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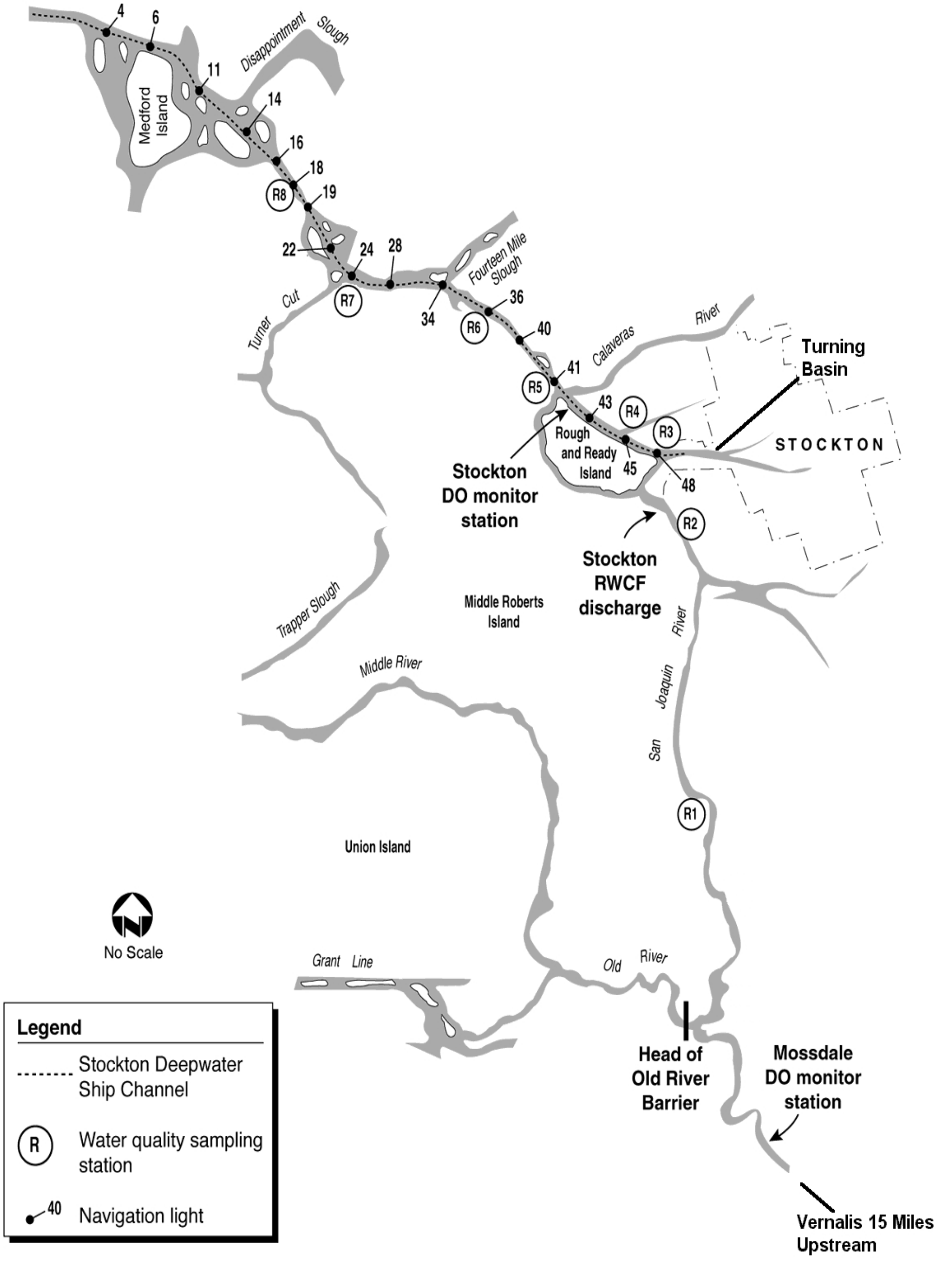
Jones & Stokes Inc. (2001a) Evaluation of San Joaquin River Flows at Stockton. Prepared for City of Stockton

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

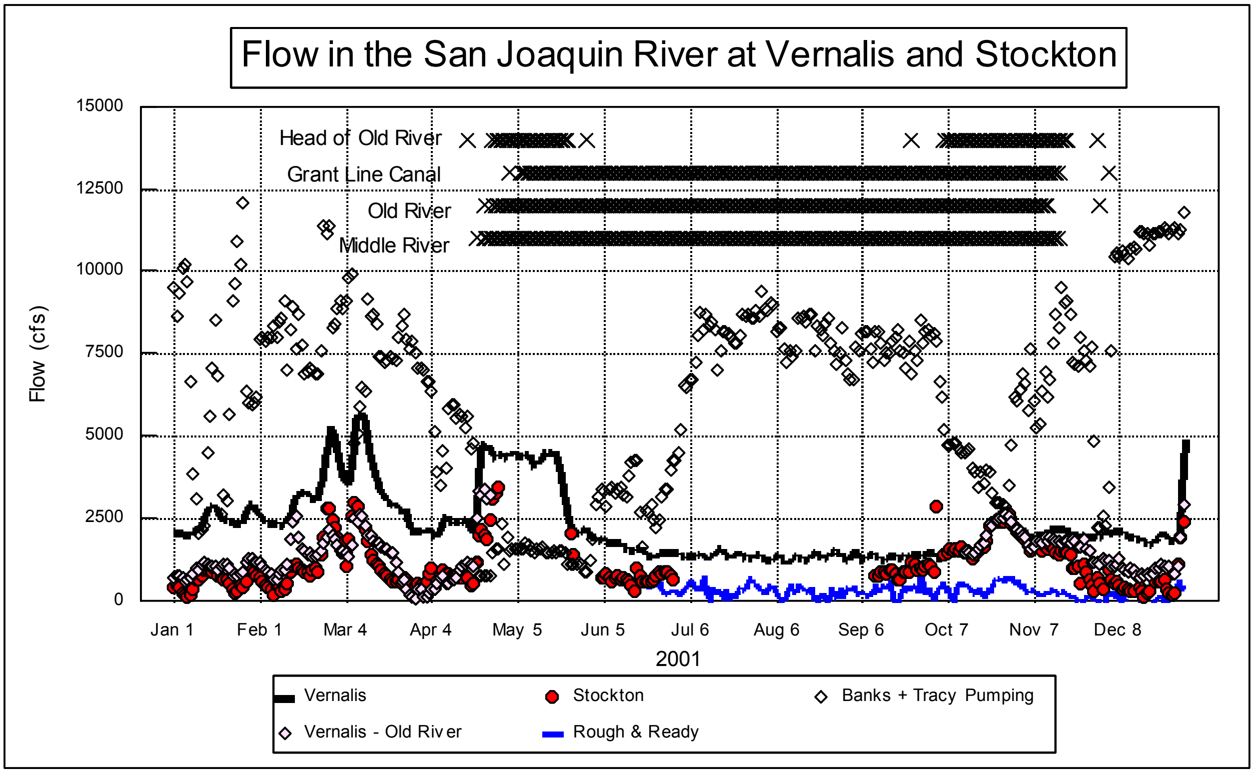


Figure 2. Daily Flows in the San Joaquin River at Vernalis and Stockton.

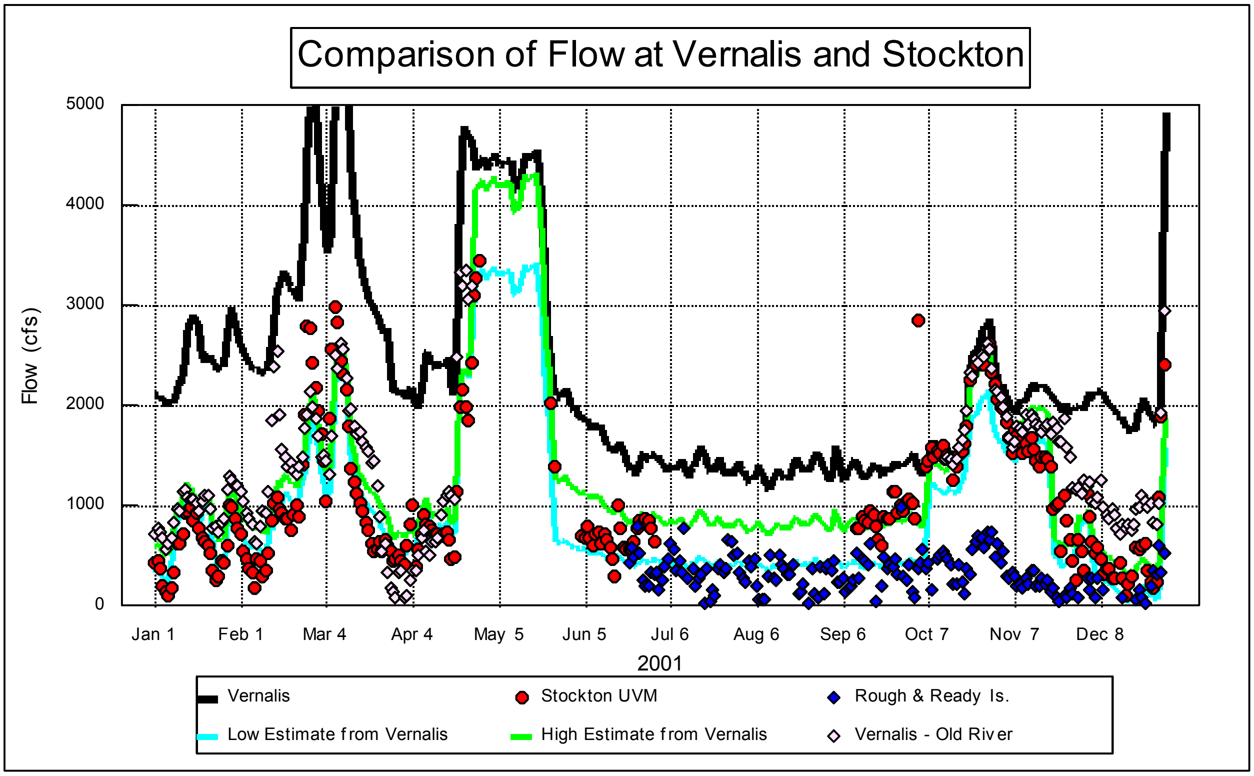


Figure 3. Daily Flows in the San Joaquin River at Vernalis and Stockton.

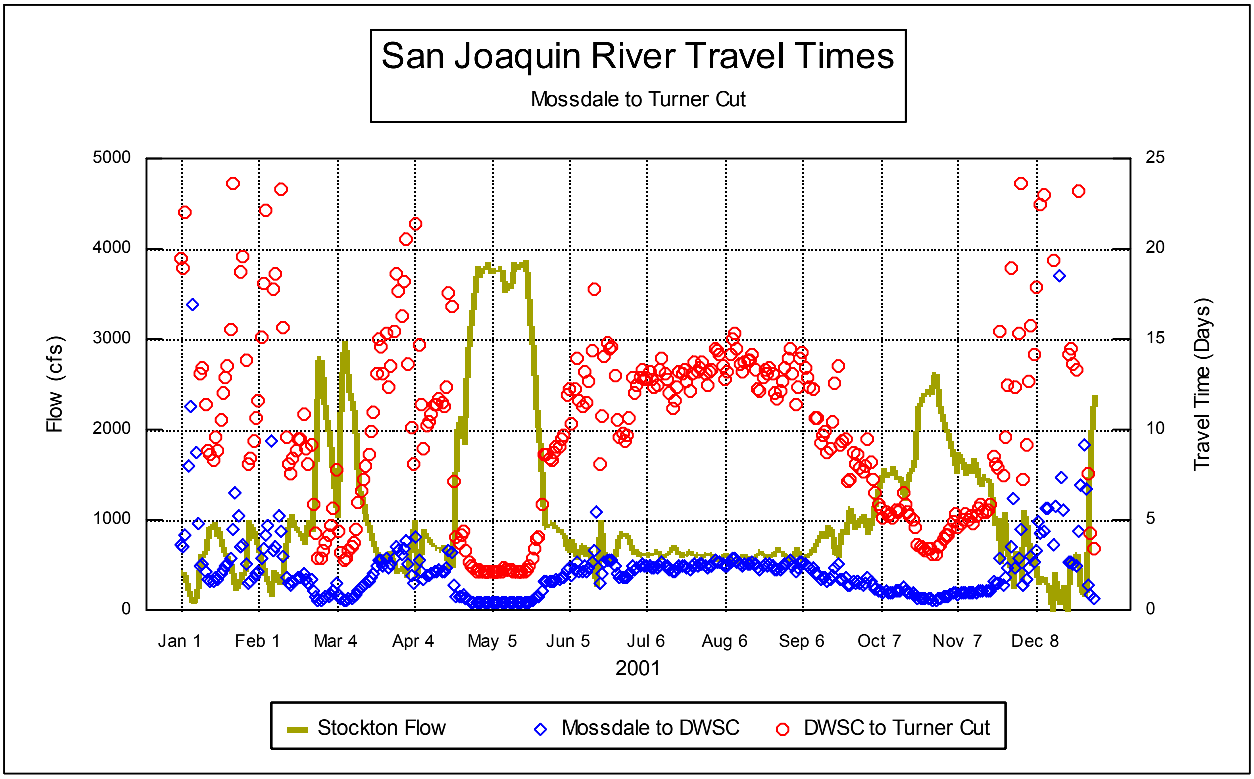


Figure 4. Estimated San Joaquin River Travel Times.

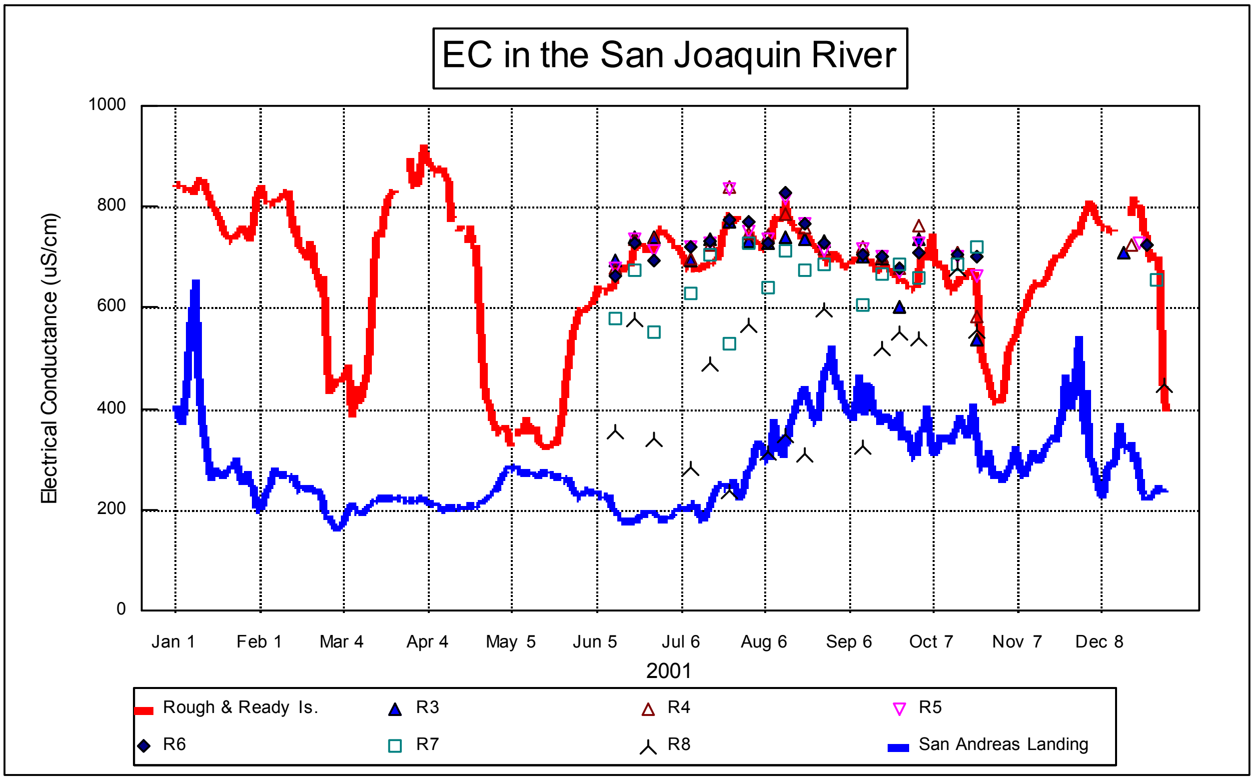


Figure 5. Electrical Conductance in the San Joaquin River and Stockton Deep Water Ship Channel.

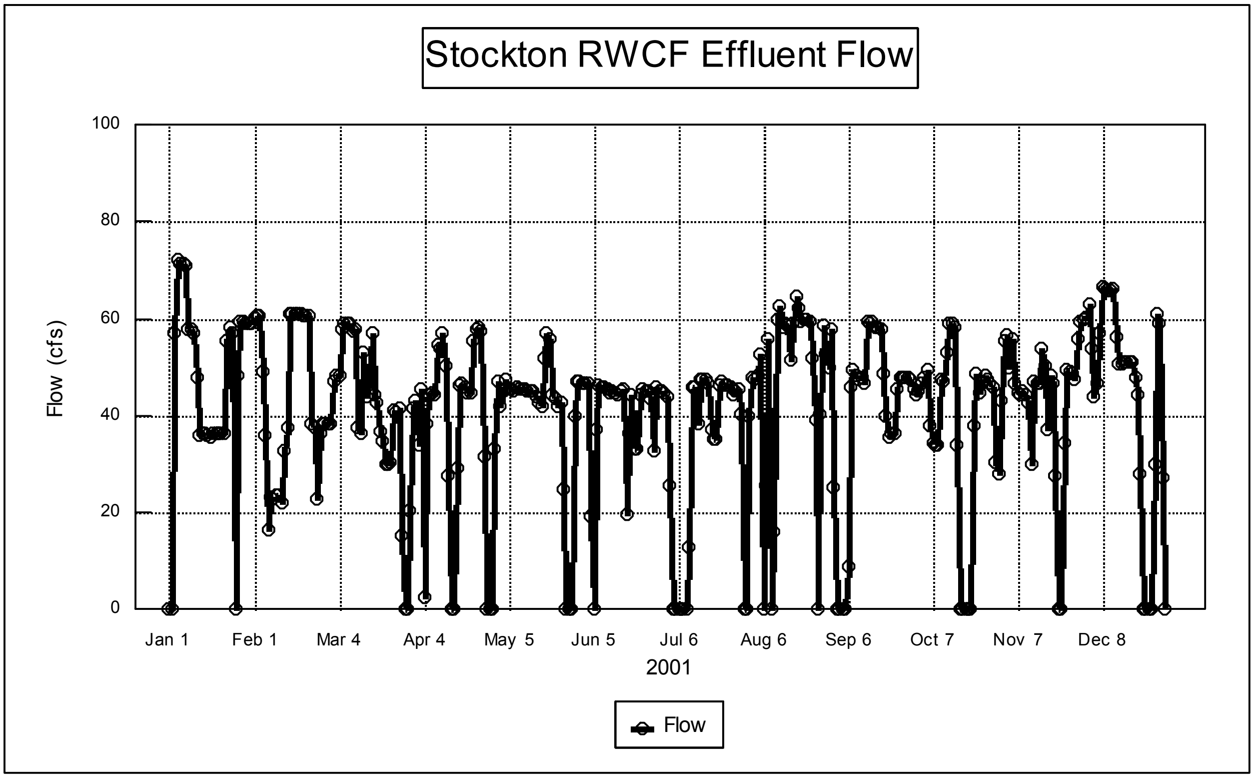


Figure 6. Stockton Regional Wastewater Control Facility Daily Discharges into the San Joaquin River.

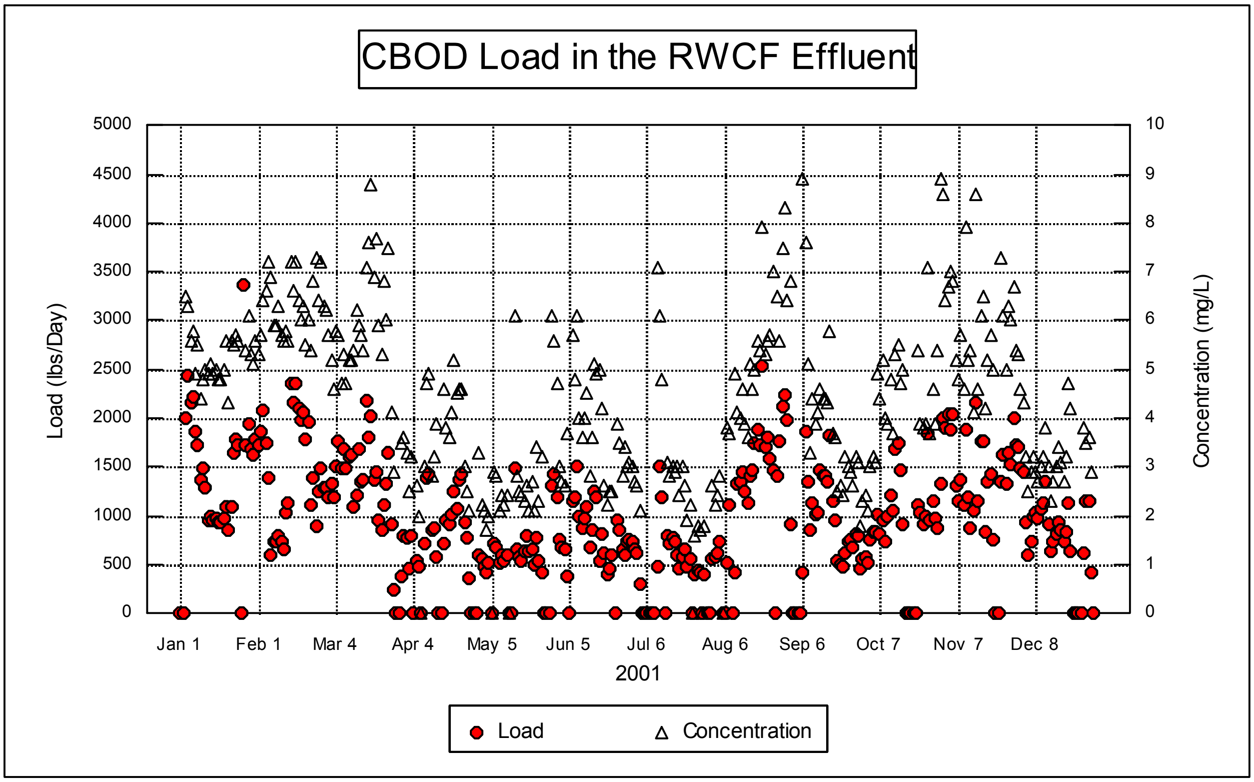


Figure 7. 5-Day Carbonaceous Biochemical Oxygen Demand Load from the RWCF.

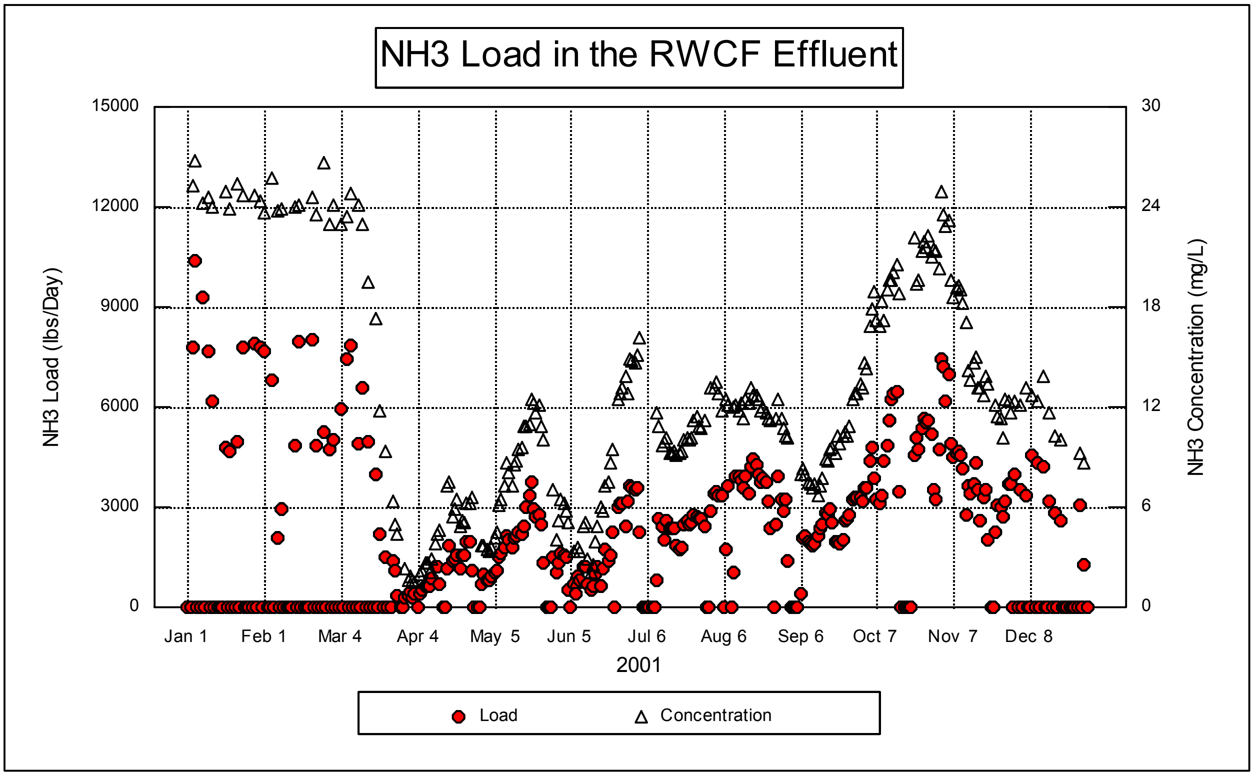


Figure 8. Ammonia Nitrogen Load from the RWCF.

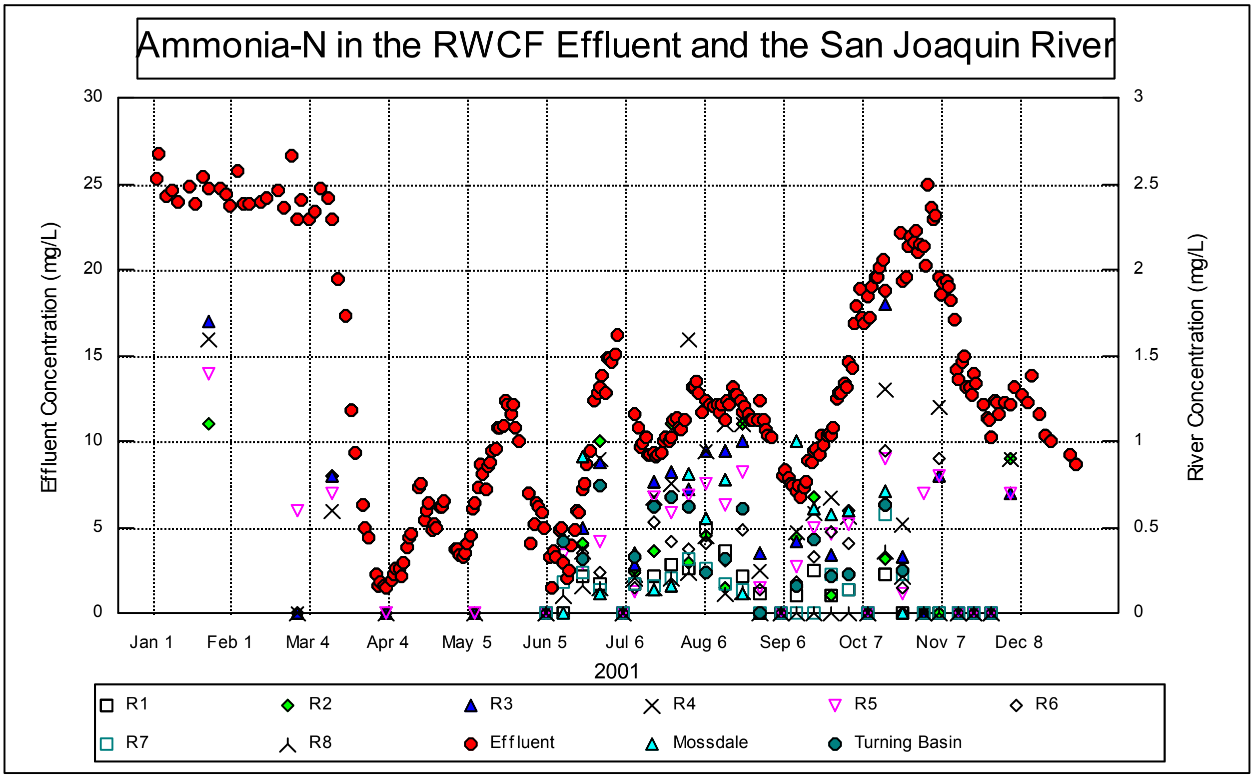
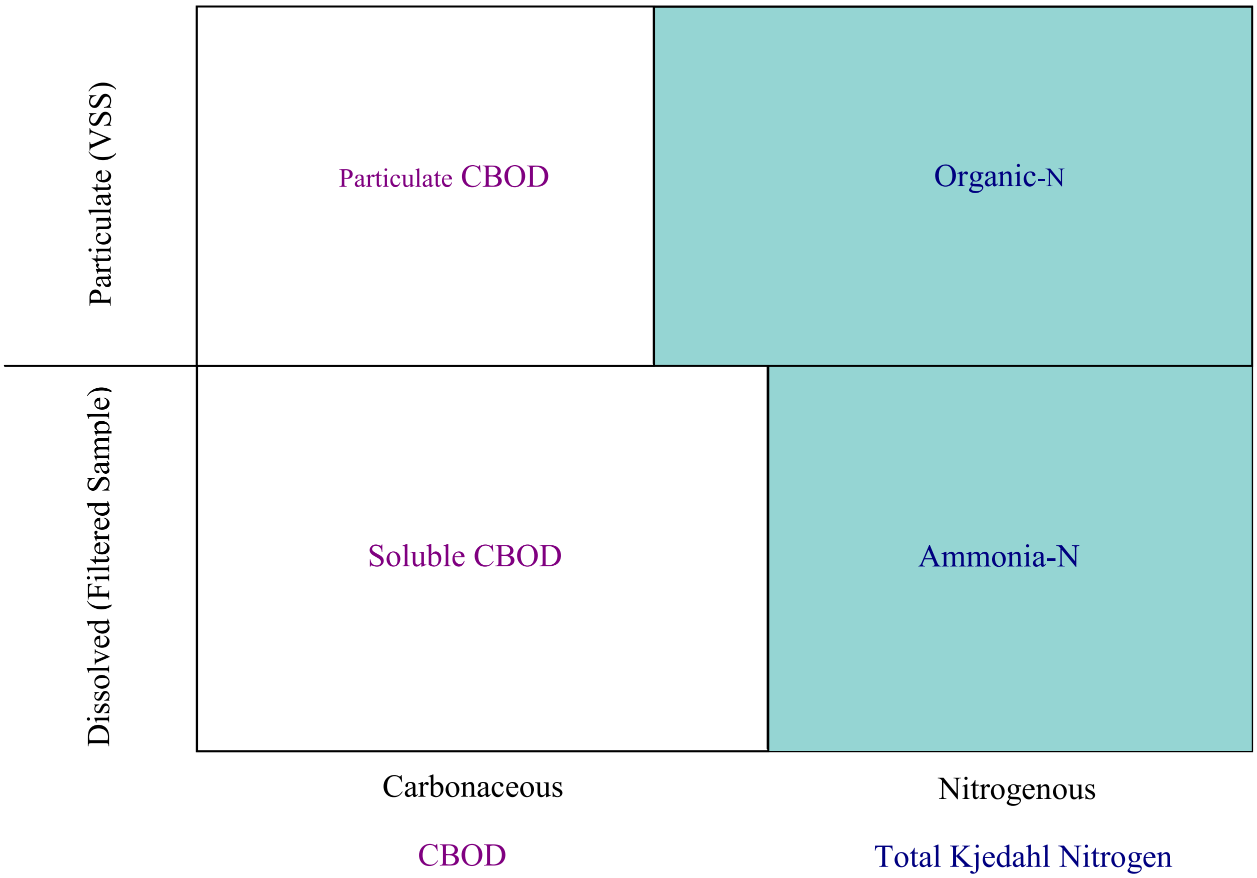


Figure 9. Ammonia in the RWCF Effluent and the San Joaquin River.

Figure 10. Conceptual Total Biological Oxygen Demand Components
A. Carbonaceous and Nitrogenous
B. Dissolved and Particulate



BOD Observed with Various Decay Rates (mg/L)

$$BOD = 10 * (1 - BOD_{Ultimate} * e^{-k * Time})$$

Decay Rate, k (day^{-1})

	0.05	0.10	0.15
0-Day	0	0	0
5-Day	2.2	3.9	5.3
10-Day	3.9	6.3	7.8
15-Day	5.3	7.8	8.9
20-Day	6.3	8.6	9.5
25-Day	7.1	9.2	9.8
30-Day	7.8	9.5	9.9
Ultimate	10.0	10.0	10.0
$BOD_{Ultimate}/BOD_5$	4.5	2.5	1.9

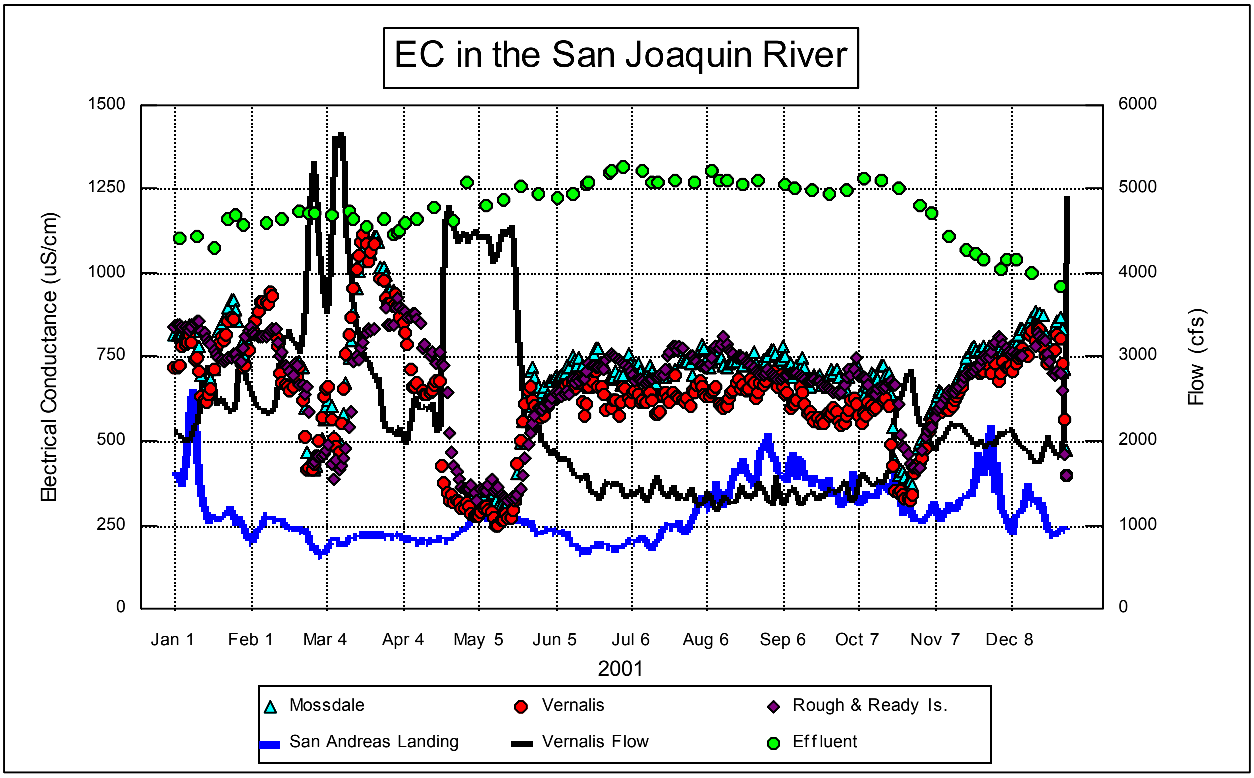


Figure 11. Electrical Conductance in the San Joaquin River.

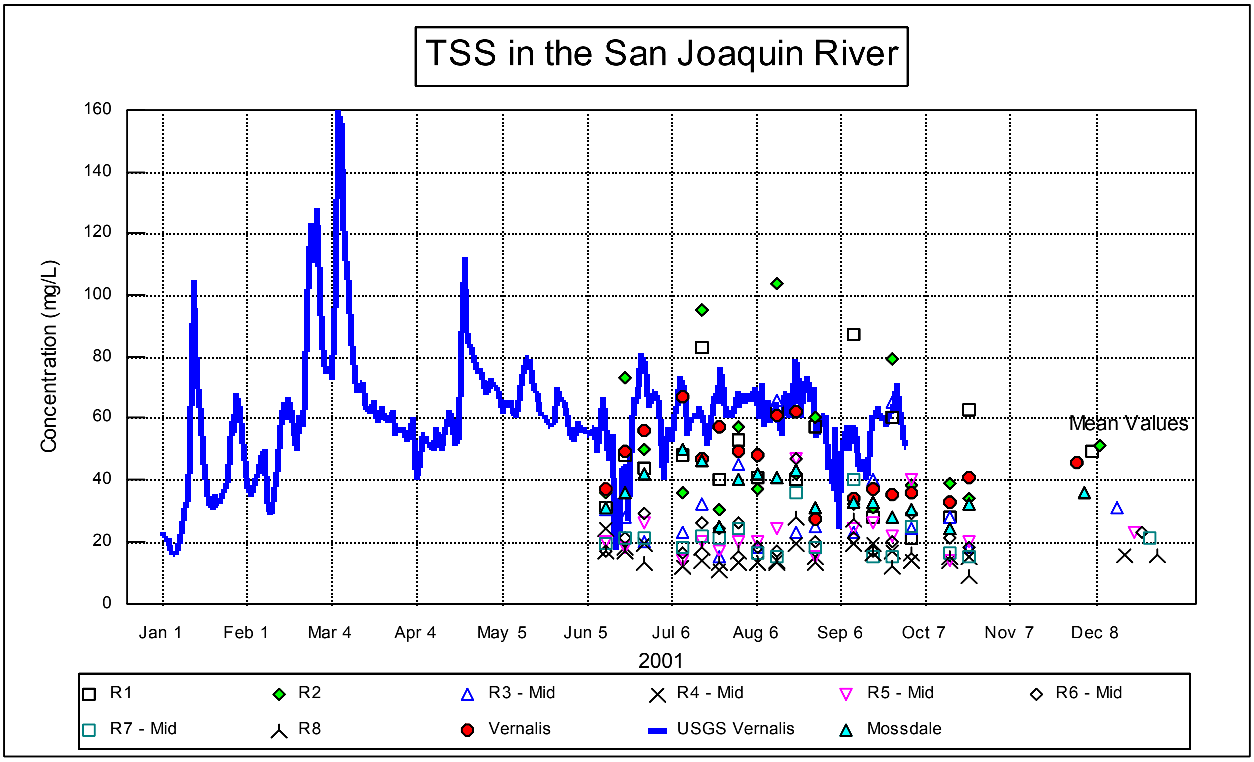


Figure 12. Total Suspended Sediments in the San Joaquin River.

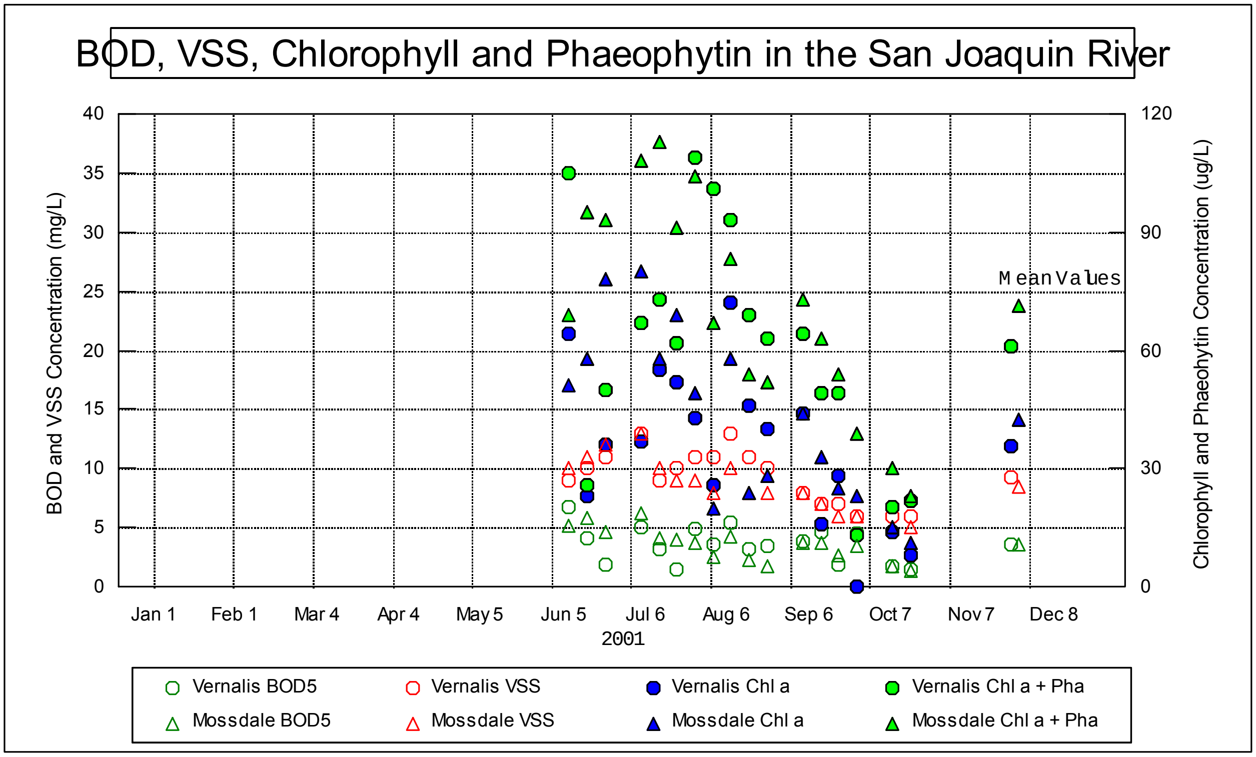


Figure 13. BOD, VSS, Chlorophyll and Phaeophytin in the San Joaquin River.

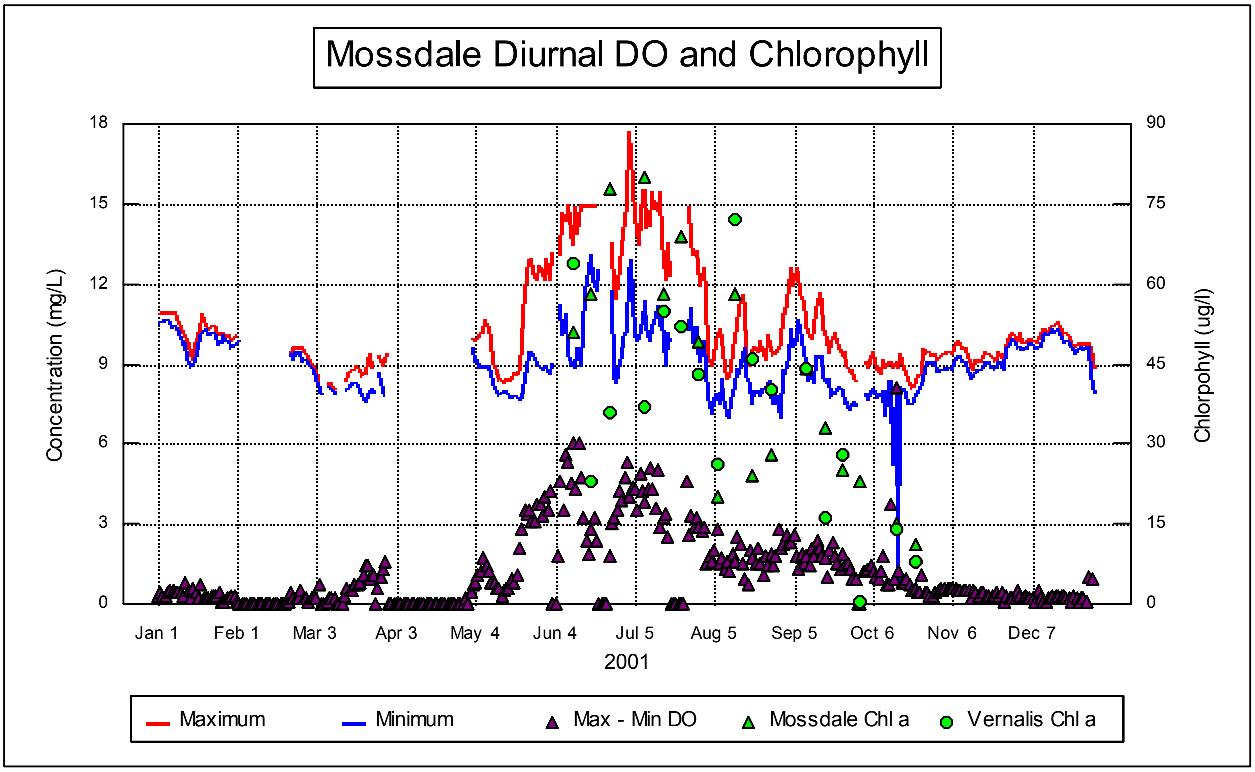


Figure 14. Diurnal DO and Chlorophyll a in the San Joaquin River at Mossdale.

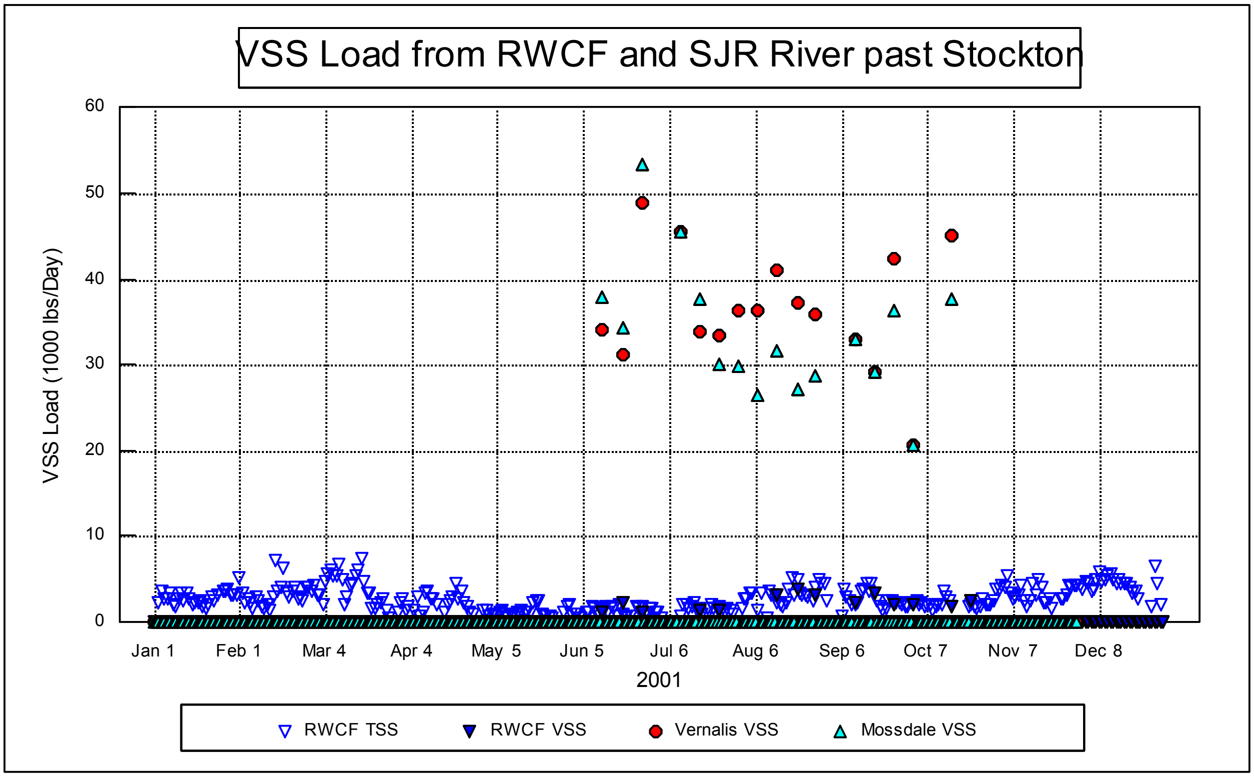


Figure 15. Daily Estimated VSS Load Entering the DWSC.

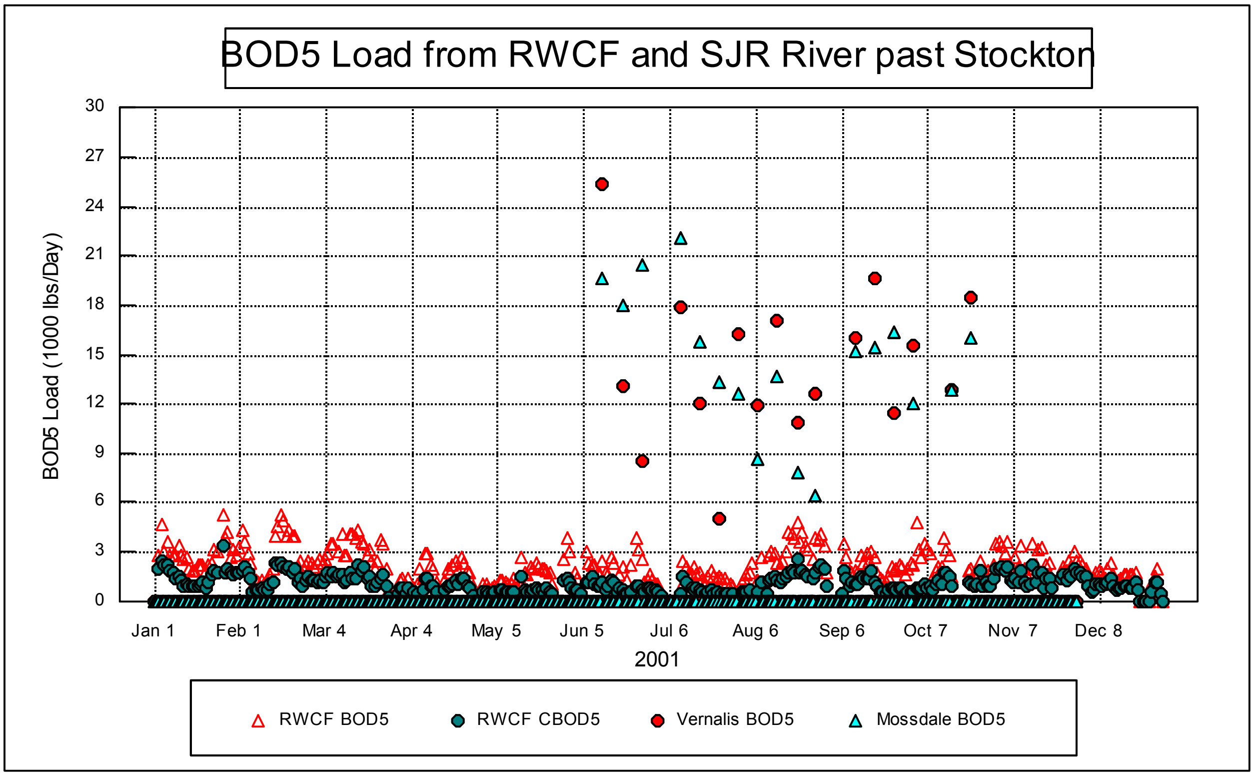


Figure 16. Daily Estimated BOD5 Load Entering the DWSC.

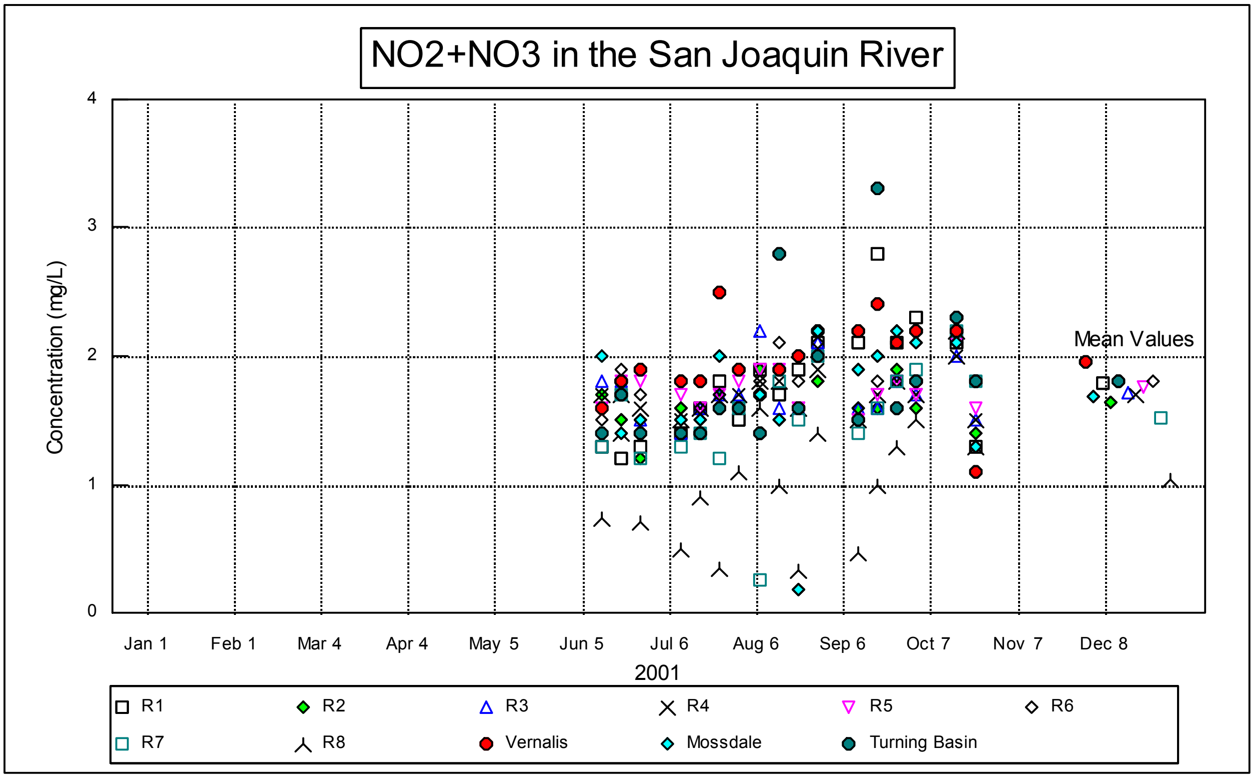


Figure 17. Nitrate + Nitrite Nitrogen in the San Joaquin River and in the DWSC.

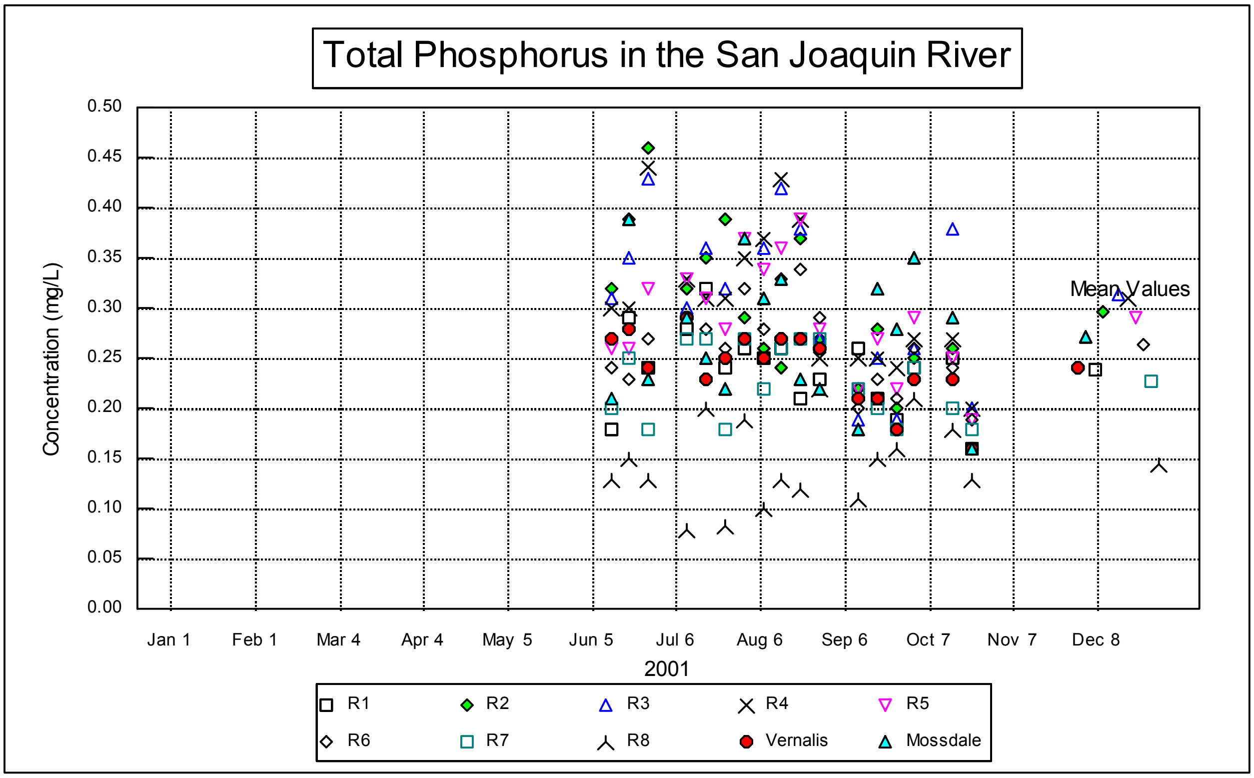


Figure 18. Total Phosphorus in the San Joaquin River and in the DWSC.

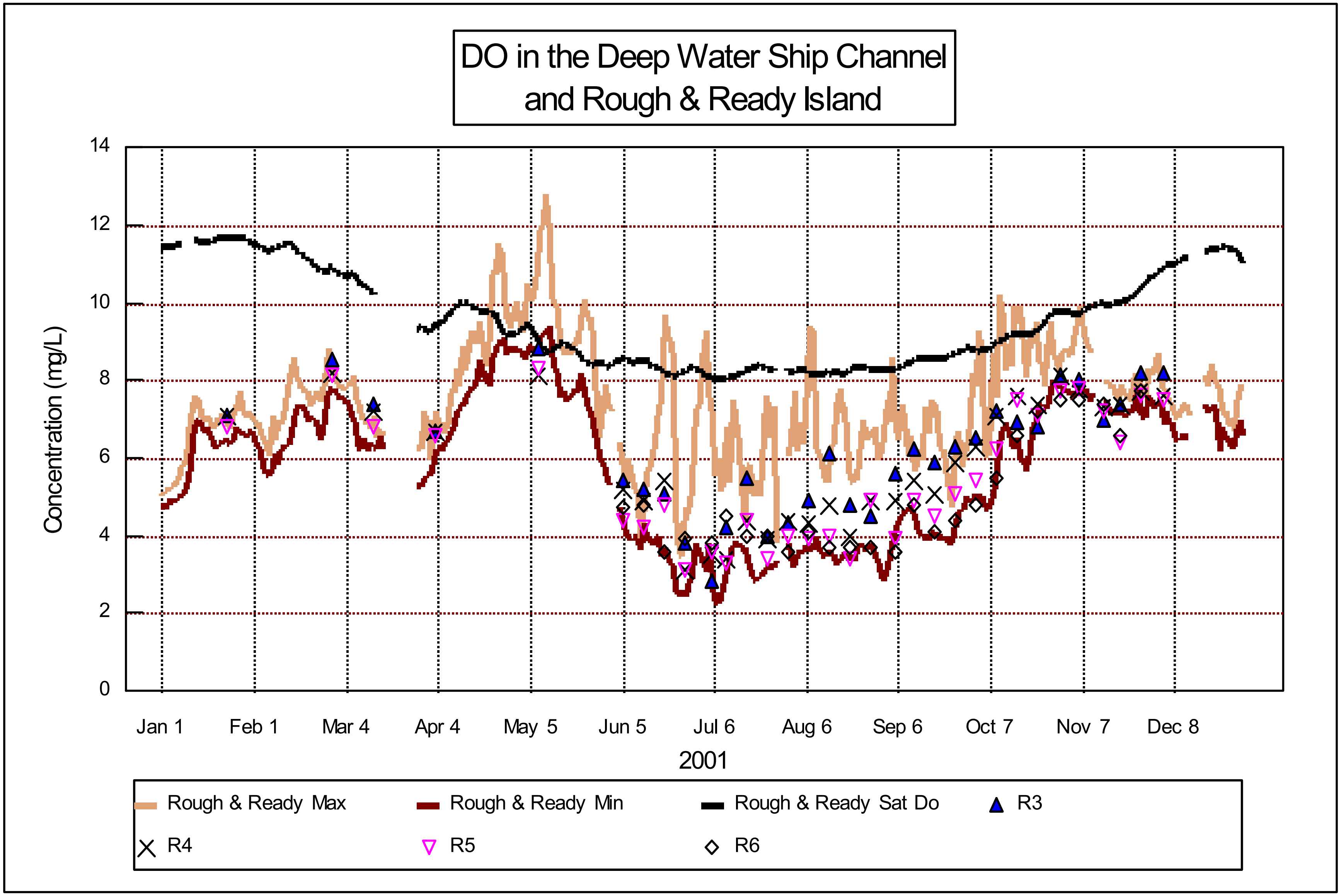


Figure 19. Daily Dissolved Oxygen Concentrations in the Stockton DWSC.

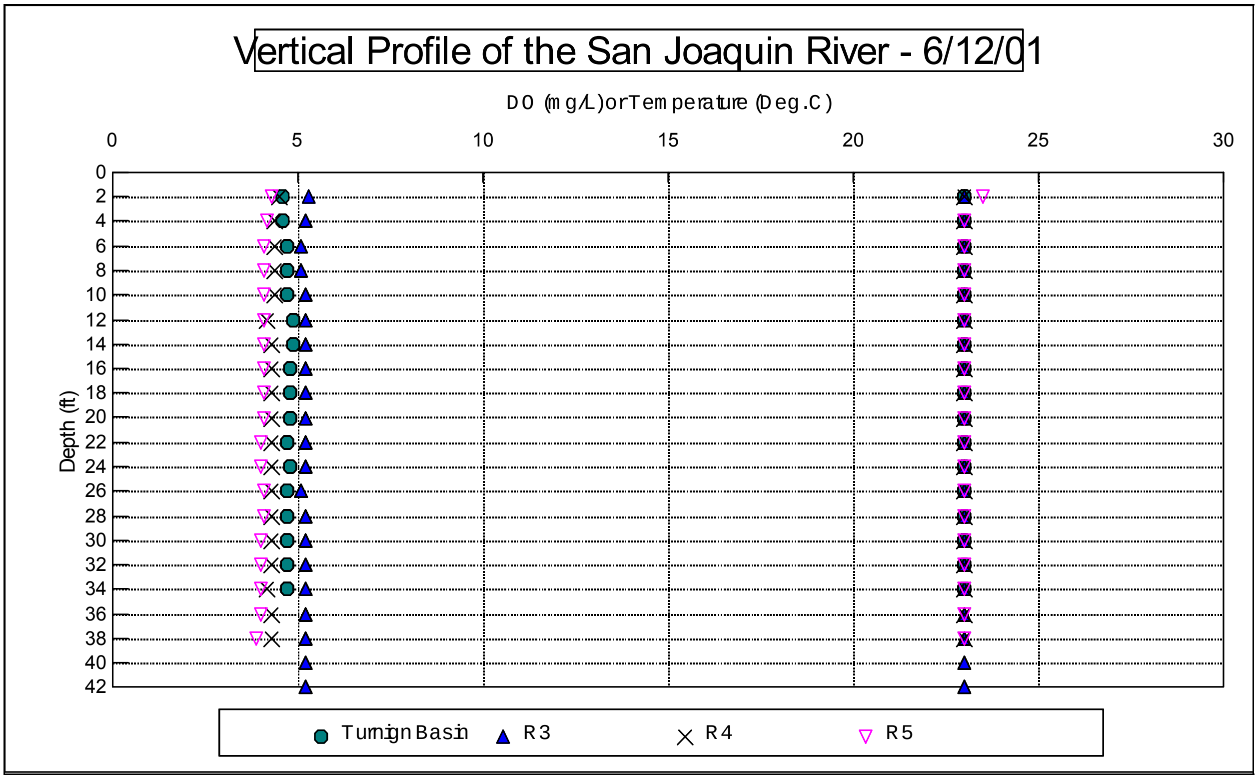


Figure 20a. Vertical Profiles of DO and Temperature in the DWSC, June 12th, 2001.

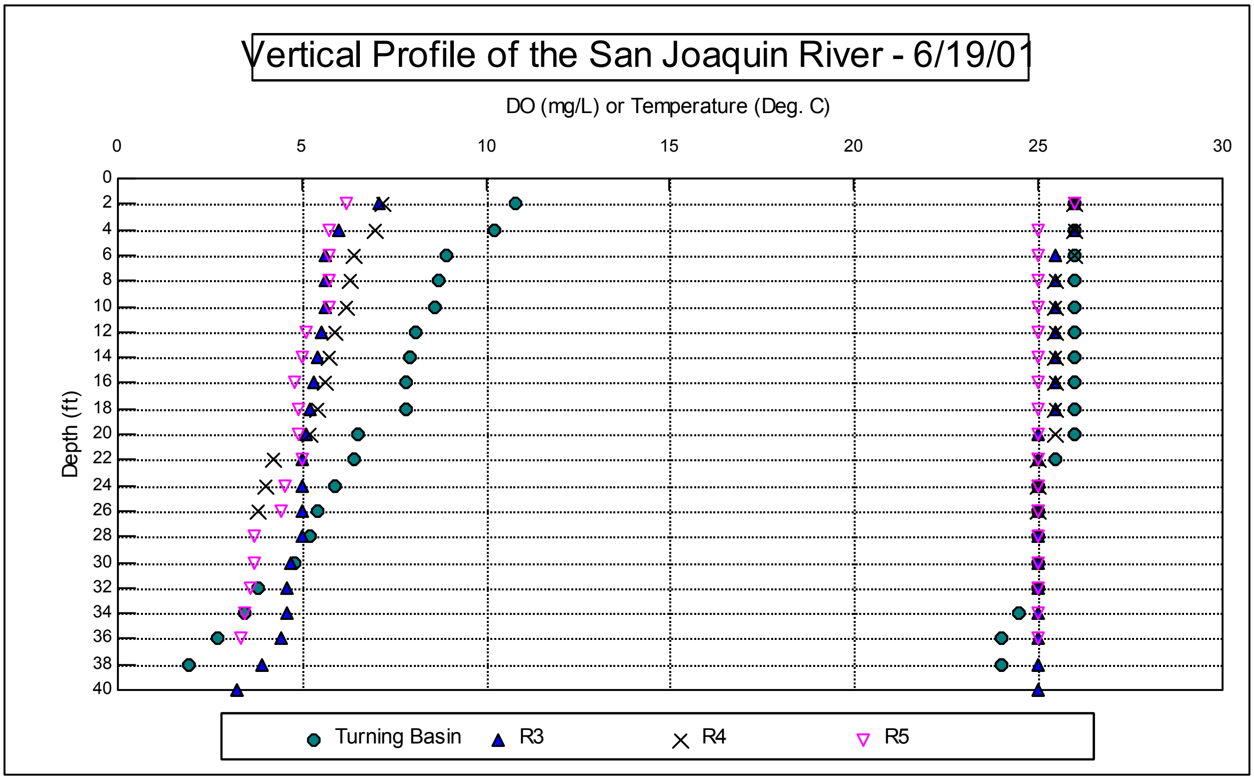


Figure 20b. Vertical Profiles of DO and Temperature in the DWSC, June 19th, 2001.

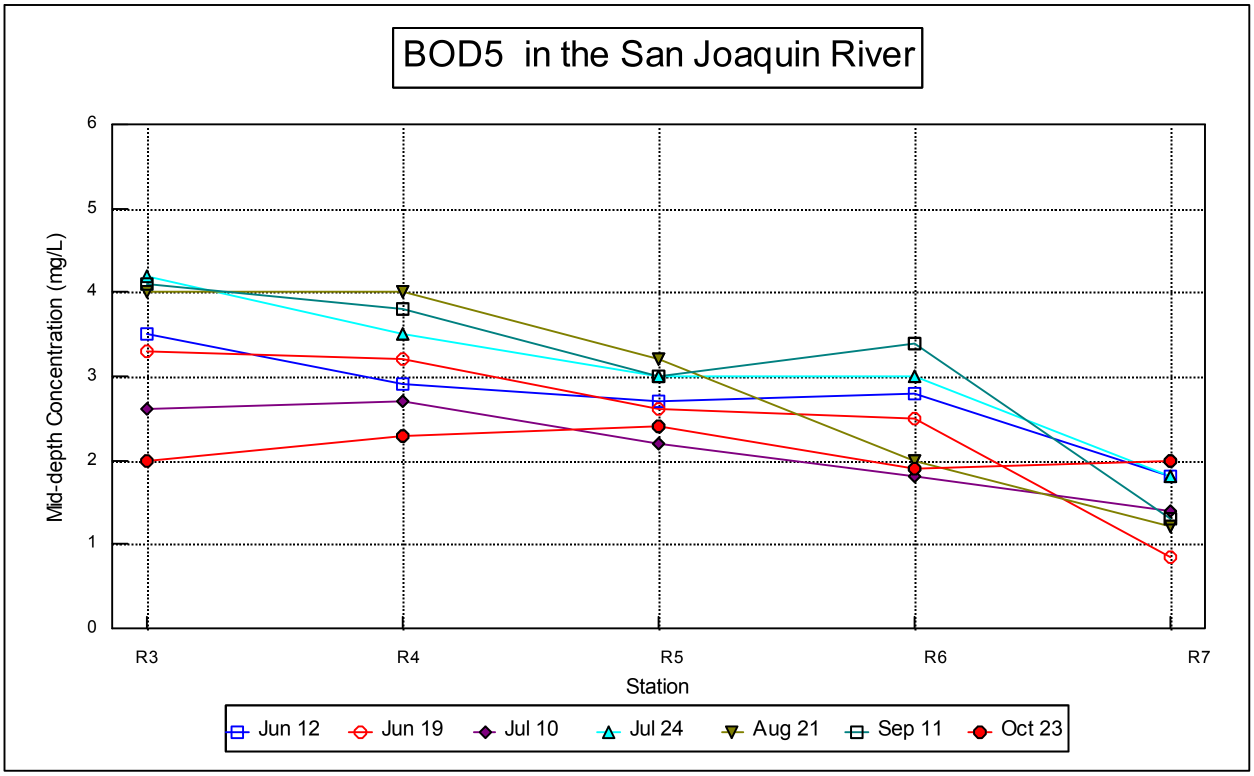


Figure 21a. BOD5 in the DWSC.

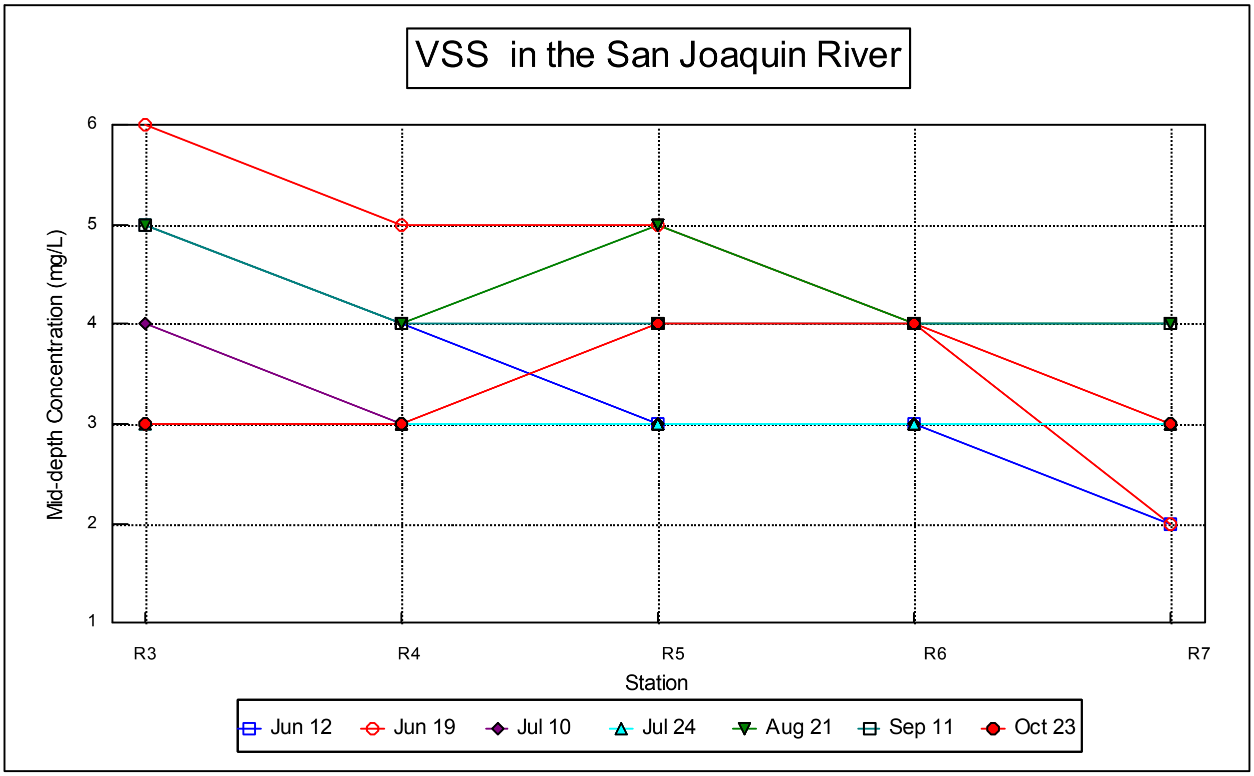


Figure 21b. VSS in the DWSC.

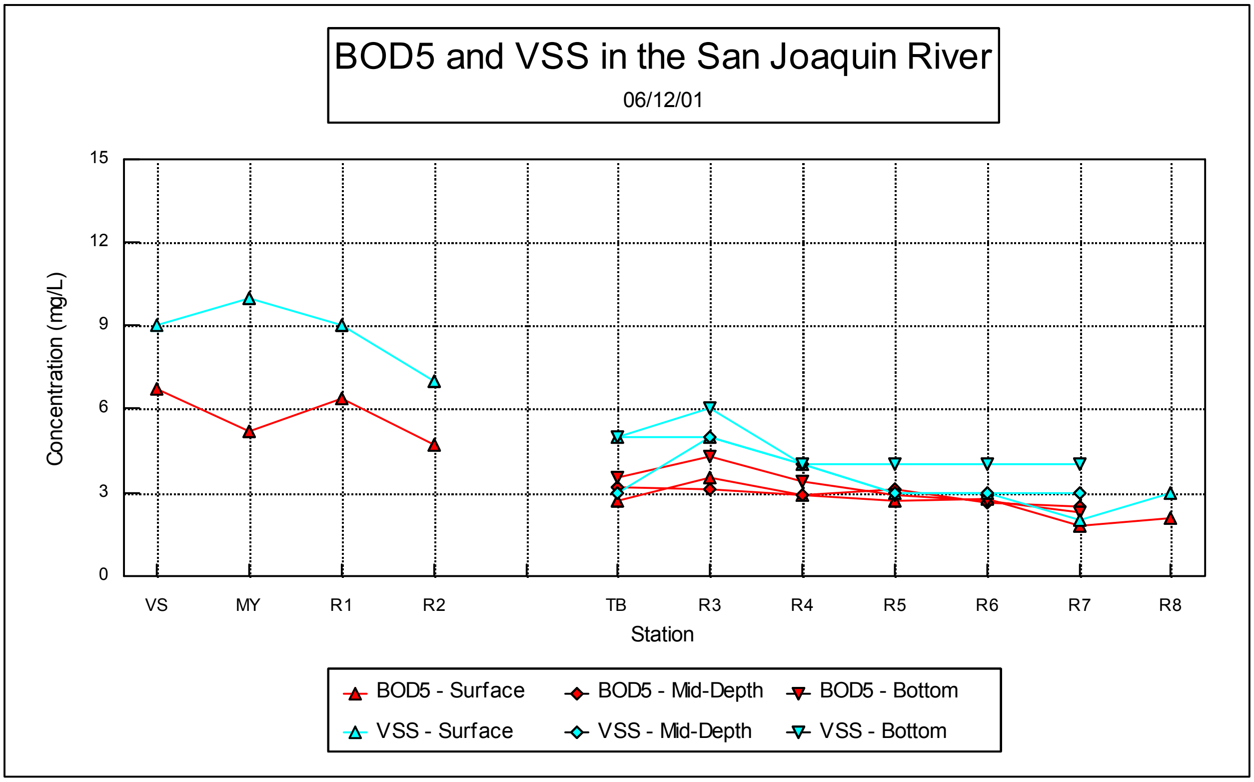


Figure 22a. Mid-depth and Bottom BOD5 and VSS concentrations in the SJR on June 12th, 2001.

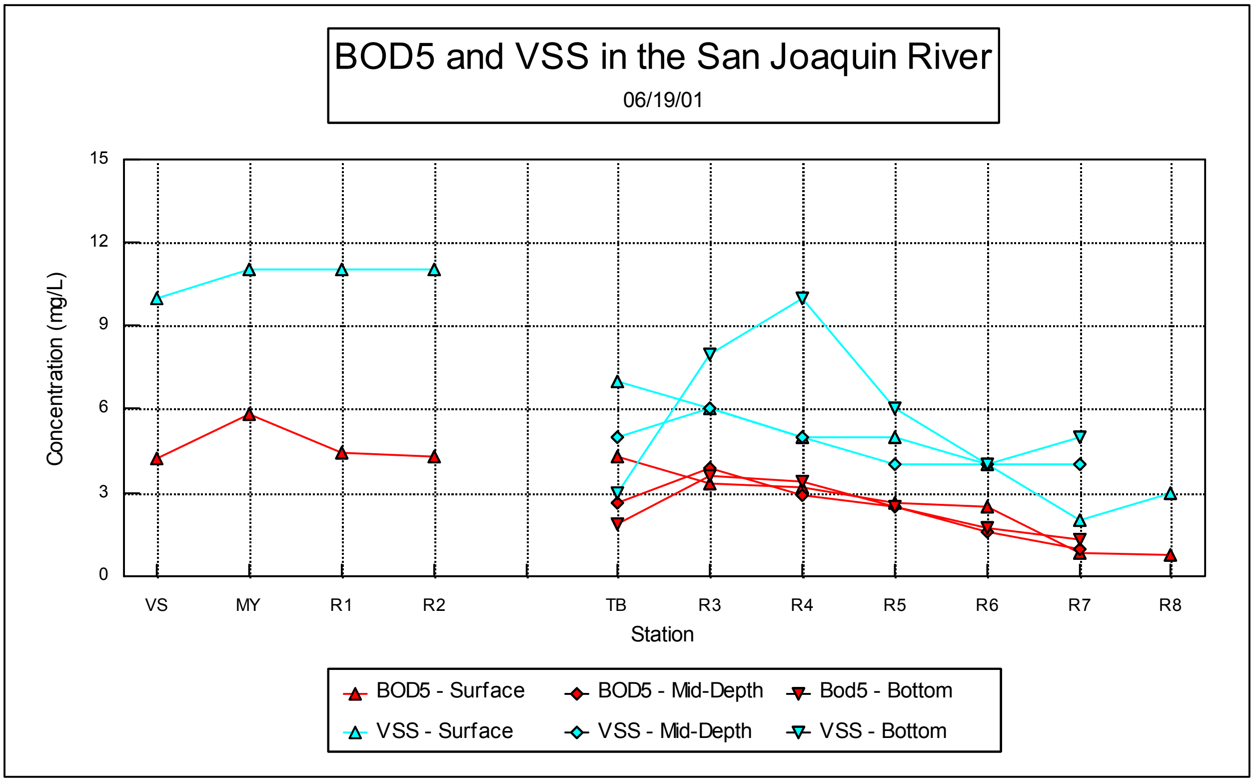


Figure 22b. Mid-depth and Bottom BOD5 and VSS concentrations in the SJR on June 19th, 2001.

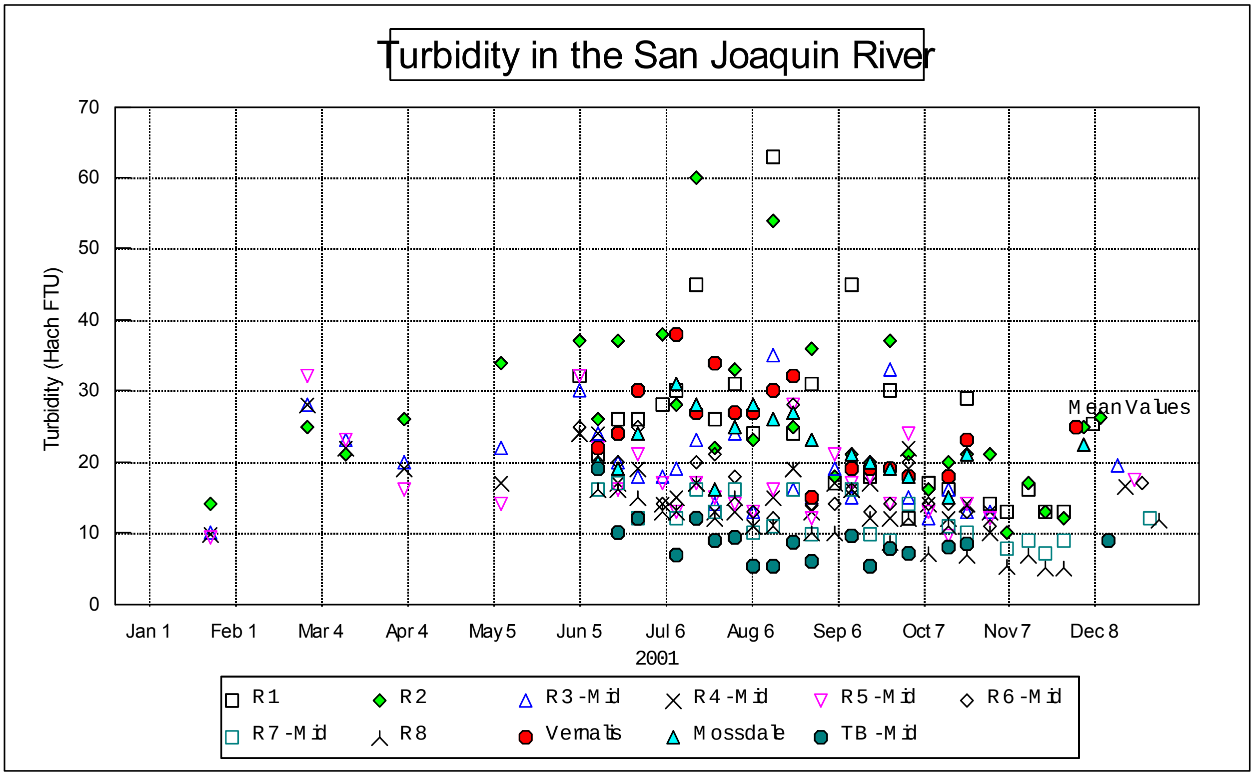


Figure 23. Turbidity in the San Joaquin River.

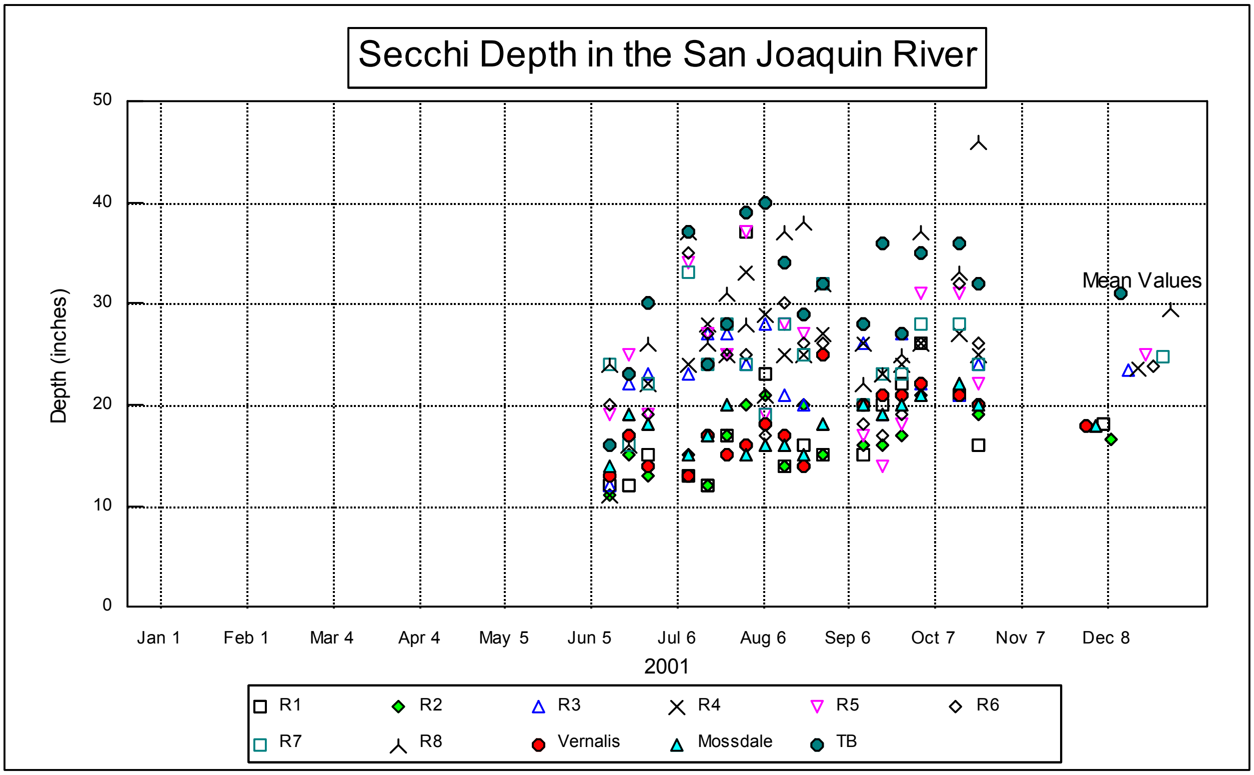


Figure 24. Secchi Depth in the San Joaquin River.

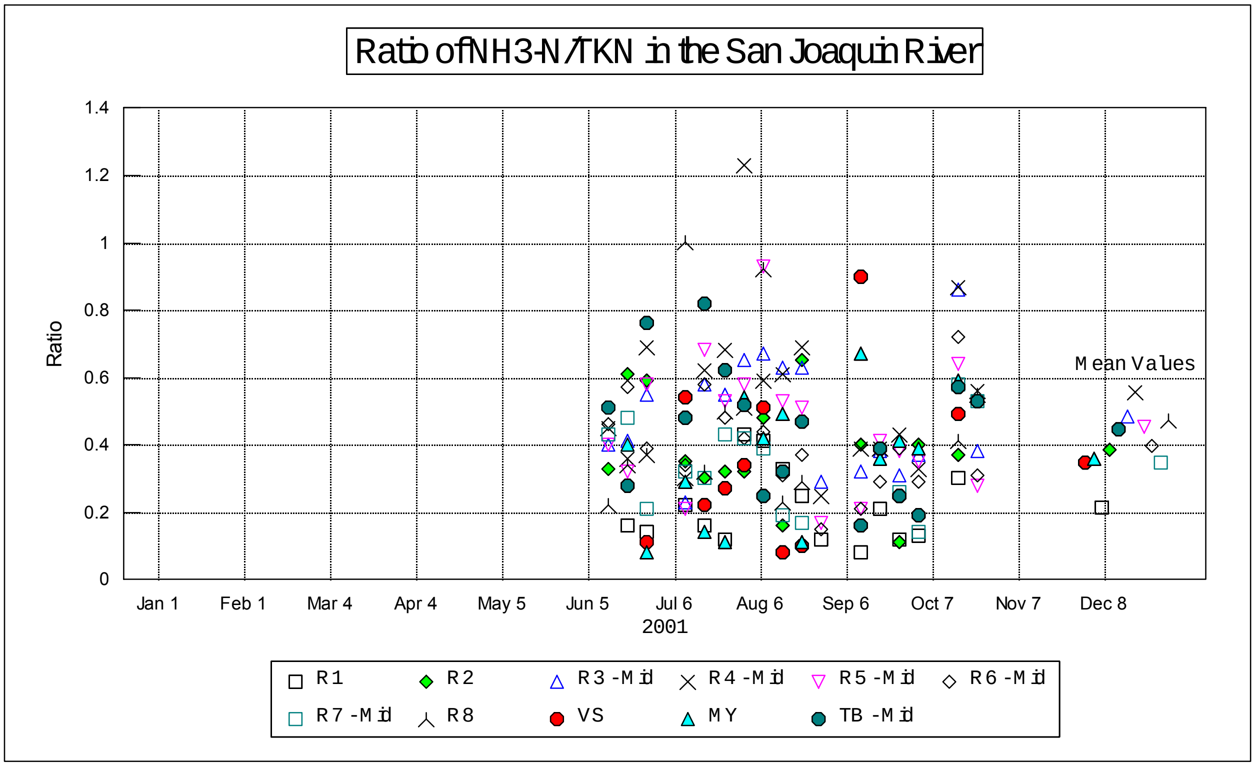


Figure 25. Ratio of Ammonia to Total Kjeldahl Nitrogen in the San Joaquin River, 2001.

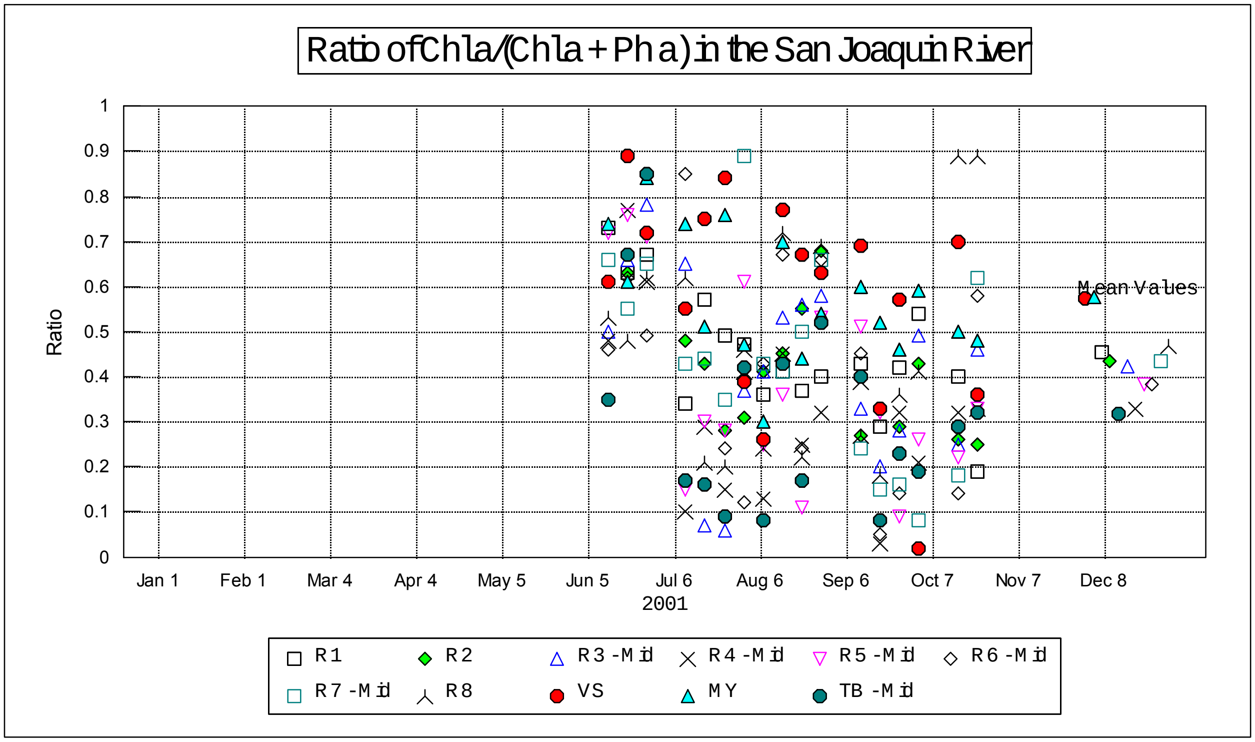


Figure 26. Ratio of Chlorophyll to Chlorophyll + Phaeophytin in the San Joaquin River, 2001.

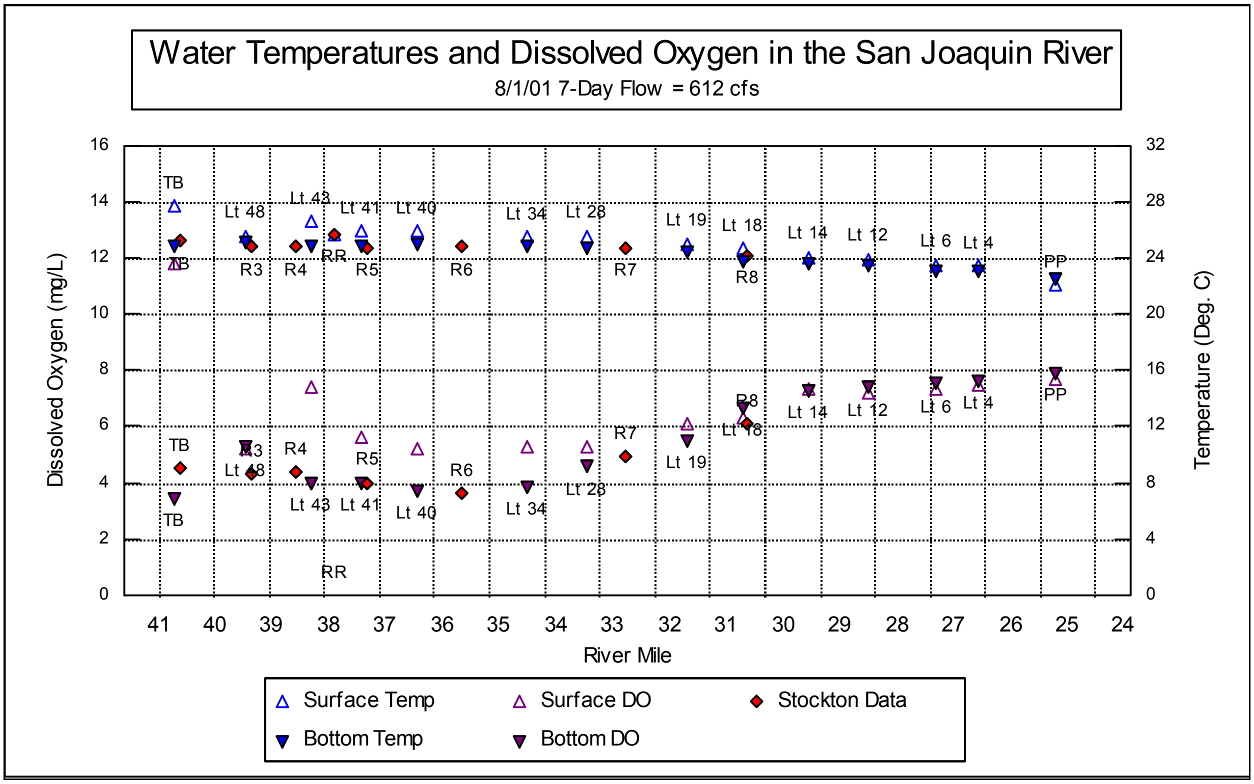


Figure 27a. Water Temperatures and Dissolved Oxygen in the San Joaquin River, August 1, 2001.

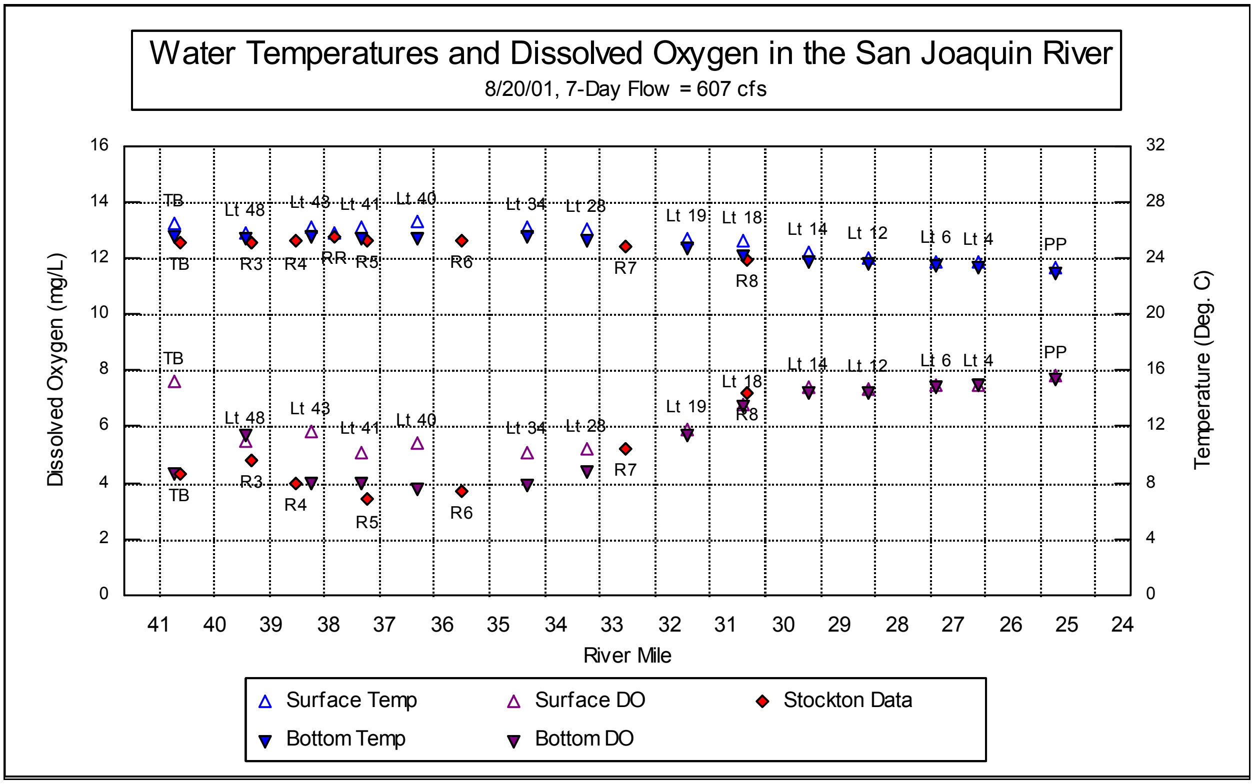


Figure 27b. Water Temperatures and Dissolved Oxygen in the San Joaquin River, August 20, 2001.

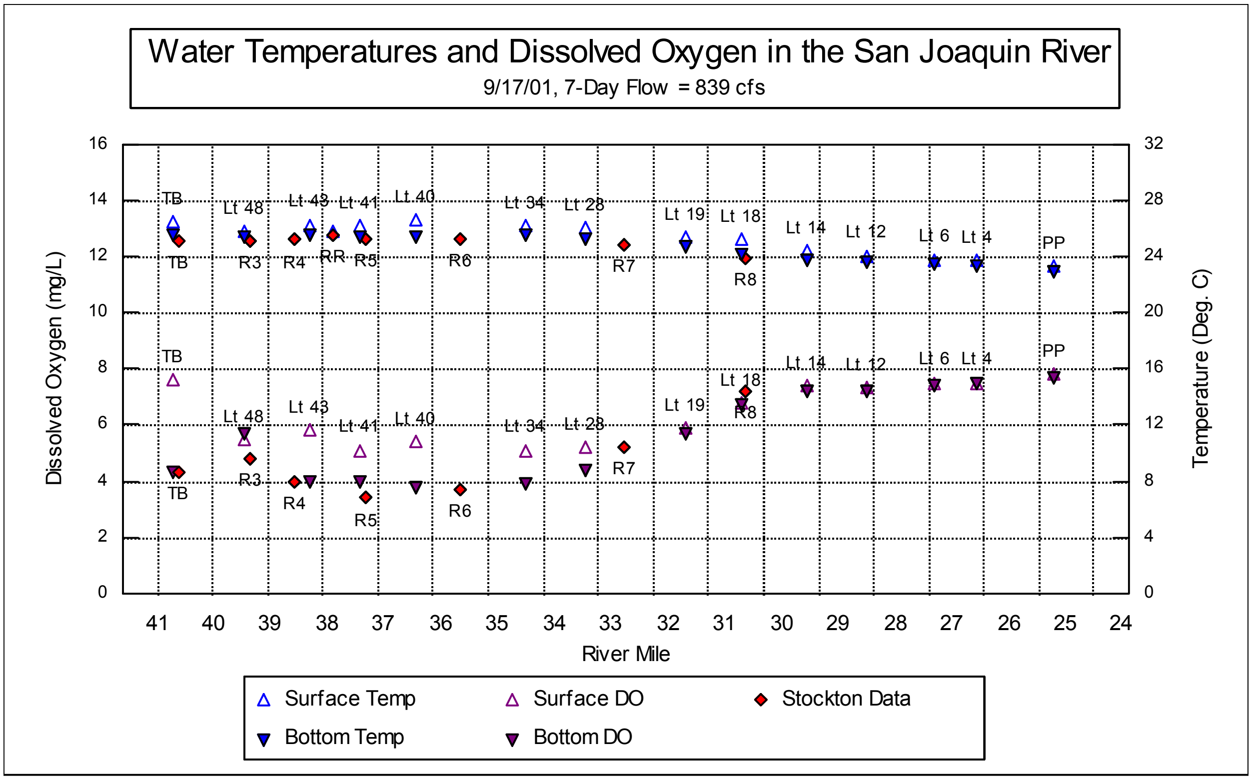


Figure 28a. Water Temperatures and Dissolved Oxygen in the San Joaquin River, September 17, 2001.

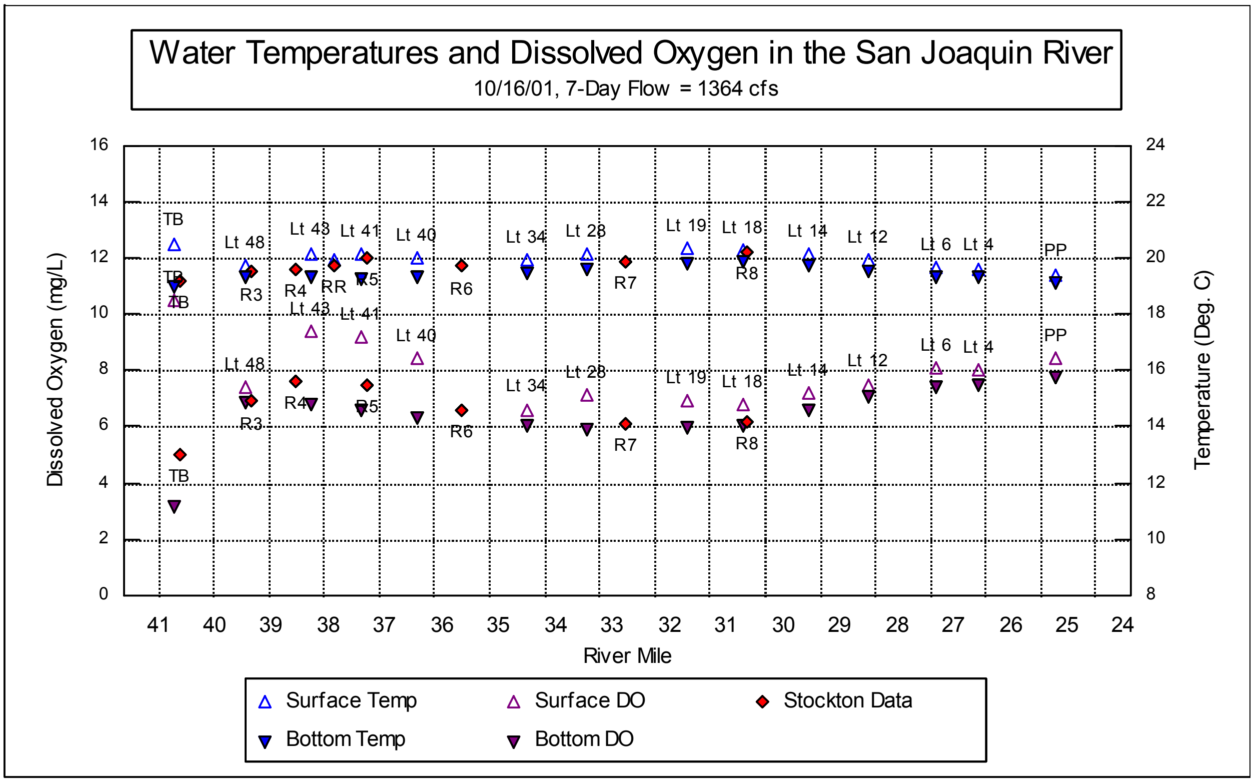


Figure 28b. Water Temperatures and Dissolved Oxygen in the San Joaquin River, October 16, 2001.

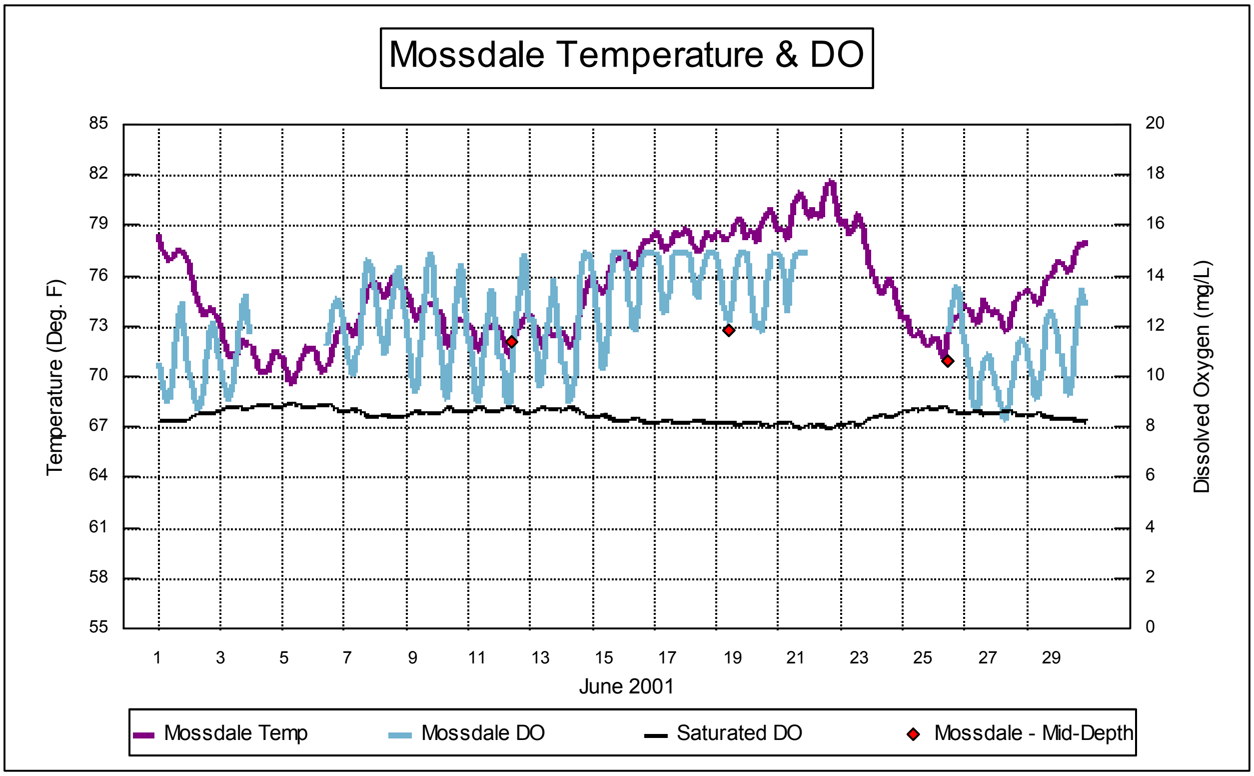


Figure 29a. Hourly Temperature, DO and Saturated DO at Mossdale, June, 2001.

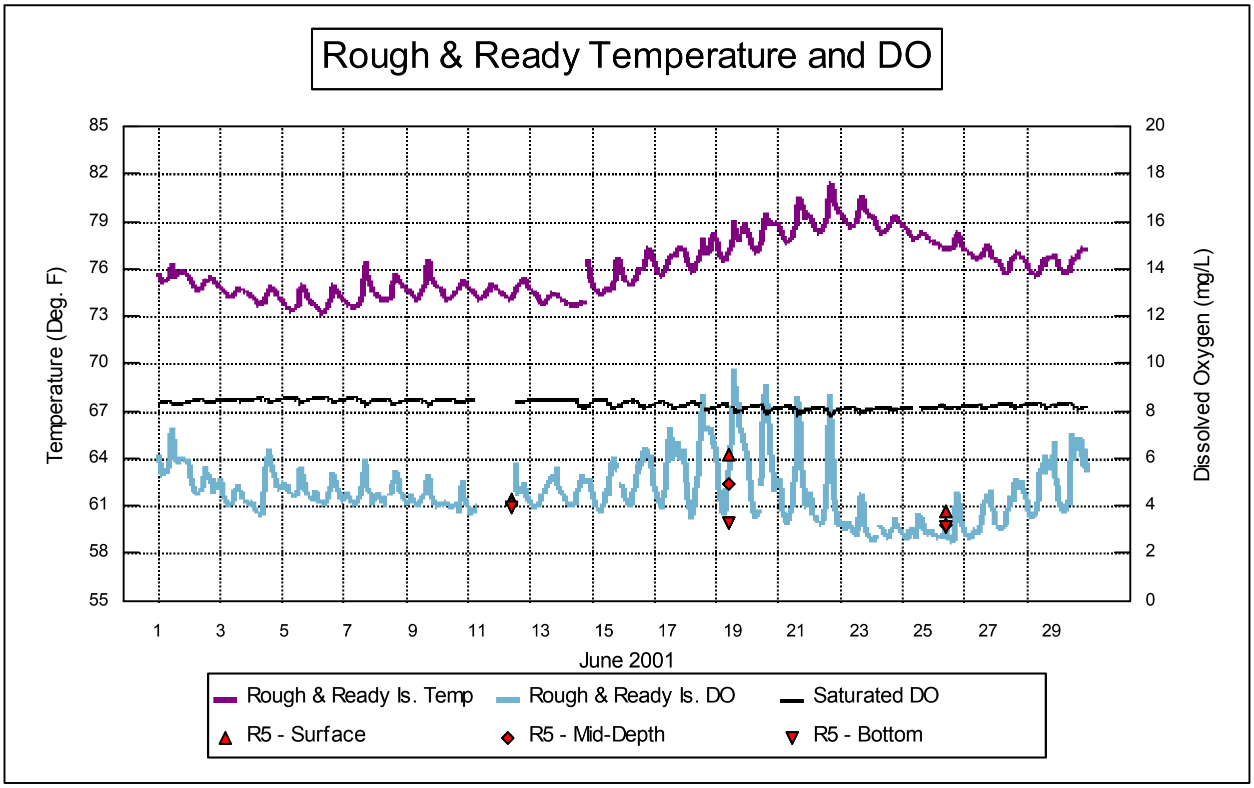


Figure 29b. Hourly Temperature, DO and Saturated DO at Rough & Ready Island, June, 2001.

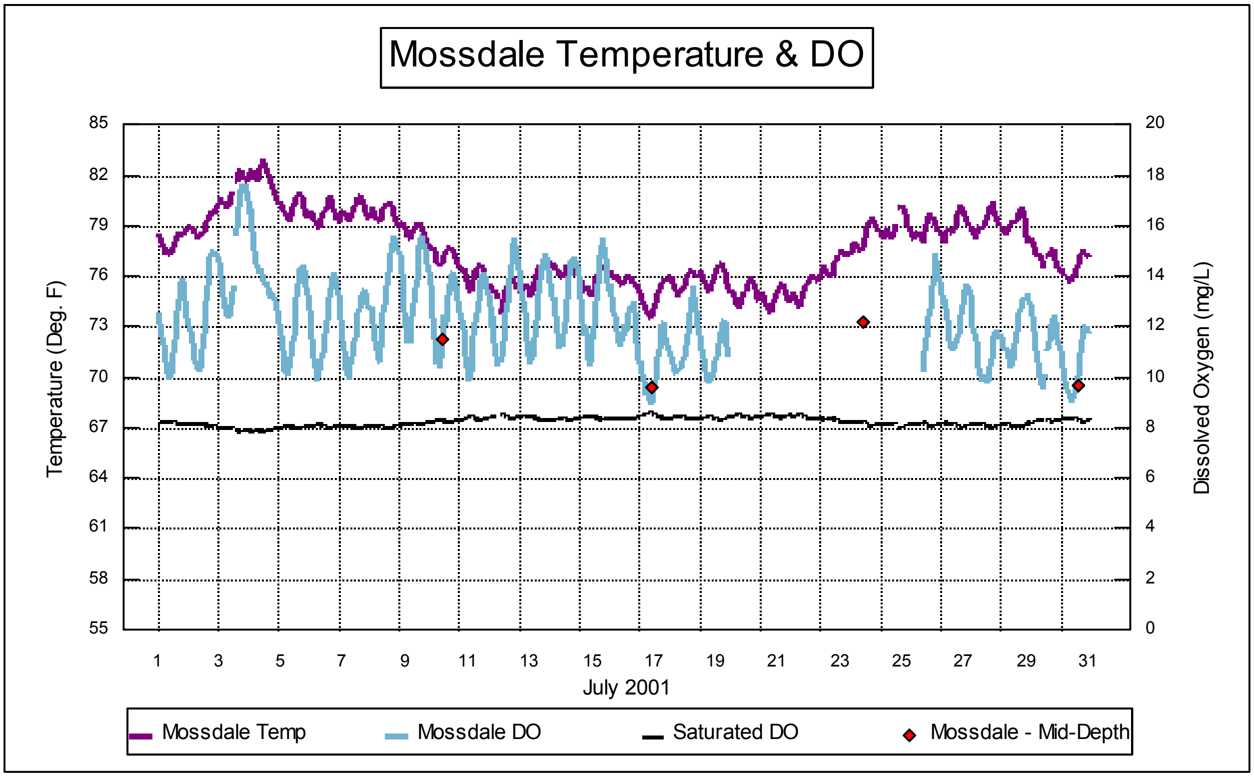


Figure 30a. Hourly Temperature, DO and Saturated DO at Mossdale, July, 2001.

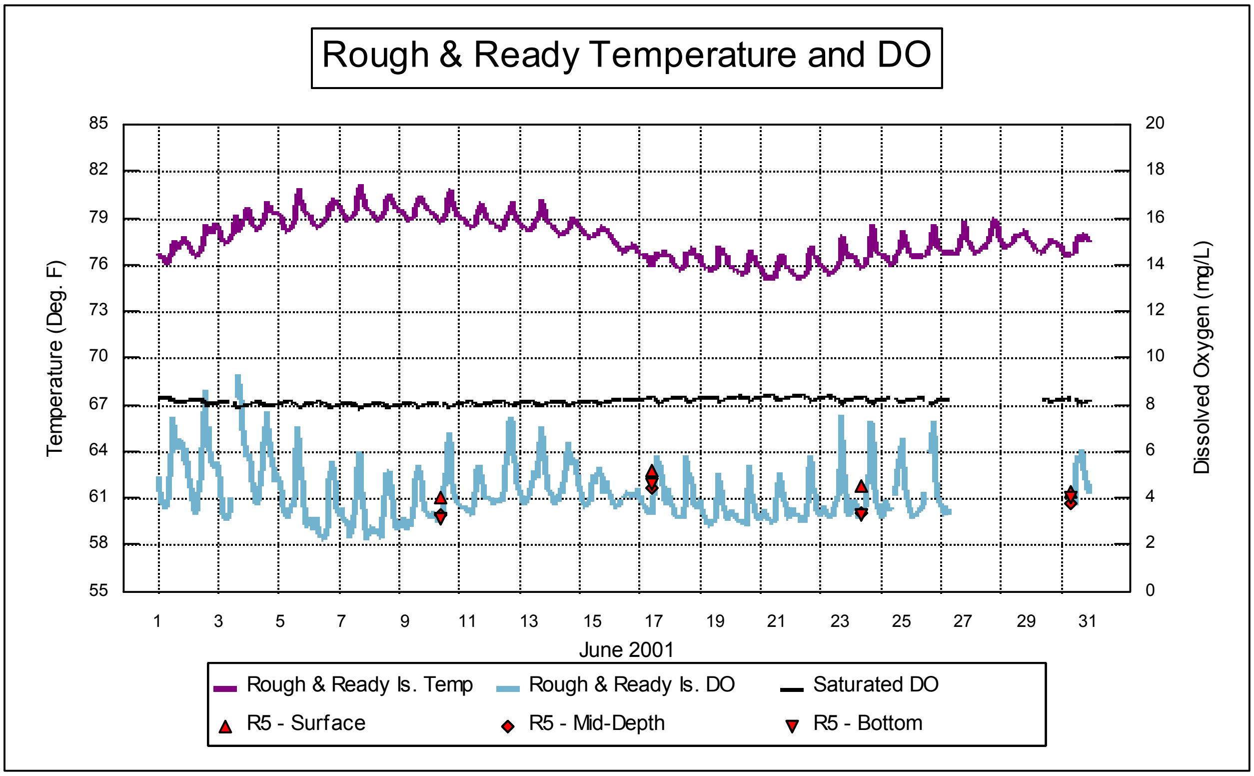


Figure 30b. Hourly Temperature, DO and Saturated DO at Rough & Ready Island, July, 2001.

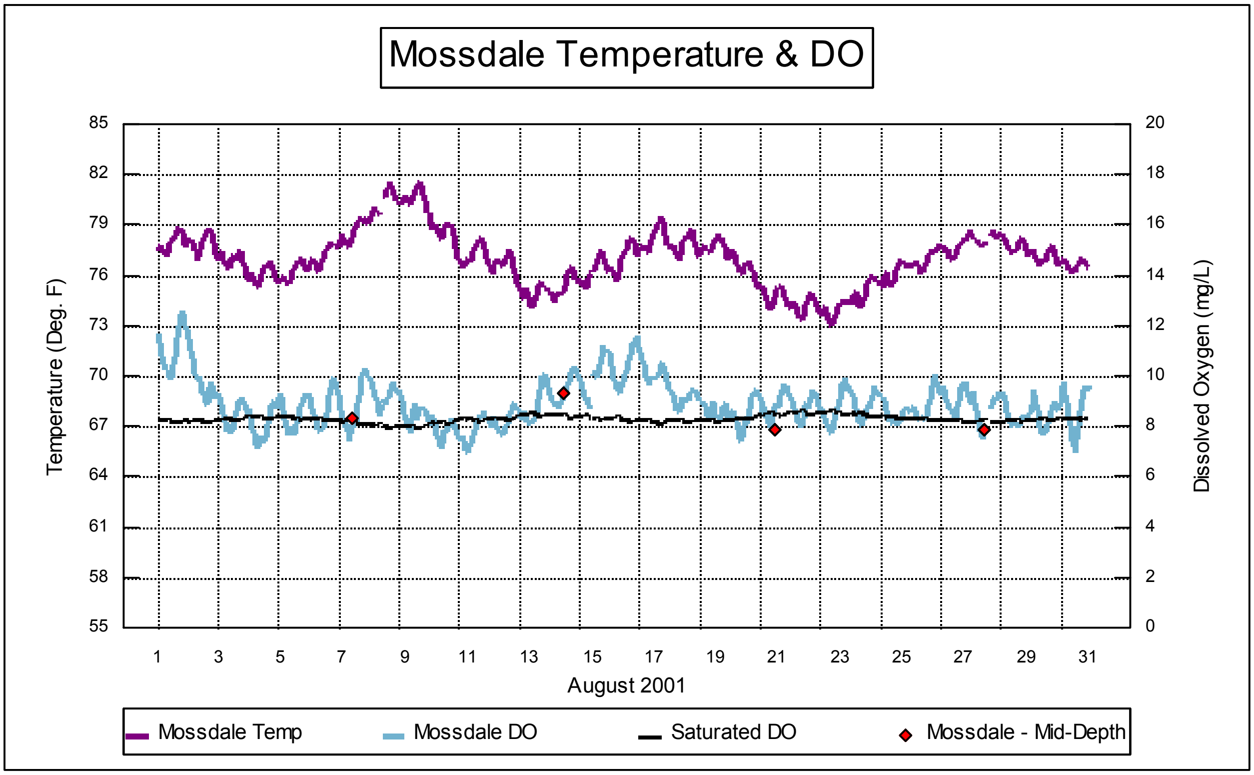


Figure 31a. Hourly Temperature, DO and Saturated DO at Mossdale, August, 2001.

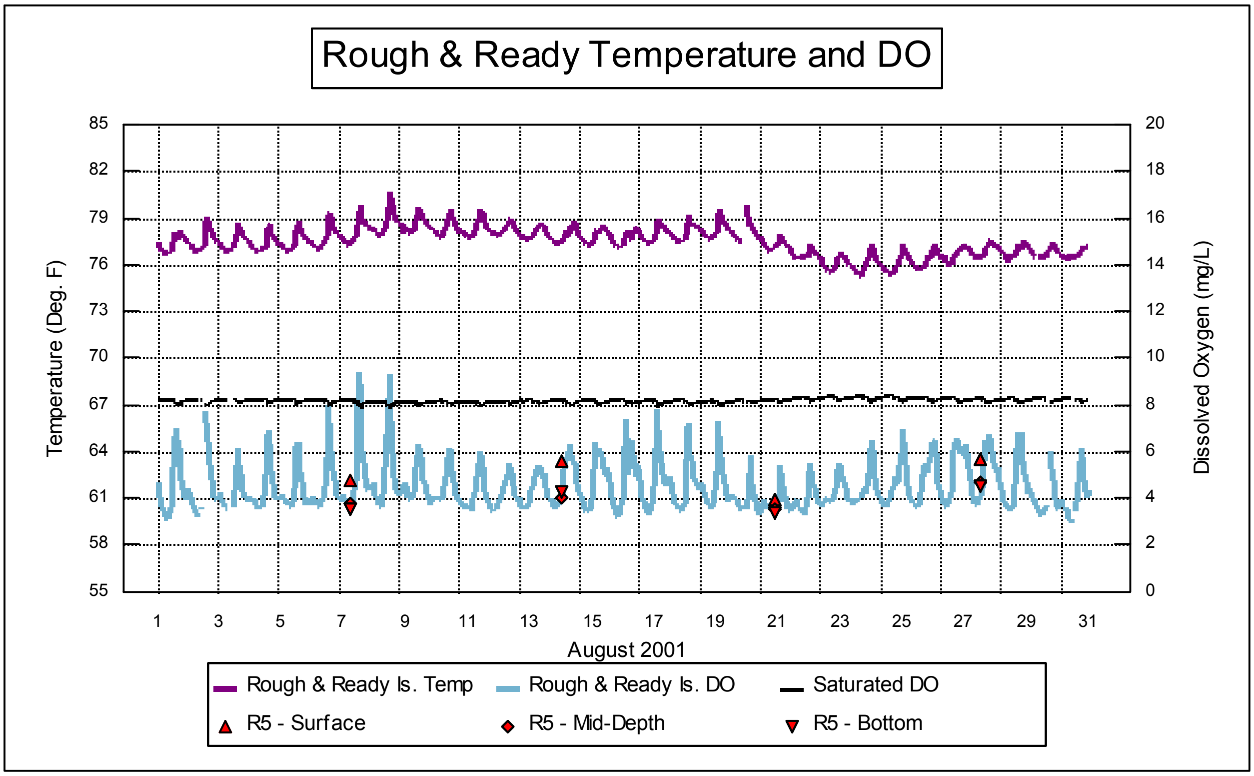


Figure 31b. Hourly Temperature, DO and Saturated DO at Rough & Ready Island, August, 2001.

Tidal Dilution of the Stockton Regional Wastewater Control Facility Discharge into the San Joaquin River

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Executive Summary

Effluent from the City of Stockton's Regional Wastewater Control Facility (RWCF) is discharged into the San Joaquin River about 1.5 miles upstream of the Deep Water Ship Channel (DWSC). The RWCF discharges an average of about 32 million gallons per day (mgd) (50 cubic feet per second [cfs]) through a 4-foot-diameter discharge pipe into about 15 feet of water. The San Joaquin River channel is about 250 feet wide at the RWCF discharge location.

The RWCF discharge is from a circular pipe, so the well-established equations for describing the performance of a round momentum jet can be applied. The jet dilution equation indicates that dilution increases linearly with distance. An initial mixing zone of about 125 feet radius from the discharge will provide an initial jet dilution of about 7–10 and will only extend halfway across the river channel. The opposite side of the river will not be affected by the effluent plume, thus preserving a zone of passage in the river across from the discharge location.

A box model of this tidal mixing process was developed using 2 rows of river segments that move back and forth with the tidal flow to simulate RWCF discharge and mixing conditions in the San Joaquin River. The 15-minute records of stage and flow from the U.S. Geological Survey (USGS) ultrasonic velocity meter (UVM) tidal flow station, located just upstream of the RWCF discharge, are used in the model. Concentrations on both sides of the river at the discharge location, at upstream river sampling station R2 (located about 1 mile upstream from the discharge), and at downstream river sampling station R3 (located 1.5 miles downstream in the DWSC) are calculated for the month of simulated tidal flows and dilution.

This type of model is sometimes referred to as a *Lagrangian model*, meaning that the boxes move upstream and downstream with the tidal flow past the discharge location. The RWCF discharge into the river segments might be compared to a bulk loader that is pouring material into a train with open cars that move back and forth on the tracks. More material is deposited into the cars that move slowly past the bulk loader

Results from the tidal river box model calculations are described and evaluated in this report. Applications of these tidal mixing model results for estimating maximum expected exposure concentrations in the San Joaquin River are discussed.

Tidal River Flow Conditions

San Joaquin River flow past the RWCF discharge is strongly tidal, with a maximum tidal velocity of about 1 ft/sec at the maximum tidal flow of about 3,000 cfs during peak flood and ebb tides. The RWCF effluent will mix into this tidal movement of San Joaquin River water. As the tidal velocity decreases from the maximum current toward slack, more of the RWCF effluent is discharged into a particular river segment and higher effluent concentrations result. The fluctuating tidal flows will sometimes move water past the RWCF discharge location several times before the net San Joaquin River flow pushes the water into the DWSC.

Lateral mixing is assumed to be proportional to the tidal river flow. A field study was conducted to directly measure the lateral spreading of the effluent ammonia concentrations in the river. The calibrated mixing rate was determined to be 1% of the tidal flow, which is about twice the original assumed mixing rate of 0.5% of the tidal flow. Both lateral mixing rates were simulated to evaluate the sensitivity of the tidal dilution patterns to the assumed lateral mixing rate.

Simulated Effluent Concentrations

Table E1 gives a summary of the simulated, tidally averaged concentrations for the east and west side of the river at the downstream station R3, at the discharge location, and at the upstream station R2, for a range of river flows between 150 cfs and 950 cfs. For example, with a river flow of 150 cfs and with the lateral mixing rate of 1% of the tidal flow, the average concentration at the upstream R2 station was 70 for the west side and 69 for the east side. The average concentrations at the discharge location were 148 on the west side and 122 on the east side. The average concentrations at the downstream R3 station were 205 for the west side and 204 for the east side. These east-side and west-side values are nearly identical at R3, but less than the expected steady-state average of 250.

This difference between the steady-state average of 250 and the simulated values at R3 is a result of the large tidal excursion. The ebb tide flow moves low-concentration water from upstream of the RWCF discharge to a location downstream of the R3 station near the end of the ebb tide. Consequently, the tidally averaged concentration at R3 will be less than the expected steady-state value. Concentrations further downstream, beyond the downstream distance of the tidal excursions, will approach an average of 250 for this assumed river flow of 150 cfs.

Table E1. Average Simulated Concentrations for Range of River Flow and Lateral Mixing Rates at the Downstream R3, Discharge Location, and Upstream R2 Stations

Net River Flow/Mix Rate	Average Dilution	Expected River Concentration	Side of River	Downstream R3 Station	Discharge Location	Upstream R2 Station
150	4	250	East	204	119	66
0.5%			West	205	151	73
150	4	250	East	204	122	69
1.0%			West	205	148	70
450	10	100	East	80	40	27
0.5%			West	82	77	33
450	10	100	East	81	43	29
1.0%			West	81	74	30
950	20	50	East	36	26	11
0.5%			West	39	64	16
950	20	50	East	37	30	13
1.0%			West	38	60	14

Measured Effluent Ammonia Concentrations and Lateral Mixing at High Slack Tide

A field survey of the maximum near-field effluent concentrations and mixing of the effluent across the river was conducted to verify the assumed lateral mixing rate. The concentrations of ammonia at several transects across the river were measured at high slack tide just upstream of the RWCF discharge location. The lateral mixing was expected to mix the west-side and east-side concentrations more completely as the distance upstream increased. Lateral concentration profiles were measured at 100-foot increments for the first 500 feet upstream of the discharge. Subsequent measurements were then made at 500-foot increments. The field survey documented the lateral mixing between the discharge and 2,500 feet upstream. At maximum tidal velocity of about 1 ft/sec, water moves upstream 2,500 feet in about 40 minutes.

The RWCF effluent ammonia concentration was about 25 milligrams per liter (mg/l). The net flow passing Stockton was estimated to be about 1,250 cfs. The RWCF discharge flow was about 35 cfs, so the fully mixed river concentration would average about 0.7 mg/l (i.e., a river dilution of about 35). The near-field ammonia concentration was expected to be somewhat higher, especially during the slack-high- tide event. The jet mixing is expected to always provide a dilution of at least 5 within 125 feet of the discharge pipe, so the maximum river ammonia concentration was expected to be less than 5 mg/l.

The ammonia concentrations were about 0.5–0.75 mg/l higher than the average upstream river concentration of about 1mg/l at all near-field locations. This increase above the river concentration probably resulted from the effluent during the previous tidal cycle. The near-field ammonia concentrations were higher than 1.75 mg/l only at the 10% and 25% lateral stations for transects from 100 feet, 200 feet, 300 feet, and 400 feet upstream. The 1000-foot transect showed some lateral mixing of ammonia to the center (50%) station, raising the center concentration to about 2 mg/l. The ammonia concentrations were not completely mixed across the river at the 1000-foot transect.

The 50% lateral location sample was about the same as the 25% lateral location at the 2,000-foot and 2,500-foot transects. The 75% lateral location sample was within 10% of the average at the 2,500-foot transect. These results indicate that complete lateral mixing requires a distance of about 0.5 miles. These results were used to calibrate the lateral mixing rate used in the box model to be 1% of the tidal flow.

Interpretation of Tidal Mixing Results for Estimating Maximum Exposure Concentrations

The box model predicts maximum instream concentrations at the discharge location during slack tide. As the current increases after slack, the plume will move with the flow and disperse across the river, gradually decreasing in concentration from the slack-tide maximums. An evaluation of maximum 15-minute concentrations under various net flow conditions, ranging from 150 cfs to 950 cfs, indicates that peak river concentrations range from about 30% to 40% of the effluent concentration.

The model predictions can be used to evaluate dilution conditions and dilution credits associated with acute and chronic water quality standards. The hourly maximum concentration predicted by the model is slightly less than the 15-minute peak concentrations, because the slack periods generally do not persist for an hour. Maximum 1-hour average west-side concentration at the discharge location is about 33% effluent at a net flow of 150 cfs. Because the peak hourly concentration does not exceed 33% at any net flow, a dilution credit equal to or greater than 2.0 (i.e., concentration dilution of 3) is appropriate for establishing 1-hour acute limits for the RWCF discharge.

The chronic standard represents a long-term average concentration that is significantly less than the peak concentrations that occur during slack-tide conditions. Over 4 days, a drifting organism will be carried upstream and downstream past the discharge location by the tidal flows. Most of this time will be spent at a concentration that is less than the steady-state average for the net flow condition. Only as the organism is transported downstream past the tidal excursion zone will the organism be exposed to the average concentration expected from the net flow, discharge, and effluent concentration.

Contents

Page

Tables and Figures

Tables **Page**

Figures **Follows Page**

Tidal Dilution of the Stockton Regional Wastewater Control Facility Discharge into the San Joaquin River

Introduction

Effluent from the City of Stockton's Regional Wastewater Control Facility (RWCF) is discharged into the San Joaquin River about 1.5 miles upstream of the Deep Water Ship Channel (DWSC). The RWCF discharges an average of about 32 million gallons per day (mgd) (50 cubic feet per second [cfs]) through a 4-foot-diameter discharge pipe into about 15 feet of water. The top of the pipe is under only about 5 feet of water at low tide (i.e., 0 feet mean sea level [msl]). The outlet pipe opening is about 25 feet from the west bank of the San Joaquin River. The water depth is a maximum of about 20 feet, with an average depth of less than 15 feet. The San Joaquin River channel is about 250 feet wide at the RWCF discharge location.

A field study of the local mixing of RWCF effluent in the San Joaquin River was performed by Systech Engineering in July 1992 to support the development of the Stockton Water Quality Model (see chapter IV of Philip Williams & Associates 1993). Rhodamine WT dye was released for 1 hour into the RWCF effluent during ebb, low slack, and flood tide conditions. The near-field dye study results are summarized in figure IV-11 of the study report (Philip Williams & Associates 1993).

During all 3 tide conditions, the dye plume was observed to spread only about halfway across the channel. The centerline dilution of the jet was measured at about 10 (dye concentration was about one-tenth of the initial effluent dye value) at stations located

100–150 feet downstream or upstream of the outlet pipe. This observed dye pattern indicates that about 9 parts of river water mixed with 1 part of effluent and moved upstream or downstream in the west side of the river channel.

No dye was observed across the river centerline, indicating that the jet was apparently deflected by the tidal current and all the RWCF effluent was initially distributed in the west side of the river channel. Because the river channel is about 250 feet wide, this observation suggests that initial mixing of the effluent plume will take place within 125 feet across the San Joaquin River and 125 feet upstream or downstream. There will always be a zone of passage along the opposite bank of the river where dilution will be greater and effects from the RWCF effluent will be reduced.

Several U.S. Environmental Protection Agency (EPA) mixing models (e.g., CORMIX) can calculate effluent dilutions at various distances from a specified jet discharge. However, these EPA models only give results for steady-state river conditions; they do not evaluate the effects of a continuous discharge into fluctuating tidal flows. Therefore, a relatively simple box model was developed to evaluate the RWCF effluent dilution patterns as a function of net river flow and measured tidal fluctuations.

A box model of this tidal mixing process was developed using 2 rows of river segments that move back and forth with the tidal flow to simulate RWCF discharge and mixing conditions in the San Joaquin River. The 15-minute records of stage and flow from the U.S. Geological Survey (USGS) ultrasonic velocity meter (UVM) tidal flow station, located just upstream of the RWCF discharge, are used in the model.

The RWCF discharge and concentration is specified and the resulting concentrations in the 2 rows of river segments are calculated for a specified number of tidal cycles (i.e., 30 days). Concentrations on both sides of the river at the discharge location, at upstream river sampling station R2 (located about 1 mile upstream from the discharge), and at downstream river sampling station R3 (located 1.5 miles downstream in the DWSC) are calculated for the month of simulated tidal flows and dilution. Some example results from the tidal river box model calculations are described and evaluated below. Applications of these tidal mixing model results for estimating maximum expected exposure concentrations in the San Joaquin River are discussed.

Momentum Jet Mixing and Dilution

The RWCF discharge is from a circular pipe, so the well-established equations for describing the performance of a round momentum jet can be applied. The momentum jet length scale (Fischer et al. 1979) is calculated to be discharge area $^{1/2}$ (i.e., 3.5 feet for a diameter of 4.0 feet). All jet parameters such as velocity, dilution, and width can be described as functions of this jet-scale length.

The area of the discharge pipe is about 12.5 square feet. With a RWCF discharge of 50 cfs, the initial discharge velocity will be about 4 feet per second (ft/sec) (i.e., 50/12.5). The round jet velocity equation indicates that centerline jet velocity decreases linearly with distance, once the gaussian-shaped velocity distribution is established at a distance of about 7 times the jet length-scale (i.e., 25 feet for the RWCF discharge pipe):

$$\text{Centerline velocity (ft/sec)} = 7 \bullet \text{jet length-scale/distance} \bullet \text{initial velocity}$$

The centerline (i.e., maximum) jet velocity is therefore reduced to 2 ft/sec at a distance of 50 feet, 1 ft/sec at a distance of 100 feet, and about 0.5 ft/sec at 200 feet.

The round jet width equation indicates that the width increases with distance:

$$\text{Jet width} = 0.25 \bullet \text{distance}$$

The RWCF jet therefore has a width of about 12.5 feet at a distance of 50 feet and a width of 25 feet at 100 feet. The jet width is equal to the maximum water depth of 20 feet at a distance of about 75 feet. The jet geometry will become distorted as the jet fills the water column.

The jet centerline (i.e., minimum) dilution equation indicates that dilution increases linearly with distance:

$$\text{Centerline dilution} = 0.25 \bullet \text{distance/jet length-scale}$$

The centerline dilution of the RWCF jet is therefore about 3.5 at a distance of 50 feet, about 7 at a distance of 100 feet, and about 10 at a distance of 150 feet. The average dilution in the round jet, with an assumed gaussian distribution of concentration in the jet, would be about 40% higher because the average concentration in a gaussian distribution is about 70% of the centerline concentration.

The zone of maximum effluent concentration will depend on the direction of the discharge jet that is deflected by the tidal flow. However, an initial mixing zone of about 125 feet radius from the discharge will provide an initial jet dilution of about 7–10 and will only extend halfway across the river channel. The opposite side of the river will not be affected by the effluent plume, thus preserving a zone of passage in the river across from the discharge location.

A series of calculations with the CORMIX model were made to verify these basic jet equations for a range of river flow. For example, with no river flow (i.e., slack tide), the simulated RWCF discharge jet moved across the river to the center of the river (125 feet) with a centerline dilution of about 8, meaning that the centerline concentration is about 12.5% (i.e., one-eighth) of the effluent concentration. The average jet concentration should be about 70% of the centerline concentration, or about 9% of the effluent concentration (with an average dilution of 11). The plume will continue to push across the river until it encounters the opposite bank and will begin to recirculate back across the river channel if the slack period lasts for an extended period of time.

With a tidal velocity of 1.0 ft/sec (maximum tidal flow conditions at Stockton), the simulated RWCF discharge jet moves about 120 feet toward the middle of the river before the jet momentum is dissipated. The centerline of the jet has a calculated dilution of 5 at this point, meaning that the centerline concentration is 20% of the effluent concentration. The average jet concentration should be about 70% of the centerline concentration, or about 15% of the effluent concentration (with an average dilution of about 7).

The CORMIX-calculated effluent plume then spreads laterally as it flows downstream (or upstream with the next flood tide). The CORMIX model can only roughly estimate the rate that the effluent will spread across the river and the distance downstream before the effluent will become evenly mixed across the river. An average of the lateral mixing coefficients that have been observed in river mixing studies is used in the CORMIX calculations. The lateral mixing is assumed to be proportional to the downstream tidal river flow.

The lateral mixing (dispersion coefficient) is assumed to be proportional to the shear velocity and depth (Fischer et al. 1979) as referenced by EPA in the *Technical Support Document for Water Quality-Based Toxics Control* (U.S. Environmental Protection Agency 1991):

$$\text{Dispersion coefficient (square feet per second [ft}^2\text{/sec])} \\ = 0.6 \bullet \text{depth (ft)} \bullet \text{shear velocity (ft/sec)}$$

The shear velocity is estimated from the slope and depth as

$$\text{Shear velocity (ft/sec)} = \\ [g\ (\text{ft/sec}^2) \bullet \text{depth (ft)} \bullet \text{slope (ft/ft)}]^{1/2}$$

where g is the gravitational acceleration (32.2 ft/sec^2).

The slope is estimated from the measured tidal velocity, using the Manning equation, as

$$\text{Slope}^{1/2} = n \bullet \text{velocity} / [1.486 \bullet R^{2/3}]$$

where *n* is the Manning coefficient (0.03) and *R* is the hydraulic radius.

For the river cross section near the RWCF, the hydraulic radius is about 11 feet, so the $R^{2/3}$ term is about 5. For Manning *n* of 0.03 and a depth of 15 feet, the lateral dispersion is proportional to the tidal velocity:

$$\text{Lateral dispersion (ft}^2\text{/sec)} = 0.8 \bullet \text{tidal velocity (ft/sec)}$$

This equation for lateral dispersion is incorporated into the box model. Because the lateral mixing rate is uncertain and a lower mixing will result in higher concentrations in the west side of the river, a range of mixing rates were simulated and compared (U.S. Environmental Protection Agency 1991). A field study was conducted to directly measure the lateral spreading of the effluent ammonia concentrations in the river. The results have been used to confirm the lateral mixing simulated with the model.

Tidal River Flow Conditions

San Joaquin River flow past the RWCF discharge is strongly tidal, with a maximum tidal velocity of about 1 ft/sec. The tidal flow is about 3,000 cfs during peak flood and ebb tides, and the cross-sectional area is about 3,000 square feet at low tide (0 feet msl), and about 4,000 square feet at high tide (4 feet msl). The tidal flows correspond to a tidal excursion (i.e., water movement) that can be tracked back and forth with the tides. The RWCF effluent will mix into this tidal movement of San Joaquin River water. The fluctuating tidal flows will sometimes move water past the RWCF discharge location several times before the net San Joaquin River flow pushes the water into the DWSC. As the tidal velocity decreases from the maximum current toward slack, more of the RWCF effluent is discharged into a particular river segment and higher effluent concentrations result.

These tidal flow conditions can be simulated with a simple box model representation. The river channel is represented by 2 rows of water segments, as illustrated in figure 1. Each water segment (box) has a constant volume of 150,000 cubic feet. The water segments are assumed to move downstream or upstream with the tidal velocity corresponding to the UVM flow measured just upstream of the RWCF. The channel depth and river cross section increases with tidal stage. The channel cross section is 3,000 square feet and is approximately rectangular (i.e., 250 feet wide and 12 feet deep) at a stage of 0 feet msl. The channel cross section increases to 4,000 square feet (i.e., 250 feet wide and 16 feet deep) at a stage of

4 feet msl. A tidal flow of 3,000 cfs corresponds to a velocity of between 1.0 ft/sec and 0.75 ft/sec, depending on the tidal stage.

The box model has 2 rows of segments, so the segment cross section area is half of the river cross section area. The segment width is 125 feet and the length with a stage of 0 feet would be 100 feet. At high stage of 4 feet, the segment length would be 75 feet. At low tide and maximum velocity of 1 ft/sec, the segments are moving past the discharge location at a rate of 1 segment every 100 seconds. In each 15-minute tidal measurement interval (900 seconds), about 9 segments move past the discharge. At slower velocities, fewer segments move past the discharge.

Tidal Mixing of Regional Wastewater Control Facility Discharge

Based on the results of the 1993 dye study and the CORMIX calculations, the effluent is assumed to enter only the nearest (west) river segments if the tidal flow is greater than 0.1 ft/sec (i.e., more than 1 segment moves past the discharge in a 15-minute time step). During relatively stagnant conditions (i.e., slack tide), when the discharge during a 15-minute tidal interval enters a single segment, the effluent plume is assumed to move across the river and enter the east side segment in a recirculation pattern. The effluent flow is mixed completely within the segment volume receiving the discharge. As the segment is transported with the tide, lateral dispersion mixes the contents of the adjacent west and east segments at a rate determined by the tidal velocity. This type of model is sometimes referred to as a *Lagrangian model*, meaning that the boxes move upstream and downstream with the tidal flow past the discharge location. The RWCF discharge into the river segments might be compared to a bulk loader that is pouring material into a train with open cars that move back and forth on the tracks. More material is deposited into the cars that move slowly past the bulk loader.

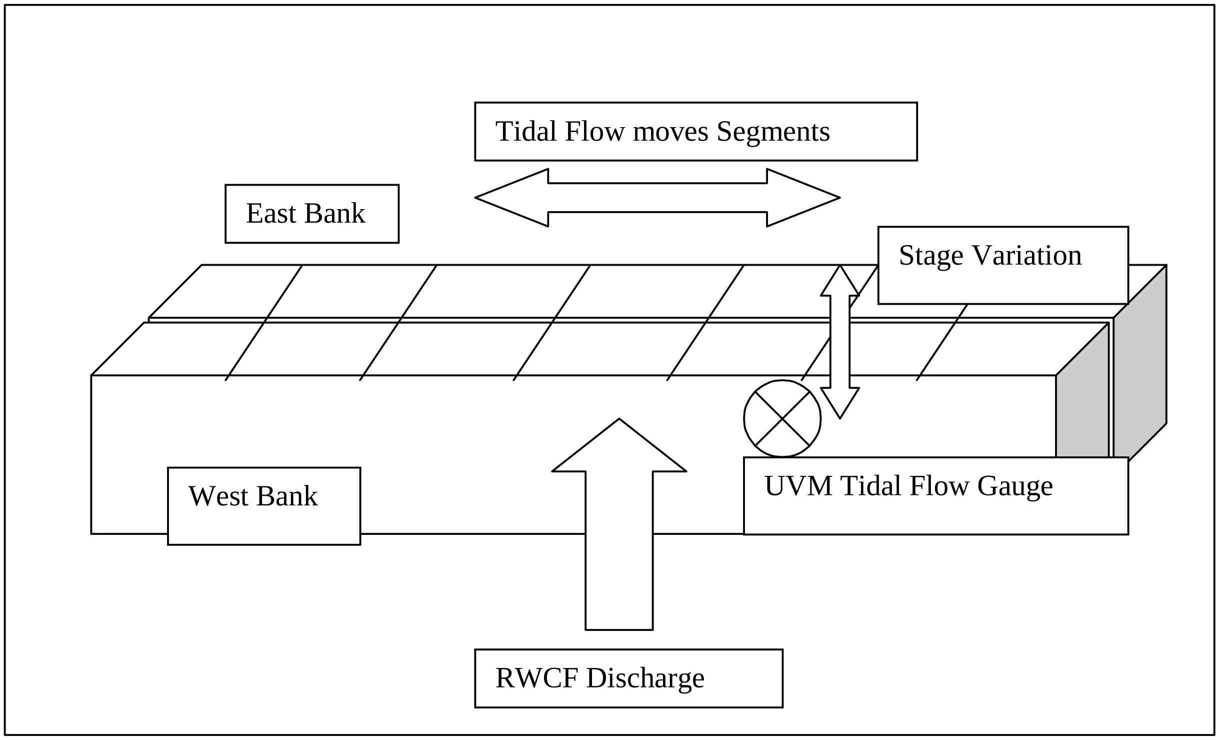


Figure 1
Layout of Box Tidal Flow Model for Evaluating Dilution of RWCF Discharge into the San Joaquin River

For example, with an assumed discharge of 50 cfs and a tidal flow of 1,500 cfs with a stage of 0 feet (low tide), the segment velocity would be 0.5 ft/sec and the effluent would discharge into each segment for about 200 seconds. The effluent volume entering the segment would total 10,000 cubic feet (i.e., 200 sec • 50 cfs) or 6.7% of the segment volume. This would represent a segment dilution of about 15 (150,000/10,000) for this tidal flow. As indicated in the jet analysis, some of this dilution would result from the jet momentum mixing (dilution of about 7–10). The additional dilution results from the nature of the box model that considers each river volume segment to be fully mixed. This assumed mixing within each segment is the main reason for selecting small volume segments and tracking many of them to simulate the full range of concentrations resulting from the dynamic tidal flow conditions.

The amount of lateral river mixing between the segment volumes is specified as a function of the tidal velocity. This mixing will slowly even out the effluent concentrations across the river. The lateral dispersion coefficient can be used to estimate the exchange flow for each pair of segments. The exchange flow is estimated as

Exchange flow (cfs) =
Area • lateral dispersion coefficient/ Length

where length is defined as half the river width (125 feet) and the area is the area between the two segments (i.e., 100 ft length • 15 ft depth). The lateral dispersion coefficient was determined to be 0.8 • tidal velocity (ft/sec), so the lateral exchange flow between segments is about 9.6 times the tidal velocity. This corresponds to a maximum exchange flow of about 10 cfs when the tidal flow is 3,000 cfs (i.e., 0.33% of the tidal flow). For modeling purposes, the lateral mixing rate is specified as 0.5% of the tidal flow as the most likely mixing rate. This assumed mixing rate might be even higher to account for the river bend near the discharge and because the reversing tidal flows are expected to produce more mixing than steady river flows. A lateral mixing rate of 0.5% of the tidal flow is equivalent to mixing about 6% of the segment volumes in each 15-minute time period during maximum tidal flows, which may last for several hours during each tidal cycle.

A field survey was conducted to confirm the assumed lateral mixing rate. Ammonia measurements were taken near opposite banks of the river and from the 25%, 50%, and 75% lateral positions at several stations upstream from the RWCF discharge at high slack tide to track the lateral mixing as the RWCF effluent mixed across the river. The results are described in a later section of this report. The calibrated mixing rate was determined to be 1% of the tidal flow, which is about twice the original assumed mixing rate of 0.5% of the tidal flow. Both lateral mixing rates were simulated to evaluate the sensitivity of the tidal dilution patterns to the assumed lateral mixing rate.

Simulation of Tidal Dilution of Regional Wastewater Control Facility Discharge into the San Joaquin River

Figure 2a shows the tidal flow of water in the San Joaquin River near the RWCF for an example period of 30 days from the September 1999 Stockton UVM measurements. Figure 2b shows the corresponding tidal stage variation during this same 30-day period. The actual tidal flows have been adjusted in the model to give a steady net downstream flow of 150 cfs, which is the estimated lowest likely net river flow passing Stockton. The RWCF discharge of 50 cfs is assumed to be constant during the month of tidal simulation. The long-term average dilution for these flow and discharge conditions would therefore be 4 (i.e., [discharge + river flow] / discharge). The downstream river concentration would be equal to 25% of effluent if this were a steady river discharge situation. The simulated effluent concentration is set at 1,000, so the expected average downstream concentration should be 250 under steady-state conditions.

River concentrations will be highest during an extended period of low net river flow. The tidal flow will mix the effluent into a portion of the river volume that corresponds to the tidal mixing volume (the volume of water moving past the discharge location and receiving some effluent during a tidal cycle). Results from a series of simulations will be shown, for a range of flow from 150 cfs to 950 cfs, to illustrate the increased dilution and reduction in the tidal variations provided by greater net river flows.

Figure 3a shows the simulated location of the discharge relative to the moving river segments corresponding to the tidal flow variations during the month of simulation. Because the net downstream flow is 150 cfs, the location of the RWCF discharge moves to higher segments over time at an average rate of 43 segments per day (1,290 for the month). To avoid having to track so many segments, the downstream segments are dropped from the model at the end of each day (or more often if the river flow is high). These downstream segments do not influence the model results because they have been displaced far downstream from the discharge and lateral mixing is complete by this time. Figure 3b shows the adjusted position; the number of segments being dropped at the end of each day is shown with a + symbol.

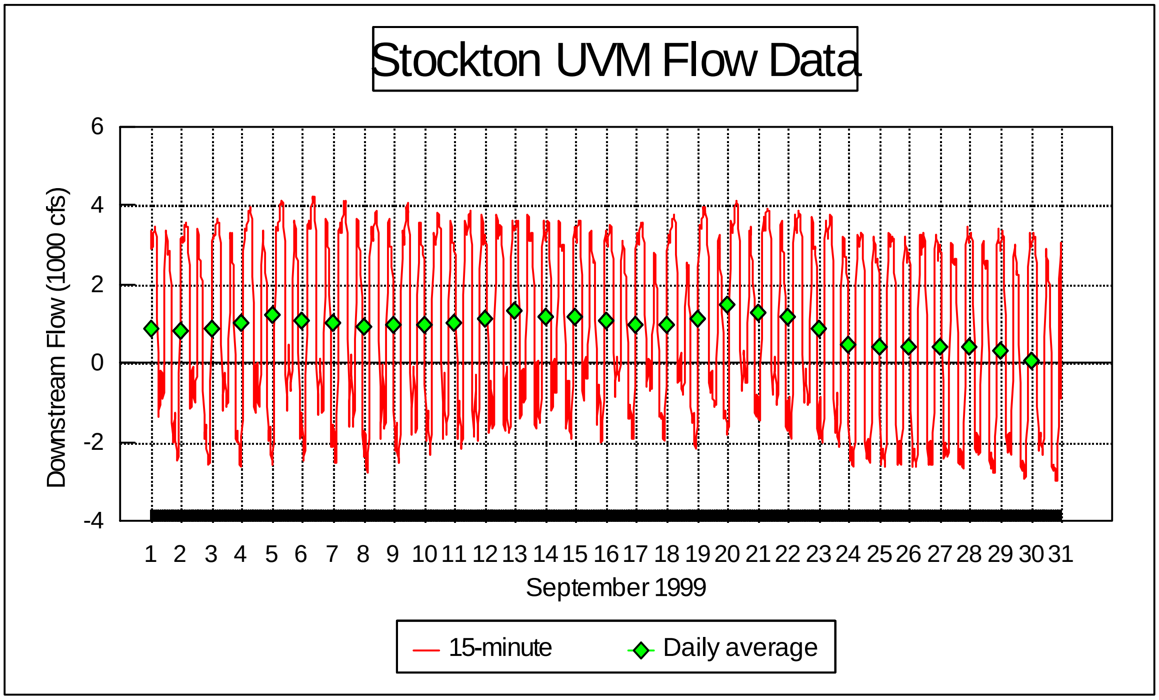


Figure 2a. Tidal Flow at Stockton UVM with Net River Flow of 100 cfs

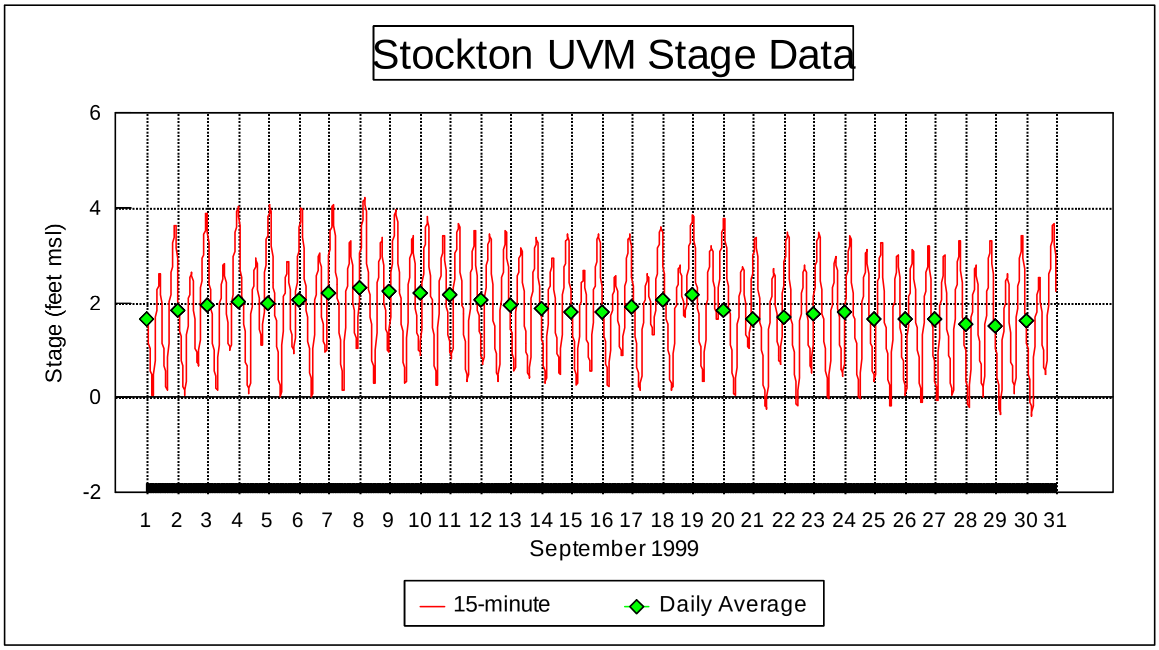


Figure 2b. Tidal Stage Variation at RWCF

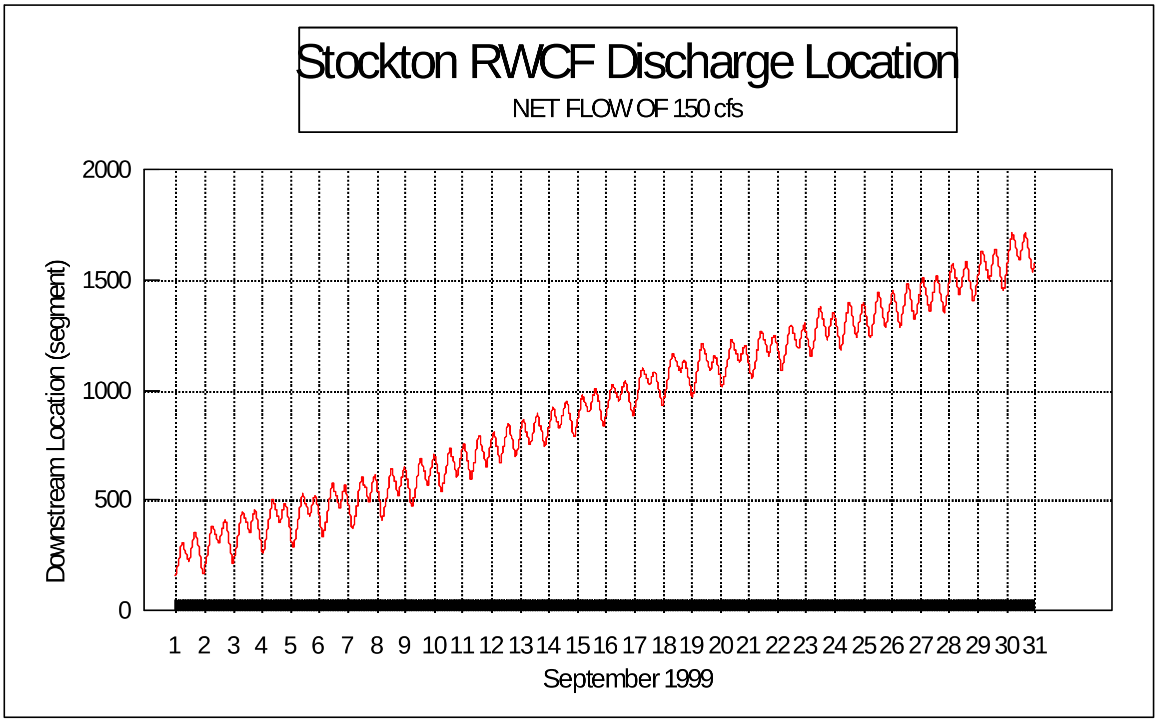


Figure 3a. Tidal Movement of RWCF Discharge with 100 cfs River Flow

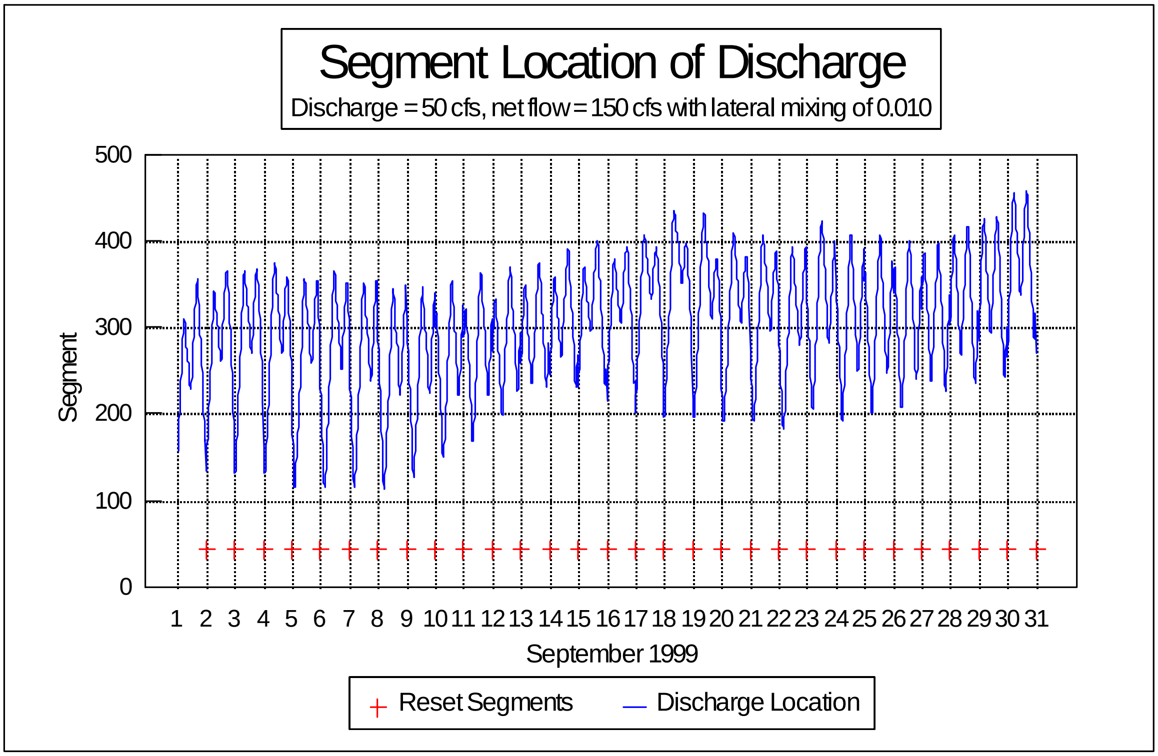


Figure 3b. Adjusted Location of RWCF Discharge Showing Tidal Movement of Segments

The tidal mixing model assumes that the RWCF discharge moves along the row of river segments, adding effluent to the segment volumes. By drawing a horizontal line through the tidal position of the discharge (figure 3a), it is possible to determine the number of times that a water volume will be influenced by the discharge. During periods of low net river flows, tidal flows generally move the water past the RWCF effluent for about 5–7 days. During this time, the water may have effluent added more than 20 discrete times (i.e., during ebb and flood periods of more than 10 tidal cycles). The water will move through the tidal mixing volume faster and have effluent added fewer times at higher river flows.

The difference between the daily maximum and minimum discharge position is an approximation of the tidal mixing volume. Figure 3a indicates that the tidal mixing volume extends about 200 segments, with a corresponding volume of about 1,400 acre-feet (af) (each pair of river segments has a combined volume of about 7 af). The tidal mixing volume changes with the lunar tidal cycle, and is smallest during the middle of the month (i.e., days 10–15) when the neap tides have the smallest tidal excursion (i.e., 2 nearly equal tides each day). The tidal mixing volume is about 150 segments (1,050 af) during this period of minimum tidal fluctuation each month.

River Concentrations with a Net Flow of 150 cfs

Figure 4 shows the simulated river concentrations at the discharge location during the month with an assumed river flow of 150 cfs and a lateral mixing rate of 1% of the tidal flow. Both the west-side and east-side river concentrations are shown as 15-minute values that fluctuate with the tidal flow. The maximum concentrations correspond to periods when the tidal flow velocity is lowest. The maximum west-side concentrations are greatest during the portions of the lunar tidal cycle when the mean tide stage is increasing (i.e., around days 10 and 24). The maximum west-side concentrations range from about 300 to 400, with an assumed effluent concentration of 1,000. The minimum concentrations correspond to periods during the day when the tidal flows are highest. The minimum east-side concentrations correspond to these same periods of maximum ebb (downstream) flow when fresh river water is moving past the discharge. The east-side concentrations are slightly less than the west-side concentrations.

The assumed lateral mixing rate is sufficient to maintain nearly complete mixing across the river with the relatively high tidal flows that are measured in this portion of the San Joaquin River. The greatest differences between the west-side and east-side concentrations occur during the slack high tides.

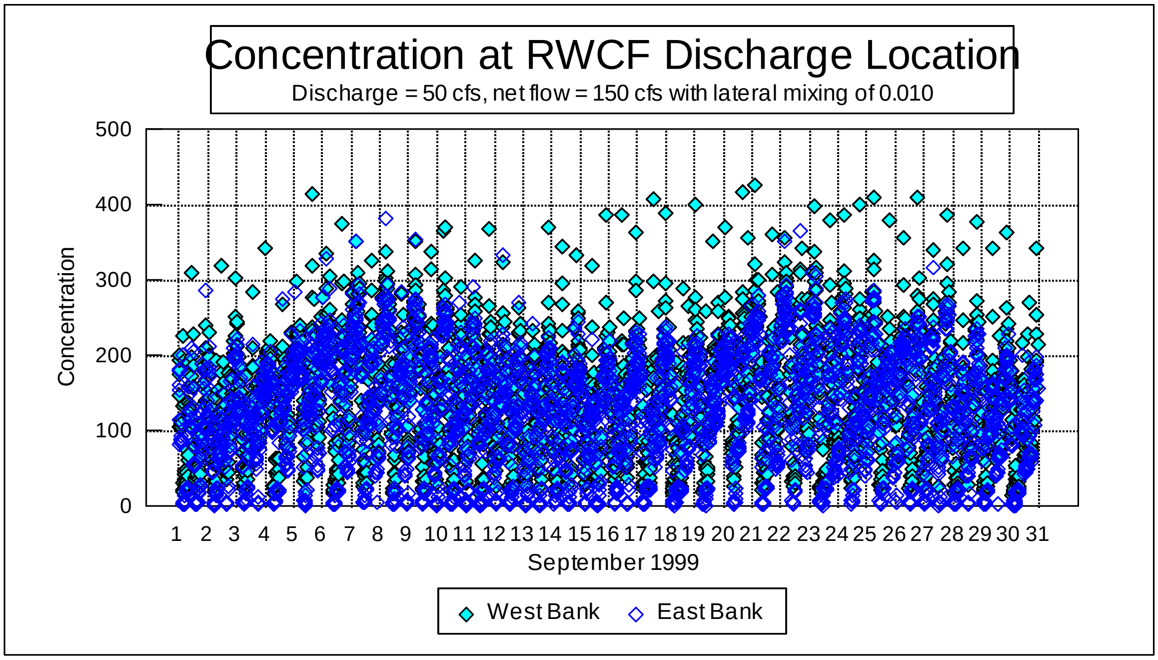


Figure 4. Simulated River Concentration at Discharge Location (East and West Banks) for 150 cfs with lateral mixing of 1% tidal flow

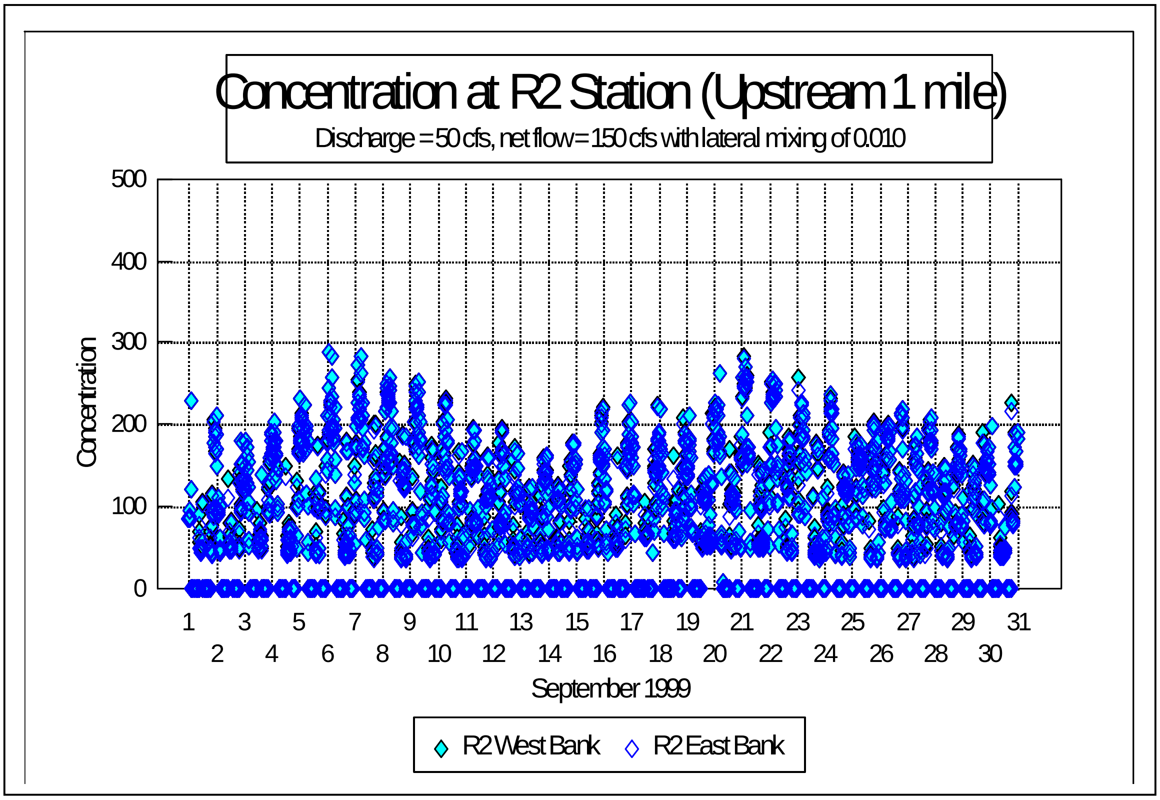


Figure 5. Simulated River Concentrations at Upstream Station R2 (East and West Banks) for 150 cfs with lateral mixing rate of 1% tidal flow

Figure 5 shows the simulated river concentrations at the upstream river monitoring station R2, located about 1 mile upstream of the discharge location. The east-side and west-side concentrations are about the same because of the strong lateral mixing caused by the tidal flows. The maximum west-side concentrations range from about 150 to 300, slightly less than the maximum concentrations at the discharge location. The minimum concentrations correspond to periods during the day when the tidal flows are moving downstream and fresh river inflow is moving past the upstream station.

Figure 6 shows the simulated river concentrations at the downstream river monitoring station R3, located about 1.5 miles downstream from the discharge location. The downstream R3 station is located in the DWSC, where the San Joaquin River channel enters the DWSC. The east-side and west-side concentrations are about the same because of the strong lateral mixing caused by the tidal flows in the river between the discharge and the R3 station. The maximum concentrations range from about 200 to 300, slightly less than the concentrations at the discharge location. The minimum concentrations correspond to water segments that have received slightly less effluent because higher tidal flows moved these segments more rapidly past the discharge location. The minimum concentrations at R3 range from about 100 to 200 during the month.

Table 1 on the following page gives a summary of the simulated, tidally averaged concentrations for the east and west side of the river at the downstream station R3, at the discharge location, and at the upstream station R2. For a river flow of 150 cfs, with the lateral mixing rate of 1% of the tidal flow, the average concentration at the upstream R2 station was 70 for the west side and 69 for the east side. The average concentrations at the discharge location were 148 on the west side and 122 on the east side. The average concentrations at the downstream R3 station were 205 for the west side and 204 for the east side. These east-side and west-side values are nearly identical at R3, but less than the expected steady-state average of 250.

This difference between the steady-state average of 250 and the simulated values at R3 is a result of the large tidal excursion. The ebb tide flow moves low-concentration water from upstream of the RWCF discharge to a location downstream of the R3 station near the end of the ebb tide. Consequently, the tidally averaged concentration at R3 will be less than the expected steady-state value. Concentrations further downstream, beyond the downstream distance of the tidal excursions, will approach an average of 250 for this assumed river flow of 150 cfs. The fluctuations in the daily maximum concentrations shown in figure 6 are the result of variations in the tidal flow patterns (that control the dilution) during the month.

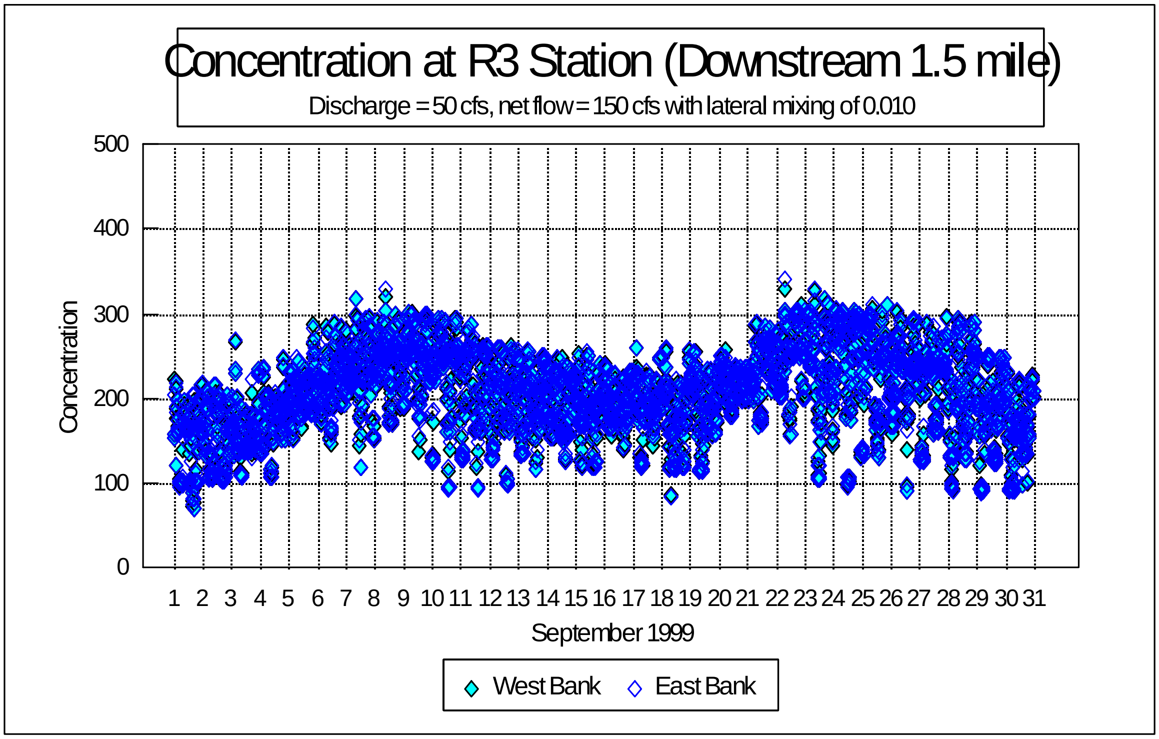


Figure 6. Simulated Concentrations at Downstream R3 Station for 150 cfs

Table 1. Average Simulated Concentrations for Range of River Flow and Lateral Mixing Rates at the Downstream R3, Discharge Location, and Upstream R2 Stations

Net River Flow/Mix Rate	Average Dilution	Expected River Concentration	Side of River	Downstream R3 Station	Discharge Location	Upstream R2 Station
150	4	250	East	204	119	66
0.5%			West	205	151	73
150	4	250	East	204	122	69
1.0%			West	205	148	70
450	10	100	East	80	40	27
0.5%			West	82	77	33
450	10	100	East	81	43	29
1.0%			West	81	74	30
950	20	50	East	36	26	11
0.5%			West	39	64	16
950	20	50	East	37	30	13
1.0%			West	38	60	14

Figure 7 shows the simulated longitudinal profile of river concentration for the west-side segments at the end of each day from day 6 through day 10, with a net river flow of 150 cfs. Segment 1 is the downstream end of the tidal model, and segment 500 is the upstream end.

The RWCF discharge location fluctuates with the tidal flow (see figure 3b) and is generally located between segments 100 and 300, with an average location near segment 265 during these 5 days. The cumulative discharge location during these 5 days is shown by the dots at the bottom of Figure 7 (i.e., each dot represents the cumulative discharge segment location in 10% increments). The river concentrations increase from the upstream edge of the tidal mixing volume (segment 300) to the downstream edge of the tidal mixing volume (segment 100). The river concentrations remain relatively constant downstream of the tidal mixing volume. A downstream river concentration of between 200 and 300 is simulated for these 5 days.

Figure 6 indicates that the maximum concentrations at R3 are increasing during these 5 days because of changes in the spring/neap tidal fluctuations. There are greater longitudinal variations in river concentrations at the upstream end of the tidal excursions. These longitudinal variations are smaller at the downstream end of simulated rows of segments because of lateral mixing and additional effluent discharges into the tidal mixing volume.

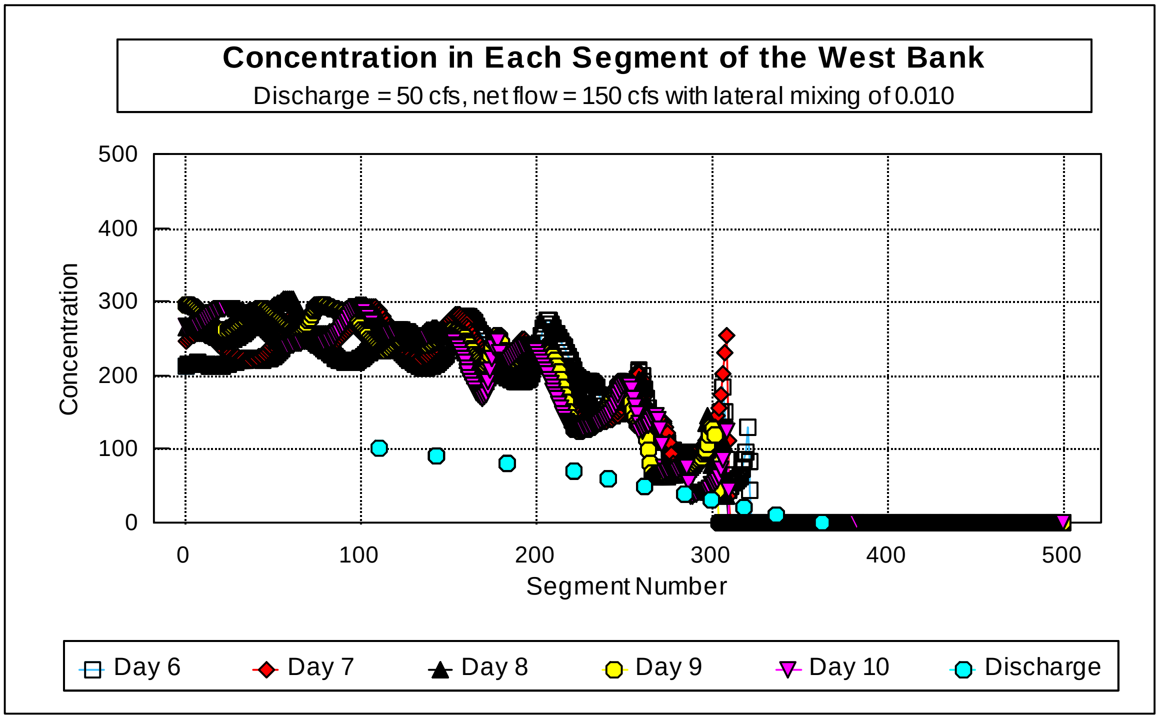


Figure 7. Longitudinal Profile of West Bank River Concentrations for 150 cfs with lateral mixing rate of 1% tidal flow

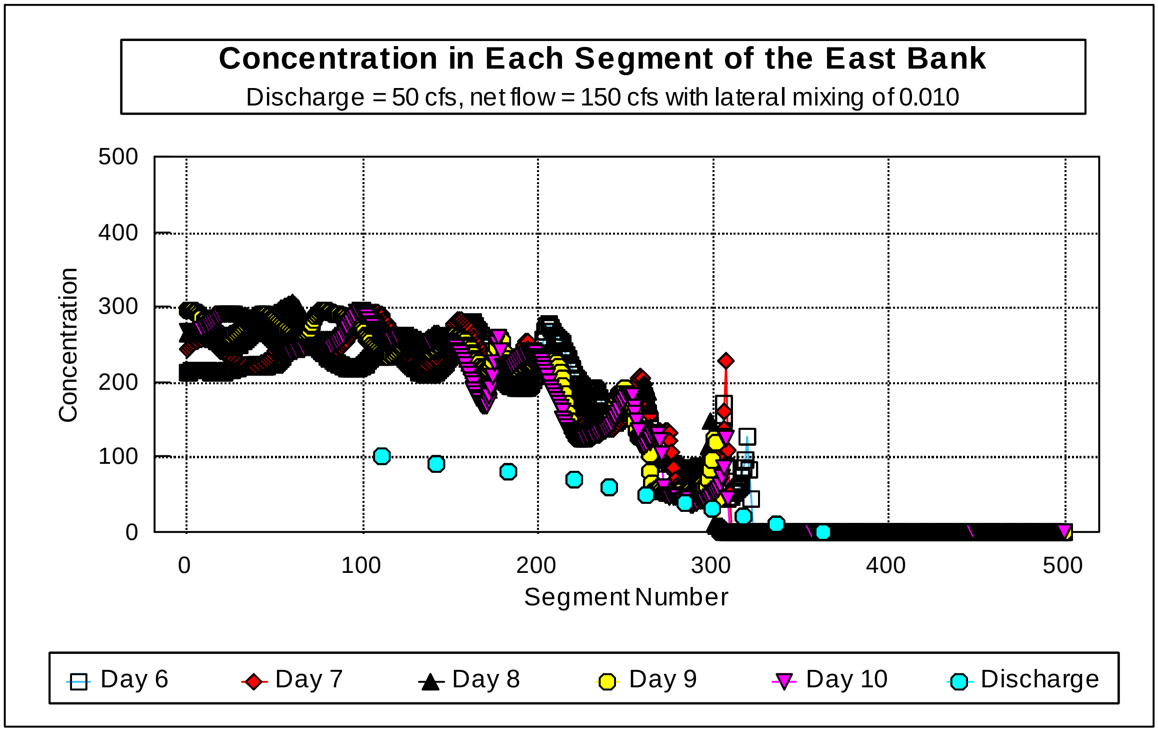


Figure 8. Longitudinal Profile of East Bank River Concentrations for 150 cfs with lateral mixing rate of 1% tidal flow

Figure 8 shows the simulated longitudinal profile of river concentration for the east-side segments at the end of each day from day 6 through day 10, with a net river flow of 150 cfs. The east-side river concentrations increase from the upstream edge of the tidal mixing volume (segment 300) to the downstream edge of the tidal mixing volume (segment 100). The east-side concentrations are only slightly less than the west-side concentrations because of the strong lateral mixing caused by the tidal flows. The river concentrations remain relatively constant downstream of the tidal mixing volume. A downstream river concentration of between 200 and 300 is simulated for these 5 days. The longitudinal concentration pattern generally follows the longitudinal distribution of the discharge location.

River Concentrations with a Net Flow of 150 cfs with Reduced Lateral Mixing

Figure 9 shows the simulated river concentrations at the discharge location with reduced lateral mixing (i.e., 0.5%) to illustrate the sensitivity of the model. Table 1 indicates that the average concentrations for the west side and the east side were 151 and 119, respectively. The east-side concentrations therefore average about 78% of the west-side values. For the higher lateral mixing rate, the east-side concentrations averaged 82% of the west-side values. Both lateral mixing rates provide very high lateral mixing near the discharge location. At this low river flow, the water moving past the discharge location has a cumulative residence time of several days (e.g., 5–7) during which the lateral mixing is working. The effluent is entering only the west side of the river at the discharge location. The lateral mixing creates more uniform concentrations both upstream and downstream of the discharge (see table 1). Lateral mixing is sufficient to produce nearly identical east-side and west-side concentrations at the upstream R2 station for the assumed mixing rate of 1% tidal flow. For the reduced mixing rate of 0.5% tidal flow, the east-side concentrations are about 85% of the west-side concentrations (i.e., 73/86).

Figure 10 shows the simulated river concentrations at the downstream station R3 with reduced lateral mixing (i.e., 0.5%). The R3 station is located about 1.5 miles downstream from the discharge, so the travel time for water to reach R3 is longer and the lateral mixing produces nearly identical east-side and west-side concentrations. The average concentrations for the east and west sides were 204 and 205, respectively. The R3 concentrations were identical to those simulated with the higher lateral mixing rate because both mixing rates were sufficient to produce complete lateral mixing at the R3 station. There are still tidal variations in the simulated concentrations at R3.

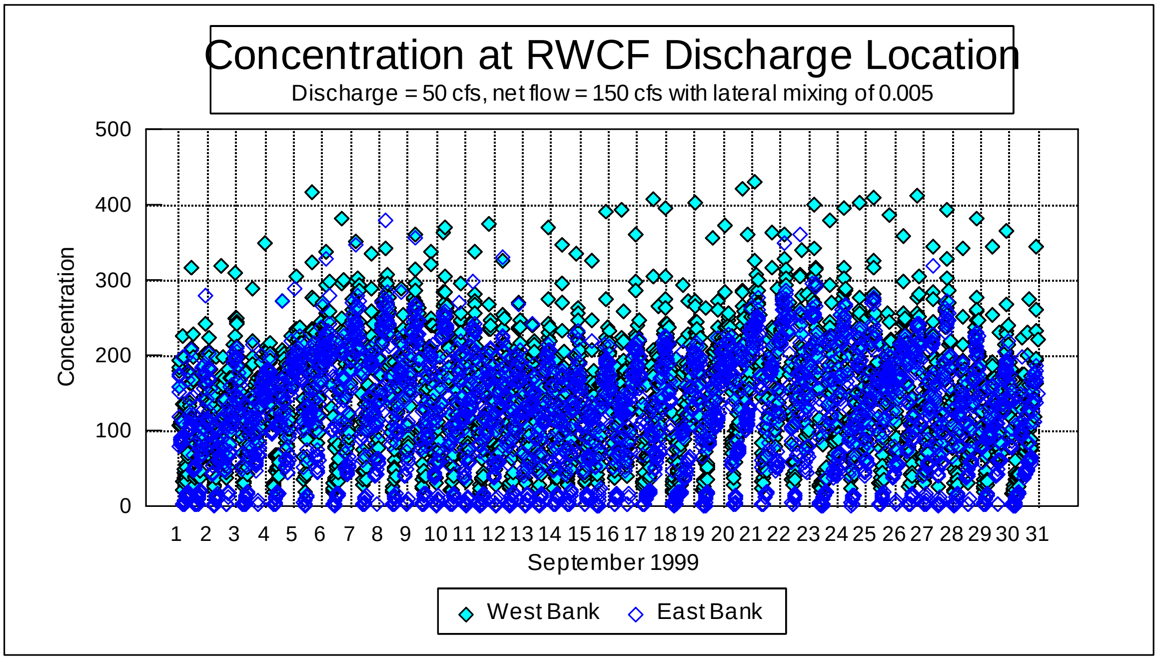


Figure 9. Simulated Concentrations at Discharge for 150 cfs with lateral mixing rate of 0.5% tidal flow

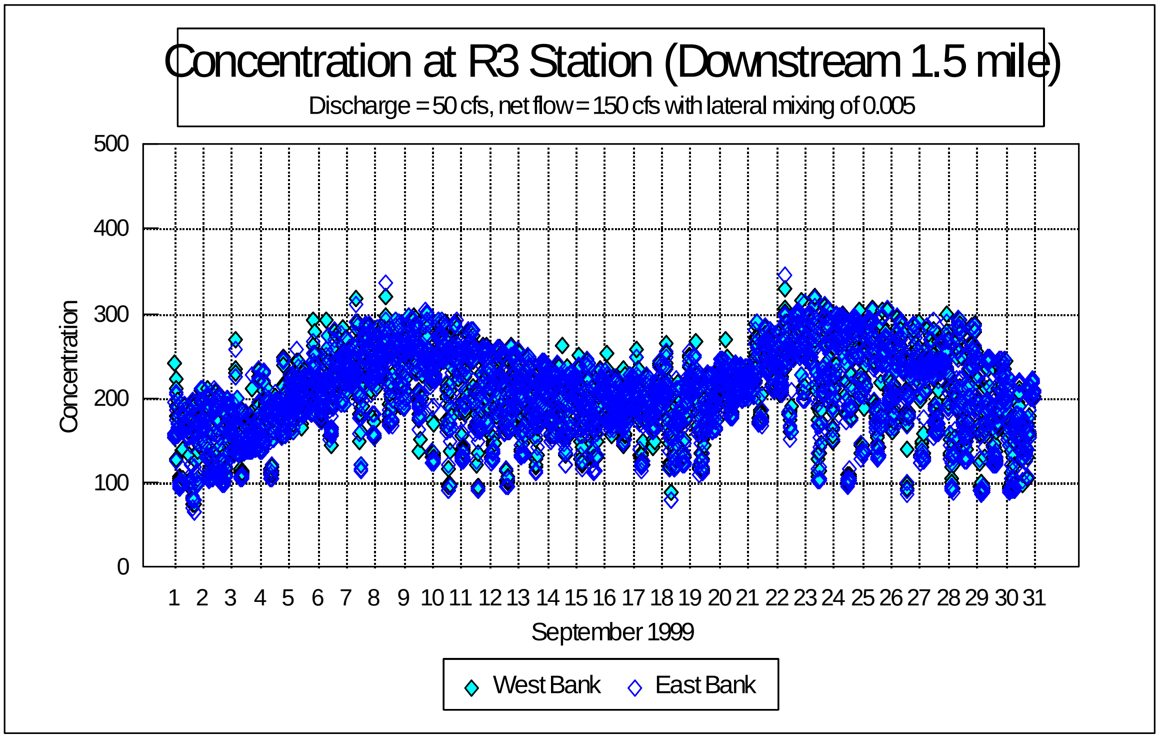


Figure 10. Simulated Concentrations at Downstream Station R3 for 150 cfs with lateral mixing rate of 0.5% tidal flow

Figure 11a shows the daily average east-side and west-side concentrations at the discharge location for the expected lateral mixing of 1.0% with an assumed river flow of 150 cfs. The daily average east-side concentrations average 82% of the west-side concentrations. Figure 11b shows the maximum hourly east-side and west-side concentrations at the discharge location. The maximum hourly values are less than 500, and the hourly maximum on the east side for each day averages about 81% of the hourly maximum on the west side.

Figures 12a and 12b show similar results for the lower lateral mixing rate of 0.5% with an assumed river flow of 150 cfs. The daily average east-side concentrations are about 78% of the west-side concentrations. The hourly maximum east-side concentrations are about 79% of the hourly maximums for the west side. Review of table 1 and these figures suggests that although the lateral mixing rate is somewhat uncertain, it is relatively high and not a strong factor in controlling the simulated concentrations at the discharge location or downstream at station R3. The calibrated lateral mixing rate is 1% of the tidal flow.

River Concentrations with a Net Flow of 450 cfs

Figure 13 shows the west-side and east-side concentrations at the discharge location with a river flow of 450 cfs. This river flow provides a dilution of 10, so the expected average river concentration is 100, with an assumed effluent concentration of 1,000. Table 1 indicates that the average east-side and west-side concentrations at the discharge location are 43 and 74 for a river flow of 450 cfs with a lateral mixing rate of 1% of the tidal flow.

Figure 14 shows the concentrations at the downstream station R3 with a flow of 450 cfs. The average west-side and east-side concentrations were both 81, indicating the effects of the lateral mixing associated with the tidal excursions and the slightly larger downstream flow. The R3 station is located within the tidal excursion zone, and concentrations are less than the expected value of 100 during periods of low tide.

Table 1 indicates that the results of the lower lateral mixing rate (0.5% tidal flow) were very similar for a river flow of 450 cfs. Average simulated concentrations at the discharge location were 40 on the east side and 77 on the west side. Average simulated concentrations at station R3 were 80 on the east side and 82 on the west side.

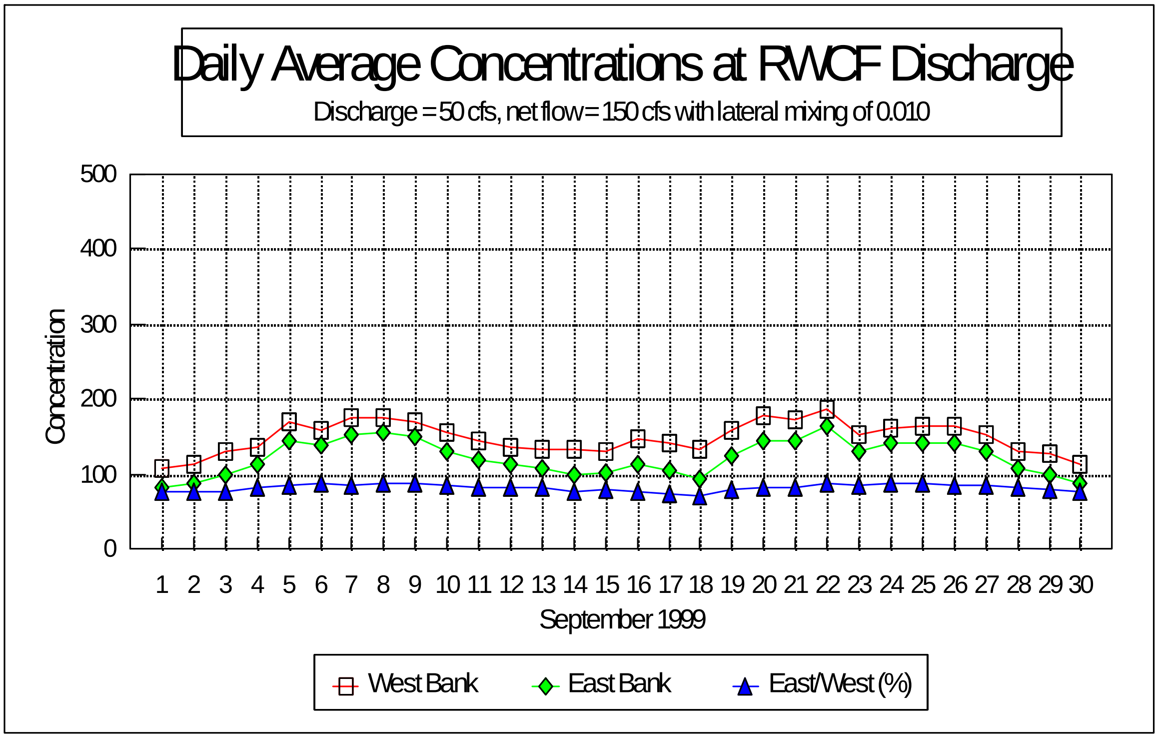


Figure 11a. Average Daily West and East Concentrations at Discharge Location for 150 cfs with Lateral Mixing of 1% Tidal Flow

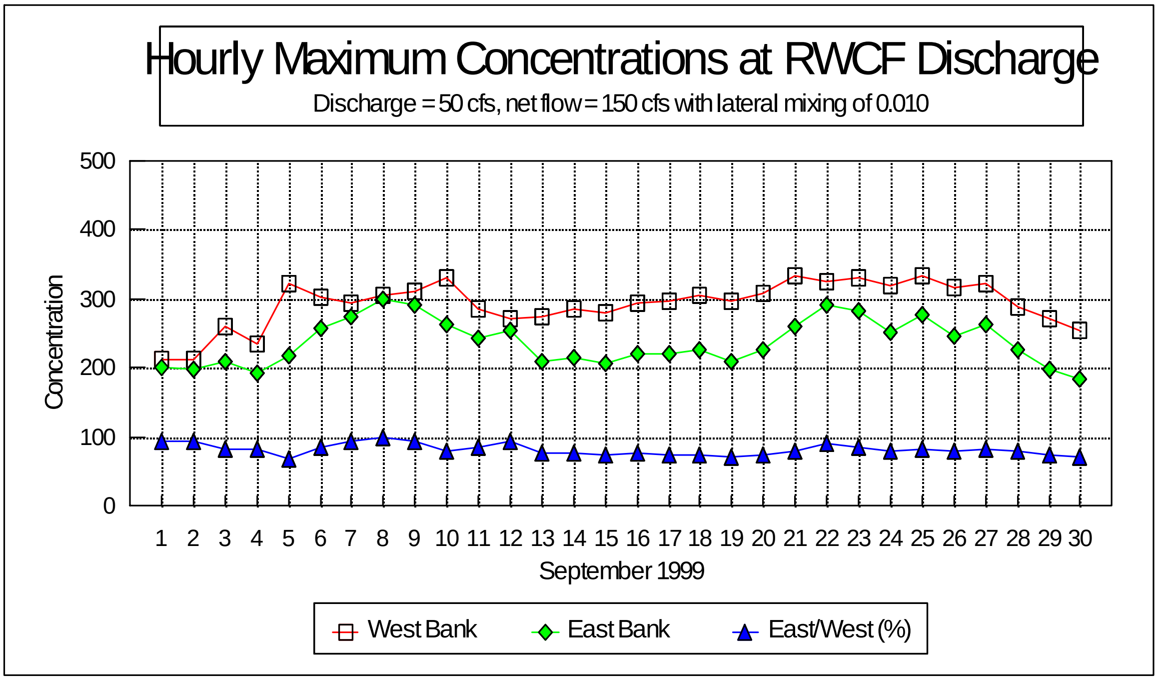


Figure 11b. Hourly Maximum East and West Concentrations at Discharge Location for 150 cfs Flow with Lateral Mixing of 1% Tidal Flow

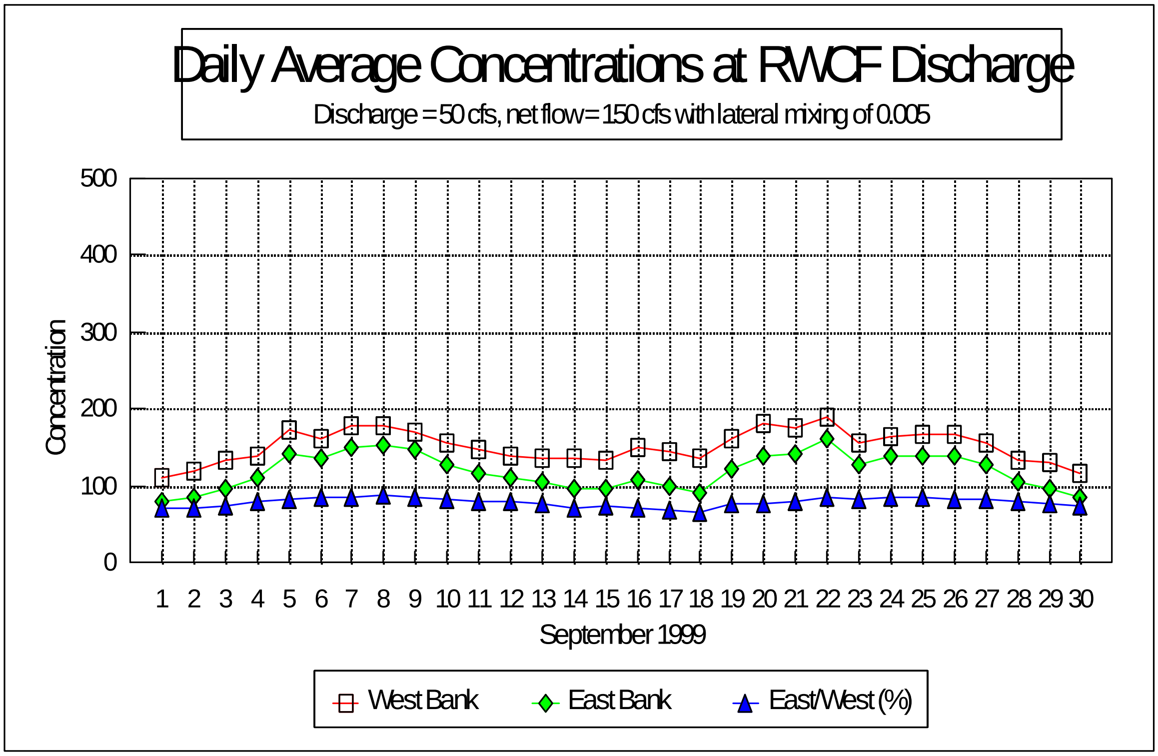


Figure 12a. Daily Average East and West Concentrations at Discharge Location for Flow of 150 cfs with Lateral Mixing of 0.5% Tidal Flow

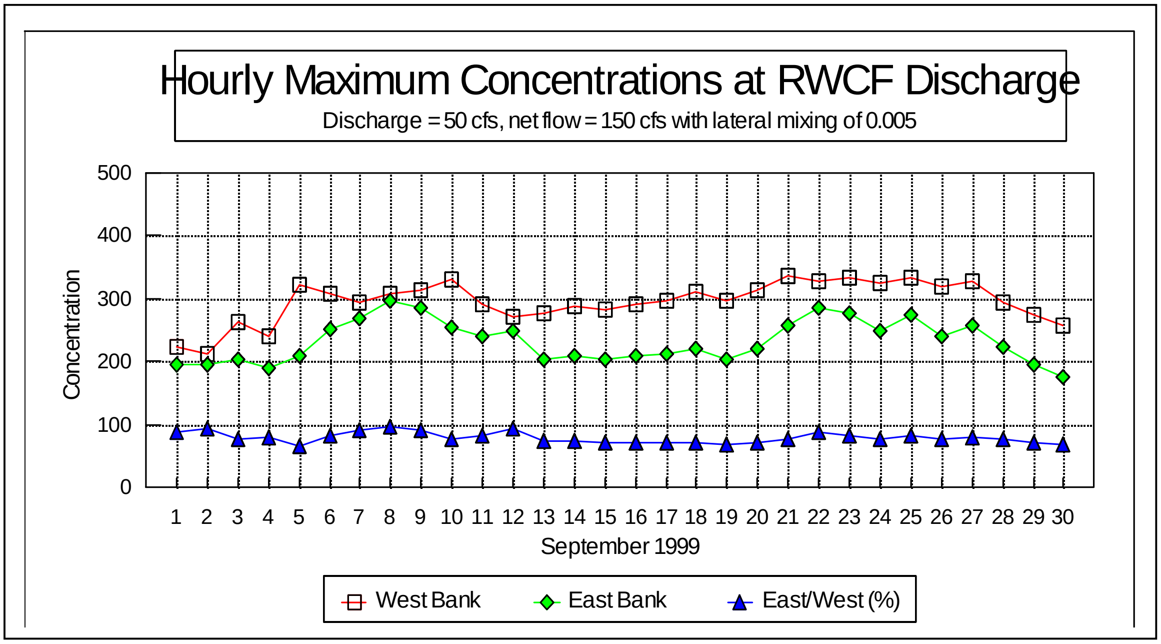


Figure 12b. Maximum Hourly East and West Concentrations at Discharge Location for 150 cfs with Lateral Mixing of 0.5% Tidal Flow

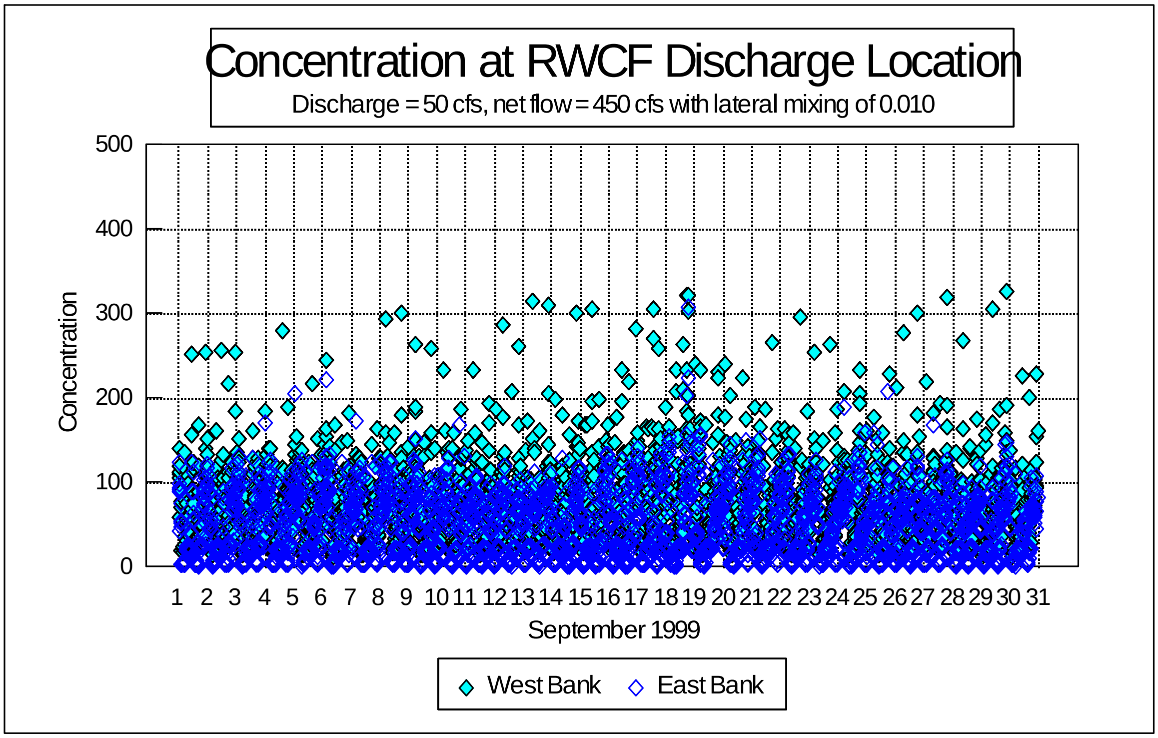


Figure 13. Simulated Concentrations at Discharge Location for 450 cfs with lateral mixing rate of 1% tidal flow

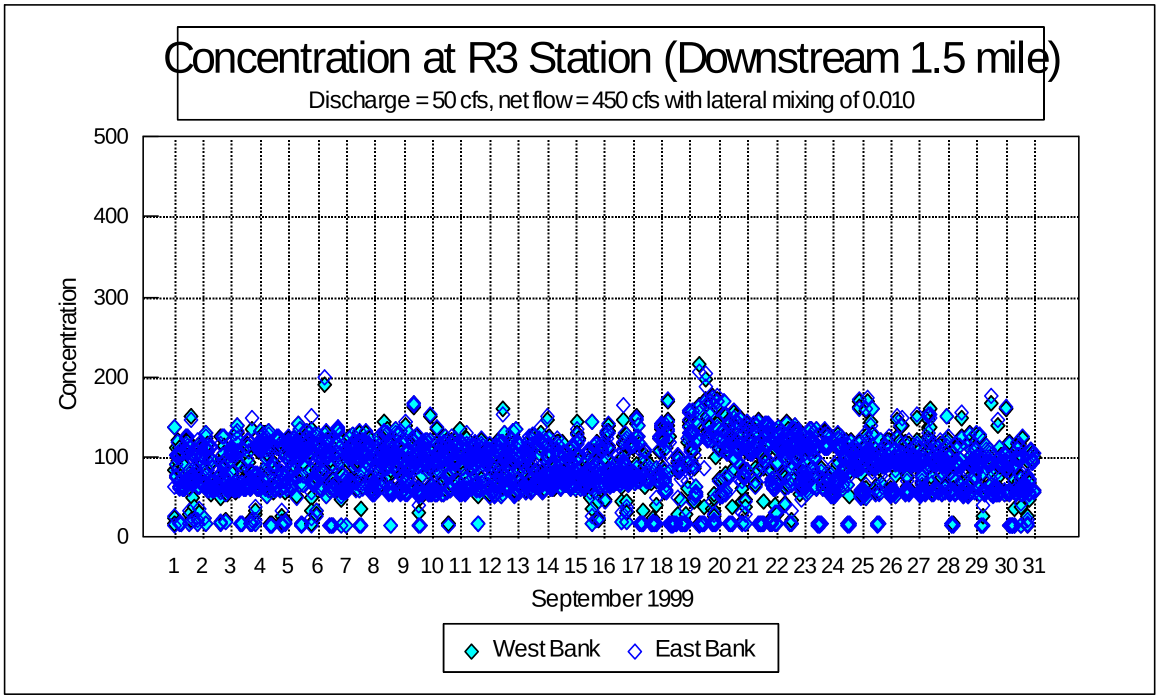


Figure 14. Simulated Concentrations at Downstream R3 Station for 450 cfs with lateral mixing rate of 1% tidal flow

River Concentrations with a Net Flow of 950 cfs

Figure 15 shows the east-side and west-side concentrations at the discharge location with a river flow of 950 cfs. This river flow provides a dilution of 20, so the expected average river concentration is only 50, with an assumed effluent concentration of 1,000. Table 1 indicates that the average east-side and west-side concentrations at the discharge location are 30 and 60 with a river flow of 950 cfs and lateral mixing rate of 1% of tidal flow.

Figure 16 shows the adjusted tidal flows for a net river flow of 950 cfs. Because the flood tide flow currents sometimes nearly equal the net assumed river flow of 950 cfs, there are short periods on several days when flow conditions are relatively stagnant and the maximum 15-minute river concentrations exceed 200 (figure 15). The maximum hourly concentrations were generally less than 250.

Figure 17 shows the concentrations at the downstream station R3 with a flow of 950 cfs. The average east-side and west-side concentrations were 36 and 39, respectively, indicating the effects of the large downstream tidal excursion associated with this high river flow. The rapid movement of water past the discharge location, except during short periods when the river flow balances the flood tide flow (see figure 3a), produces a widely fluctuating concentration pattern in the river downstream of the discharge. Maximum concentrations at R3 exceed 250 for a river flow of 950 cfs when the average is less than 50.

Figure 18 shows the concentrations at the upstream station R2 with a flow of 950 cfs and a lateral mixing rate of 1% of the tidal flow. The average east-side and west-side concentrations were 13 and 14, respectively, indicating the effects of this high river flow. The flood tide flows were not sufficient to move effluent upstream to the R2 station except during the strongest flood tides. The concentrations are often 0 at the upstream R2 station.

Regional Wastewater Control Facility Effluent Concentrations During a Typical Daily Tidal Cycle

Figure 19 shows the simulated concentrations for the west-side and east-side river segments at the RWCF discharge location on September 10, 1999. The measured tidal stage and adjusted tidal flows (i.e., for a 950-cfs daily average net flow) during the day are shown with the solid lines in the 2 panels. The west-side and east-side concentrations, relative to an effluent concentration of 1,000 units, are shown for each 15-minute tidal interval in each panel.

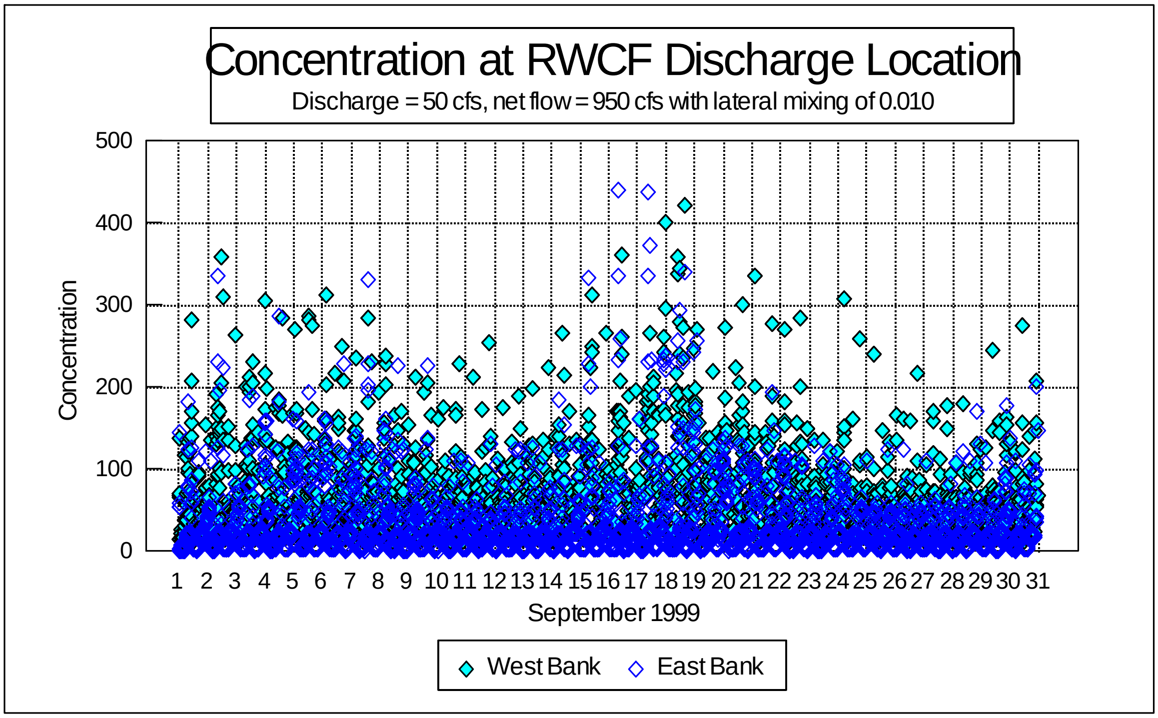


Figure 15. Simulated Concentrations at Discharge Location for 950 cfs with lateral mixing rate of 1% tidal flow

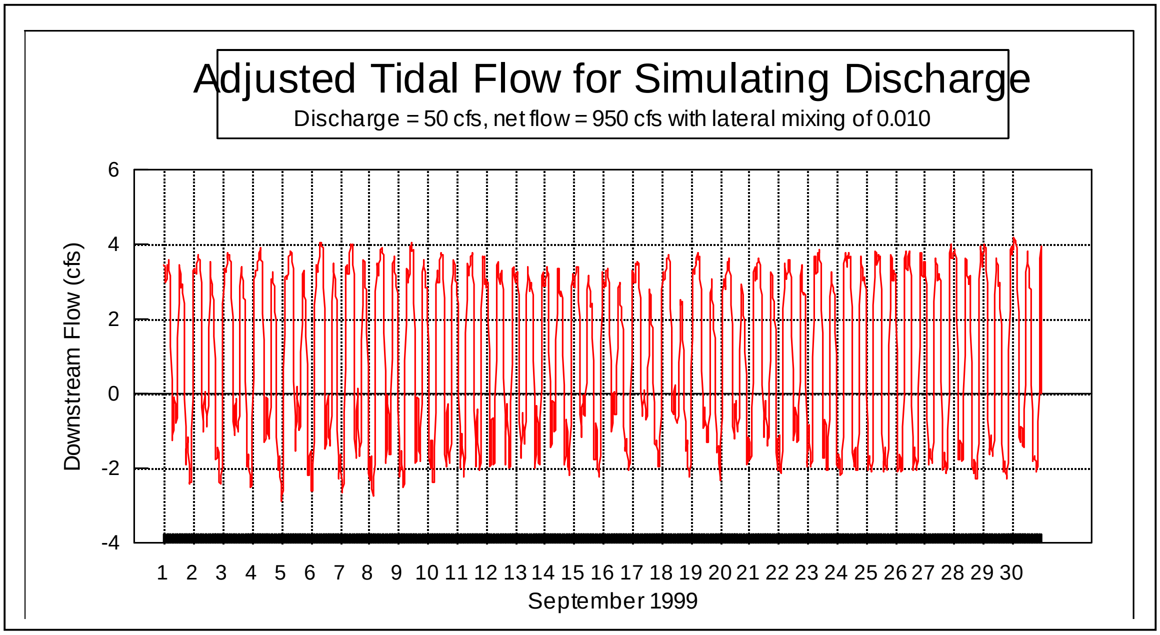


Figure 16. Adjusted Tidal Flow for Simulating Net River Flow of 950 cfs

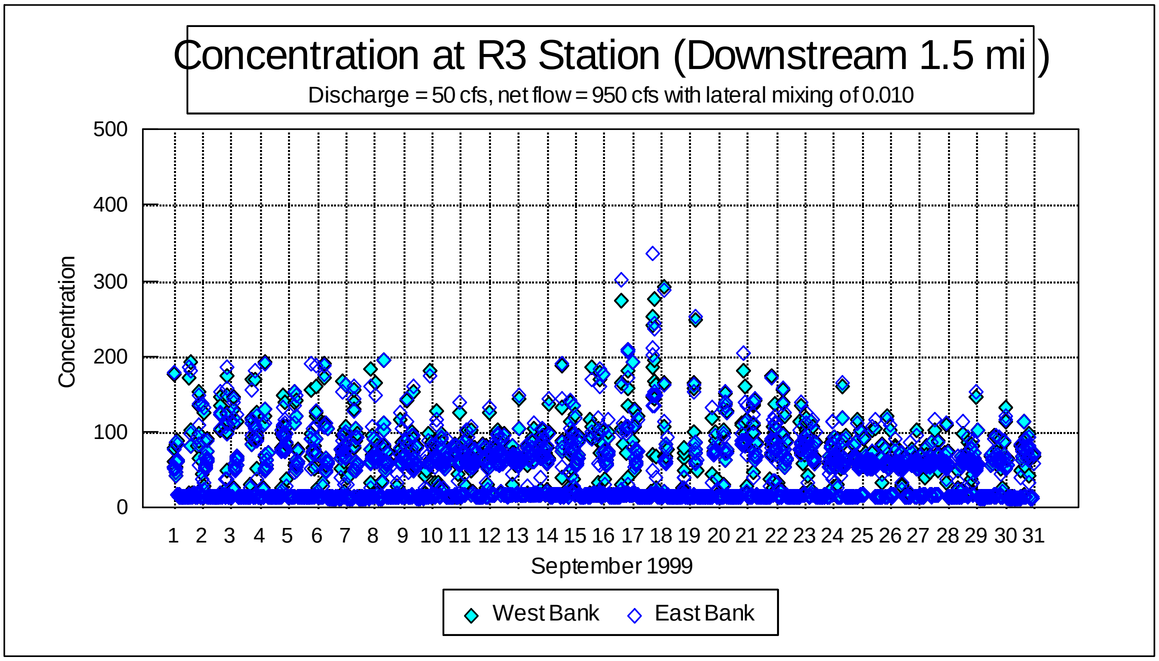


Figure 17. Simulated Concentrations at Downstream Station R3 for 950 cfs with lateral mixing rate of 1% of tidal flow.

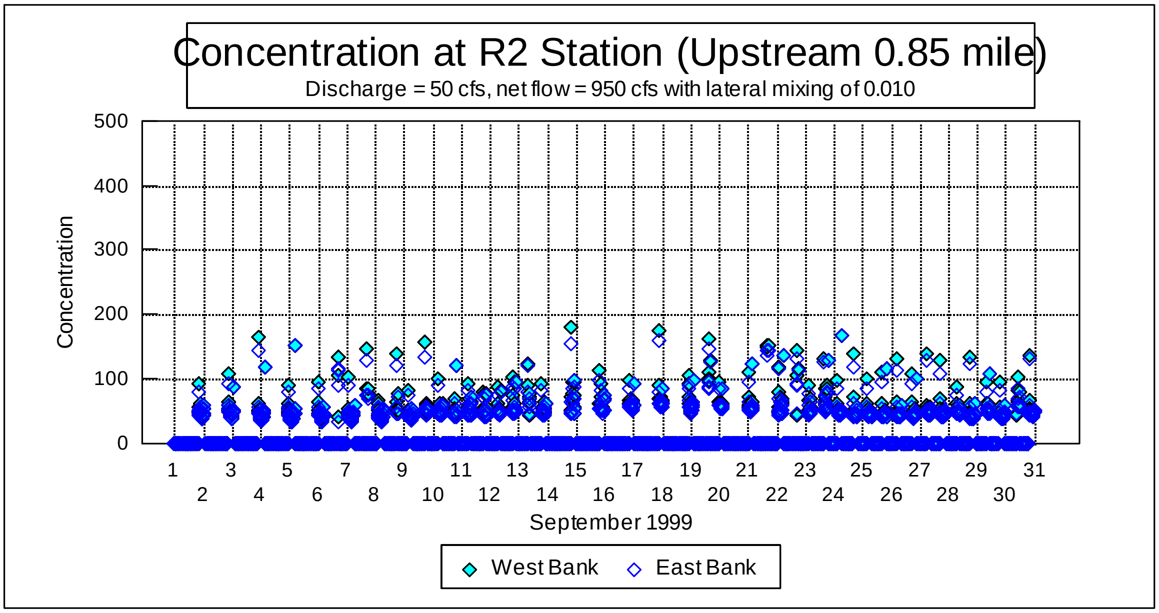
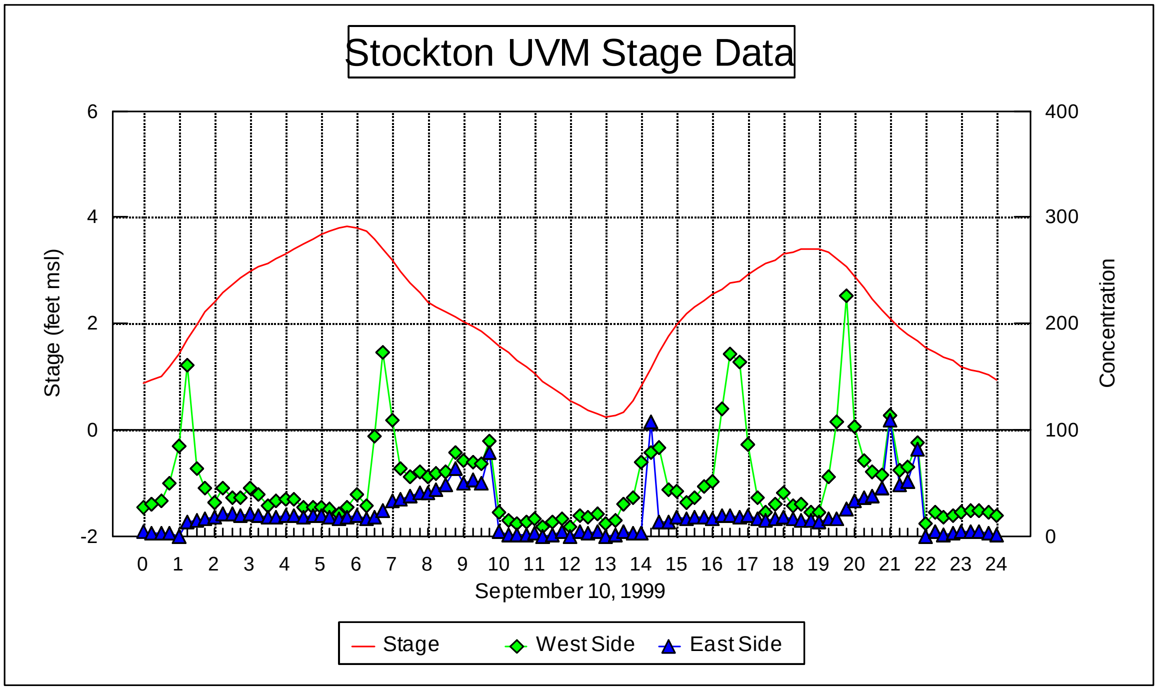


Figure 18. Simulated Concentrations at Upstream R2 Station for 950 cfs with lateral mixing of 1% tidal flow.



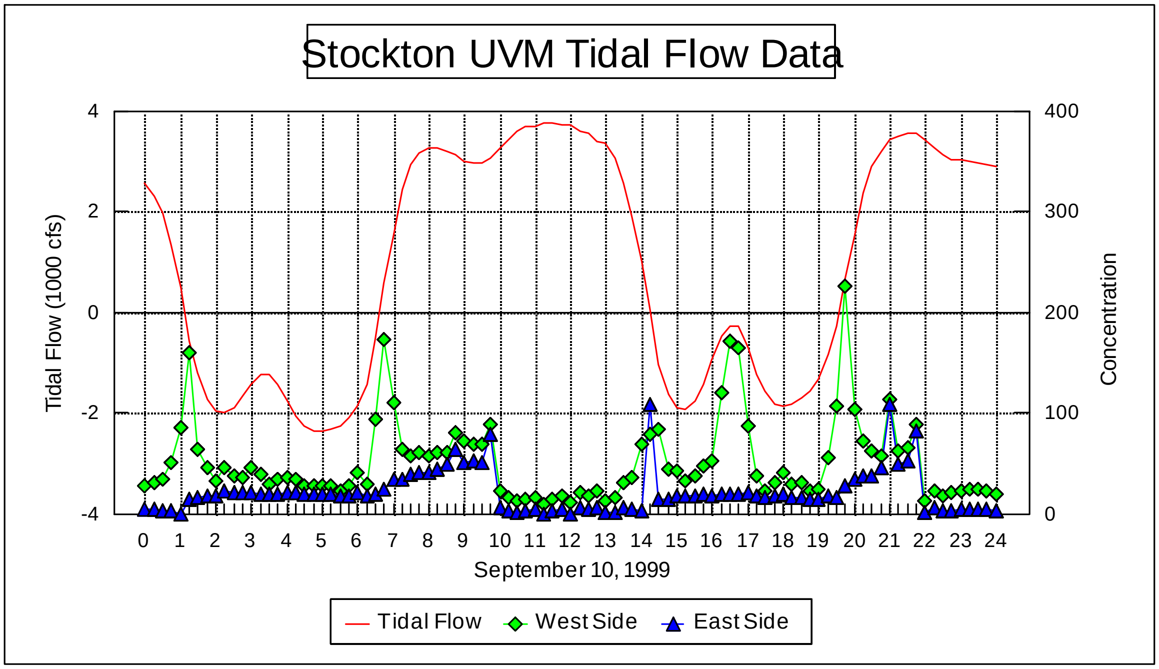


Figure 19. Simulated West and East Bank Concentrations at Discharge Location during Tidal Cycle of September 10, 1999, with Assumed River Flow of 950 cfs

Figure 19 demonstrates the model calculations and illustrates the near-field concentration patterns that result from the constant discharge into the fluctuating tidal flows in the San Joaquin River near Stockton.   The selected day (September 10) begins with a low-tide stage of about 1 feet msl, and the tide is rising (flood tide) with a high tide stage of about 4 feet occurring at hour 6. The tidal flow is changing from ebb to flood, and the first slack tide occurs at hour 1. The flood-tide flow is only about 2,000 cfs because it is moving against the assumed river flow of 950 cfs. The upstream tidal flow reverses direction by hour 7 (the second slack tide is about half an hour after high tide) and the ebb-tide flow is 3,000–4,000 cfs because of the assumed river flow of 950 cfs. The falling tide reaches a low-tide stage of 0.3 feet at hour 13. The third slack tide occurs at hour 14 as the tide switches from ebb to flood. The floodflow is less than 1,000 cfs during the afternoon, with the second high-tide stage of 3.5 feet at hour 19. The fourth slack tide occurs at hour 20 and the tide stage declines to about 1.0 feet by the end of the day.

The simulated effluent concentrations on the west side and east side of the river at the RWCF discharge location are the direct result of these fluctuating tidal flows. West-side concentrations are increasing during the first hour as the ebb flow slackens and reverses. A peak concentration is simulated during the slack tide at hour 1. The west-side concentration varies during the flood tide from hour 1 to hour 6 because of the tidal flow velocity and because some of these segments that are moving upstream were already dosed with the effluent during the previous day’s ebb tide.

A second peak concentration is simulated at hour 7 during the second slack tide. Concentrations increase until hour 10 because these segments are receiving a third dose of effluent. After hour 10, however, the ebb tide has moved fresh river water downstream past the RWCF discharge. West-side concentrations are low and uniform until the next slack tide at hour 14. The east-side concentrations are 0 during this period because the discharge is assumed to enter only the west side of the river.

The east-side concentration increases slowly between hours 15 and 20 (flood tide) because lateral mixing is moving effluent across the river as these segments are moving upstream. West-side concentrations increase at hour 16 because the measured tidal flows are reduced during the hour. The highest west-side concentrations of the day are simulated at hour 20. Some of the segments moved slowly past the discharge at the end of the flood tide and are then moving past the discharge at the beginning of the ebb tide. The highest west-side concentrations occur during low tidal-flow periods that generally occur during slack tide as the tidal flow changes direction. This change in tidal flow generally takes place 4 times each day, about half an hour after the high tides and the low tides.

There can also be periods of relatively slow moving water during the flood tides, especially if the assumed river flow is relatively high.

The east-side concentrations approach the west-side concentrations after 1–2 hours of tidal flow. This can be seen between hours 6 and 9 and between hours 19 and 22. In both these periods, segments that moved upstream during flood tide have moved downstream past the discharge location during the ebb tide. However, actual mixing may be more rapid because the river bend near the discharge location and the railroad bridge (2 piers) located 500 feet upstream may promote more rapid mixing than the lateral mixing process used in this model.

Simulated Increase in Effluent Concentration During Slack High Tide

Figure 20 illustrates the simulated west-bank concentrations during the high slack-tide event at hour 8 on September 10. The simulated location of the RWCF discharge was moving from right to left past segment 210 at the end of hour 6 (upstream tidal flow) with a concentration of 50 upstream of the discharge and about 25 downstream of the discharge. This indicates that the simulated segment concentrations were increasing by about 25 during this flood-tide period. By the end of hour 7, the RWCF location was at segment 175, and by the end of hour 8, the RWCF was located at segment 165 and the slack tide had occurred, producing a concentration peak of about 250 in 2 segments.

By the end of hour 9, the tide had reversed and was moving downstream, so the location of the RWCF discharge was approaching segment 200. The segment concentrations were about 75 downstream of the RWCF discharge and about 50 upstream, indicating that the effluent concentration in the discharge segment was increasing by about 25 during this ebb tide. This is consistent with an average tidal flow of 2,000 cfs that would provide a dilution of about 40 for the simulated effluent flow of 50 cfs. Each time the tidal flow passes the RWCF discharge location, the river concentration will increase by about 25 (i.e., 1,000/40).

It can be hard to decipher the superposition of concentration patterns caused by several tidal movements together with the net river flow past the discharge location. For example, the peak concentration at segment 275 was produced by the discharge during the previous low-tide slack period. The ebb tidal flow moved the segments downstream, so the simulated location of the RWCF discharge moved to the highest number segments. The number of segments between the peak concentrations that result from the high and low slack tides is about 100 segments (i.e., 275 and 175), representing a distance of about 2 miles. The effluent concentration pattern

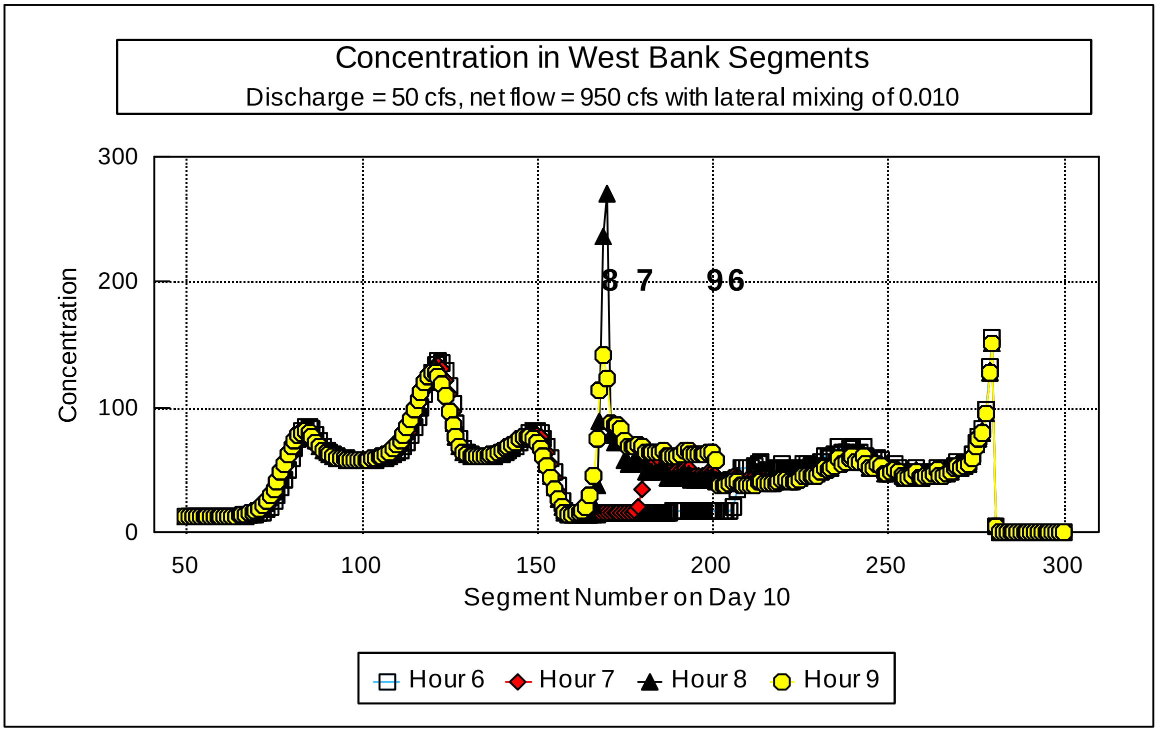


Figure 20. Simulated West Bank Concentrations During High Slack Tide Event on Hour 8 of September 10, 1999

between segments 50 and 150 was the result of the previous day's tidal cycle.

These simulated concentration patterns at the high slack tide during day 10 were similar to the concentrations actually observed during the high-slack-tide field survey described in the next section.

Measured Effluent Concentrations and Lateral Mixing at High Slack Tide

A field survey of the maximum near-field effluent concentrations and mixing of the effluent across the river was conducted to verify the assumed lateral mixing rate. The concentrations of ammonia at several transects across the river were measured at high slack tide just upstream of the RWCF discharge location. The lateral mixing was expected to mix the west-side and east-side concentrations more completely as the distance upstream increased. Lateral concentration profiles were measured at 100-foot increments for the first 500 feet upstream of the discharge. Subsequent measurements were then made at 500-foot increments. The field survey documented the lateral mixing between the discharge and 2,500 feet upstream. At maximum tidal velocity of about 1 ft/sec, water moves upstream 2,500 feet in about 40 minutes.

Figure 21 shows the river in the vicinity of the RWCF discharge pipe and the layout of the sampling transects. The field study plan was to sample water immediately after high slack tide at 5 lateral locations (i.e., west bank, 25%, 50%, 75% and east bank) on transects located 100 feet upstream, 200 feet upstream, 300 feet upstream, 400 feet upstream, and 500 feet upstream. These samples would be used to evaluate the lateral mixing rate in the near-field mixing zone located within 2 river widths (i.e., 500 feet) of the discharge. A similar mixing zone is assumed to occur downstream of the discharge during periods of ebb flow. Survey stakes were placed along the west levee at measured distances upstream of the discharge pipe to denote transect locations. The railroad bridge is located about 400 feet upstream; the State Route 4 bridge (river station R2) is located about 4,500 feet upstream of the RWCF discharge.

Surveys were conducted during 2 consecutive days (January 17 and 18, 2001). Water samples were collected from mid-depth (6–8 feet) and ammonia concentrations were measured using the colorimetric method on both days. Samples for laboratory analysis of ammonia concentrations were also collected on the second day of the survey.

The RWCF effluent ammonia concentration was about 25 milligrams per liter (mg/l). The Vernalis river flow was about 2,500 cfs, so the net flow passing Stockton was estimated to be about

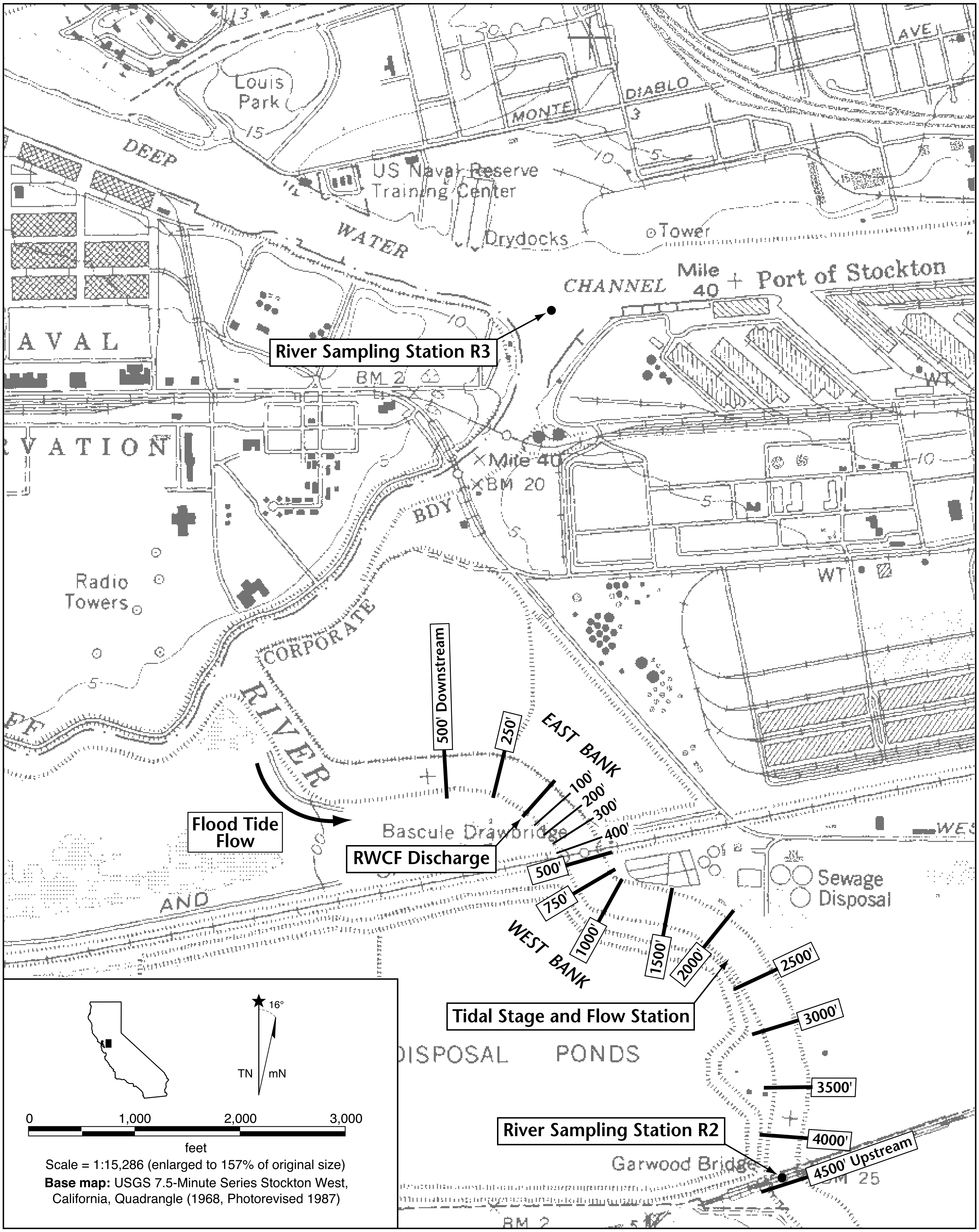


Figure 21. San Joaquin River in the Vicinity of RWCF Discharge with Sampling Locations for Near-Field Mixing Study

1,250 cfs. The RWCF discharge flow was about 35 cfs, so the fully mixed river concentration would average about 0.7 mg/l (i.e., a river dilution of about 35). The near-field ammonia concentration was expected to be somewhat higher, especially during the slack-high-tide event. The jet mixing is expected to always provide a dilution of at least 5 within 125 feet of the discharge pipe, so the maximum river ammonia concentration was expected to be less than 5 mg/l.

Electrical conductivity (EC) measurements were used on the first day to identify the RWCF effluent mixing across the river. However, the difference between the river EC of about 470 µS/cm and the effluent EC of about 1,070 µS/cm was not enough to produce a very distinct lateral gradient of EC values. The initial difference of 600 µS/cm would be reduced to 125 µS/cm with a jet dilution of 5, and the EC difference would be only 60 µS/cm with a river dilution of 10. The highest EC measured at the river transects was 510 µS/cm, indicating a dilution of 15. To reduce the time required to collect the transect samples, EC measurements were not made during the second day of the survey. Continuous monitoring of EC at selected transect locations near the upstream railroad bridge for a 1-month study period might provide additional evidence that the effluent is relatively well mixed.

Tables 2a and 2b give the colorimetric ammonia measurements from the transect samples collected on the 2 days. The pattern of lateral mixing was similar but not identical for the 2 surveys.

Table 2a. January 17, 2001, Sampling Event—High Tide at 12:38 p.m.

		Ammonia (colorimetric) at Sample Point (mg/l)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream						
100’	1:45 p.m.	3.54	3.44	3.24	4.68	1.72
200’	1:51 p.m.	3.42	3.18	2.48	1.82	1.66
300’	1:58 p.m.	2.90	2.76	1.80	1.53	1.51
400’	2:06 p.m.	2.48	2.24	1.62	1.83	1.80
500’	2:14 p.m.	2.14	1.84	1.94	1.88	1.62
Downstream						
500’	2:21 p.m.	–	4.62	2.00	2.78	–
1,000’	2:30 p.m.	–	1.78	3.50	4.44	–
Effluent Boil /a/						
0’	2:40 p.m.	7.28	–	–	–	–
0’	2:40 p.m.	9.40	–	–	–	–

Note: /a/ = Replicated samples

Table 2b. January 18, 2001, Sampling Event—High Tide at 1:40 p.m.

		Ammonia (colorimetric) at Sample Point (mg/l)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream						
100’	1:45 p.m.	2.72	3.70	1.70	1.84	1.88
200’	1:50 p.m.	3.24	3.78	1.68	1.68	1.61
300’	1:57 p.m.	3.80	3.34	1.59	1.55	1.54
400’	2:05 p.m.	3.50	2.84	1.54	1.56	1.58
750’	2:14 p.m.	3.46	2.44	1.91	1.60	1.56
Mossdale						
	4:20 p.m.	–	–	–	–	1.06

Figure 22 shows the ammonia concentrations (colorimetric method) from the 5 transects at slack high tide on January 17. Ammonia concentrations were highest along the west bank near the discharge, and decreased across the river and upstream of the discharge. The 75% sample from the 100-foot transect was about 1 mg/l higher than the other samples at this transect nearest the discharge, and was the only sample that deviated from the lateral mixing pattern. The ammonia concentrations were fully mixed at the transect located 500 feet upstream from the discharge.

The slack high tide had already occurred (high tide at 12:40 p.m.) when the transect sampling began at 1:45 p.m., and water was moving downstream at a rate of at least 0.5 ft/sec during the 25 minutes that was required to collect these transect samples. This suggests that the 500-foot transect may have moved downstream from 1,500 feet upstream during the sampling event. The mixing distance that was measured during the first day may be much greater than 500 feet. Complete lateral mixing may therefore not occur until a distance greater than 500 feet upstream. The distance required for complete lateral mixing may be as much as 2,500 feet (i.e., 1,500 feet upstream + 1,000 feet back downstream to the 500-foot transect).

Because the tidal flow was already moving downstream when the transects were completed, additional samples were collected 500 feet and 1,000 feet downstream of the discharge. These samples indicated that the river was not yet fully mixed at these downstream locations. There is some indication that the river bend (see figure 21) was causing effluent to be transported across the river, because at the transect 1,000 feet downstream, the 25% sample ammonia was about 2 mg/l but the 75% sample ammonia was 4.5 mg/l. Normally, surface water is found to flow from the inside to the outside of river bends. Researchers observed this phenomenon on the second day when they began drifting across the river in a boat at 1:10 p.m., 30 minutes before high tide. It took about 10 minutes to drift from the west bank, 350 feet downstream of the discharge, to

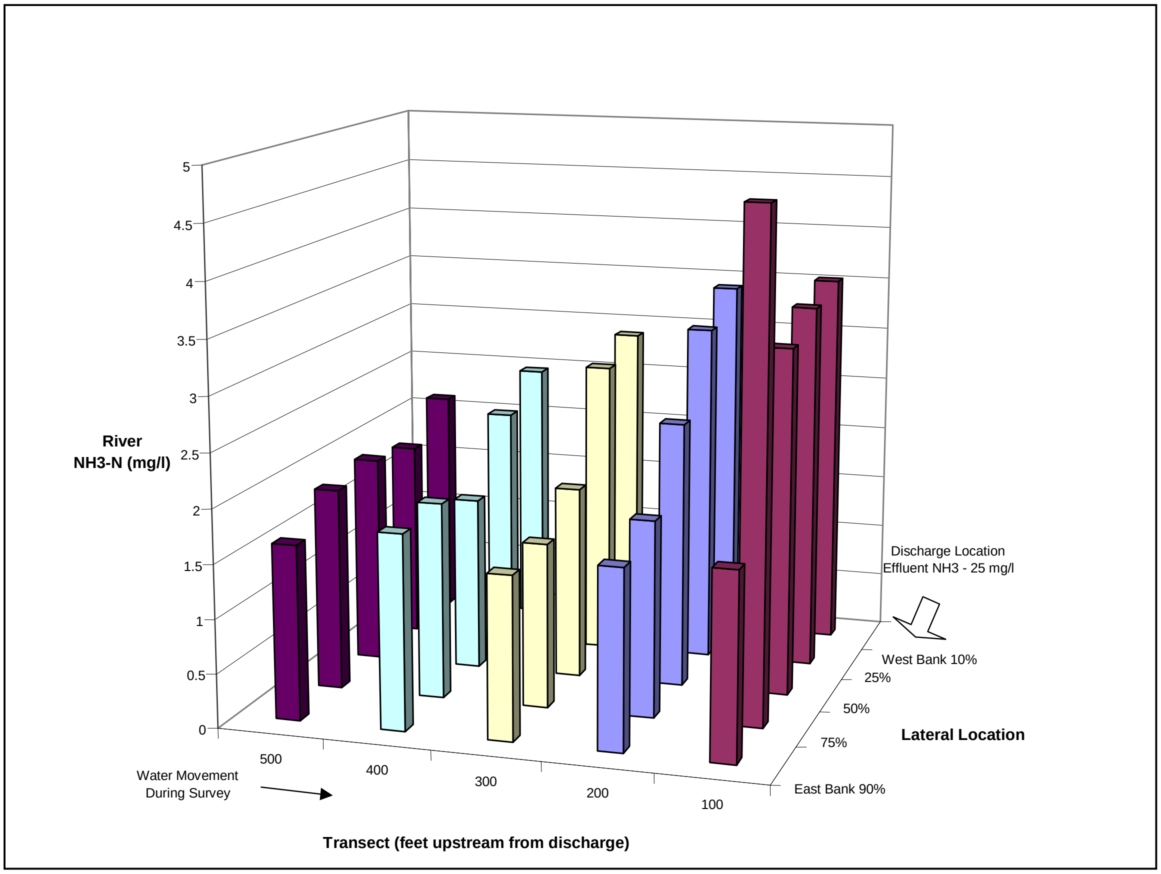


Figure 22. Results of Colormetric Ammonia Concentrations from Near-Field Mixing Study on January 17, 2001

the east bank, opposite the discharge, so the boat traveled 0.5 ft/sec diagonally across the river.

Figure 23 shows the ammonia concentrations (colorimetric method) from the transect samples collected on the second day of the survey, January 18. Collection of samples began at 1:45 p.m., just after high tide. Water bottles were released as drogue floats to track water movement during the sampling event. Sampling of the 5 transects was completed by 2:15 p.m. Water movement averaged about 0.5 ft/sec during the 30 minutes of sampling (moving 900 feet upstream). Because the water movement was still in the upstream direction, the planned transect at 500 feet was moved upstream to 750 feet.

The ammonia concentrations were about 0.5–0.75 mg/l higher than the average background (i.e., Mossdale) river concentration of about 1mg/l at all locations. This increase above the Mossdale river concentration probably resulted from the effluent during the previous tidal cycle. The ammonia concentrations were considerably higher than 1.75 mg/l only at the 10% and 25% lateral stations for transects from 100 feet, 200 feet, 300 feet, and 400 feet upstream. The 750-foot transect showed some lateral mixing of ammonia to the center (50%) station, raising the center concentration to about 2 mg/l. The ammonia concentrations were not completely mixed across the river at the 750-foot transect.

Figure 24 shows the ammonia concentrations (laboratory results) from the second day of the survey. These laboratory ammonia concentrations confirm the colorimetric values. Table 2c on the following page gives the laboratory ammonia results. Laboratory QA/QC results were good for the 3 batches of samples. Laboratory control and matrix spikes were within 10% of expected recovery values. Comparison of the laboratory and colorimetric ammonia values indicates that the colorimetric values were about 10% higher than laboratory values (tables 2b and 2c).

Time series measurements were made at the 100-foot transect at 1:27 and 1:41 p.m. before the transect survey sampling was initiated. The 25% location samples were each 2.9 mg/l; the center and 75% location samples were each 1.8 mg/l. These samples suggest that the downstream water that was moving past the effluent at high tide (but before slack conditions) had an ammonia concentration of 1.8 mg/l and the effluent was increasing the west-side concentration by about 1 mg/l. The sample from the downstream station R3 at 11:55 a.m. of 1.6 mg/l confirms the average ammonia concentration of about 1.4–1.8 mg/l. The upstream river concentration measured at Mossdale on January 18 was 1.0 mg/l. This is a relatively high ammonia concentration that may have been elevated by surface runoff from the previous week's moderate rainfall.

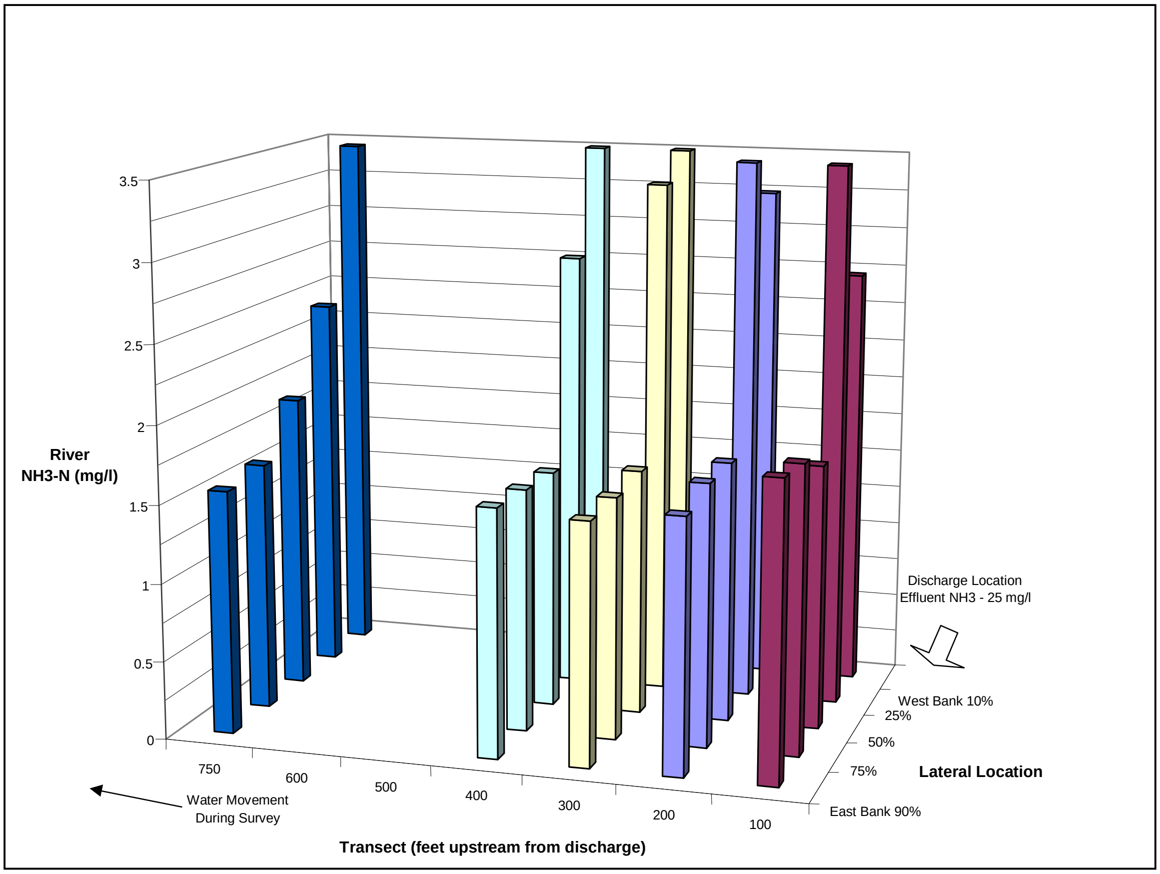


Figure 23. Results of Colormetric Ammonia Concentrations from Near-Field Mixing Study on January 18, 2001

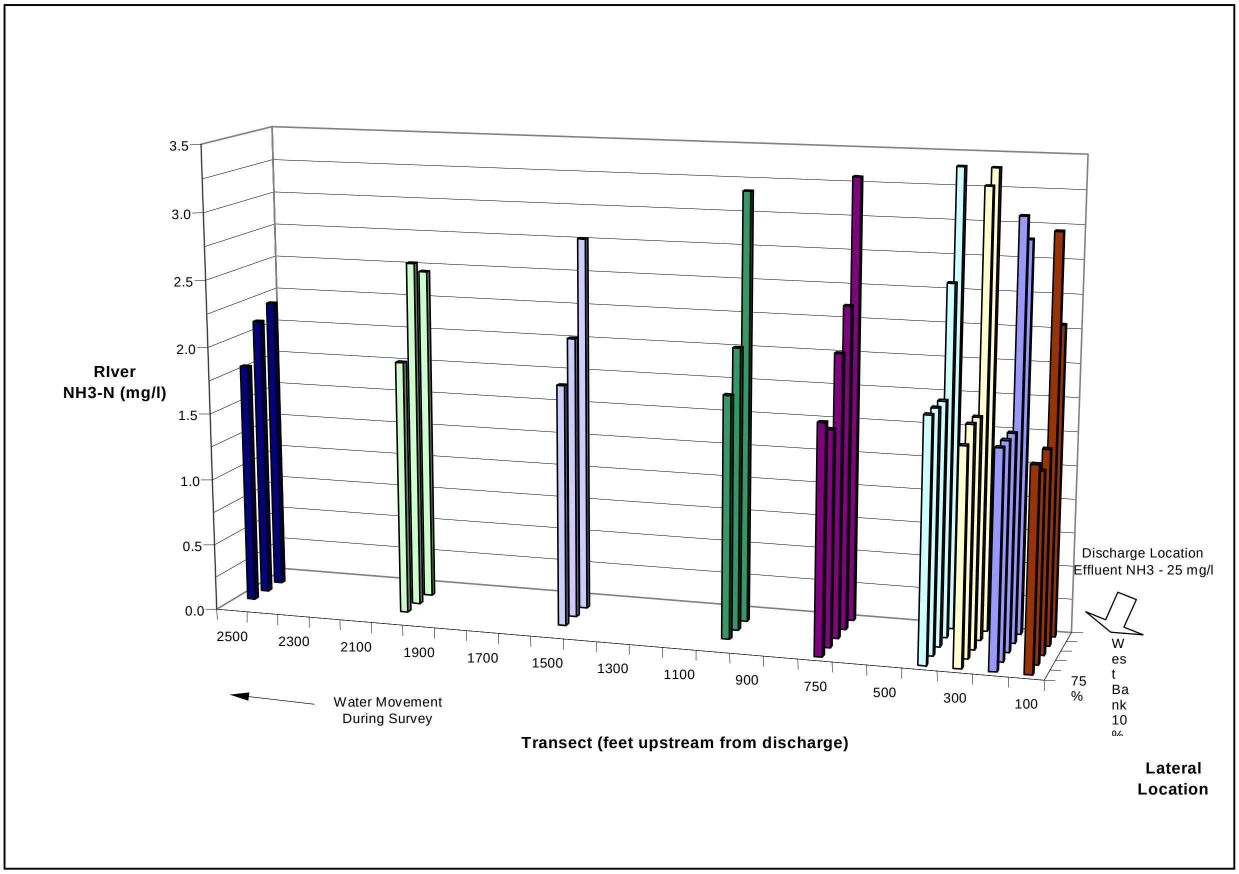


Figure 24. Results of Laboratory Analysis of Ammonia Concentrations from Near-Field Mixing Study on January 18, 2001

Table 2c. January 18, 2001, Sampling Event Laboratory Ammonia Data—High Tide at 1:40 p.m.

		Ammonia at Sample Point (mg/l—EPA 350.2)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream Samples						
100’	1:45 p.m.	2.3	3.0	1.5	1.4	1.5
200’	1:50 p.m.	2.9	3.1	1.6	1.6	1.6
300’	1:57 p.m.	3.4	3.3	1.7	1.7	1.6
400’	2:05 p.m.	3.4	2.6	1.8	1.8	1.8
750’	2:14 p.m.	3.3	2.4	2.1	1.6	1.7
1,000’	2:25 p.m.	–	3.2	2.1	1.8	–
1,500’	2:29 p.m.	–	2.8	2.1	1.8	–
2,000’	2:38 p.m.	–	2.5	2.6	1.9	–
2,500’	2:42 p.m.	–	2.2	2.1	1.8	–
Time Series Samples						
100’	1:27 p.m.	–	2.9	1.8	1.8	–
100’	1:41 p.m.	–	2.9	1.8	1.8	–
100’	2:20 p.m.	–	2.9	5.0	3.1	–
Mossdale Sample						
	4:20 p.m.	1.0	–	–	–	–
River Monitoring Location R3 Sample						
	11:55 a.m.	1.6	–	–	–	–

Note:
Laboratory QA/QC procedures were as follows: Three lab batches of 10 samples each. Lab blanks were nondetectable. Lab and matrix spikes were within 90%–110% recovery. Lab duplicates were within 10% allowable tolerance.

The difference between the 2 days appears to be the actual distance that the river water has moved since passing the discharge location. Complete lateral mixing must require at least 1,000 feet. The water collected at the 500-foot transect on the first day may have actually moved 1,500 feet upstream during the 30 minutes after high tide and then moved back downstream 1,000 feet during the 30 minutes after slack tide. The difficulty of sampling during slack tide indicates that the river velocity is reduced only briefly after high or low tide. The river flow reverses within an hour of the high or low tides, and the period of slack current is very short. There is very little opportunity for high effluent concentrations to occur during these short periods of slack tide.

The laboratory samples collected on January18 include transects from 1,000 feet, 1,500 feet, 2,000 feet, and 2,500 feet. The ammonia concentrations determined by laboratory analysis are given in table 2c and illustrated in figure 22. The 50% lateral location sample was about the same as the 25% lateral location at the 2,000-foot and

2,500-foot transects. The 75% lateral location sample was within 10% of the average at the 2,500-foot transect. These results indicate that complete lateral mixing requires a distance of about 0.5 miles. These results were used to calibrate the lateral mixing rate used in the box model to be 1% of the tidal flow.

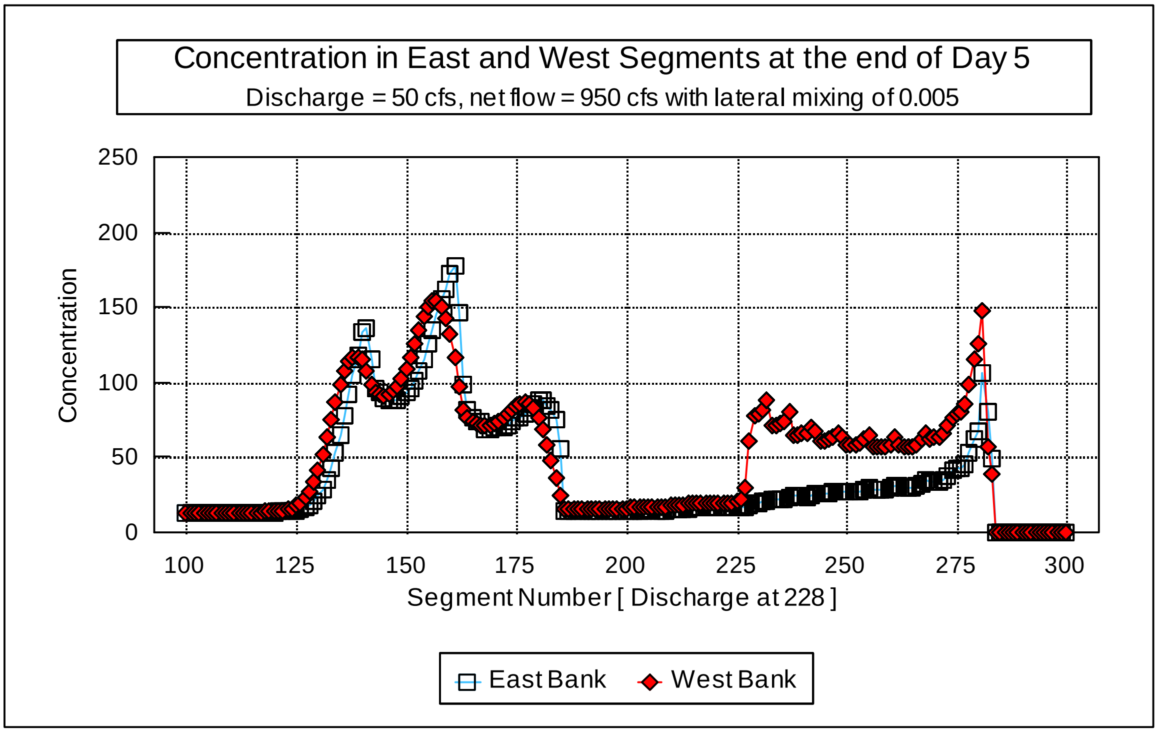
The maximum ammonia concentrations observed within 500 feet of the RWCF discharge location were about 2.5 mg/l higher than the ammonia concentrations at the east bank. This observation indicates that the effluent experienced an initial dilution factor of 10, which corresponds with previous estimates of jet dilution. The fully mixed ammonia concentrations were approximately 0.7 mg/l greater than the Mossdale concentration, as expected if the net river flow was 1,250 cfs.

Calibration of the Lateral Mixing Rate

The results from the field survey were used to calibrate the model coefficient for lateral mixing. Figure 25 shows the simulated concentrations in the east-side and west-side segments at the end of day 5 for 2 estimates of the lateral mixing rate. Low tide occurred at about 11 p.m., with the discharge location at segment 280 (i.e., segments have moved downstream so the discharge was located in segment 280 at low tide). The flood tide is moving segments upstream, and the discharge is located near segment 225 at midnight of day 5. The west-side concentration was increased from 25 to 75 by the discharge, while the east-side concentration remained at 25.

The top graph of figure 25 shows the simulated results for the original estimate of lateral mixing rate equal to 0.5% of the tidal flow. The east-side and west-side concentrations were not fully mixed, even at segment 275, located about 1 mile upstream of segment 225. The field data from the near-field mixing study indicated that complete mixing occurred more rapidly, and that the west-side and east-side concentrations were fully mixed within a distance of less than 2,500 feet (0.5 mile) from the discharge.

The bottom graph indicates that the higher simulated lateral mixing rate of 1% of tidal flow provided considerably more lateral mixing, with the east-side and west-side concentrations approaching the mixed concentration of about 50 within 25 segments upstream of the discharge. These calibration results suggest that the lateral mixing rate in this portion of the San Joaquin River is approximately 1% of tidal flow. This calibrated lateral mixing rate suggests, in turn, that 20 cfs of water will be exchanging between each pair of model segments during a typical tidal flow of 2,000 cfs. This relatively high lateral mixing rate is consistent with the expected effects of tidal flow conditions and river bends that are located both upstream and downstream of the discharge location. This calibrated rate of



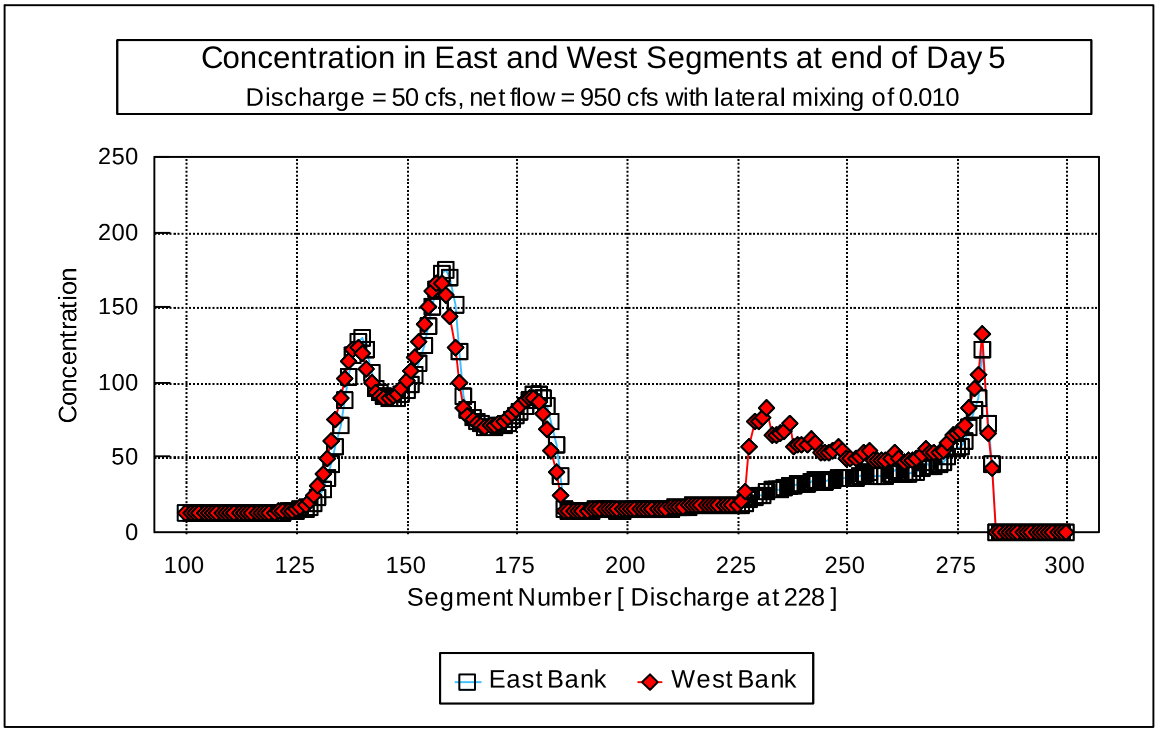


Figure 25. Simulated Concentrations for Lateral Mixing Rates of 0.5 and 1.0 % Tidal Flow

lateral mixing equal to 1% of the tidal flow is the most likely value for accurately simulating the near-field mixing and tidal dilution of the RWCF discharge.

Interpretation of Tidal Mixing Results for Estimating Maximum Exposure Concentrations

Instream sampling indicated that the effluent is diluted significantly as the jet discharge mixes into the tidal flow of the San Joaquin River. Sampling done as part of this study and the dye study conducted in 1993 both indicate that the discharge jet induces mixing at a ratio of 9 parts river water to 1 part effluent (i.e., concentration dilution of 10). The instream effluent concentration is elevated on the west side only, where the outfall pipe is located. As the discharge plume is carried upstream or downstream with the tidal current, the plume mixes across the width of the river until lateral mixing is complete. This process extends over a distance of about 2,500 feet (i.e., about 10 river widths) and may take up to 1 hour to complete.

In general, the Lagrangian box model with 2 lateral segments provided a reasonable simulation of the observed mixing. Model predictions at sampling station R2 (located 0.85 mile upstream of the outfall), using alternative lateral mixing coefficients of 0.5% and 1.0% of the tidal flow, suggested that mixing would be sufficient to reduce the difference between east-bank and west-bank concentrations to less than 10. Instream sampling indicates that lateral mixing is nearly complete within 2,500 feet and that the higher mixing rate of 1% tidal flow is the best estimate of lateral mixing in this portion of the San Joaquin River.

The box model predicts maximum instream concentrations at the outfall during slack tide. Depending upon the period within the spring/neap lunar tidal cycle, the maximum concentrations during slack tides will vary. As the current increases after slack, the plume will move with the flow and disperse across the river, gradually decreasing in concentration from the slack-tide maximums. An evaluation of maximum 15-minute concentrations under various net flow conditions, ranging from 150 cfs to 950 cfs, indicates that peak concentrations range from about 30% to 40% effluent. At low flow (150 cfs), the slack period is of relatively short duration but the background concentration is elevated, giving rise to a peak concentration of 40% effluent (see figure 4). As the net flow increases to 450 cfs, the peak concentration decreases toward 30% (see figure 13). However, at elevated flows of 950 cfs, the net flow works to counteract the flood tide and may prolong the slack tidal flow condition. Consequently, the short-term peak concentration approaches 40% even though the background concentration is reduced significantly (see figure 15).

The model predictions can be used to evaluate dilution conditions and dilution credits associated with acute and chronic water quality standards. Acute water quality standards are defined with averaging periods ranging from 1 hour (applicable to most acute water quality standards) to 3 hours (recommended in the 1999 update for the EPA acute ammonia criteria). Chronic water quality standards are defined with averaging periods ranging from 4 days (most chronic standards) to 30 days (ammonia). Compliance with the appropriate water quality standard may be assessed through consideration of an organism drifting with the plume. Because the model predicts instream concentration on a continuous basis at discrete 15-minute intervals, maximum concentrations corresponding to the specified averaging period may be determined from the 15-minute model results.

At a minimum, the acute standard for many pollutants uses an average exposure over 1 hour. The hourly maximum concentration predicted by the model is slightly less than the 15-minute peak concentrations, because the slack periods generally do not persist for an hour. Figure 11b indicates that the maximum 1-hour average west-side concentration at the discharge location is about 33% effluent at a net flow of 150 cfs. Because the peak hourly concentration does not exceed 33% at any net flow, a dilution credit equal to or greater than 2.0 (i.e., concentration dilution of 3) is appropriate for establishing 1-hour acute limits for the RWCF discharge. The dilution credit appropriate for the 3-hour acute standard (ammonia) would be slightly greater than the 1-hour credit.

The chronic standard represents a long-term average concentration that is significantly less than the peak concentrations that occur during slack-tide conditions. Over 4 days, a drifting organism will be carried upstream and downstream past the discharge location numerous times by the tidal flows. Most of this time will be spent at a concentration that is less than the steady-state average for the net flow condition. Only as the organism is transported downstream past the tidal excursion zone will the organism be exposed to the average concentration expected from the net flow and discharge conditions (see figures 7 and 8). After a few days, the segment will be displaced beyond the influence of the discharge and the exposure concentration will equal the steady-state value.

In summary, the maximum 4-day average exposure concentration will equal the steady-state value for the given net flow condition, but the location for this maximum exposure is considerably downstream of the discharge location. The 30-day average exposure concentration is also equal to the expected steady-state concentration. In either case, the dilution credit can be calculated as the average net river flow divided by the average effluent flow. Both analyses are contingent upon a conservative substance. If decay occurs, the 4-day and 30-day average exposure concentrations could be much less than the steady-state mixed concentration.

If exposure is based on an organism residing in a particular reach of the river, the dilution credit will be significantly greater than that based on a drifting organism (as indicated in table 1) for organisms located within the excursion distance from the outfall. Organisms found downstream of the tidal excursion (e.g., about 2 miles) will be exposed to the expected steady-state concentration.

Summary

A tidal mixing model was developed for the Stockton RWCF to illustrate and evaluate the patterns of tidal dilution that would be expected for a range of river flows considering the actual tidal flow fluctuations measured at the Stockton UVM station.

The tidal flows create more complex dilution patterns than would be expected for a river discharge without the tidal influence that the Stockton RWCF discharge experiences. A little effluent is added to the river by the RWCF discharge as the tidal flows move past the discharge location several times during relatively low river flow (less than 1,000 cfs).

Because river water moves back and forth several times within the tidal mixing zone, the lateral mixing processes maintain relatively well-mixed conditions. At the discharge location, the average daily east-side concentrations are expected to remain within 80% of the west-side concentrations during periods with relatively low river flow (less than 1,000 cfs). The hourly concentrations can be considerably higher than the daily average values on the west side of the river, but the lateral mixing caused by tidal flows will achieve complete lateral mixing within a distance of about 2,500 feet from the RWCF outfall (upstream or downstream).

The maximum concentrations at any selected station will vary during the month because of the variations in tidal fluctuations that limit the tidal mixing zone during days with neap tides (i.e., less tidal variation) and during days when the net tidal movement is slightly upstream (i.e., average tidal stage increase).

The maximum instream effluent concentrations will be no greater than 40% effluent and are expected to occur during slack tide periods when the tidal flow is reduced. This maximum concentration is somewhat independent of the net river flow between 150 cfs and 950 cfs. Average exposure concentrations will approach the expected steady-state fully-mixed condition for averaging periods of 4 days or more.

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Blue values are interpolated, for all years

For this estimate:	Low Estimate	High Estimate
Red	= (0.5 - 0.075*(Pumping/Vernalis Flow))*Vernalis Flow	= (0.5 - 0.05*(Pumping/Vernalis Flow))*Vernalis Flow
Purple	= 0.75*Vernalis Flow	= 0.95*Vernalis Flow
Black	= 0.30*Vernalis Flow	= 0.60*Vernalis Flow
Orange	= 0.75*Vernalis Flow	= 0.90*Vernalis Flow

Date	**SJR at Stockton UVM Flow 1999 cfs**	**SJR at Stockton UVM Flow 2000 cfs**	**SJR at Stockton UVM Flow 2001 cfs**	**SJR at Stockton UVM Flow Low Estimate 2001 cfs**	**SJR at Stockton UVM Flow High Estimate 2001 cfs**	**SJR at Stockton UVM Flow Estimate 2001 cfs**
1-Jan	1680	457	414	343	580	**414**
2-Jan	1660	528	426	396	612	**426**
3-Jan	1640	500	367	332	565	**367**
4-Jan	1670	344	188	263	515	**188**
5-Jan	1660	150	134	251	507	**134**
6-Jan	1610	284	90	288	529	**90**
7-Jan	1520	200	173	515	681	**173**
8-Jan	1390	272	318	758	854	**318**
9-Jan	1200	263	616	886	963	**616**
10-Jan	1030	298	602	964	1014	**602**
11-Jan	930	183	710	1073	1127	**710**
12-Jan	1040	440	910	1172	1228	**910**
13-Jan	1060	171	939	1081	1193	**939**
14-Jan	946	203	979	1032	1171	**979**
15-Jan	833	230	839	911	1088	**839**
16-Jan	874	608	912	767	979	**912**
17-Jan	989	849	765	780	951	**765**
18-Jan	1170	947	671	1025	1090	**671**
19-Jan	1340	1029	627	1005	1085	**627**
20-Jan	1720	946	596	1023	1098	**596**
21-Jan	2420	887	518	806	947	**518**
22-Jan	2850	986	342	521	748	**342**
23-Jan	2540	958	233	463	704	**233**
24-Jan	3700	1235	288	368	641	**288**
25-Jan	4390	1596	430	436	691	**430**
26-Jan	4750	1934	413	385	686	**413**
27-Jan	4420	1656	583	942	1100	**583**
28-Jan	4510	1559	995	1039	1189	**995**
29-Jan	4350	1548	965	998	1146	**965**
30-Jan	4010	1513	858	927	1077	**858**
31-Jan	3950	1847	755	858	1013	**755**
1-Feb	4390	675	696	691	889	**696**
2-Feb	3870	535	534	654	853	**534**
3-Feb	3310	291	445	629	825	**445**
4-Feb	3040	508	364	598	797	**364**
5-Feb	3210	443	320	590	790	**320**
6-Feb	3320	577	161	563	771	**161**
7-Feb	3390	382	453	580	779	**453**
8-Feb	4250	316	433	534	746	**433**
9-Feb	4990	363	288	524	739	**288**
10-Feb	5950	346	347	501	729	**347**
11-Feb	6920	209	517	744	919	**517**
12-Feb	7330	1224	842	768	974	**842**
13-Feb	7880	1813	1005	869	1092	**1005**
14-Feb	8200	2810	1068	1045	1236	**1068**
15-Feb	8240	4615	963	970	1188	**963**
16-Feb	7700	5152	914	1089	1282	**914**

17-Feb	7220	5224	853	1129	1301	**853**
18-Feb	6980	5986	856	1073	1247	**856**
19-Feb	7020	6544	746	1051	1228	**746**
20-Feb	7160	6618	905	1038	1213	**905**
21-Feb	7410	6808	1002	1010	1182	**1002**
22-Feb	7700	6359	882	1164	1336	**882**
23-Feb	8190	7018	1389	1284	1473	**1389**
24-Feb	7870	7616	1905	1334	1618	**1905**
25-Feb	7040	8060	2783	1568	1846	**2783**
26-Feb	6520	7132	2770	1804	2089	**2770**
27-Feb	6140	6614	2420	1912	2119	**2420**
28-Feb	5850	6841	2174	1715	1925	**2174**
29-Feb		8013				
1-Mar	5710	7903	1933	1498	1720	**1933**
2-Mar	5420	7935	1716	1262	1489	**1716**
3-Mar	5100	7103	1438	1162	1384	**1438**
4-Mar	5140	6914	1037	1088	1316	**1037**
5-Mar	4870	6900	1853	1130	1375	**1853**
6-Mar	4590	7703	2548	1612	1860	**2548**
7-Mar	4350	8534	2970	2449	2569	**2970**
8-Mar	4050	7874	2813	2375	2501	**2813**
9-Mar	3810	7856	2440	2400	2546	**2440**
10-Mar	3860	7821	2305	2331	2492	**2305**
11-Mar	4000	7666	2149	2065	2224	**2149**
12-Mar	4200	7481	1785	1575	1803	**1785**
13-Mar	4260	7401	1358	1426	1642	**1358**
14-Mar	4090	7275	1225	1271	1487	**1225**
15-Mar	3980	6923	1116	1133	1342	**1116**
16-Mar	3970	6441	1010	1114	1299	**1010**
17-Mar	3680	6267	937	1057	1242	**937**
18-Mar	3510	5987	812	1010	1190	**812**
19-Mar	3450	5364	735	970	1152	**735**
20-Mar	3510	5084	616	935	1120	**616**
21-Mar	3420	5224	537	922	1105	**537**
22-Mar	3320	4441	554	870	1052	**554**
23-Mar	3180	3771	618	803	1002	**618**
24-Mar	2980	3461	528	737	946	**528**
25-Mar	2890	3433	652	726	943	**652**
26-Mar	2730	3331	598	664	861	**598**
27-Mar	2800	3194	524	506	697	**524**
28-Mar	2670	2969	433	480	676	**433**
29-Mar	2540	2694	457	509	696	**457**
30-Mar	2430	2485	495	544	720	**495**
31-Mar	2330	2357		528	704	**444**
1-Apr	2190	2183	392	513	687	**392**
2-Apr	2080	1842		586	753	**594**
3-Apr	1850	1521		582	748	**797**
4-Apr	2020	1286	999	542	701	**999**
5-Apr	1770	1216	377	603	731	**377**
6-Apr	1820	1110	550	745	842	**550**
7-Apr	2000	1009	709	893	980	**709**
8-Apr	2230	864	899	929	1042	**899**
9-Apr	2560	1016	794	962	1063	**794**
10-Apr	2460	1067	776	775	920	**776**
11-Apr	2780	1169	**742**	756	904	**742**
12-Apr	2930	1723	708	763	911	**708**
13-Apr	3030	2210	711	794	931	**711**
14-Apr	2990	2935	689	778	919	**689**

15-Apr	2870	4446	703	786	925	**703**
16-Apr	2800	5412	715	839	971	**715**
17-Apr	2770	6024	652	714	853	**652**
18-Apr	2860	6639	460	711	826	**460**
19-Apr	2960	6811	481	747	867	**481**
20-Apr	2950	6222	1135	1694	1722	**1135**
21-Apr	2830	5825	1971	2254	2272	**1971**
22-Apr	2930	5940	2148	2339	2358	**2148**
23-Apr	3060	6031	1966	2297	2315	**1966**
24-Apr	2900	6083	1849	2290	2308	**1849**
25-Apr	3080	5886	2426	**2779**	**3225**	**2426**
26-Apr	3080	5763	3091	3269	4141	**3091**
27-Apr	2860	5494	**3260**	3298	4177	**3260**
28-Apr	2840	5310	3429	3355	4249	**3429**
29-Apr	2980	5062		3354	4248	3801
30-Apr	3130	5165		3269	4141	3705
1-May	2980	5024		3323	4209	3766
2-May	2940	4952		3337	4227	3782
3-May	3060	4760		3388	4291	3839
4-May	3280	4636		3326	4213	3770
5-May	3190	4684		3322	4208	3765
6-May	3080	4867		3318	4202	3760
7-May	3160	5028		3314	4197	3755
8-May	3060	5276		3349	4242	3795
9-May	3190	5520		3326	4212	3769
10-May	3220	5498		3110	3939	3524
11-May	3040	5487		3129	3963	3546
12-May	2810	5199		3145	3983	3564
13-May	2940	4927		3245	4110	3677
14-May	3070	4992		3391	4295	3843
15-May	3300	4670		3345	4237	3791
16-May	3190	4137		3383	4285	3834
17-May	2770	3954		3374	4274	3824
18-May	2110	3544		3419	4331	3875
19-May	1790	2866		3226	4086	3656
20-May	1620	1883		2894	3665	3279
21-May	1520	1626		2486	3149	2818
22-May	1360	1505		2092	2650	2371
23-May	1400	1377		1822	2308	2065
24-May	1560	1357	2012	**1229**	**1791**	**2012**
25-May	1320	1707	1378	637	1274	**1378**
26-May	1230	1625		624	1249	936
27-May	1300	1543		625	1249	937
28-May	1300	1483		644	1289	967
29-May	1290	1169		652	1304	978
30-May	1030	1130		615	1229	922
31-May	1130	956		596	1191	893
1-Jun	1040	1077		597	1193	895
2-Jun	1170	1167		571	1142	856
3-Jun	1490	1269		555	1111	833
4-Jun	1600	1310	677	564	1129	**677**
5-Jun	1640	1420	661	558	1116	**661**
6-Jun	1680	1387	783	542	1083	**783**
7-Jun	1780	1233	662	541	1082	**662**
8-Jun	1670	1440	581	541	1082	**581**
9-Jun	1540	1580	698	541	1082	**698**
10-Jun	1480	1604	718	541	1082	**718**
11-Jun	1380	1642	611	515	1030	**611**

12-Jun	1490	1688	700	483	966	**700**
13-Jun	1590	1724	639	480	959	**639**
14-Jun	1590	1511	563	475	949	**563**
15-Jun	1620	1093	455	462	925	**455**
16-Jun	1720	846	281	473	946	**281**
17-Jun	1620	684	1000	487	973	**1000**
18-Jun	1570	1019	754	479	959	**754**
19-Jun	1590	1003	576	442	883	**576**
20-Jun	1710	754	547	413	826	**547**
21-Jun		757	557	422	844	**557**
22-Jun		667	556	418	835	**556**
23-Jun		765	622	392	783	**622**
24-Jun		699	768	422	844	**768**
25-Jun		936	843	457	914	**843**
26-Jun		708	825	455	909	**825**
27-Jun		615	860	444	889	**860**
28-Jun	1240	588	835	443	885	**835**
29-Jun	1100	503	759	453	907	**759**
30-Jun	973	673	629	446	892	**629**
1-Jul	883	691		446	893	670
2-Jul	923	479		431	862	647
3-Jul	987	629		418	836	627
4-Jul	1200	527		404	807	605
5-Jul	1310	505		421	842	631
6-Jul	1100	485		419	837	628
7-Jul	1090	662		407	814	611
8-Jul	813	717		422	844	633
9-Jul	673	744		435	869	652
10-Jul	782	590		433	866	649
11-Jul	900	650		404	809	607
12-Jul	839	561		387	775	581
13-Jul	701	758		411	823	617
14-Jul	563	775		421	841	631
15-Jul	658	659		446	892	669
16-Jul	816	724		480	959	720
17-Jul	825	759		464	929	697
18-Jul	830	719		437	874	656
19-Jul	840	597		408	815	612
20-Jul	824	515		412	824	618
21-Jul	706	664		404	809	607
22-Jul	665	776		425	850	638
23-Jul	601	925		444	887	666
24-Jul	777	788		413	825	619
25-Jul	762	677		391	782	586
26-Jul	729	648		406	812	609
27-Jul	688	817		402	803	603
28-Jul	810	760		391	782	586
29-Jul	854	856		412	824	618
30-Jul	892	943		432	865	648
31-Jul	875	882		408	816	612
1-Aug	1100	860		404	808	606
2-Aug	1090	621		371	742	556
3-Aug	982	456		376	752	564
4-Aug	918	697		381	761	571
5-Aug	811	877		397	794	595
6-Aug	845	1022		420	841	630
7-Aug	767	999		407	814	611
8-Aug	906	767		381	763	572

9-Aug	971	616		358	715	536
10-Aug	795	741		351	703	527
11-Aug	972	839		372	745	558
12-Aug	972	841		395	789	592
13-Aug	911	819		406	812	609
14-Aug	936	776		391	781	586
15-Aug	1100	680		389	778	584
16-Aug	1050	612		388	776	582
17-Aug	798	583		380	760	570
18-Aug	757	767		404	808	606
19-Aug	825	1015		439	878	659
20-Aug	812	1279		443	886	665
21-Aug	792	1228		417	835	626
22-Aug	895	1085		403	806	605
23-Aug	787	1179		412	824	618
24-Aug	912	1537		402	804	603
25-Aug	902	1436		411	823	617
26-Aug	892	1498		446	893	670
27-Aug	771	1664		459	919	689
28-Aug	909	1562		443	886	664
29-Aug	1170	1356		424	848	636
30-Aug	1250	1285		401	803	602
31-Aug	1180	1314		387	774	581
1-Sep	925	1257		371	742	557
2-Sep	859	1469		413	825	619
3-Sep	873	1472		474	948	711
4-Sep	972	1592		436	872	654
5-Sep	1200	1563		387	775	581
6-Sep	1080	1398		376	752	564
7-Sep	1010	1301		403	806	604
8-Sep	900	1068		416	833	625
9-Sep	990	1198		434	868	651
10-Sep	1000	1352		439	877	658
11-Sep	1080	1402	762	421	842	**762**
12-Sep	1190	1324	761	398	795	**761**
13-Sep	1310	1184	871	377	753	**871**
14-Sep	1240	1110	835	384	767	**835**
15-Sep	1180	1145	817	404	809	**817**
16-Sep	1100	1658	925	417	834	**925**
17-Sep	1000	1557	904	419	838	**904**
18-Sep	1000	1260	773	419	838	**773**
19-Sep	1070	919	645	399	797	**645**
20-Sep	1410	675	598	392	784	**598**
21-Sep	1250	921	879	412	824	**879**
22-Sep	1200	1581	1829	404	809	**866**
23-Sep	880	1699	853	412	824	**853**
24-Sep	459	1738	1137	429	857	**1137**
25-Sep	430	1728	1120	425	851	**1120**
26-Sep	426	1321	921	426	851	**921**
27-Sep	425	1118	1000	421	842	**1000**
28-Sep	454	1216	934	424	847	**934**
29-Sep	344	786	1030	435	869	**1030**
30-Sep	230	699	1060	449	898	**1060**
1-Oct	269	637		454	907	680
2-Oct	348	402		425	850	638
3-Oct	535	803		399	797	598
4-Oct	496	1170		390	781	585
5-Oct	559	1522		403	805	604

6-Oct	538	1414	**781**	**1098**	940
7-Oct	534	1670	1160	1391	1275
8-Oct	546	1852	1231	1477	1354
9-Oct	512	1843	1186	1423	1304
10-Oct	585	2027	1175	1410	1293
11-Oct	509	2319	1144	1373	1258
12-Oct	697	2459	1110	1332	1221
13-Oct	611	2310	1124	1349	1449
14-Oct	454	2081	1161	1393	1480
15-Oct	481	2079	1152	1382	1452
16-Oct	631	2107	1132	1358	1393
17-Oct	655	1934	1136	1364	1459
18-Oct	689	1879	1189	1427	1565
19-Oct	776	2094	1284	1541	1656
20-Oct	703	2259	1385	1661	1740
21-Oct	606	2474	1580	1895	1943
22-Oct	552	2580	1882	2258	2321
23-Oct	524	2452	1887	2264	2282
24-Oct	710	2464	1924	2309	2460
25-Oct	612	2301	1992	2390	2416
26-Oct	548	2315	2088	2506	2486
27-Oct	584	2326	2078	2493	2469
28-Oct	613	2435	2146	2575	2608
29-Oct	660	2348	2042	2450	2547
30-Oct	575	2209	1858	2229	2354
31-Oct	506	2140	1698	2038	2144
1-Nov	594	2040	1643	1972	2122
2-Nov	490	1878	1650	1980	2078
3-Nov	501	1948	1593	1912	1983
4-Nov	516	1794	1521	1825	1886
5-Nov	458	1762	1484	1781	1665
6-Nov	536	1660	1455	1746	1573
7-Nov	519	1752	1438	1725	1629
8-Nov	493	1493	1520	1824	1776
9-Nov	485	1487	1519	1823	1762
10-Nov	363	1390	1523	1827	1728
11-Nov	375	1449	1580	1895	1906
12-Nov	398	1425	1624	1949	1797
13-Nov	356	1268	1662	1994	1906
14-Nov	289	1341	1639	1967	1857
15-Nov	449	1372	1634	1960	1795
16-Nov	352	1353	1639	1967	1788
17-Nov	548	1412	1649	1978	1728
18-Nov	413	1507	1621	1945	1789
19-Nov	362	1517	1599	1919	1802
20-Nov	321	1534	**1042**	**1292**	1705
21-Nov	304	1545	485	665	1824
22-Nov	336	1547	467	646	1764
23-Nov	215	1484	448	626	1628
24-Nov	236	1382	372	572	1622
25-Nov	236	1312	437	627	1861
26-Nov	140	1367	433	615	1577
27-Nov	194	998	443	620	1475
28-Nov	286	362	398	590	1167
29-Nov	185	68	635	755	1155
30-Nov	280	555	837	892	1171
1-Dec	345	534	811	867	1110
2-Dec	227	551	812	876	1245

3-Dec	305	576	893	950	1188
4-Dec	243	554	788	873	1217
5-Dec	185	584	472	662	1032
6-Dec	122	421	273	534	1012
7-Dec	91	310	279	544	1064
8-Dec	209	282	287	547	1238
9-Dec	84	246	248	514	973
10-Dec	229	237	221	484	890
11-Dec	489	264	217	475	867
12-Dec	360	210	178	446	949
13-Dec	506	290	162	431	893
14-Dec	555	362	147	414	759
15-Dec	518	342	103	383	704
16-Dec	446	404	73	353	793
17-Dec	438	351	49	328	761
18-Dec	393	546	48	327	791
19-Dec	416	340	63	333	746
20-Dec	420	342	48	327	798
21-Dec	321	253	116	394	956
22-Dec	397	264	155	435	971
23-Dec	372	283	196	476	1091
24-Dec	367	266	144	427	1032
25-Dec	289	299	112	393	971
26-Dec	235	303	101	379	1015
27-Dec	316	257	70	351	826
28-Dec	219	226	69	351	810
29-Dec	175	243	241	519	1016
30-Dec	111	273	823	1105	1908
31-Dec	140	280	1591	1885	2930