

III. Long-Term Biochemical Oxygen Demand Measurements

Long-term biochemical oxygen demand (BOD) measurements were performed with water and trapped sediments collected from the DWSC and the San Joaquin River.

Materials and Methods

Selected water and sediment samples were placed in 300-mL BOD bottles without dilution or seeding. Measurements of dissolved oxygen were performed periodically over 40 days using a DO electrode and meter. Readings were periodically checked with a different meter and by the Winkler method (APHA, AWWA, and WEF, 1998). When DO levels were measured below 4 or 5 mg/L, reaeration was accomplished by shaking the sample in a 4-L Erlenmeyer flask until saturation was achieved. One or two blanks and glucose-glutamic acid standards (with seed) were also included with each trial.

The kinetic rate decay constant and the ultimate BOD, L_0 , was estimated by linearizing the data and fitting with a least-squares line. Assuming the decay of organic matter to behave as a first-order reaction,

$$BOD_t = L_0[1 - e^{-kt}]$$

where BOD_t is the biochemical oxygen demand calculated at time, t , in mg/L, k is the first-order decay rate constant, and L_0 is the ultimate BOD. Determination of k and L_0 is determined graphically by using the following linear approximation of the above equation:

$$\left[\frac{t}{y_t} \right]^{1/3} = (kL_0)^{-1/3} + \left[\frac{k^{2/3}}{6L_0^{1/3}} \right] t,$$

where $y_t = BOD_t$.

A plot of $\left[\frac{t}{y_t} \right]^{1/3}$ vs. t is a straight line with slope $m = \frac{1}{6}k^{2/3}L_0^{-1/3}$ and y-intercept of $b = (kL_0)^{-1/3}$. The first-order rate constant and ultimate BOD are calculated from $k=6m/b$ and $L_0=1/(6mb^2)$.

Estimates of the decay constant and ultimate BOD

Examples of the BOD data are presented in Figures III-1 through III-3 for the September 14, 2000 data. The goodness of fit was evaluated by squared correlation coefficients (R^2) and visual inspection. Anomalous data points were selectively removed so as not to skew the fitted line. However, virtually all the k values were estimated with at least five data points. The sediment oxygen demand was determined by subtracting the water contribution and dividing by the TSS, VSS, chlorophyll a , or chlorophyll a plus pheophytin a concentration. Figure III-3 shows the milligrams of oxygen demand associated with the trapped sediments per milligram of trapped VSS.

Table III-1 presents the first-order decay constant, k at 20°C, ultimate BOD, and the correlation coefficient for the San Joaquin River. Tables III-2 through III-4 contain these parameters for the DWSC water samples. The BOD_{ult}/BOD_5 ratio can be determined by,

$$BOD_{ult} / BOD_5 = 1 / (1 - e^{-k \times 5}),$$

Figure III-4 presents the decay constant for water samples collected from the San Joaquin River and the DWSC for each monitoring run conducted from August through November. The highest decay rates ranged from a high of 0.17 d^{-1} in late August to 0.06 d^{-1} in November. While the decay constant decreased with time, the ultimate BOD remained fairly constant throughout the late summer and fall months as shown in Figure III-5. However, a number of high BOD_{ult} values were measured in the San Joaquin during a flood tide and at Lt. 48 in the DWSC during both flood and ebb tides on November 9. These high BOD values could be associated with ammonia releases from the Stockton wastewater treatment plant outfall.

Trapped sediment decay rates, k , and regression coefficients, R^2 , are presented in Tables III-6 and III-7, respectively. The sediment rates are more variable than the water decay rates, ranging from approximately 0.03 to 0.23 d^{-1} . For many of the data sets the highest decay rates were associated with sediments collected from the upper traps and decreased with trap depth. This may be caused by higher fractions of refractory organic matter captured in the traps near the channel bottom. Tables III-8 through III-11 provide the BOD_{ult} per mass of TSS, VSS, chlorophyll a , and chlorophyll a plus pheophytin a in the sediments. The chlorophyll a plus pheophytin a normalization seems to yield the most consistent oxygen demand per constituent mass, suggesting that most of the sediment BOD is associated with decaying phytoplankton.

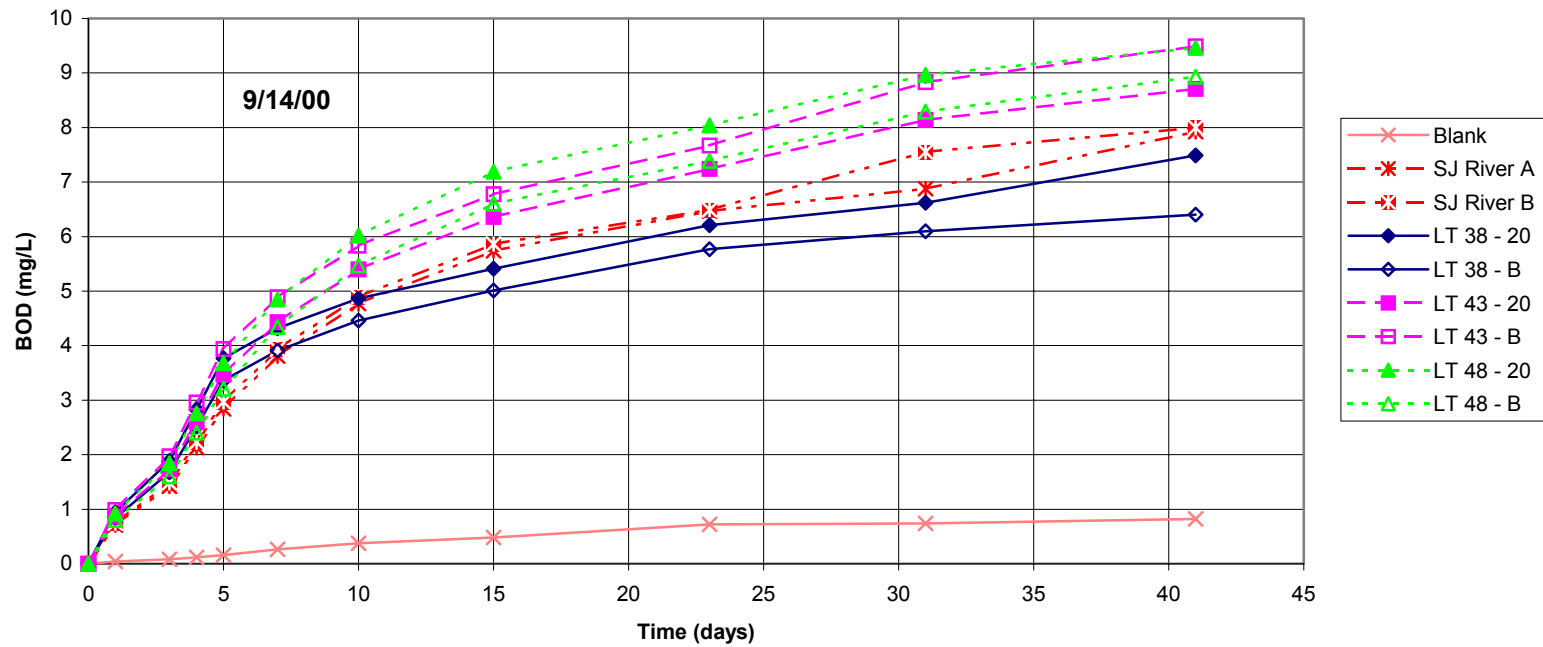


Figure III-1. Typical BOD measurements for water samples collected in the DWSC or San Joaquin River.

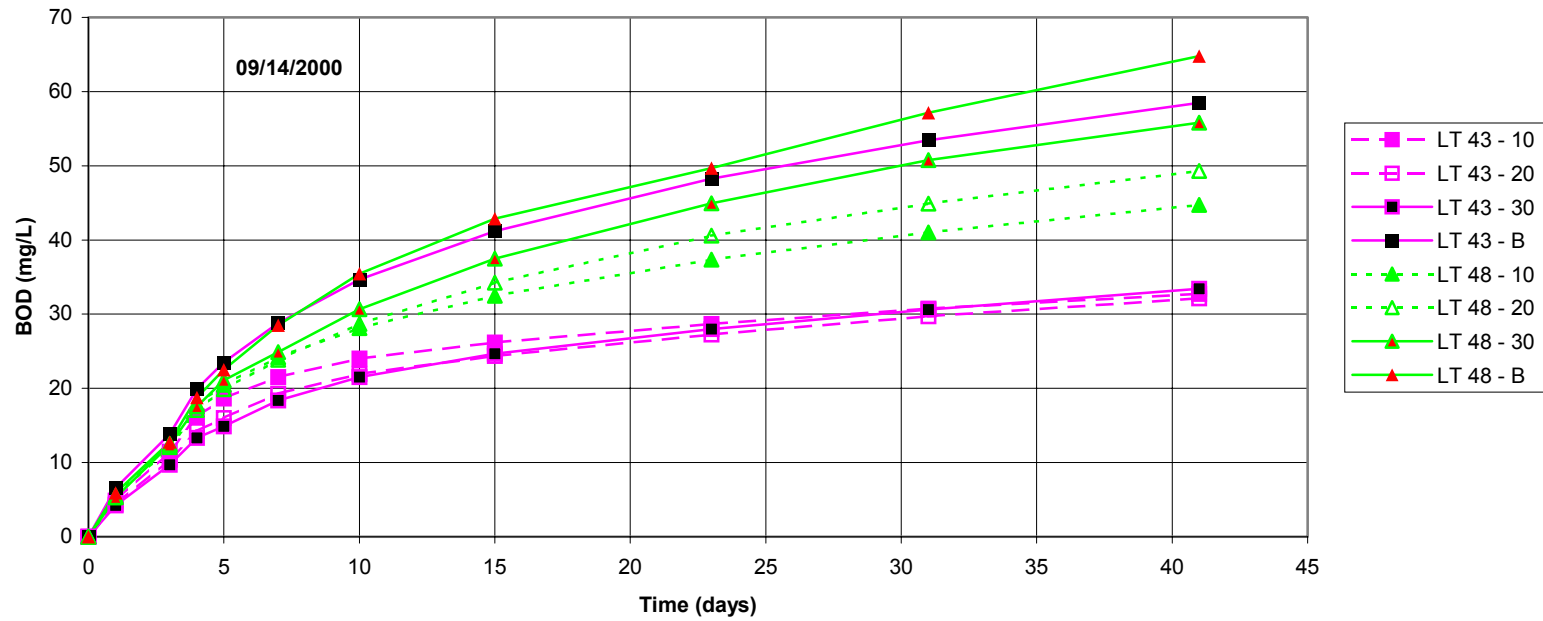


Figure III-2: Typical BOD measurements for trapped sediments suspended in DWSC water.

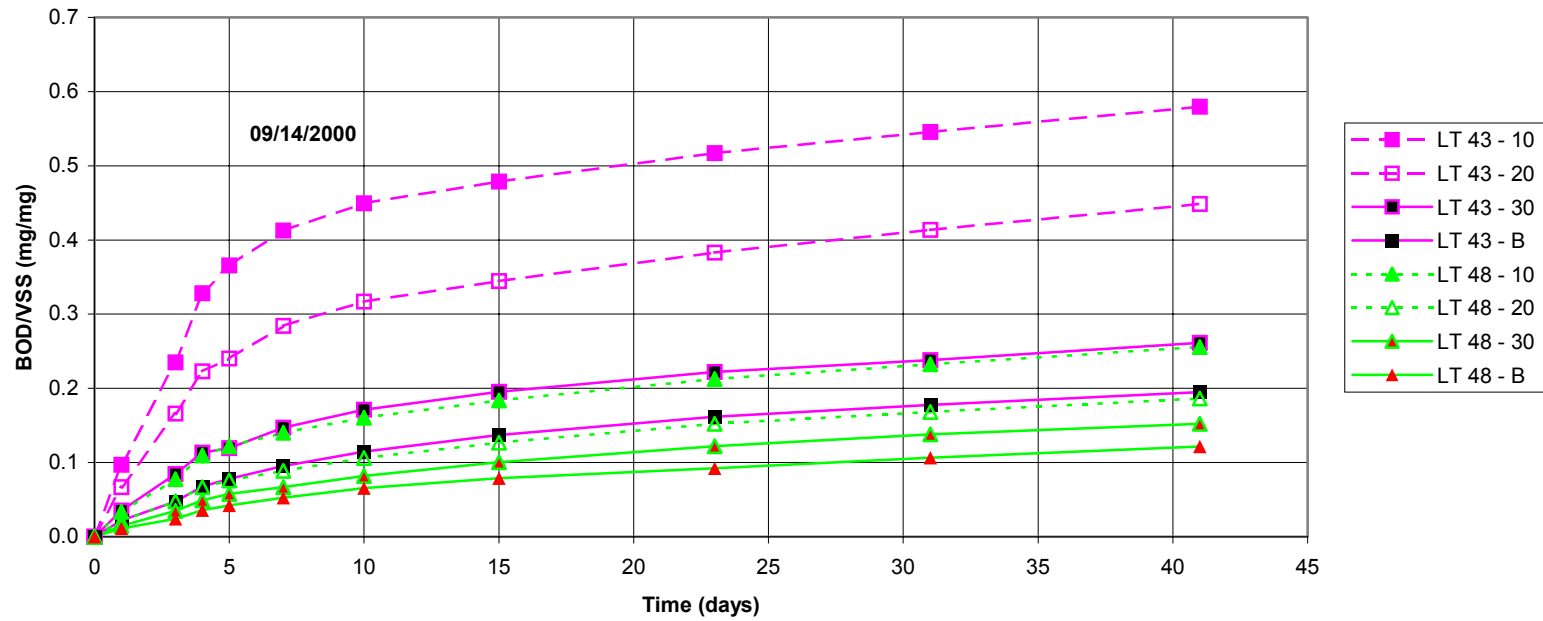


Figure III-3: The exerted BOD for trapped sediments after the water contribution is subtracted. The sediment BOD is also divided by the VSS concentration of the sediment-water suspension.

Table III-1 San Joaquin River BOD regression data and other water quality parameters.

Parameters for San Joaquin River Samples									
Units = varying									
Parameter	Tide	Date							
		7/27/00 (Spring - 3)	8/16/00 (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	Tide	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
BOD _{uL,t,k} (days ⁻¹)	25 Hour Composite		0.095	0.132	0.083		0.104	0.101	0.071
BOD _{uL,t,L_o} (mg/L O ₂)			15.3	11.4	8.1		7.8	5.8	5.8
BOD _{uL,t,R²}			0.990	0.947	0.943		0.997	0.976	0.993
TSS (mg/L)		47.4	30.2	26.8	28.6	Ebb	28.0	---	32.0
VSS (mg/L)		8.1	6.3	5.1	4.9		4.2	---	3.4
Chl <i>a</i> (mg/L)			55.1	39.8	39.8		27.2	19.8	4.0
Chl <i>a</i> + Ph <i>a</i> (mg/L)			73.0	62.6	62.6		42.2	29.5	6.4
Turbidity (NTU)		36	25	25	26		27	27	24
BOD _{uL,t,k} (days ⁻¹)							0.101	0.096	0.052
BOD _{uL,t,L_o} (mg/L O ₂)							6.3	5.2	20.0
BOD _{uL,t,R²}							0.997	0.963	0.929
TSS (mg/L)						Flood	26.2	---	18.4
VSS (mg/L)							4.2	---	3.1
Chl <i>a</i> (mg/L)							34.2	15.5	5.4
Chl <i>a</i> + Ph <i>a</i> (mg/L)							48.2	22.8	8.2
Turbidity (NTU)							23	21	19
Hatched area indicate composite samples or experiment not performed for that date									

Table III-2: BOD rate constants for DWSC waters.

BOD Rate Constant (k) - Water Samples

Units = day⁻¹

Location	Depth (ft)	Date						
		7/27/00 (Spring - 3)	8/16/00 (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ¹	8.2		0.116	---	---	0.112	0.116	---
	16.4		---	---	0.124	---	---	---
	24.6		---	---	---	---	---	---
	B		---	0.157	0.119	0.127	0.125	---
LT. 38 ²	8.2					0.122	0.110	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.112	0.124	---
LT. 43 ¹	8.2		---	0.161	---	---	---	0.075
	16.4		---	0.173	0.090	---	---	---
	24.6		---	0.147	---	---	---	---
	B		---	---	0.097	---	---	0.076
LT. 43 ²	8.2					---	---	0.083
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.082
LT. 48 ¹	8.2		---	---	---	0.105	0.076	0.078
	16.4		---	---	0.086	---	---	---
	24.6		---	---	---	---	---	---
	B		---	---	0.079	0.110	0.097	0.058
LT. 48 ²	8.2					0.111	0.109	0.076
	16.4					---	---	---
	24.6					---	---	---
	B					0.114	0.109	0.079

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

Hatched area indicate composite samples or experiment not performed for that date

Table III-3: Ultimate BOD fitted values for DWSC waters.

Units = mg / L

Location	Depth (ft)	Date						
		7/27/00 (Spring - 3)	8/16/00 (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ¹	8.2		9.4	---	---	7.5	8.2	---
	16.4		---	---	7.2	---	---	---
	24.6		---	---	---	---	---	---
	B		---	6.7	6.7	7.0	8.2	---
LT. 38 ²	8.2					6.0	6.2	---
	16.4					---	---	---
	24.6					---	---	---
	B					6.6	7.2	---
LT. 43 ¹	8.2		---	7.0	---	---	---	10.5
	16.4		---	5.7	8.9	---	---	---
	24.6		---	7.3	---	---	---	---
	B		---	---	9.4	---	---	9.0
LT. 43 ²	8.2					---	---	11.4
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	10.4
LT. 48 ¹	8.2		---	---	---	10.1	10.9	16.4
	16.4		---	---	10.0	---	---	---
	24.6		---	---	---	---	---	---
	B		---	---	9.4	6.8	10.5	19.3
LT. 48 ²	8.2					6.9	6.3	16.9
	16.4					---	---	---
	24.6					---	---	---
	B					6.5	7.4	15.3

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

Hatched area indicate composite samples or experiment not performed for that date

Table III-4: Least-square regression coefficients (R^2) for DWSC waters.

Location	Depth (ft)	Date						
		7/27/00 (Spring - 3)	8/16/00 (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ¹	8.2		0.948	---	---	0.997	0.968	---
	16.4		---	---	0.970	---	---	---
	24.6		---	---	---	---	---	---
	B		---	0.987	0.971	0.993	0.961	---
LT. 38 ²	8.2					0.992	0.957	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.978	0.956	---
LT. 43 ¹	8.2		---	0.981	---	---	---	0.992
	16.4		---	0.969	0.955	---	---	---
	24.6		---	0.981	---	---	---	---
	B		---	---	0.957	---	---	0.997
LT. 43 ²	8.2					---	---	0.994
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.998
LT. 48 ¹	8.2		---	---	---	0.989	0.965	0.981
	16.4		---	---	0.948	---	---	---
	24.6		---	---	---	---	---	---
	B		---	---	0.936	0.996	0.994	0.990
LT. 48 ²	8.2					0.995	0.959	0.993
	16.4					---	---	---
	24.6					---	---	---
	B					0.996	0.964	0.992

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

Hatched area indicate composite samples or experiment not performed for that date

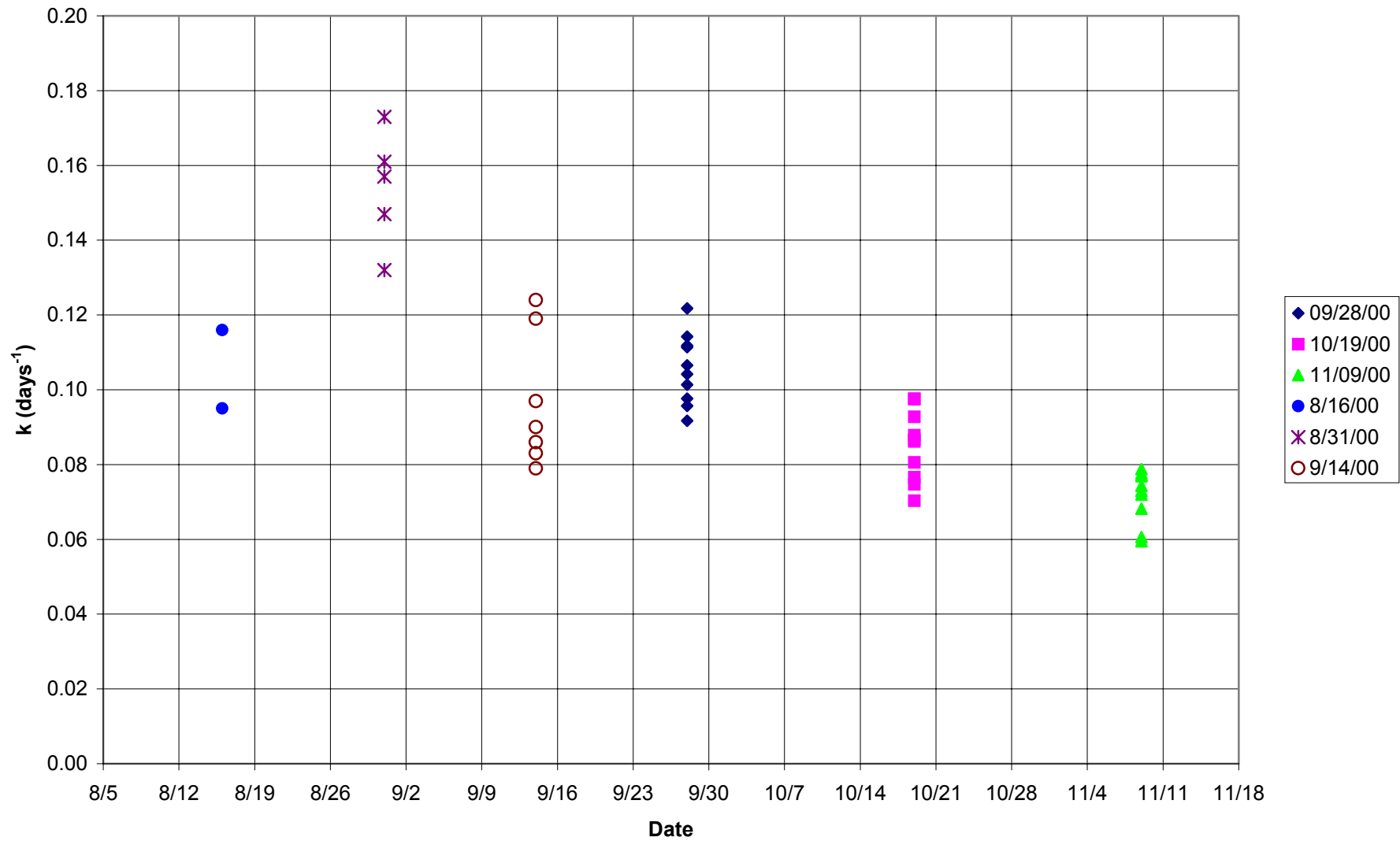


Figure III-4: BOD decay constants at 20° C for DWSC and San Joaquin River water.

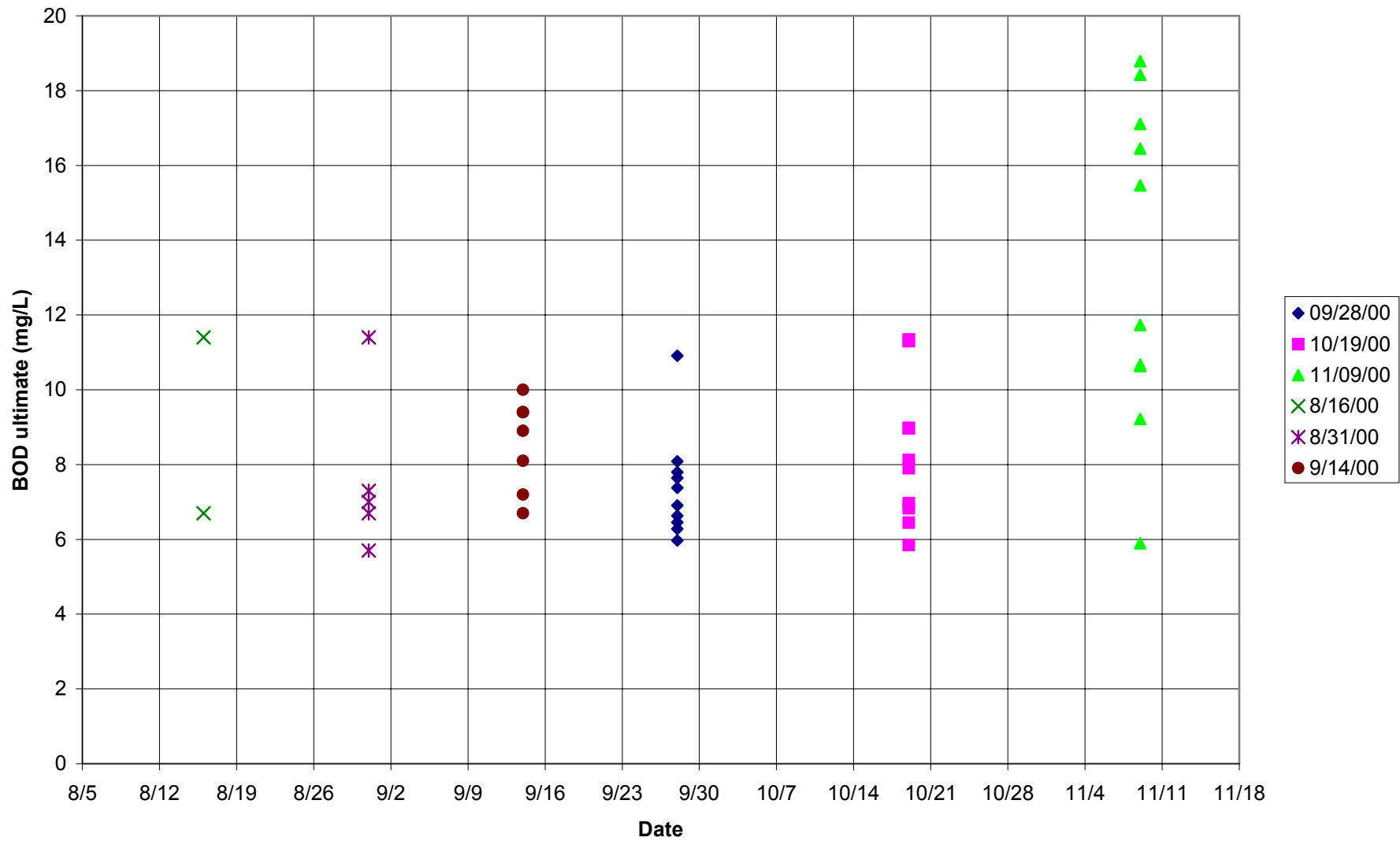


Figure III-5: Ultimate BOD during the study period for DWSC and San Joaquin River water.

Table III-6: BOD first-order decay rate constants for trapped sediments in the DWSC (units = day⁻¹).

Location	Depth (ft)	Date						
		7/27/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2		0.000	---	---	0.158	0.065	---
	16.4		0.065	---	---	---	---	---
	24.6		---	---	---	---	---	---
	B		0.010	0.067	---	0.092	0.016	---
LT. 38 ²	8.2					0.117	0.057	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.075	0.022	---
LT. 43 ¹	8.2		---	0.121	0.162	---	---	0.123
	16.4		---	0.117	0.148	---	---	---
	24.6		---	0.091	0.131	---	---	---
	B		---	---	0.105	---	---	0.159
LT. 43 ²	8.2					---	---	0.189
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.226
LT. 48 ¹	8.2		---	---	0.129	0.243	0.034	-0.558
	16.4		---	---	0.109	---	---	---
	24.6		---	---	0.096	---	---	---
	B		---	---	0.091	0.074	0.050	0.104
LT. 48 ²	8.2					0.027	0.073	0.043
	16.4					---	---	---
	24.6					---	---	---
	B					0.055	0.069	---

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

Table III-7: Least-square regression coefficients (R^2) for DWSC waters.

Regression Coefficient (R^2) - Sediment Samples

Units = none

Location	Depth (ft)	Date						
		7/27/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2		0.000	---	---	0.778	0.138	---
	16.4		0.919	---	---	---	---	---
	24.6		---	---	---	---	---	---
	B		0.119	0.979	---	0.710	0.944	---
LT. 38 ²	8.2					0.865	0.988	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.995	0.837	---
LT. 43 ¹	8.2		---	0.978	0.983	---	---	0.996
	16.4		---	0.972	0.980	---	---	---
	24.6		---	0.981	0.981	---	---	---
	B		---	---	0.974	---	---	0.977
LT. 43 ²	8.2					---	---	0.928
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.954
LT. 48 ¹	8.2		---	---	0.974	0.988	0.998	0.770
	16.4		---	---	0.972	---	---	---
	24.6		---	---	0.972	---	---	---
	B		---	---	0.974	0.962	0.902	0.997
LT. 48 ²	8.2					0.869	0.991	0.777
	16.4					---	---	---
	24.6					---	---	---
	B					0.994	0.993	0.727

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

Table III-8: Ultimate BOD/TSS of sediment trapped in the DWSC.
 Units = mg O₂/ mg TSS

Location	Depth (ft)	Date						
		7/27/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2		0.131	---	---	0.033	-0.001	---
	16.4		0.001	---	---	---	---	---
	24.6		---	---	---	---	---	---
	B		0.002	0.013	---	0.012	0.020	---
LT. 38 ²	8.2					0.027	0.020	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.012	0.019	---
LT. 43 ¹	8.2		---	0.058	0.076	---	---	0.010
	16.4		---	0.036	0.048	---	---	---
	24.6		---	0.017	0.025	---	---	---
	B		---	---	0.018	---	---	0.019
LT. 43 ²	8.2					---	---	0.018
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.003
LT. 48 ¹	8.2		---	---	0.024	0.038	0.014	-0.001
	16.4		---	---	0.016	---	---	---
	24.6		---	---	0.014	---	---	---
	B		---	---	0.010	0.026	0.016	0.035
LT. 48 ²	8.2					0.018	0.015	-0.055
	16.4					---	---	---
	24.6					---	---	---
	B					0.011	0.012	---

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

Table III-9: Ultimate BOD/VSS of sediments trapped in the DWSC.
 Units = mg O₂ / mg VSS

Location	Depth (ft)	Date						
		7/27/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2		1.205	---	---	0.327	-0.010	---
	16.4		0.006	---	---	---	---	---
	24.6		---	---	---	---	---	---
	B		0.025	0.131	---	0.115	0.224	---
LT. 38 ²	8.2					0.236	0.191	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.113	0.185	---
LT. 43 ¹	8.2		---	0.494	0.619	---	---	0.091
	16.4		---	0.343	0.453	---	---	---
	24.6		---	0.188	0.279	---	---	---
	B		---	---	0.188	---	---	0.180
LT. 43 ²	8.2					---	---	0.158
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	0.026
LT. 48 ¹	8.2		---	---	0.247	0.413	0.165	-0.010
	16.4		---	---	0.176	---	---	---
	24.6		---	---	0.145	---	---	---
	B		---	---	0.113	0.258	0.205	0.381
LT. 48 ²	8.2					0.225	0.182	-0.663
	16.4					---	---	---
	24.6					---	---	---
	B					0.150	0.159	---

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

Table III-10: Ultimate BOD/Chl *a* of sediments trapped in the DWSC.
 Units = mg O₂/ mg Chl *a*

Location	Depth (ft)	Date						
		7/27/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2			---	---	0.55	-0.01	---
	16.4			---	---	---	---	---
	24.6			---	---	---	---	---
	B			0.36	---	0.22	0.52	---
LT. 38 ²	8.2					0.45	25.98	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.34	0.60	---
LT. 43 ¹	8.2			1.72	1.23	---	---	-0.30
	16.4			0.64	0.50	---	---	---
	24.6			0.28	0.16	---	---	---
	B			---	0.31	---	---	1.33
LT. 43 ²	8.2					---	---	0.57
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	---
LT. 48 ¹	8.2			---	0.55	0.10	0.22	0.02
	16.4			---	0.22	---	---	---
	24.6			---	0.19	---	---	---
	B			---	0.15	0.19	0.26	0.97
LT. 48 ²	8.2					0.26	0.40	-0.99
	16.4					---	---	---
	24.6					---	---	---
	B					0.41	0.56	---

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

Table III-11: Ultimate BOD/(Chl *a* + Ph *a*) for sediments trapped in the DWSC.
 Units = mg O₂/ mg Chl *a* + Ph *a*

Location	Depth (ft)	Date						
		7/26/00 ³ (Spring - 3)	8/16/00 ³ (Spring + 2)	8/31/00 (Spring + 3)	9/14/00 (Spring + 1)	9/28/00 (Spring + 1)	10/19/00 (Neap + 0)	11/9/00 (Spring - 2)
LT. 38 ^{1,4}	8.2			---	---	0.062	-0.003	---
	16.4			---	---	---	---	---
	24.6			---	---	---	---	---
	B			0.040	---	0.035	-0.007	---
LT. 38 ²	8.2					0.072	0.082	---
	16.4					---	---	---
	24.6					---	---	---
	B					0.038	0.080	---
LT. 43 ¹	8.2			0.102	0.102	---	---	0.085
	16.4			0.088	0.068	---	---	---
	24.6			0.055	0.044	---	---	---
	B			---	0.043	---	---	0.193
LT. 43 ²	8.2					---	---	0.189
	16.4					---	---	---
	24.6					---	---	---
	B					---	---	---
LT. 48 ¹	8.2			---	0.087	0.042	0.060	-0.011
	16.4			---	0.042	---	---	---
	24.6			---	0.048	---	---	---
	B			---	0.025	0.048	0.060	0.090
LT. 48 ²	8.2					0.062	0.091	-0.490
	16.4					---	---	---
	24.6					---	---	---
	B					0.052	0.095	---

¹ 9/28, 10/19, & 11/9 - Ebb Tide

² 9/28, 10/19, & 11/9 - Flood Tide

³ Size 10 Sediment Trap

⁴ 9/14 Trap lost

Hatched area indicate composite samples or experiment not performed for that date

