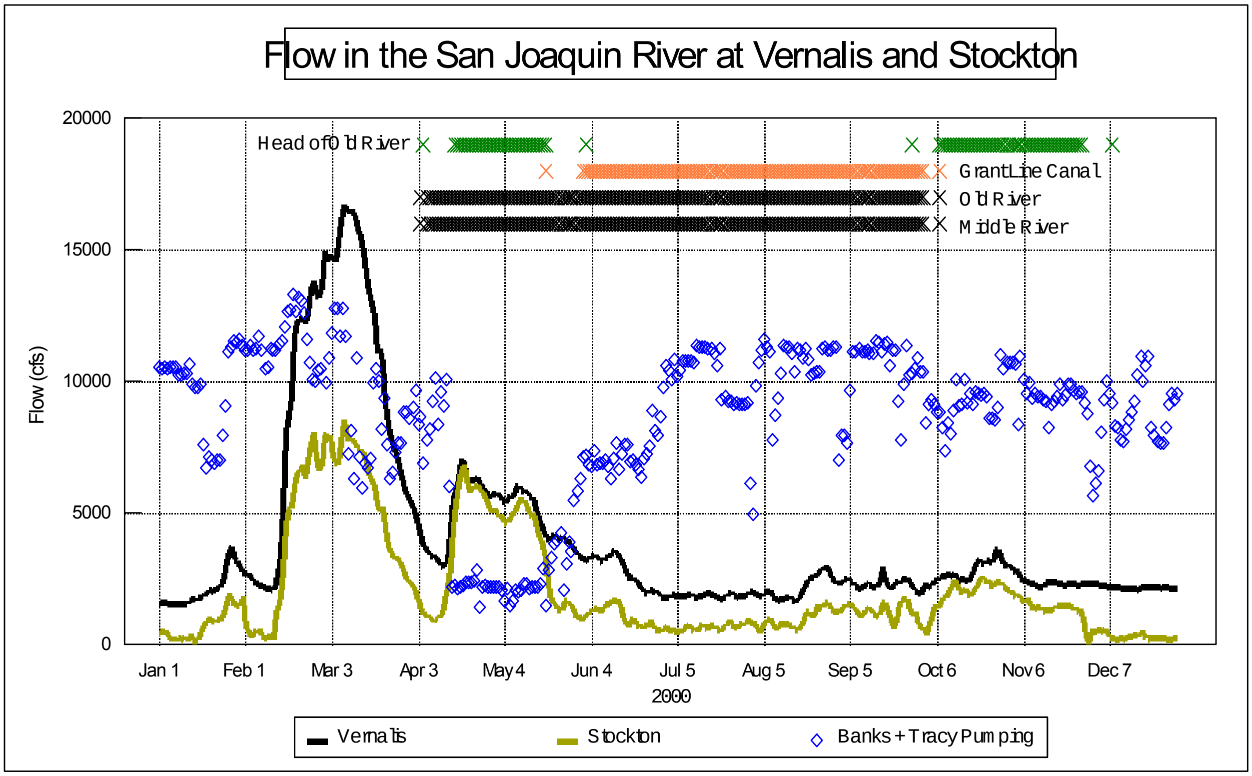


Figure 2. Daily Flows in the San Joaquin River at Vernalis and Stockton.

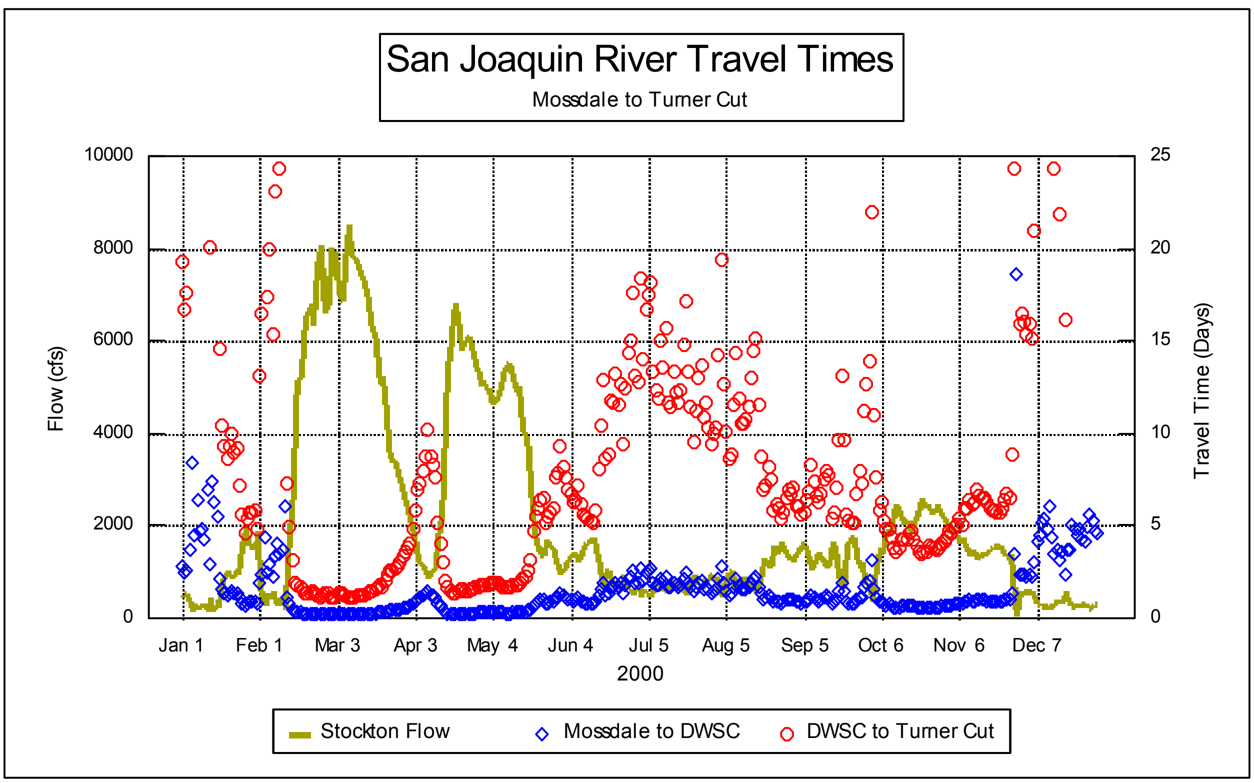


Figure 3. Estimated San Joaquin River Travel Times.

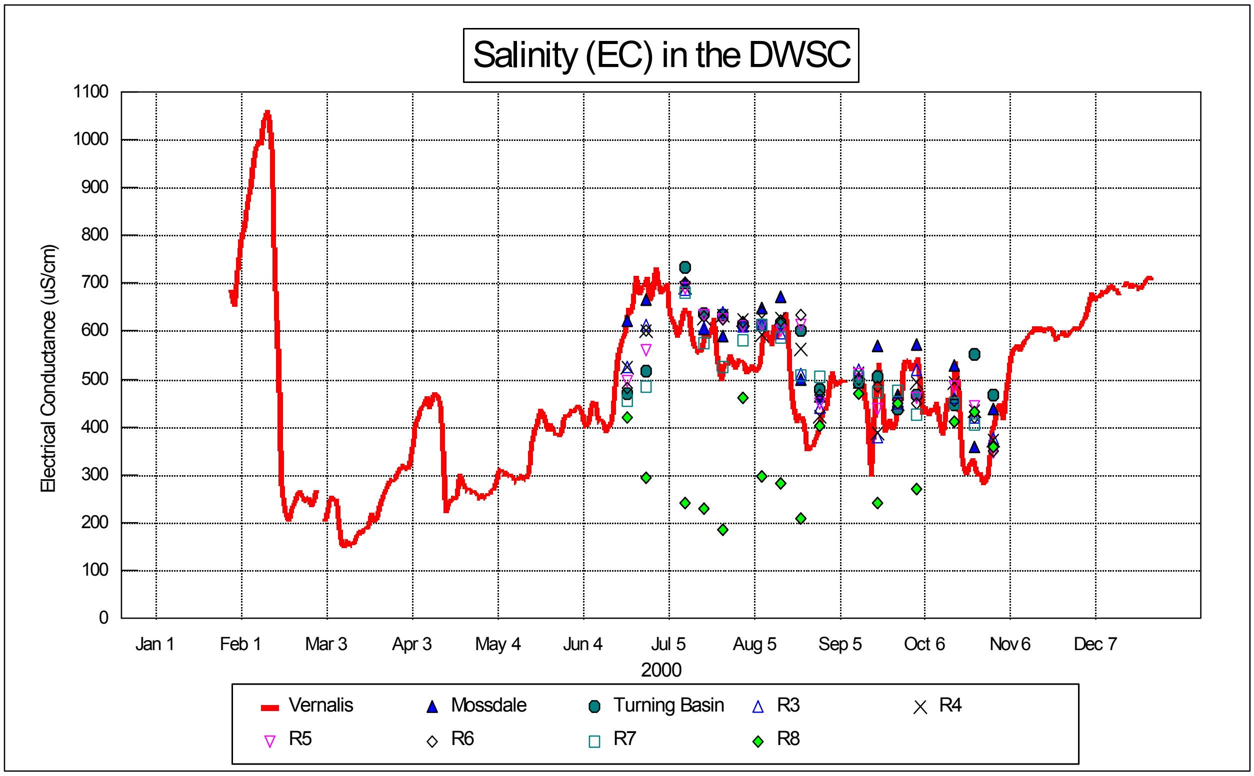


Figure 4. Electrical Conductance in the San Joaquin River and Stockton Deep Water Ship Channel.

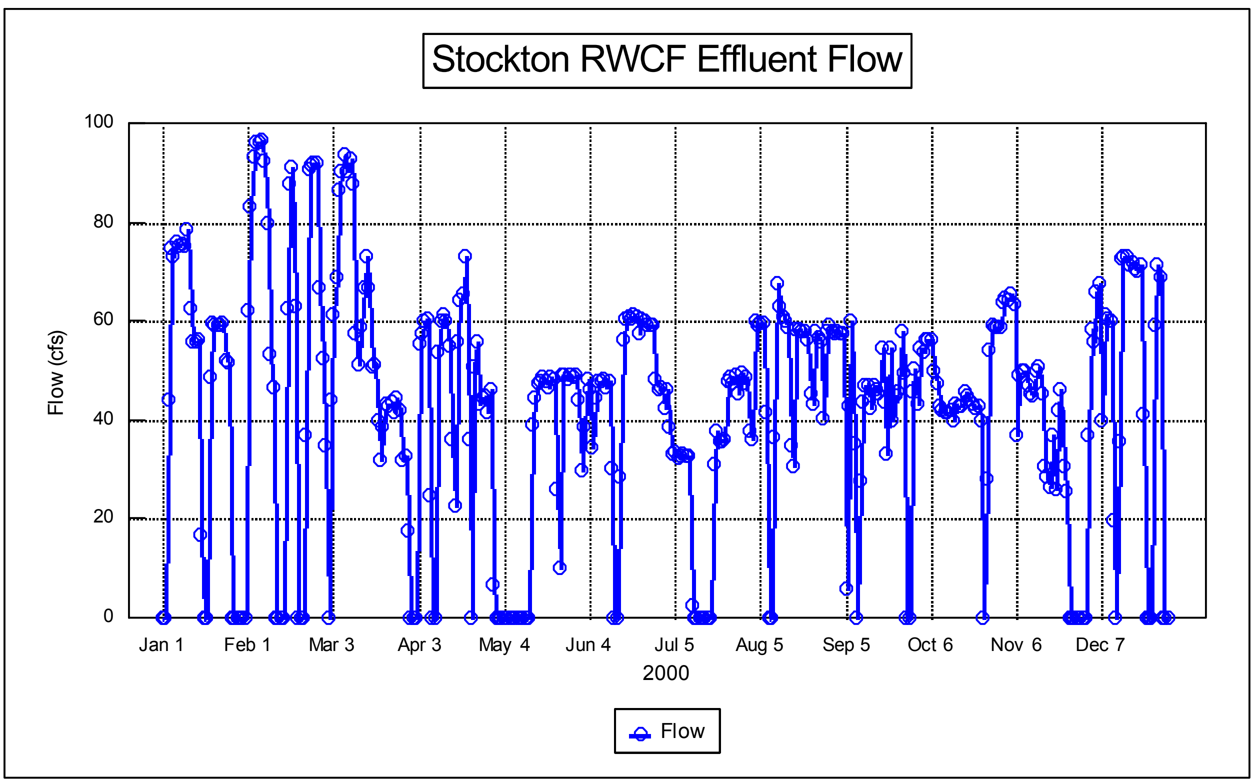


Figure 5. Stockton Regional Wastewater Control Facility Daily Discharges into the San Joaquin River.

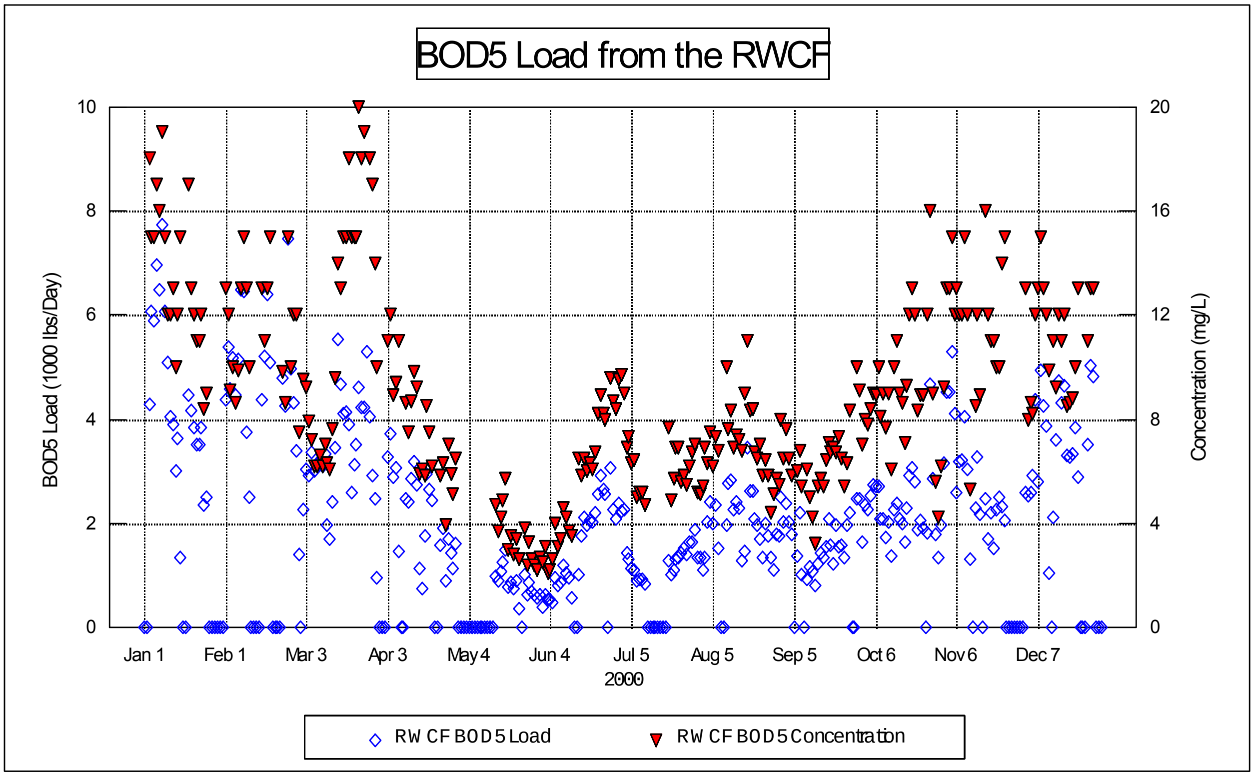


Figure 6. 5-Day Biochemical Oxygen Demand Load from RWCF.

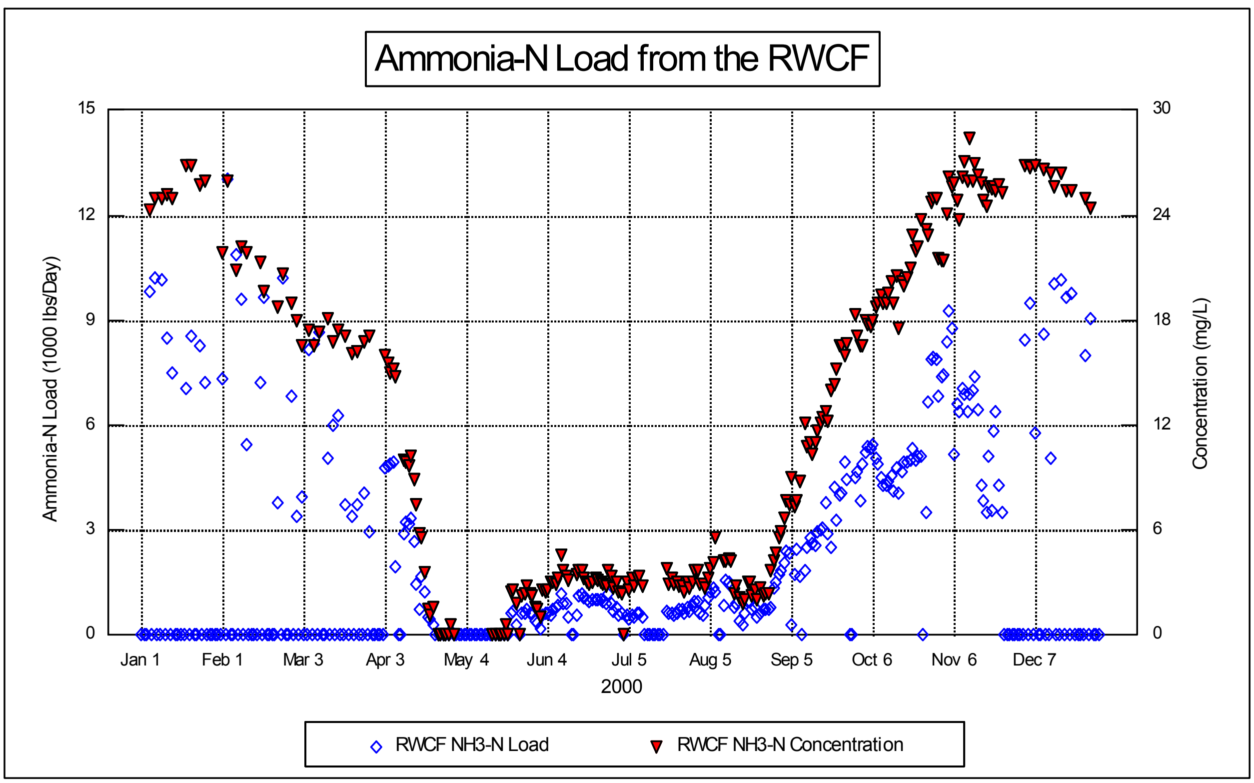


Figure 7. Ammonia Nitrogen Load from RWCF.

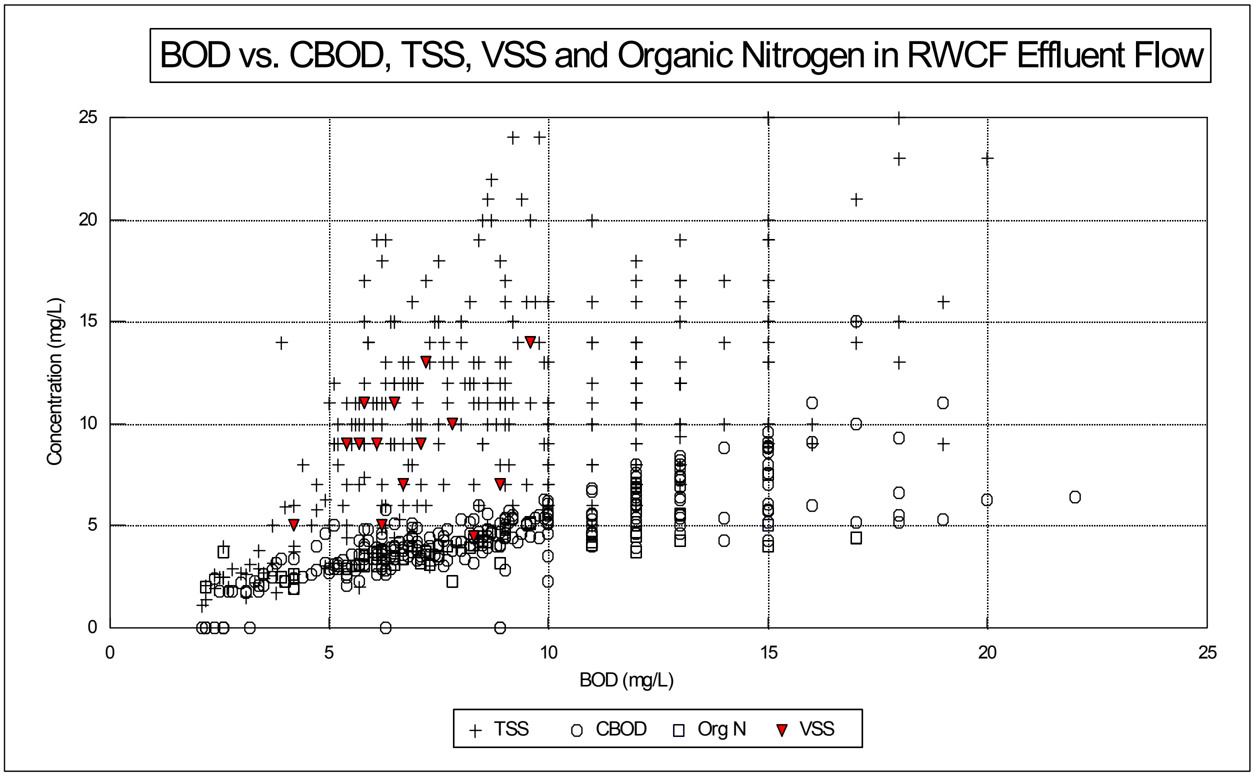


Figure 8. BOD vs. CBOD, TSS, VSS and Organic Nitrogen in RWCF Flow.

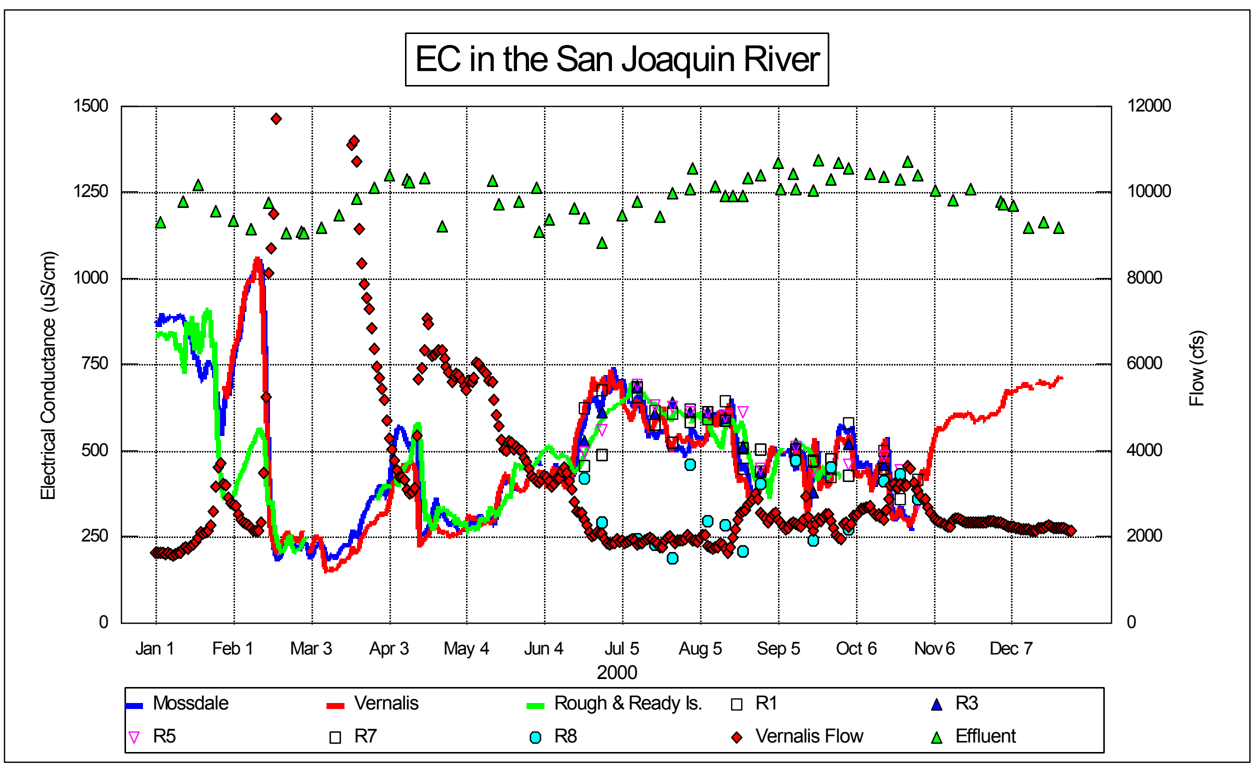


Figure 9. Salinity in the San Joaquin River

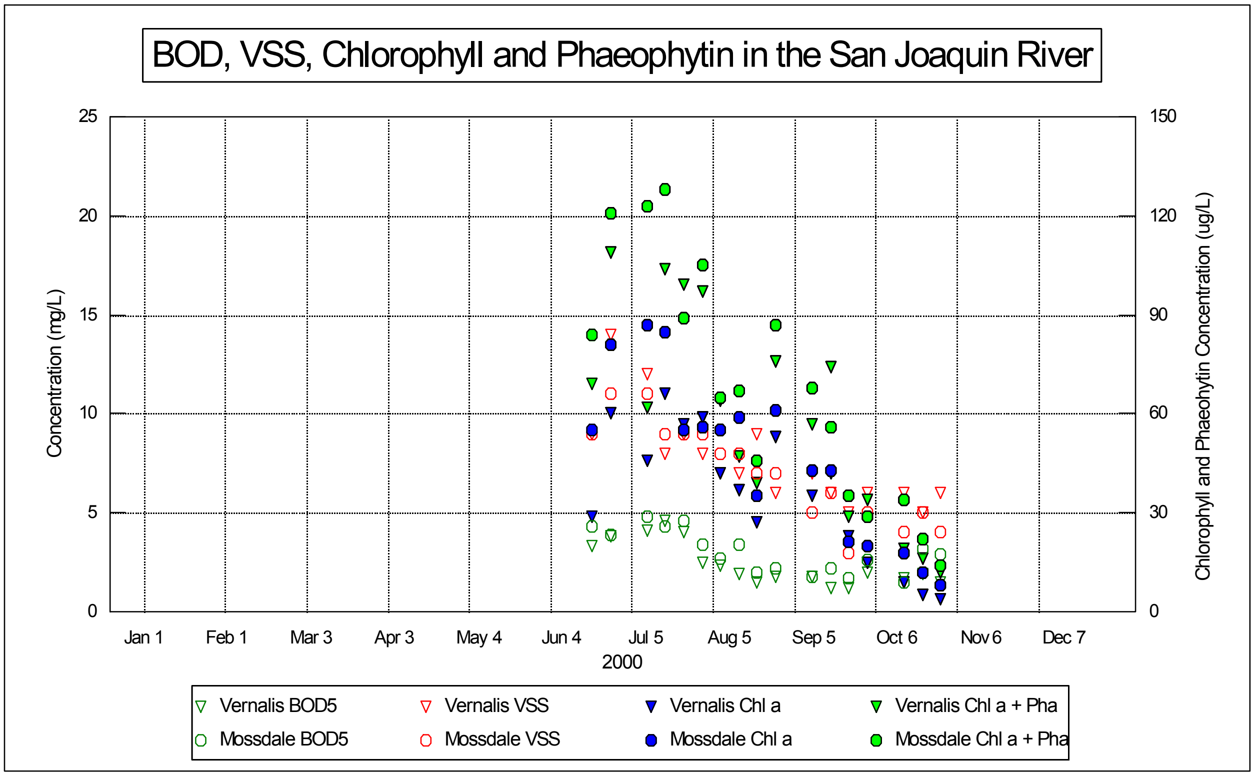


Figure 10. BOD, VSS, Chlorophyll and Phaeophytin in the San Joaquin River.

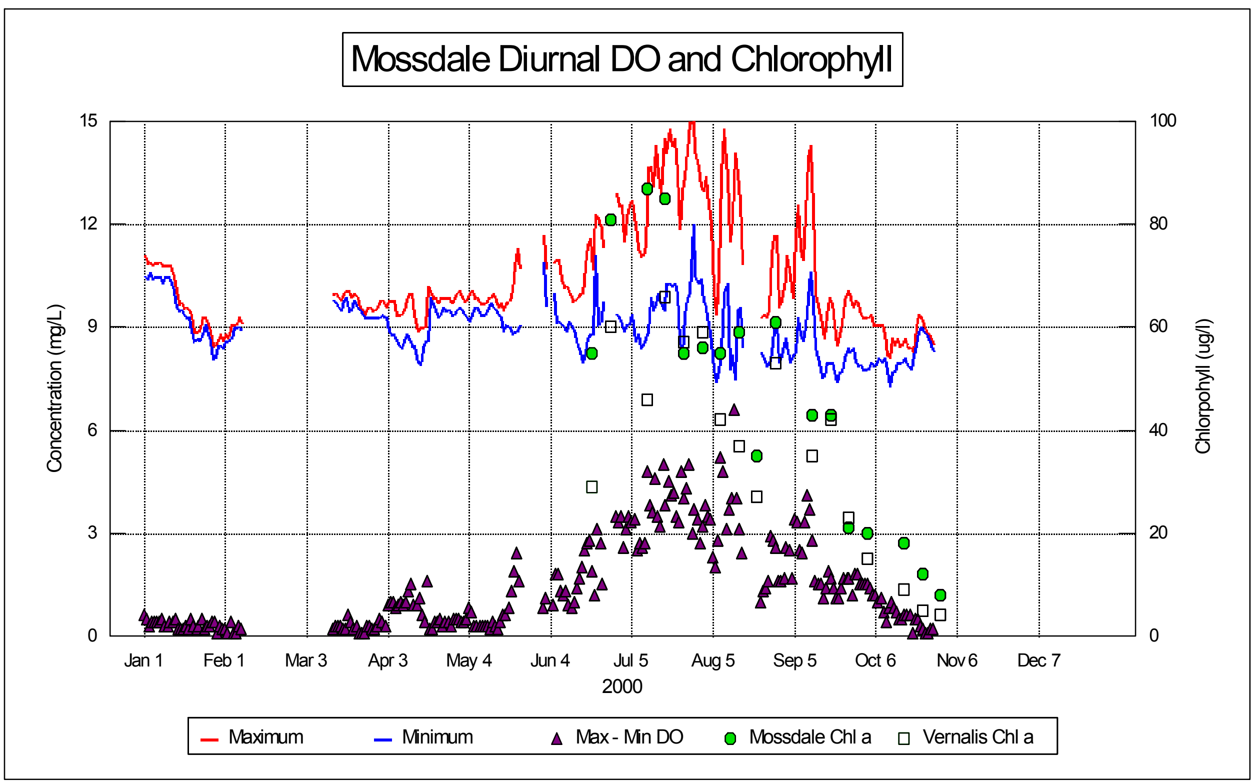


Figure 11. Diurnal DO and Chlorophyll a in the San Joaquin River at Mossdale.

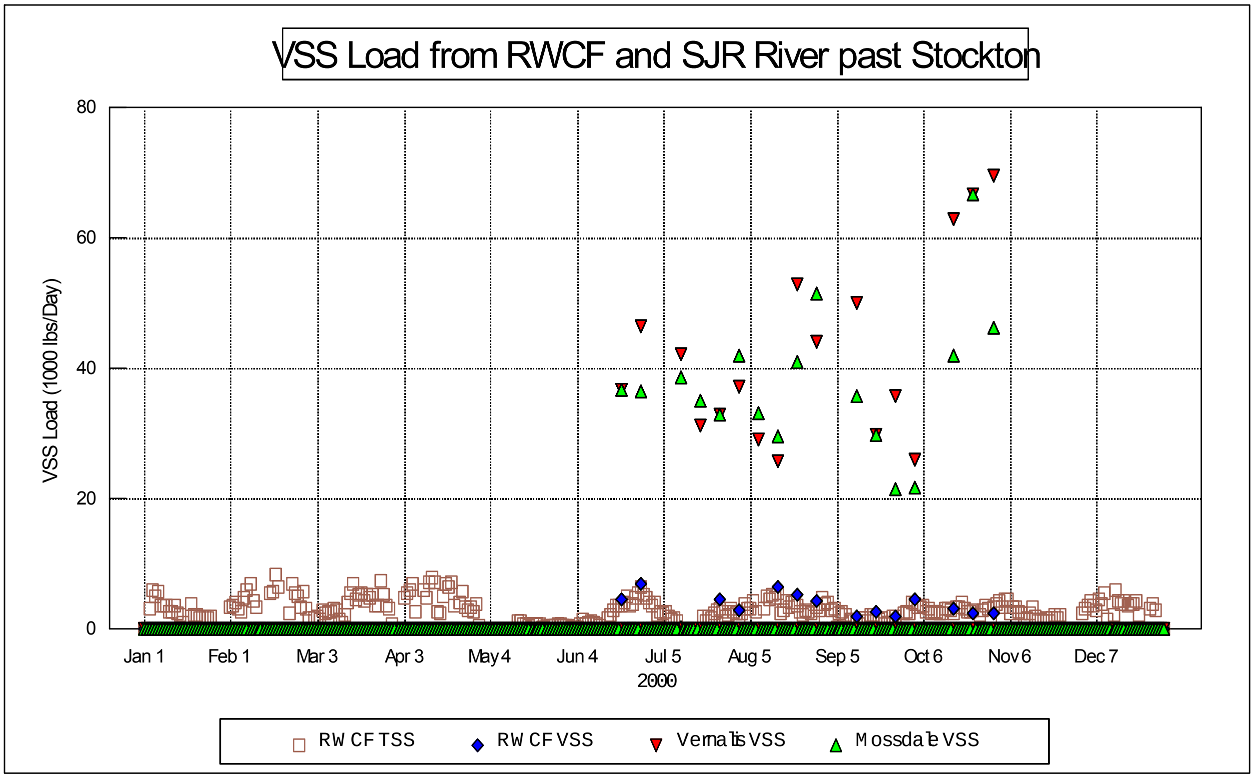


Figure 12. Daily Estimated VSS Load Entering the DWSC.

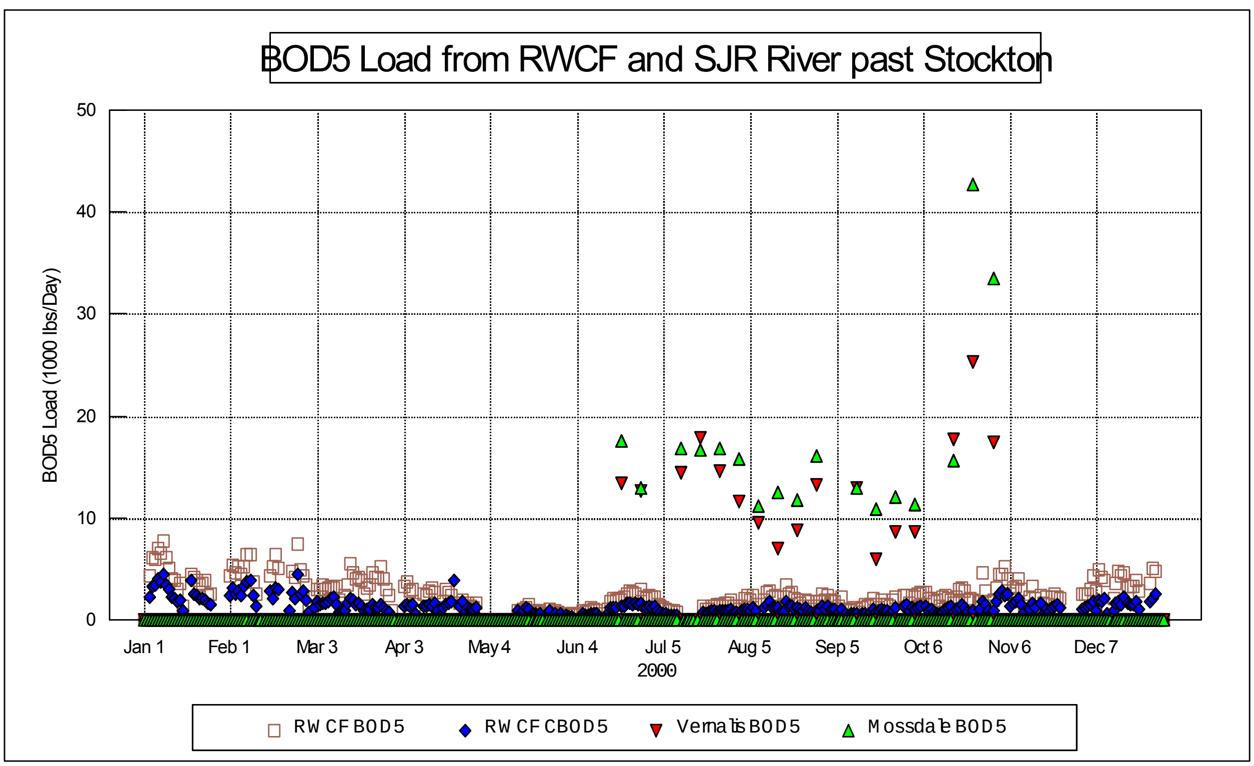
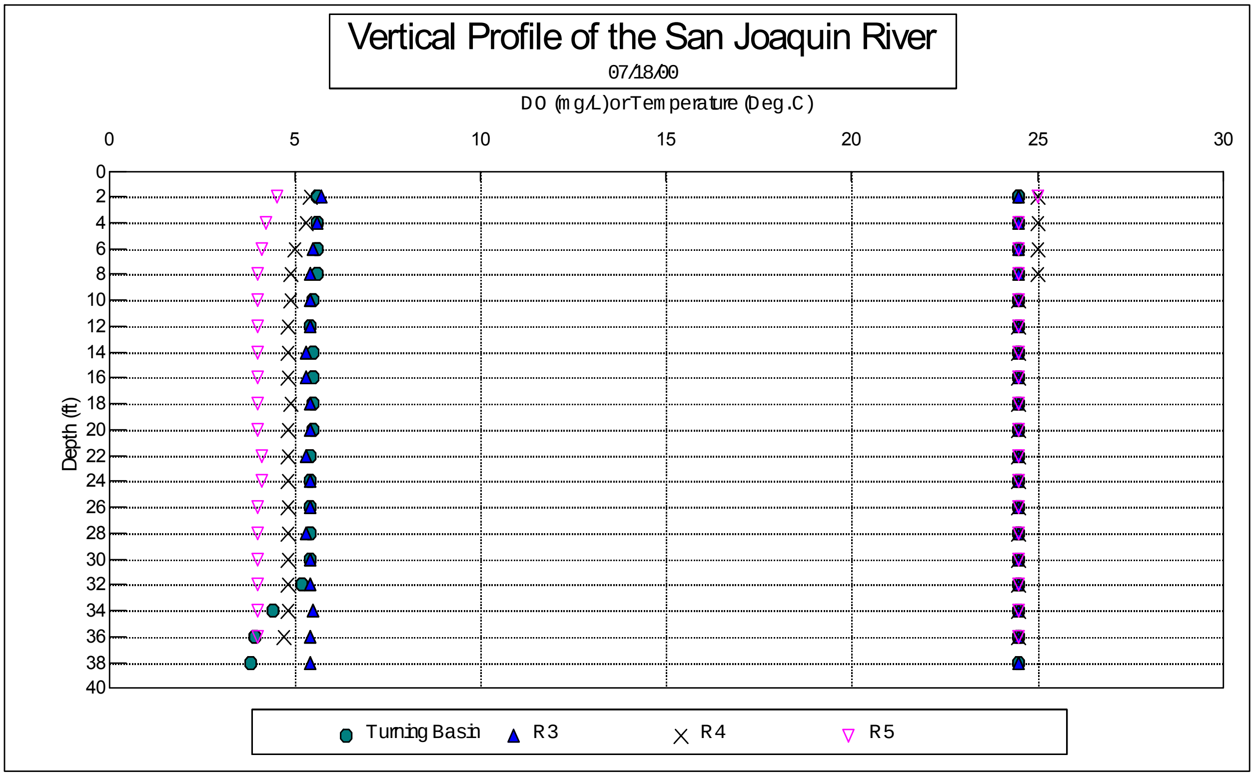


Figure 13. Daily Estimated BOD5 Load Entering the DWSC.



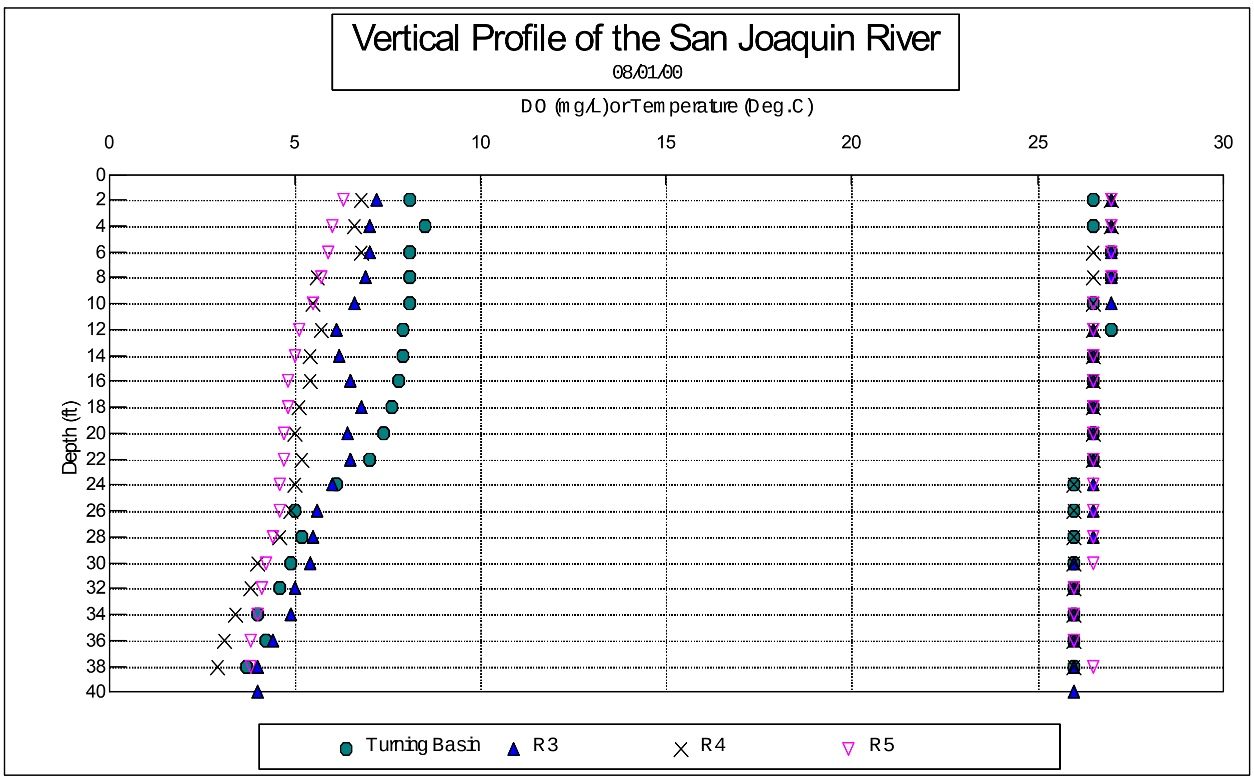


Figure 14. Vertical Profiles of DO and Temperature in the DWSC, July 18th and August 1st, 2000.

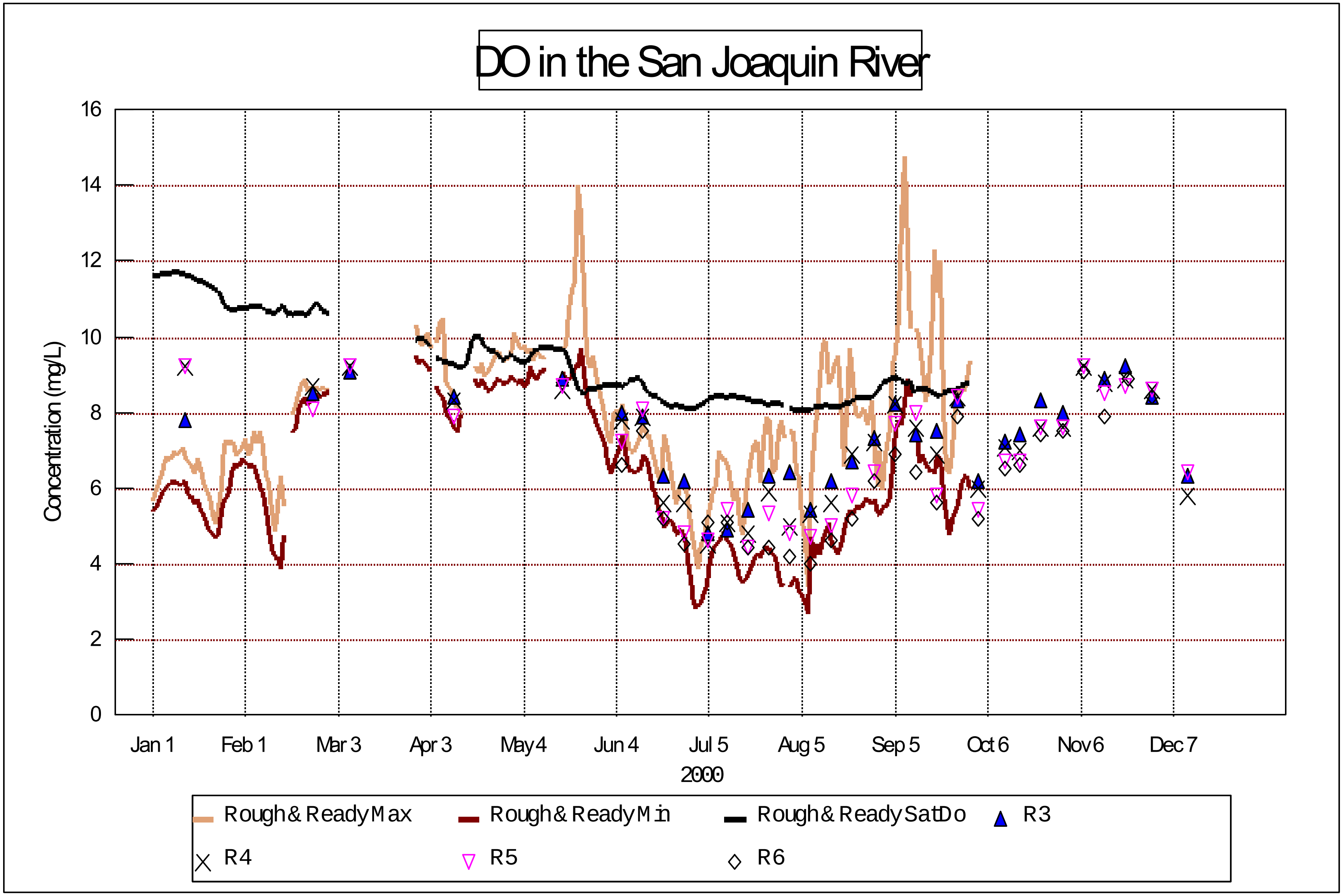


Figure 15. Daily Dissolved Oxygen Concentrations in the Stockton DWSC.

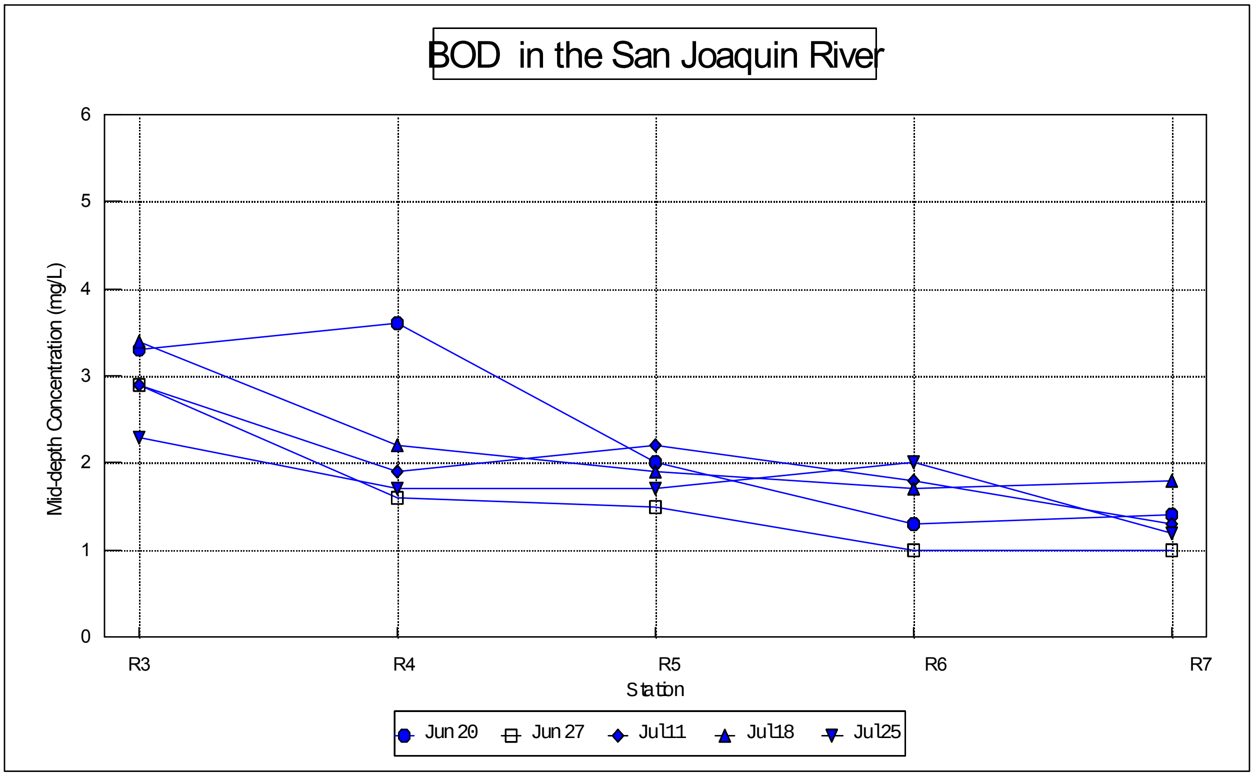


Figure 16. BOD5 in the DWSC.

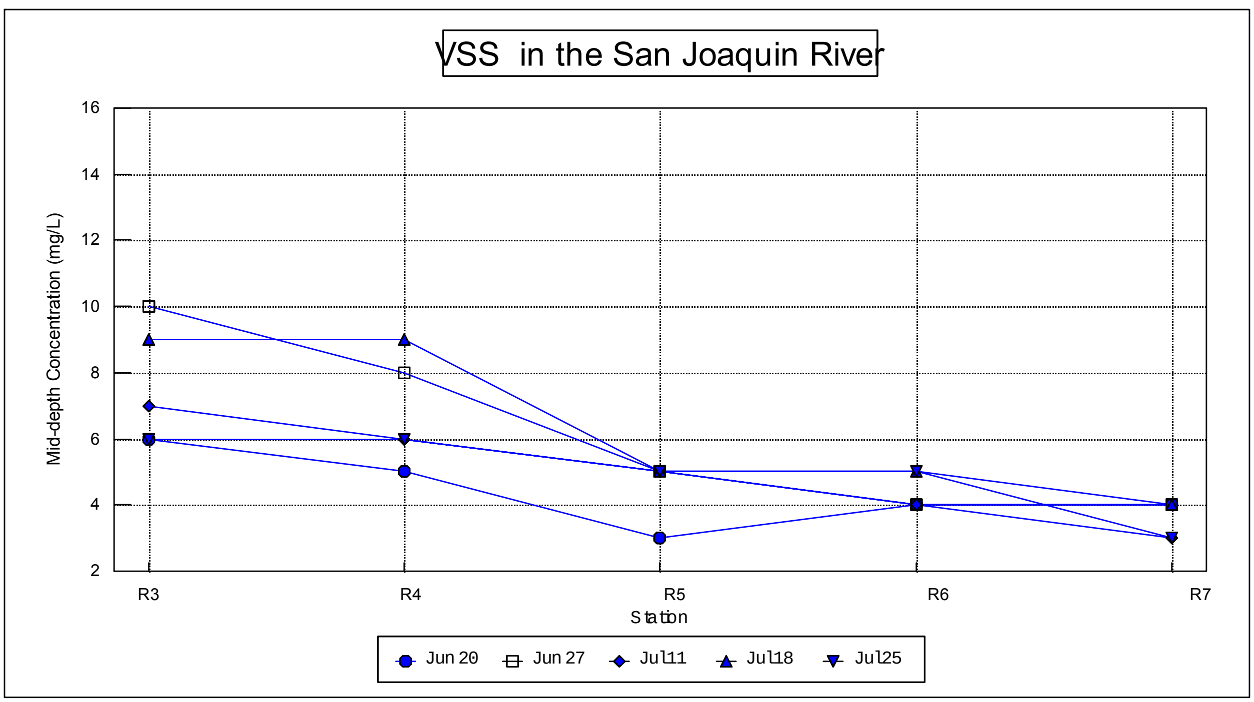
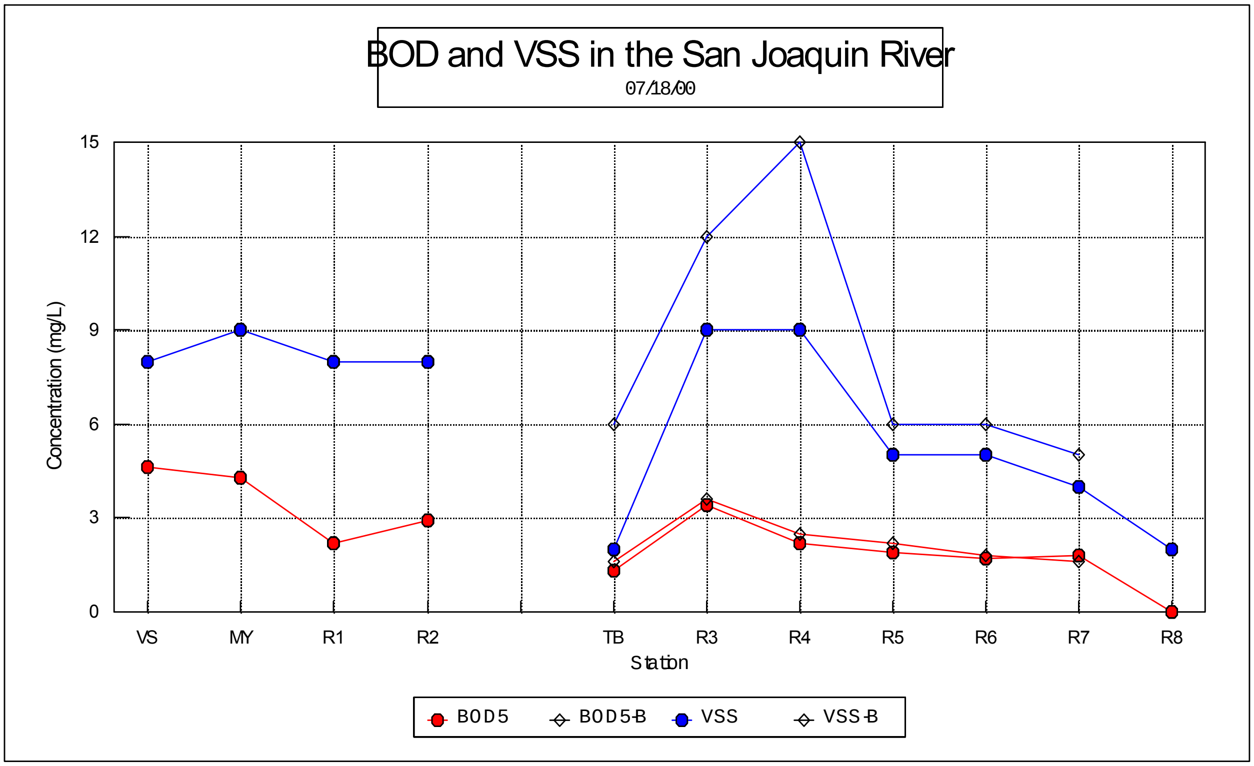


Figure 17. VSS in the DWSC.



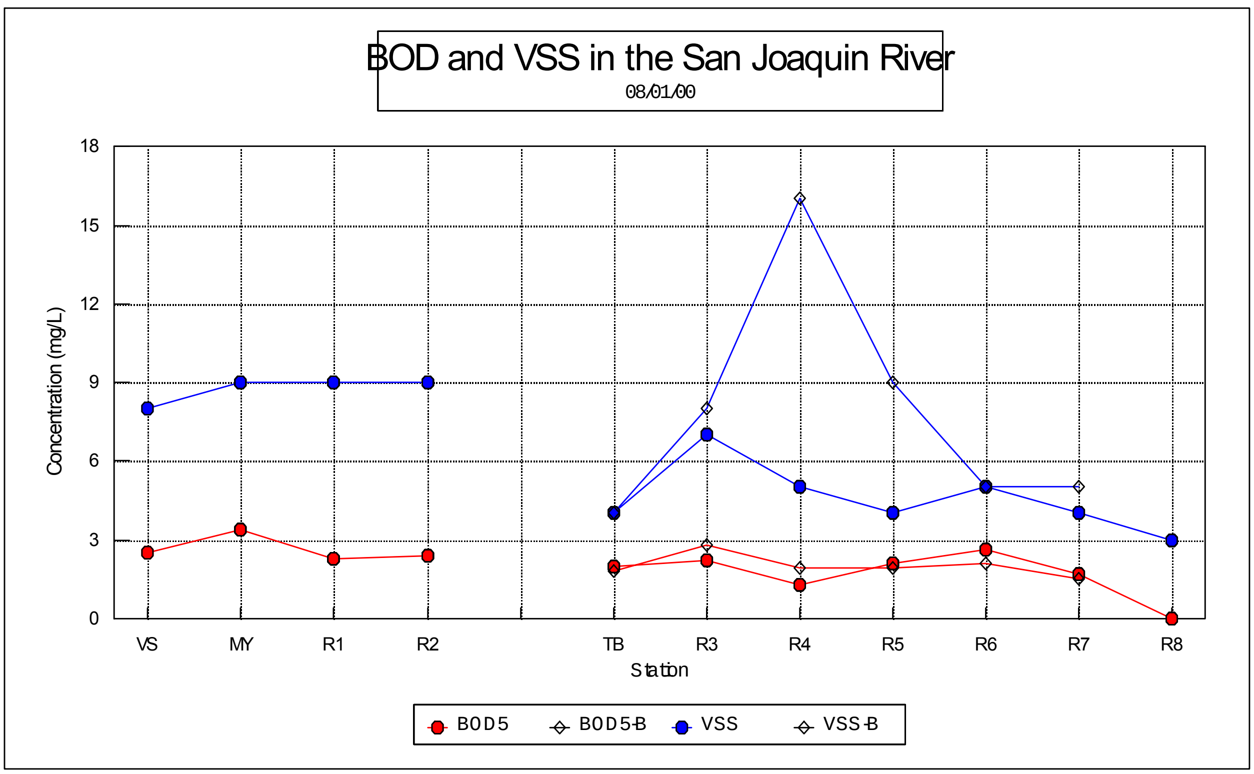


Figure 18. Mid-depth and Bottom BOD5 and VSS concentrations in the SJR on July 18th and August 1st, 2000.

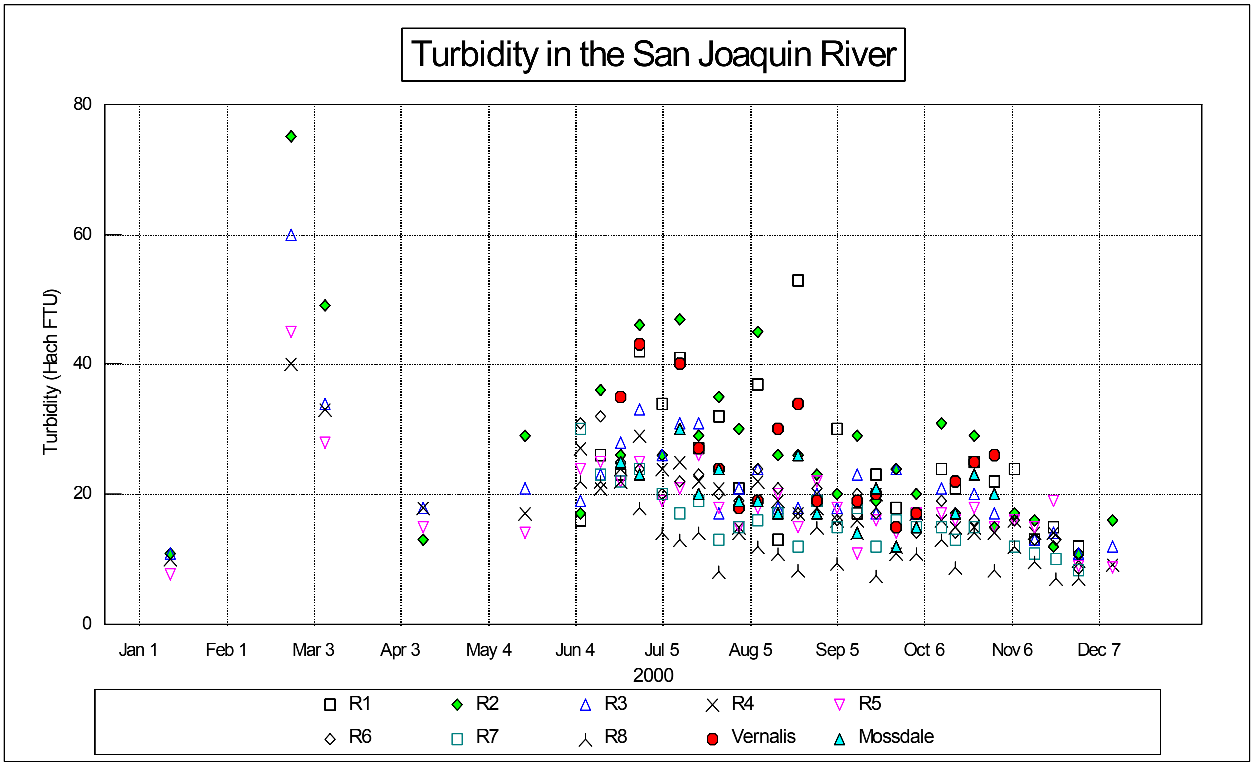


Figure 19. Turbidity in the San Joaquin River.

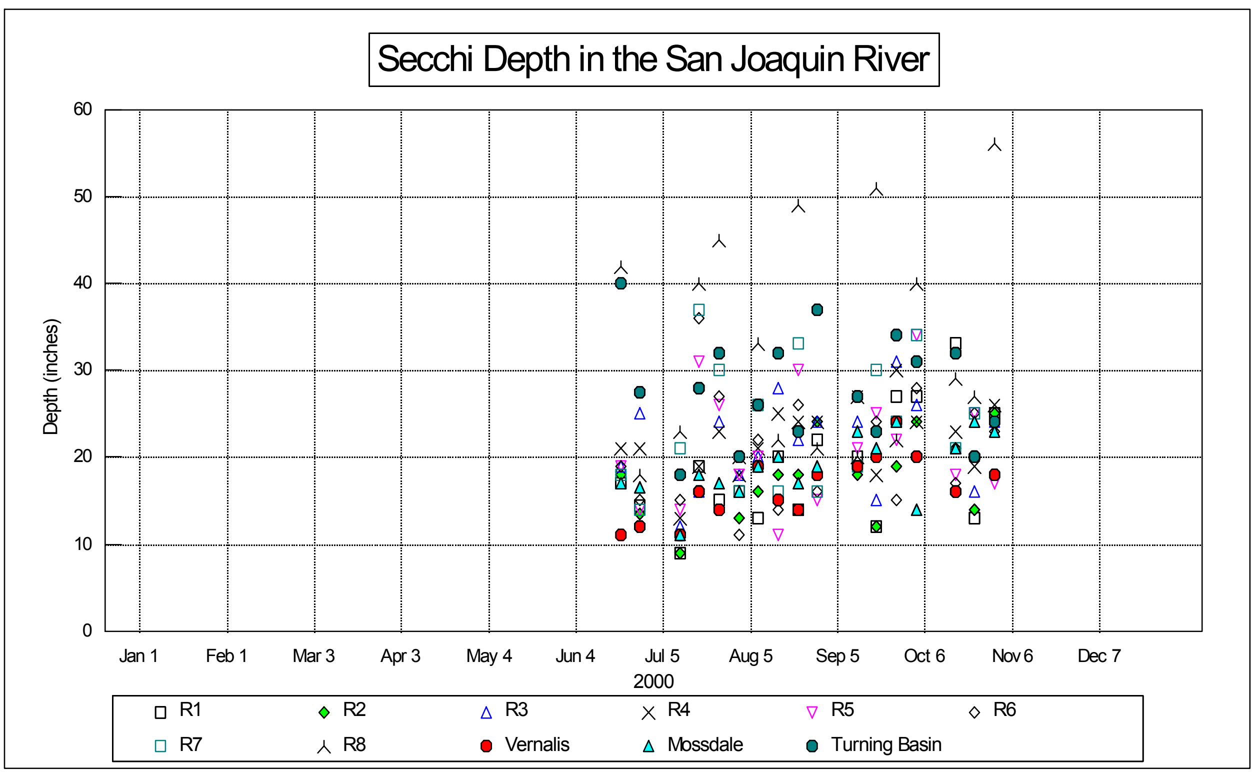


Figure 20. Secchi Depth in the San Joaquin River.

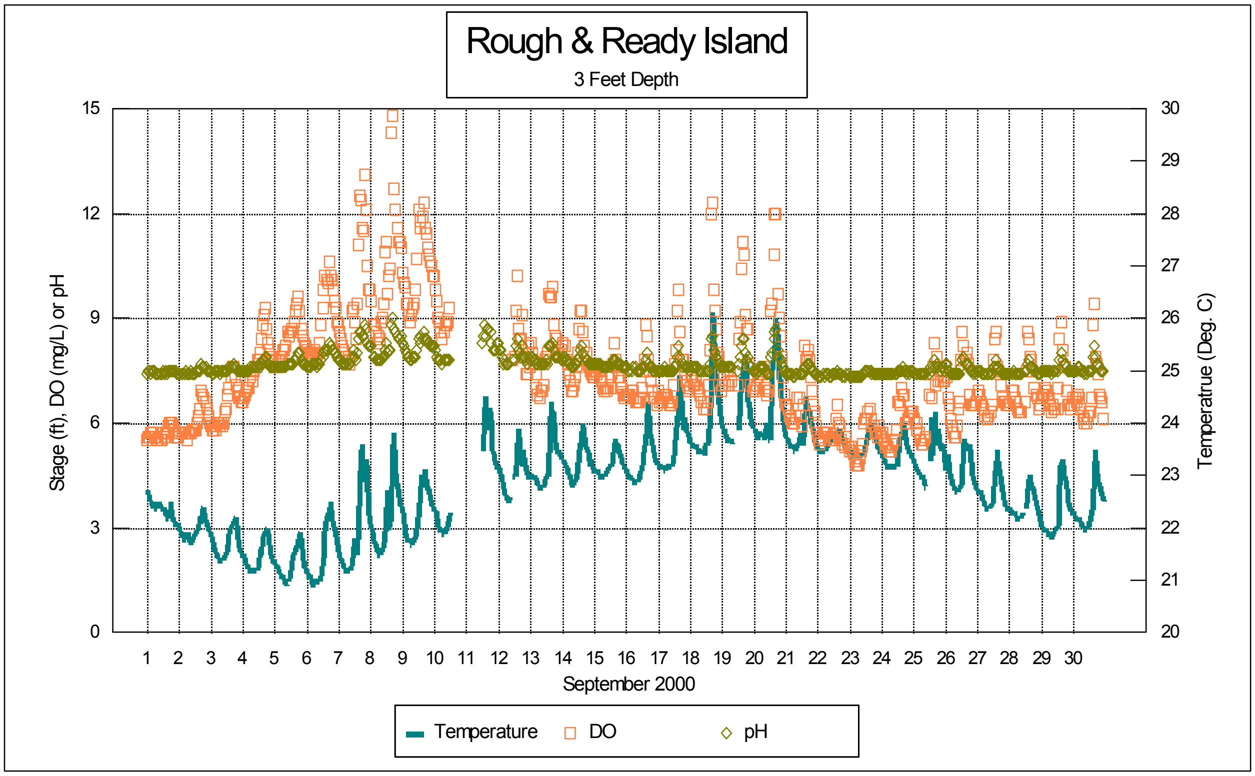


Figure 21. Hourly Temperature, DO and pH at Rough & Ready Island, September,2000.

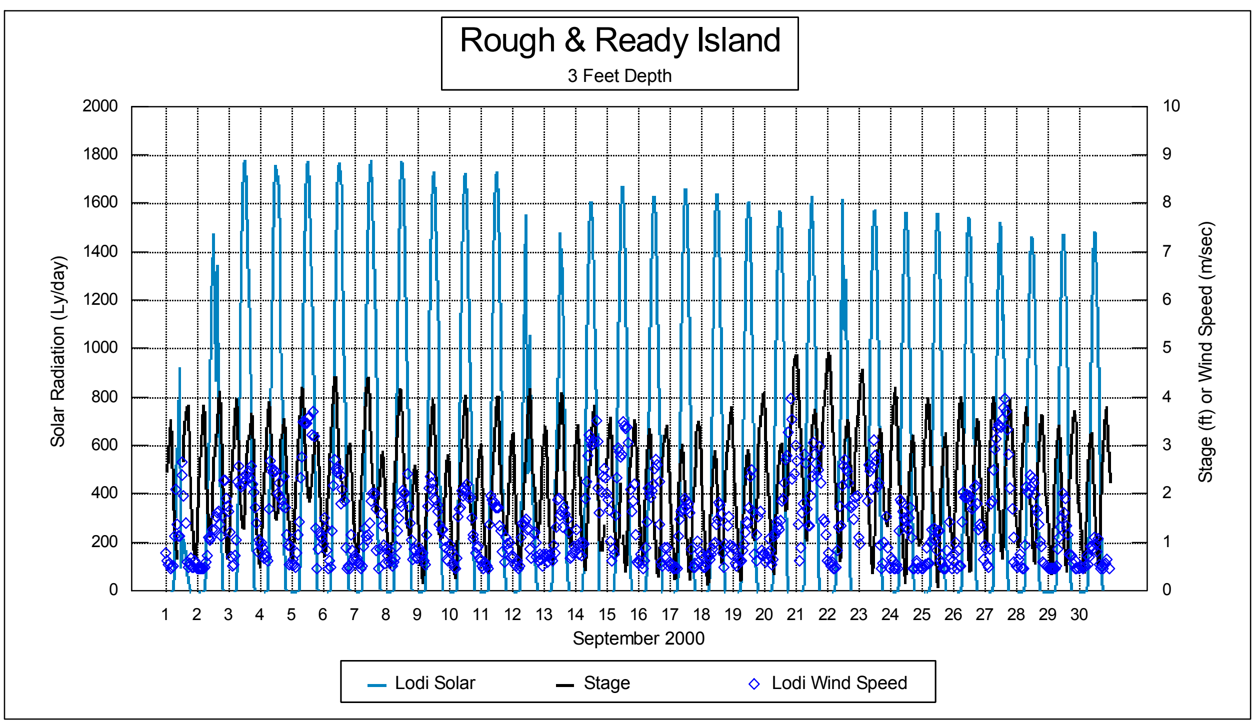


Figure 22. Hourly Solar Radiation, River Stage and Wind Speed, September, 2000.