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The Resources Agency
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South Delta Temporary Barriers Project

2006 South Delta Temporary Barriers Monitoring Report

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Chapter 1. Introduction

The Department of Water Resources (DWR) issued the Draft Environmental Impact Report and Environmental Impact Statement for the South Delta Water Management Program in 1990. Objectives of the program are to achieve the following:

1. Increase water levels, circulation patterns and water quality in the southern Delta area for local agricultural diversions.
2. Improve operational flexibility of the State Water Project to help reduce fishery impacts and improve fishery conditions.

Because of concerns related to both agriculture and the fisheries, the Temporary Barriers Project (TBP) was initiated to better determine effects of installing permanent barriers in the southern Delta. A five-year program began in 1991 to test a facsimile of the proposed barriers. In 1996, this test was extended for another five years. In 2001, DWR received an extension from the US Army Corp of Engineers to construct and operate the South Delta Temporary Barrier Project from 2001-2007. Because of varying hydrological conditions, and therefore varying hydrodynamic patterns, as well as concerns for endangered species, the number of barriers installed and the installation schedules have been different each year of the program. The barrier installation and removal dates are based on the US Army Corp of Engineers 404 Permit, the California Department of Fish and Game 1601 Permit and various Temporary Entry Permits required from landowners and local reclamation districts. Table 1-1 shows installation and removal dates for the various years of the Project.

Although the South Delta TBP has been in place since 1991, the Middle River barrier and the fall Head of Old River barrier have been installed in earlier years under different programs. The Grant Line Canal barrier was installed for the first time in 1996, at a site about 4.5 miles east of the originally proposed location. In 1997, the spring Head of Old River barrier was installed with two 48-inch culverts. In 1998, none of the barriers were installed due to high river flows throughout the spring and summer. In 1999, the Head of Old River barrier was not installed in the spring or the fall but the other barriers were installed. In 2000 through 2004 all the barriers were installed (Table 1-1). In 2005, and 2006 the Spring Head of Old River Barrier was not installed due to excessively high flows in the San Joaquin River (SJR). The Fall Head of Old River Barrier was not installed in 2006 due to favorable dissolved oxygen conditions.

Subsequent to the 2001 project extension, a new DWR Monitoring Plan was developed that specifically complies with the requirements of: 1) the April 4, 2001 California Department of Fish and Game (DFG) Incidental Take Permit No. 2081-2001-009-BD, 2) the March 29, 2001 DFG Streambed Alteration Agreement No. BD-2001-0001, 3) the April 5, 2001 National Marine Fisheries Service (now called NOAA Fisheries) Biological Opinion (BO), 4) the March 30, 2001 Fish and Wildlife Service BO for the Department of Water Resources Temporary Barriers Project 2001-2007.

The DWR Monitoring Plan consists of specific elements that are discussed in the following chapters. DWR participates in and /or funds these monitoring efforts. In some cases, funding may be augmented by Interagency Ecological Program (IEP) and /or CALFED funds. The elements of the monitoring plan came from permit conditions required by DFG, NOAA Fisheries, and USFWS. It covers fish species including salmon, steelhead, delta smelt and splittail. Also included are terrestrial species such as Swainson's hawks, pond turtles, and sensitive plants. The following are brief descriptions of each chapter.

Chapter 2. Fish Monitoring and Water Quality Analysis (Prepared by Tobi Rose, DFG)

In 2001, a pilot study was developed to provide an experimental approach to determining the behavioral response of fish with the installation of the temporary barriers in the south Delta, however, this project was cancelled due to insufficient data collection and recapture capabilities. A revised program was planned for 2003, however, funding and personnel shortages precluded implementation, therefore the fish monitoring study has not been conducted since 2002. Future studies are planned but implementation will be dependent on the availability of necessary staff.

Water quality analysis was conducted and physical water quality parameters were monitored not only for their possible effect on the fisheries but for other pertinent biological information, such as null zones.

Chapter 3. Kodiak Trawling in Old and San Joaquin Rivers (Prepared by Andy Rockriver, DFG)

Fish entrainment monitoring at the Spring Head of Old River Barrier (SHORB) was designed and implemented by the Department of Fish and Game (DFG) to evaluate and quantify fish entrainment with the following specific objectives:

- Determine the total number of juvenile Chinook salmon and other fish species entrained through the culverts at the HORB.
- Determine the percentage of coded-wire tagged (CWT) salmon released at Mossdale and Durham Ferry entrained into Old River.
- Determine tidal and diel effects on juvenile Chinook salmon entrainment.

The results are intended to provide information on the design and operation of a future permanent operable barrier at the head of Old River. In years 2005 and 2006 the SHORB was not installed due to high flows in the SJR, therefore Kodiak Trawls were conducted instead.

Chapter 4. Salmon Smolt Survival Investigations (Prepared by Patricia Brandes, USFWS)

This section describes the methods used in conducting the 2006 Vernalis Adaptive Management Plan (VAMP) Chinook salmon smolt survival investigations, and presents results of the calculated survival indices and absolute survival estimates for juvenile Chinook salmon during the VAMP 2005 test period.

Chapter 5. Barrier Effects on SWP and CVP Entrainment (Prepared by Jim Long, DWR)

This chapter discusses the effects the TBP has on fish entrainment at the Skinner (State Water Project) and Tracy (Central Valley Project) fish facilities. Hydrodynamic particle tracking models were used to estimate the likelihood of fish entrainment at the export facilities.

Chapter 6. 2006 Swainson's Hawk Monitoring (Prepared by Mike Bradbury, DWR)

This section describes Swainson's hawk observations and the effects of the barriers construction activities on nesting pairs within ½ mile radius of the sites.

Chapter 7. Water Elevations (Prepared by Mike Abiouli, DWR)

Monitoring was conducted to determine the effects of the barriers on water surface elevations and circulations patterns in the southern Delta channels.

Chapter 8. South Delta Water Quality (Prepared by Shaun Philippart, DWR)

This monitoring was conducted to evaluate the changes in various water quality parameters due to installation and operation of the barriers. The water quality parameters measured included water temperature, dissolved oxygen, specific electrical conductivity, and turbidity. Water samples were also sent to an analytical laboratory for analysis of dissolved ammonia, dissolved nitrite and nitrate, dissolved organic nitrogen, dissolved orthophosphate, chlorophyll *a*, and pheophytin *a*.

Chapter 9. Hydrologic Modeling (Prepared by Bob Suits DWR)

The DWR Delta Simulation Model, DSM2-Hydro, was used to conduct a hydrodynamic simulation of the effects the temporary barriers have on water levels in the south Delta for the year 2006. The DSM2-simulated stages and flows are then compared to historical data in the south Delta.

Table 1-1. Schedule of Installation and Removal Dates for South Delta Temporary Barriers from 1987 through 2006
(11x17 table)

Chapter 2. Fisheries Monitoring and Water Quality Analysis

Introduction

The South Delta Temporary Barriers Project (TBP) began in 1991 and consists of the construction, operation, and monitoring of four temporary rock fill barriers. Three of the barriers, located in three south Delta channels (Grant Line Canal, Old and Middle rivers), are constructed seasonally and operate during the agricultural season, usually April through November. They are designed for two purposes: (1) the improvement of water levels and circulation patterns for agricultural users and (2) the collection of data for the design of permanent barriers. The fourth barrier, located at the head of Old River, is designed in the spring as a fish barrier to prevent fall-run San Joaquin River Chinook salmon smolts, as well as Central Valley steelhead smolts, in the San Joaquin River watershed from migrating down through Old River towards the Central Valley Project (CVP) and the State Water Project (SWP) export facilities. This barrier is also installed in the fall to increase water quality on the San Joaquin River downstream of the barrier. Of those four barriers, the Middle River barrier (MR) near Victoria Slough has been installed since 1987; the Old River at Tracy barrier (DMC) has been installed since 1991; the Grant Line Canal barrier (GLC) near the Tracy Boulevard bridge has been installed since 1996; and the spring head of Old River barrier (SHORB) was installed in 1992, 1994, 1996, 1997, and 2000-2004. In 1998, high flows in south Delta channels prevented the installation of all four temporary barriers, however, the monitoring program continued as planned.

Since 1992, a seasonal fish-sampling program has monitored the fishery resources and water quality in the project area. From 1996 through 2000, the fish monitoring program was changed from a year round sampling study, that gathered only descriptive (qualitative) information, to a study conducted March through October concentrated on providing not only qualitative but quantitative measures of potential effects of the barriers on the various fish species inhabiting the channels. In 2001, a pilot study was developed to provide an experimental approach to determining the behavioral response of fish to the installation of the temporary barriers. However, this project was cancelled due to insufficient data collection and recapture capabilities.

Fisheries monitoring was not conducted from 2002 through 2006, however, physical water quality parameters were monitored not only for their possible affects on the fisheries but for other pertinent biological information, such as null zones. A null zone occurs when the upstream flow of water negates the downstream flow of water, creating an area with zero net flow and potentially poorer water quality for fisheries. The objectives of the 2006 study plan were:

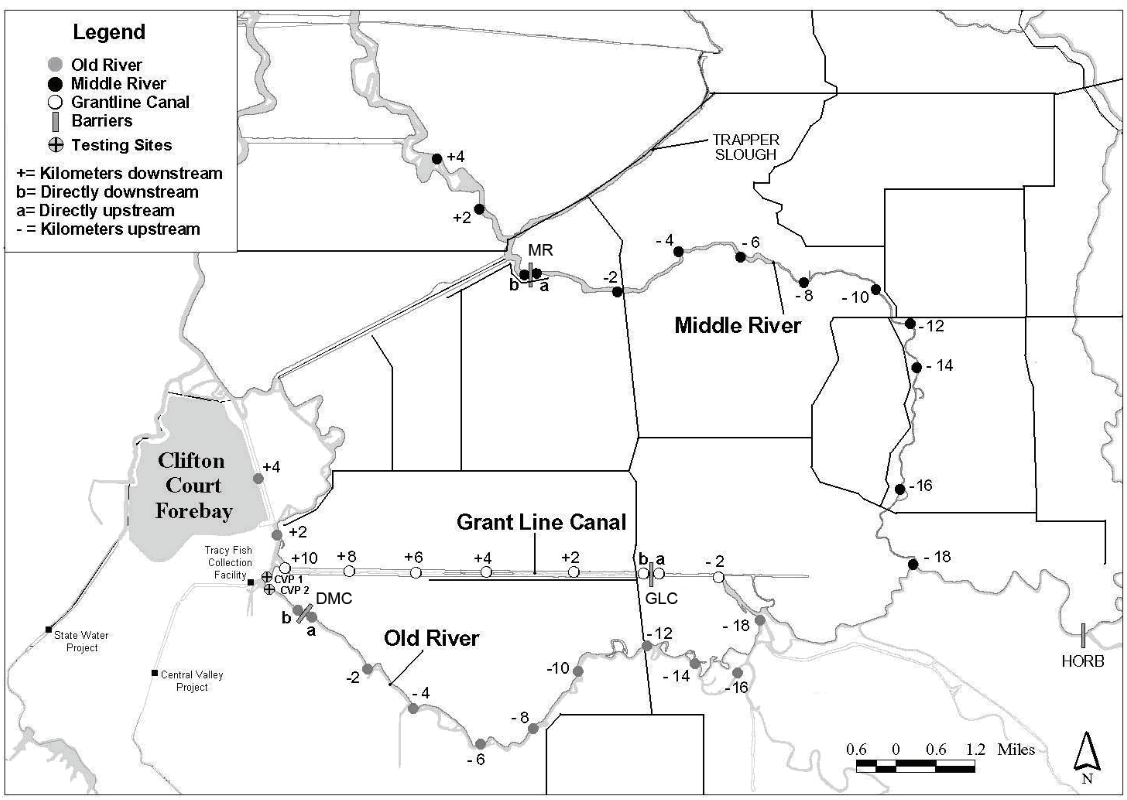
- Determine water quality profiles of the channels affected by the temporary barriers.
- Determine if there are null zones within the south Delta, upstream of the three barriers.

Materials and Methods

Thirty-four permanent water quality sites were sampled on Grant Line Canal, Old and Middle rivers (Figure 2-1). Six new permanent water quality sites were added this year so that the sites in all three channels are now set at approximately 2 km intervals. A hydrolab was used to determine water temperature in ºC, dissolved oxygen in mg/L, and specific conductance in µmhos/cm (the water's ability to conduct an electric current and is directly related to the total dissolved salts or ions normalized to 25ºC). Turbidity was measured in NTUs (the degree to which light is scattered by suspended particles) using a portable turbidimeter. Two replicate water samples were collected at each site at depths equal to 40 and 60 percent of the total depth. Water samples were taken from downstream to upstream at the beginning of each tidal stage (ebb and flood tides). Tidal stage, location, and time were recorded at each permanent site. Monthly average air temperature for Rough and Ready Island was collected off of the California Data Exchange Center website (cdec.water.ca.gov).

Each channel's water quality parameters were compared over time (months) and location (sampling sites). Three different water quality profiles were graphed for each channel and parameter: (1) the monthly average in relation to the barrier (Figures 2-2 through 2-5); (2) the yearly average in relation to the barrier (Figure 2-6); and (3) the monthly average (Figure 2-7). As in previous years, the data used for analysis was an average of the four samples taken at each location. Statistical analysis was not performed because of insufficient data collection due to various mechanical difficulties of equipment, other project requirements, and the presence of water hyacinth early in the season making navigation through Middle River impossible.

Figure 2-1. 2006 water quality sampling sites in the south Delta.



Results and Discussion

The water quality results from 2006 are similar to results from previous years. All three sets of graphs show similar trends. However, there were some differences and they are addressed in the following sections.

Specific Conductance (Figures 2-2, 2-6A, 2-7A)

In all three channels the specific conductance was significantly lower throughout the monitoring period than in previous years. The yearly and monthly averages in all three channels were similar throughout and between the sampling areas. This suggests a relationship between specific conductance and both location and the time of year. Old River had the highest overall specific conductance of all three channels. Starting in July there is an obvious increase in all three channels average monthly specific conductance. These spikes in specific conductance occur in Old River just below to 18 km upstream of the DMC, in Middle River 2 km to 18 km upstream of the MR, and the entire length of Grant Line Canal.

The results indicate a possible relationship between specific conductance and both location and the time of year. This is the first time specific conductance has shown a definite connection to a time-based variable. This variable is flow and became relatively apparent this year due to the high flows early in the season (Figure 2-9). When the flows are high specific conductance is low and as the flows decrease the specific conductance increases. This is most likely due to the diminished flushing effect that the high flows have on the local water conditions. Add to the lower flow conditions the reduced tidal influence due to increased water exports at the CVP and SWP facilities and it is apparent that at the same time of year that the flows decrease and the exports increase the specific conductance increases (Figure 2-10). The areas where specific conductance spikes in Old and Middle rivers could indicate areas of possible null zones throughout the year (Figure 2-11). Variances in the data may be caused by high flows from the San Joaquin River, San Joaquin River water quality, and/or farming activities, such as agricultural diversion/return locations, amount of water used and returned, and the time of year it is used.

Dissolved Oxygen (Figures 2-3, 2-6B, 2-7B)

As in previous years, the 2006 dissolved oxygen values for Old and Middle rivers were initially elevated during the spring and then decreased throughout the summer months, before improving again in the fall. Grant Line Canal had a decline in dissolved oxygen from spring to summer with a small increase in July. All three channels had similar monthly dissolved oxygen patterns that suggest a relationship between dissolved oxygen and the time of year. An important characteristic for Old and Middle rivers is that at some point the dissolved oxygen fell below 5.0 mg/L, the minimum water quality objective stated in the California Regional Water Quality Control Board's Basin Plan (4th ed.). However, this was not common compared to previous years and all monthly dissolved oxygen averages, except Middle River in July, stayed above this critical point. Grant Line Canal had the highest overall dissolved oxygen readings and had no apparent sag below the barrier as seen in previous years. A slight sag is apparent in Old River directly below and above the barrier and Middle River's dissolved oxygen sag was located approximately 4 to 6 km upstream of the MR.

Results suggest a possible relationship between dissolved oxygen and the time of year. The areas where dissolved oxygen sags in Old and Middle rivers could indicate areas of possible null zones throughout the year (Figure 2-11). Variances in dissolved oxygen may be due to high flows from the San Joaquin River, San Joaquin River water quality, water temperature, water hyacinth, water agitation, localized (agricultural) nutrient loading, and/or primary production.

Water Temperature (Figures 2-4, 2-6C, 2-7C)

The 2006 water temperatures are similar to previous years in that the profiles for all three channels began low and then increased over the summer, before decreasing again in the fall. This trend is opposite of the dissolved oxygen profile. All three channels show approximately identical monthly averages in water temperature that suggests a relationship between water temperature and the time of year. Also, the water temperature for all three channels is lower in the spring than previous years, peaks in July, than quickly lowers for the remainder of the sampling season. Water temperatures were similar among all three channels. Also, average monthly water temperatures in all three channels tracked well with the average monthly air temperature (Figure 2-8).

The results indicate a possible relationship between water temperature and the time of year. This means that the water temperature of all channels varies greatly month to month but varies insignificantly site to site. Water temperature seems to follow air temperature based on the graphical data.

Turbidity (Figures 2-5, 2-6D, 2-7D)

As in previous years, the turbidity measurements of 2006 typically stayed well below 50 NTU's. The yearly averages for all three channels were similar. This suggests a relationship between specific conductance and the time of year. Old and Middle rivers had increased turbidity upstream of the barriers while Grant Line Canal did not increase upstream of the barrier. The spike located 14 km upstream of the MR was not evident this year nor in 2005 as it had been for 2002 through 2004.

These results indicate a possible relationship between turbidity and the time of year. This is the first time turbidity has shown a definite connection to a time-based variable. This variable is flow and became relatively apparent this year due to the high flows early in the season (Figure 2-9). When flows are high the turbidity may slightly increase due to the disturbance of the sediment. However, these high flows also move the water out of the system faster. So, turbidity is affected by the water coming into the system rather than other outside sources that would normally have affected the turbidity of the slower moving water. The varying turbidity might also be due to various activities (outside sources), such as agricultural diversion/return operations and locations, suspended solids from agricultural runoff, water recreation (water agitation), bottom feeders, etc.

In summary, the water quality in the south Delta appeared to be better in 2006 than in previous years with lower specific conductance and higher dissolved oxygen readings in all three channels. This could be the result of a wet water year. The higher flows down the San Joaquin River in 2006 may have helped improve water quality in the south Delta by increasing water flow through the south Delta channels. These high flows helped create a possible relationship between all four water quality parameters and the time of year (months). Furthermore, there is still a slight relationship between the water quality parameters, specific conductance and turbidity, and location (sampling sites), however this relationship is diminished by the incoming flows affect on the water quality. Potential null zones are present in Middle River and Old River due to sags in dissolved oxygen and spikes in specific conductance. Old River's dissolved oxygen null zone is again oddly located directly downstream of the barrier. No null zones are apparent for Grant Line Canal. Water temperature seems to tracks the ambient air temperature and thus air temperature may have an indirect effect on dissolved oxygen levels (Figure 2-8). Finally, all the water quality parameters seem to be affected by similar activities such as agricultural diversion/return operations and locations, water agitation, localized nutrient loading, suspended solids from agricultural runoff, primary production, algae blooms, erosion, bottom feeders, high flow, and a wet water year.

Efforts were made again this year to pinpoint the cause/area of water quality concerns on Old River (sag in dissolved oxygen located directly below the barrier). To determine if dissolved oxygen was low upstream as well as downstream of the Tracy Fish Collection Facility (TFCT), two dissolved oxygen testing sites were added to Old River in 2005 and were sampled again in 2006 (Figure 2-1). The water quality profiles, with the testing sites included (Figure 2-12), suggests between the TFCT and the DMC dissolved oxygen decreases, while temperature also decreases, and specific conductance increases. All three water profiles in Figure 2-12 are small in scale to point out slight changes in water quality and should not be compared to other water quality profiles not of the same scale. This trend may indicate that tidal influence in this area of Old River is diminished due to the fact that water quality parameters worsen directly after the TFCT. All testing sites included this year will be included again in next years sampling season to help monitor these potentially poor water quality locations.

Due to high water flows this year the aggressive growth of water hyacinth was not an issue on any of the channels. However, at the beginning of the sampling season Middle River was still congested with hyacinth from the previous years growth spurt. It took approximately one month for this mass of hyacinth to clear out of Middle River and made data collection inconsistent during that time.

Recommendations

A similar study is planned for 2007 to further evaluate effects of the temporary barriers on the south Delta water quality. Testing sites selected to monitor potential null zones/areas of concern in 2006 will remain a part of the water quality monitoring program in 2007. Finally, the possibility/feasibility of collecting flow data along with water quality data will be considered to help with data analyses.

Figure 2-2. Monthly specific conductance in relation to the barriers.

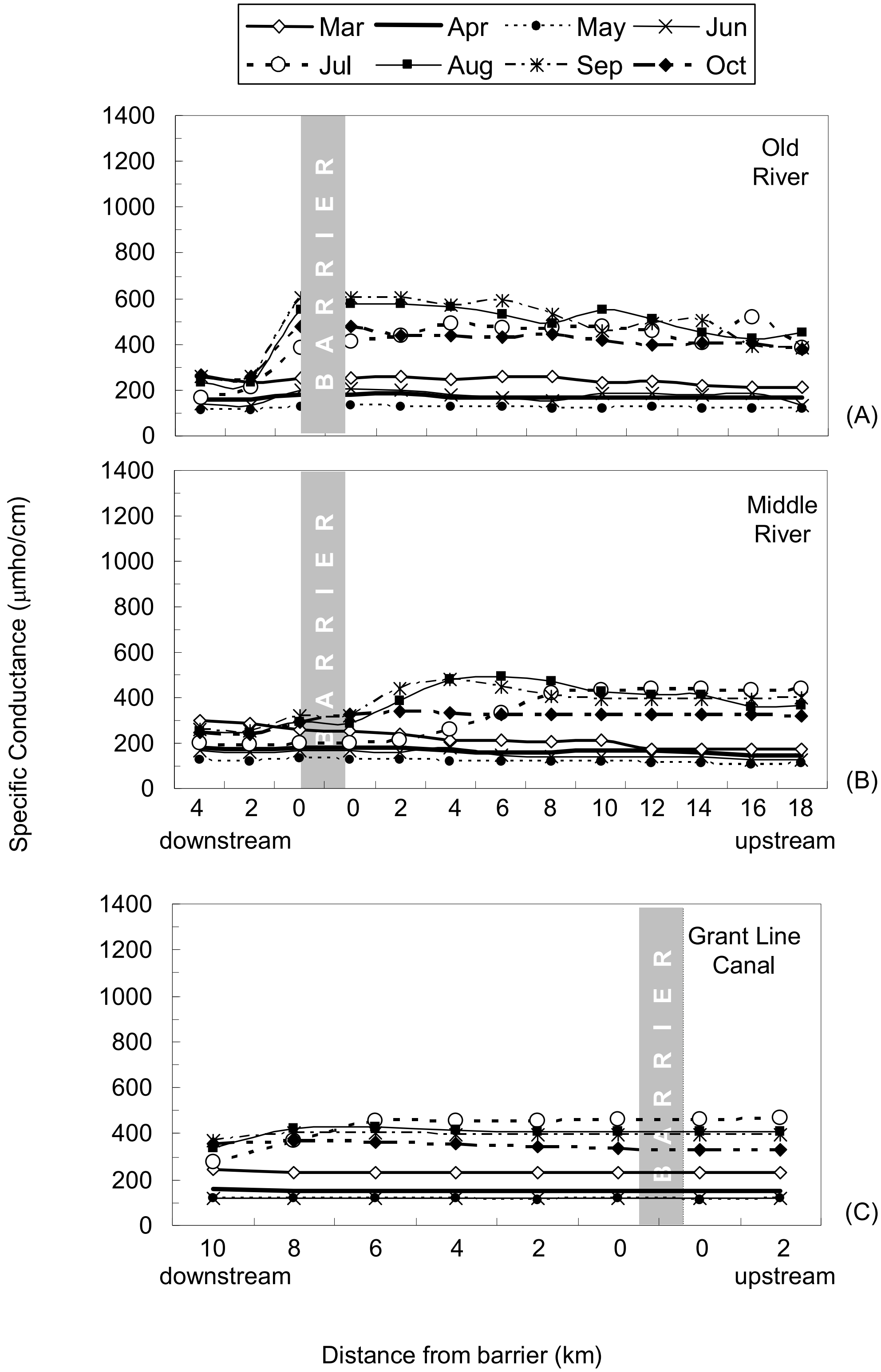


Figure 2-3. Monthly dissolved oxygen in relation to the barriers.

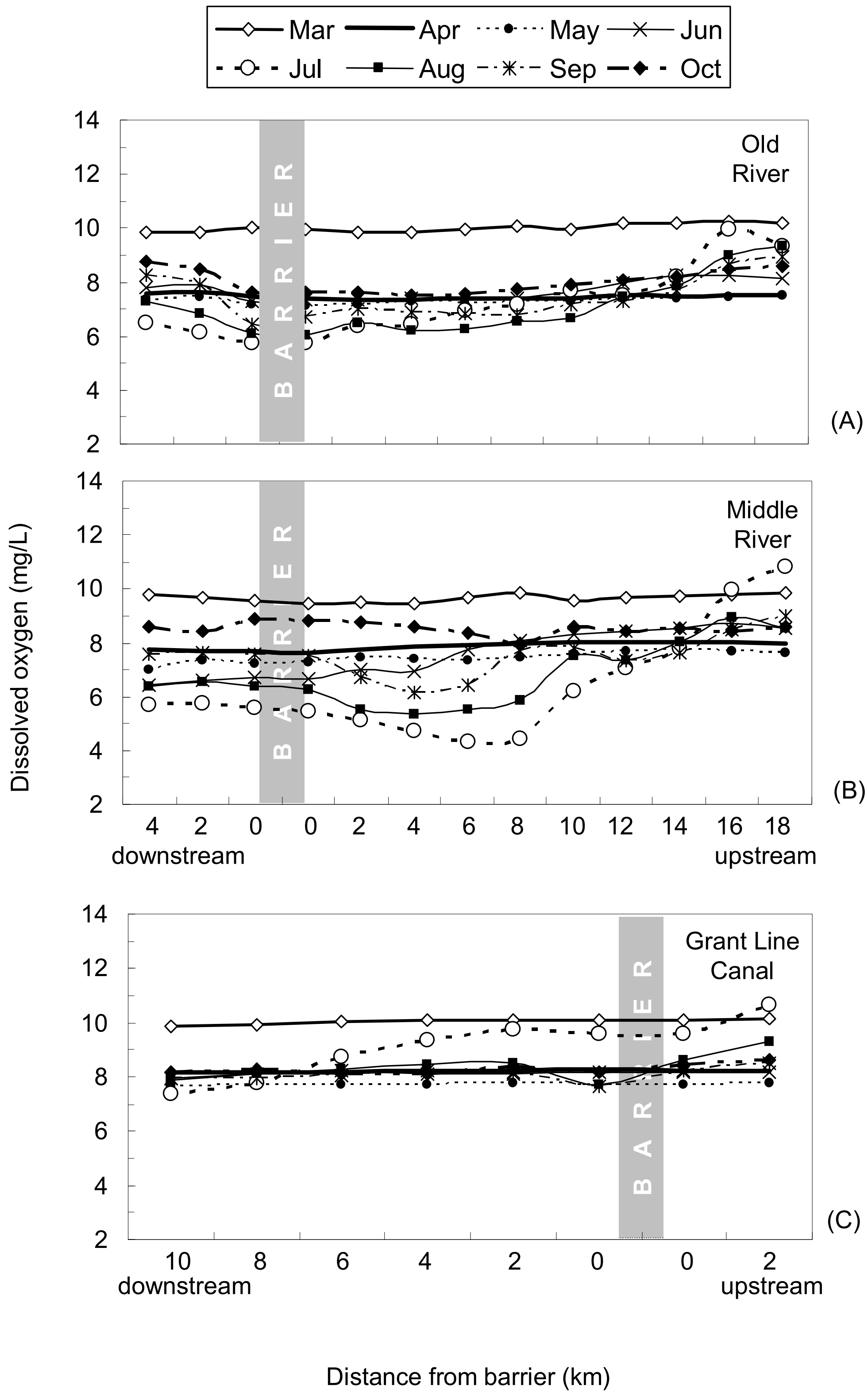


Figure 2-4. Monthly water temperature in relation to the barriers.

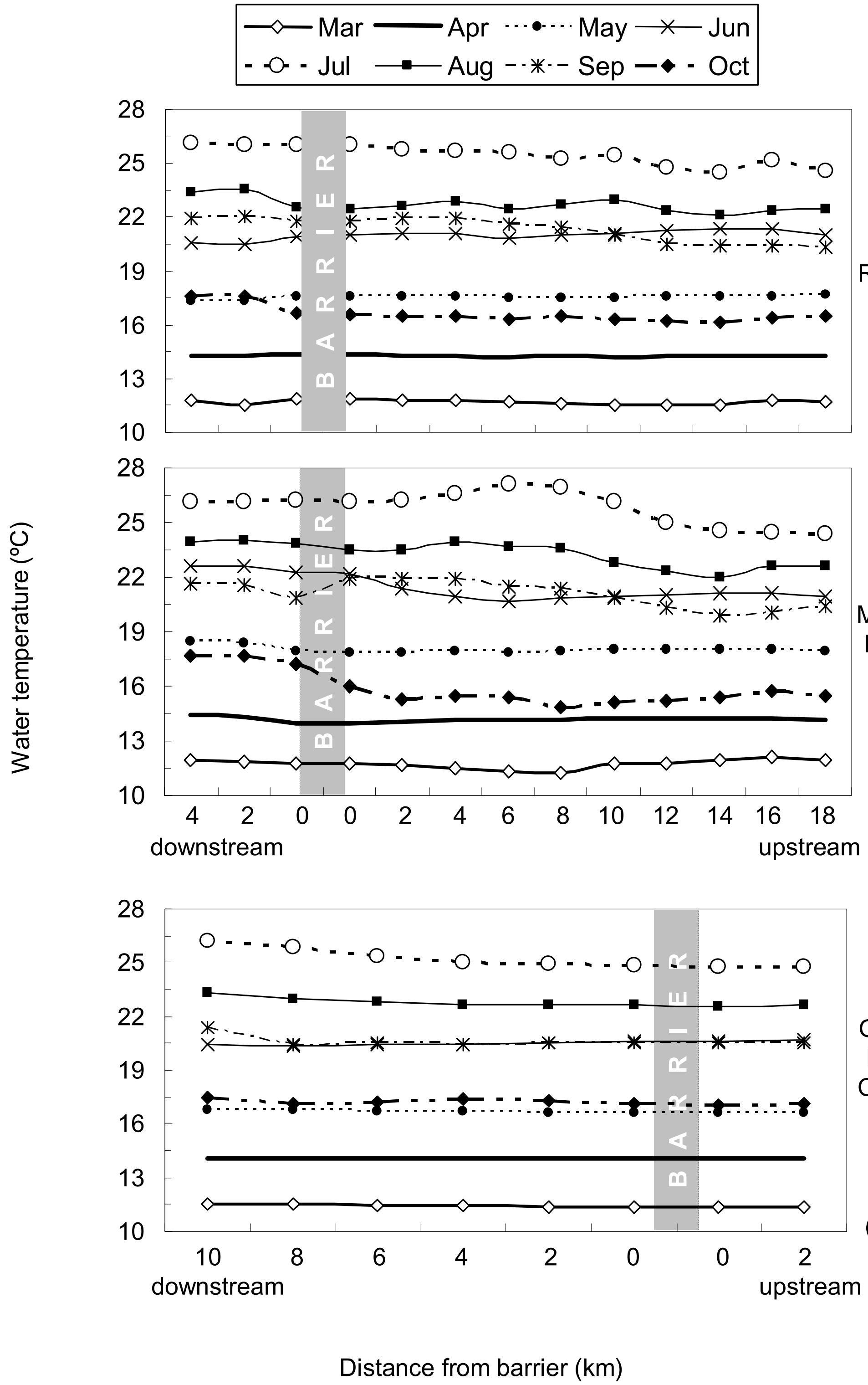


Figure 2-5. Monthly turbidity in relation to the barriers.

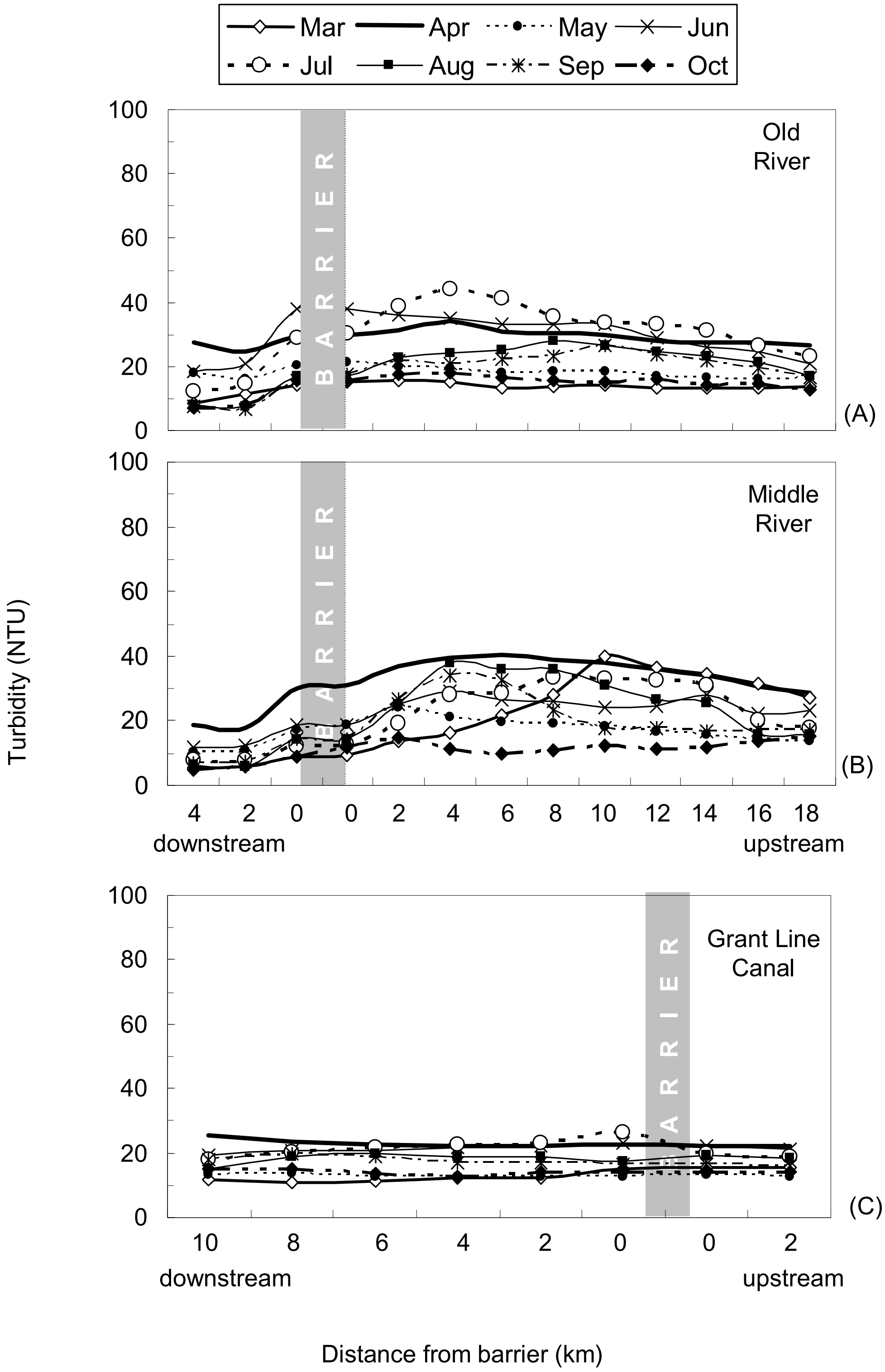


Figure 2-6. Yearly water quality parameters in relation to the barriers. Grant Line Canal was sampled 10km downstream to 2km upstream of the barrier. Old and Middle rivers were sampled 4km downstream to 18km upstream of the barriers.

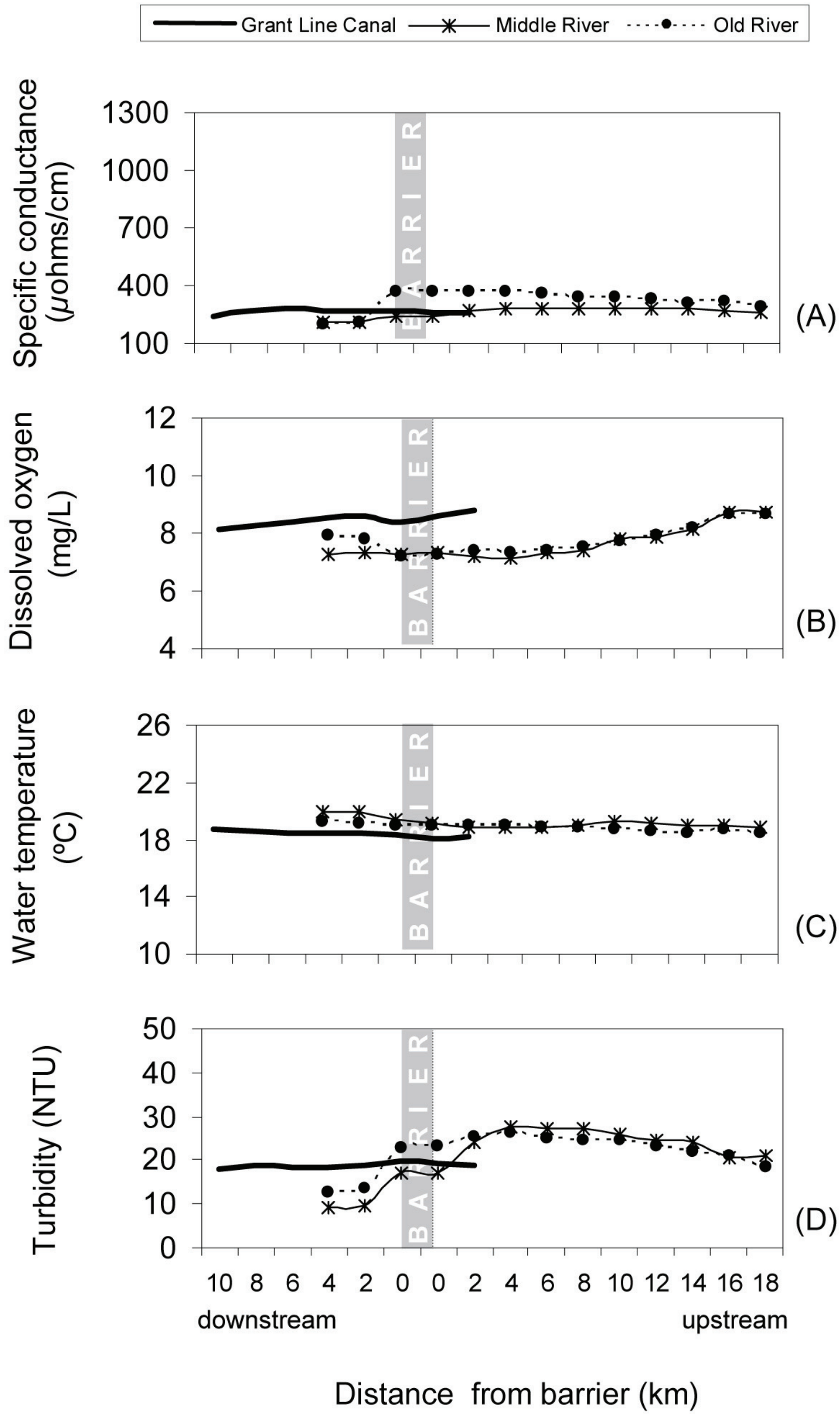


Figure 2-7. Monthly water quality parameters.

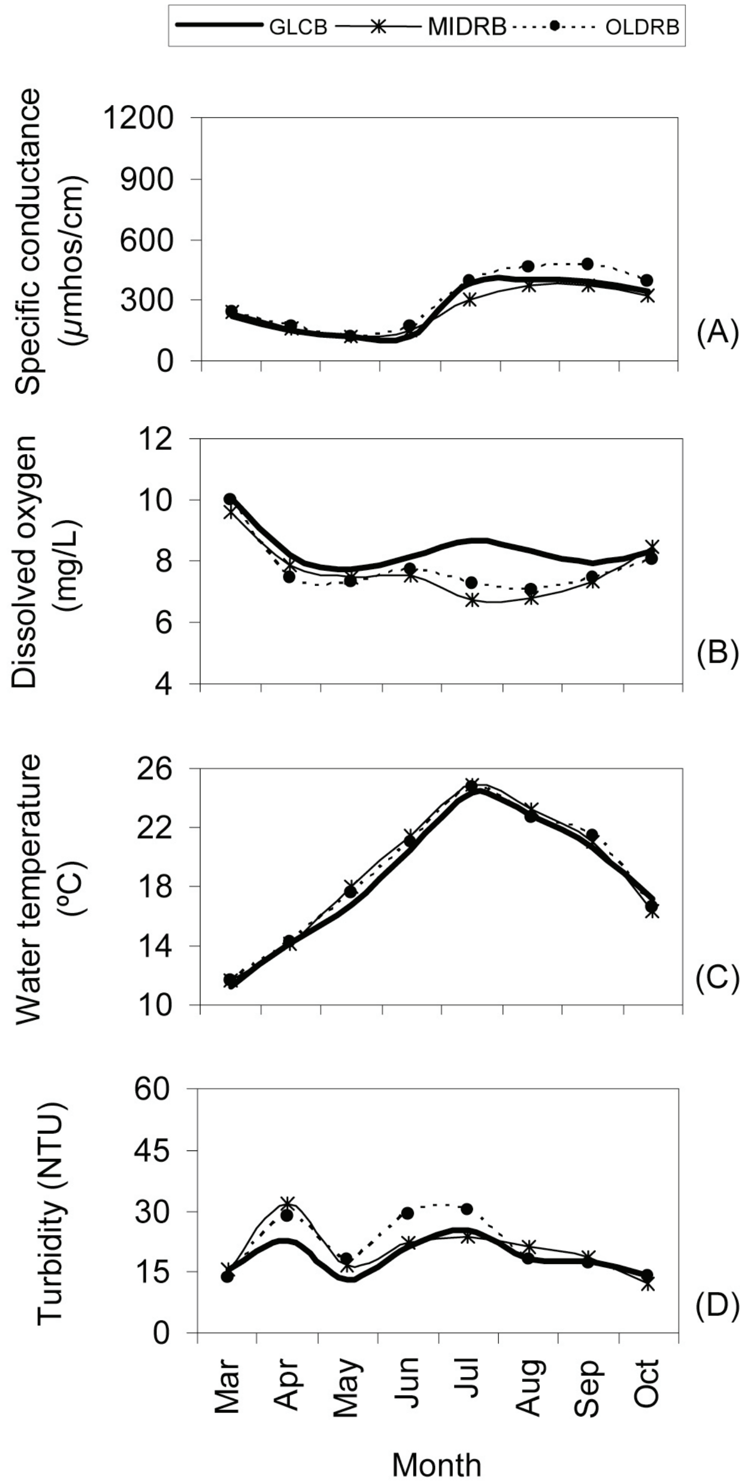


Figure 2-8. Monthly water temperature, air temperature, and dissolved oxygen for the south Delta.

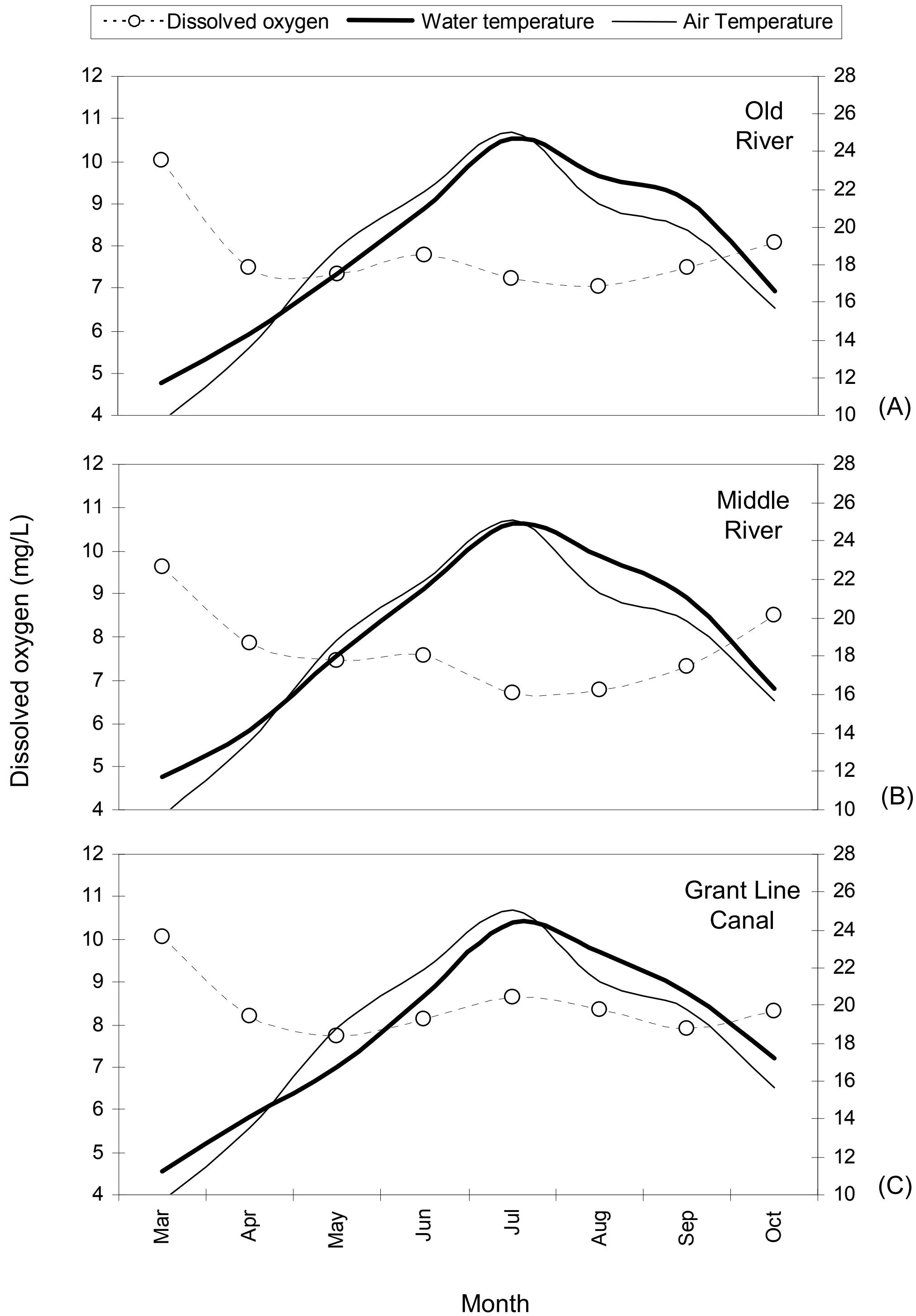


Figure 2-9. San Joaquin River mean daily flows, at Vernalis, California.

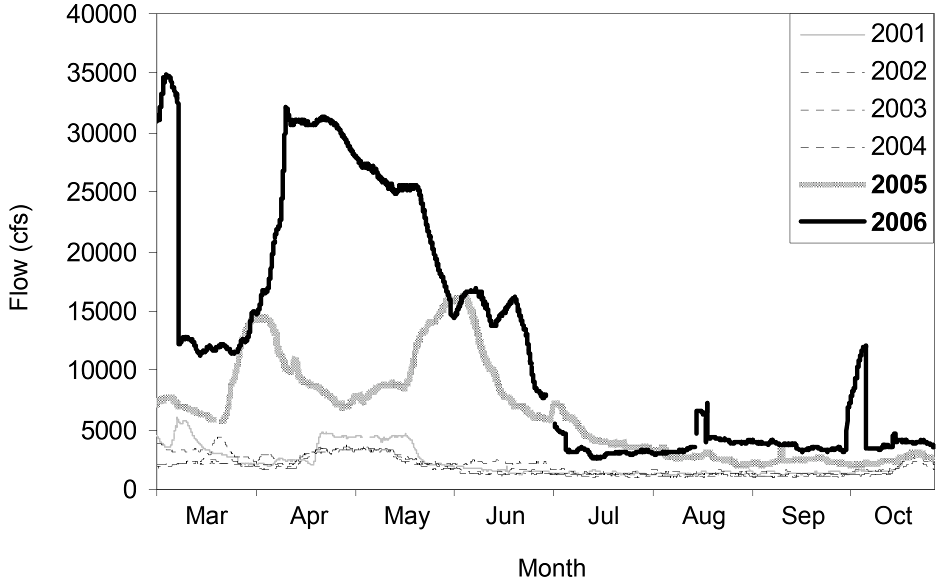


Figure 2-10. South Delta flows and daily exports.

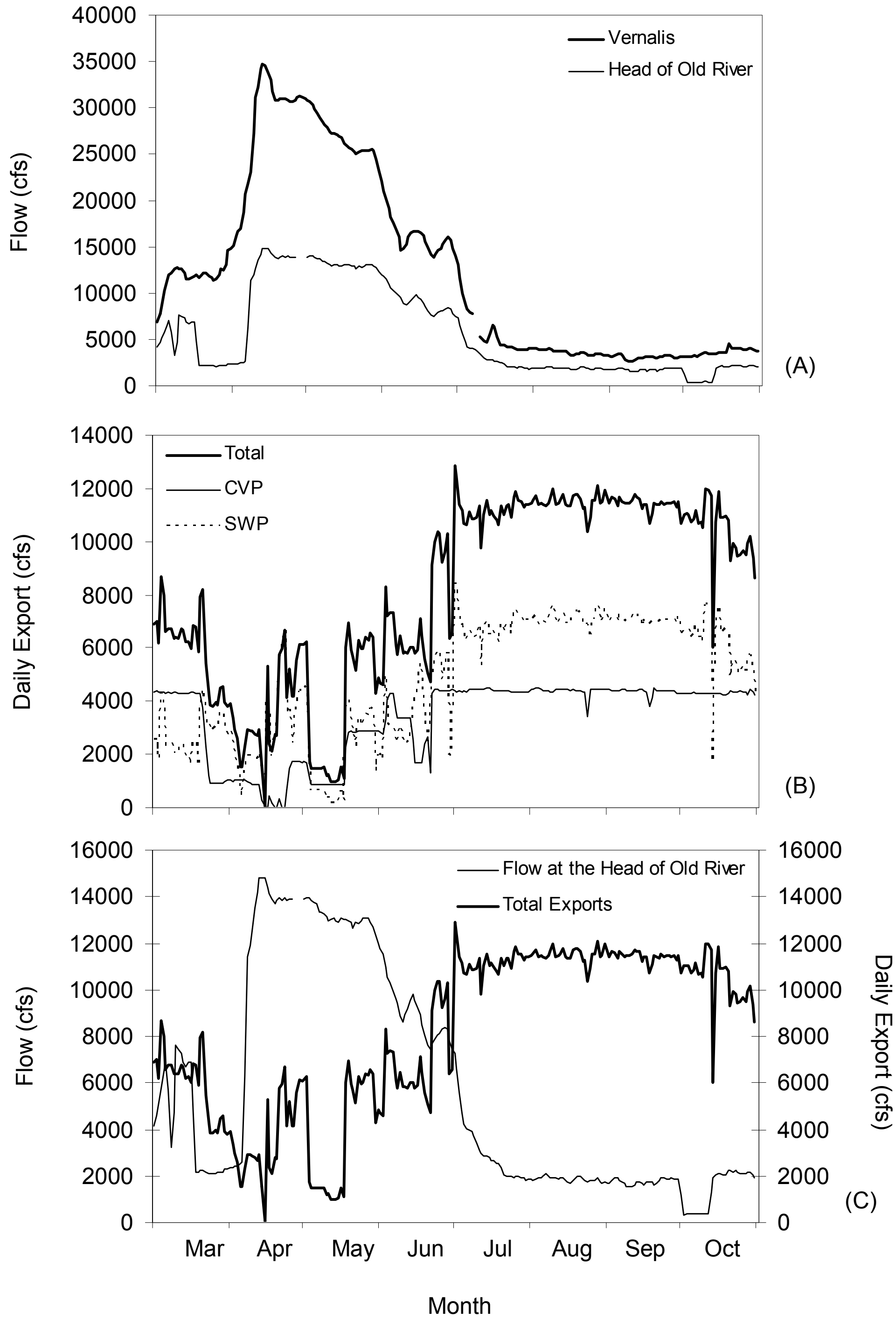


Figure 2-11. Map of possible null zones in the south Delta.

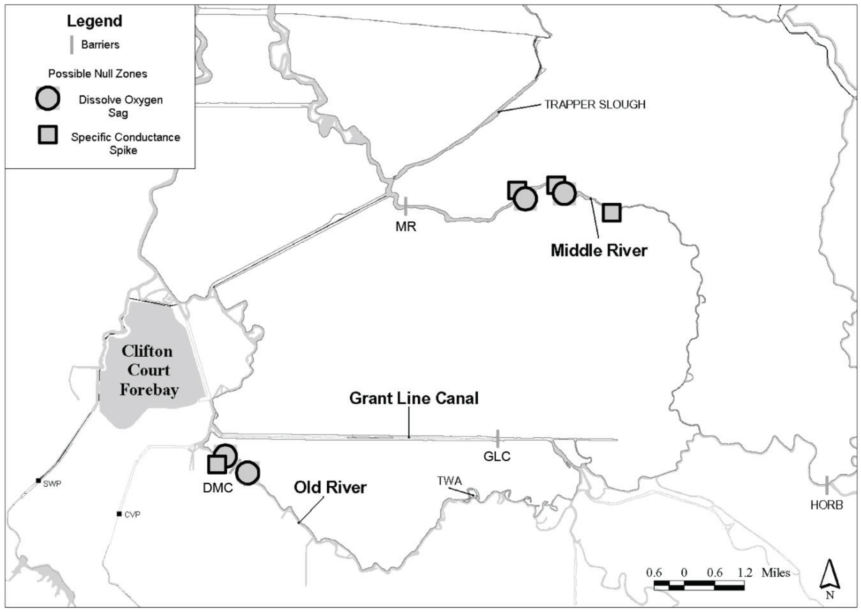
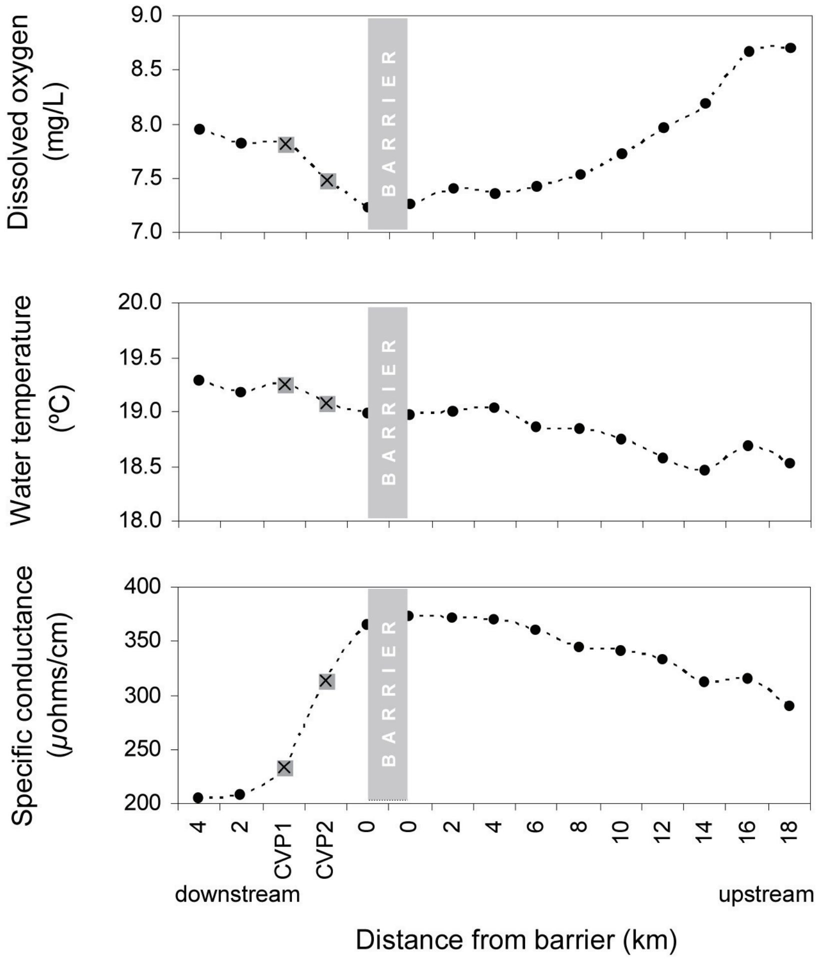


Figure 2-12. Yearly water quality parameters in relation to the Old River at Tracy Barrier, including testing sites.



Chapter 3. Kodiak Trawling in Old and San Joaquin Rivers

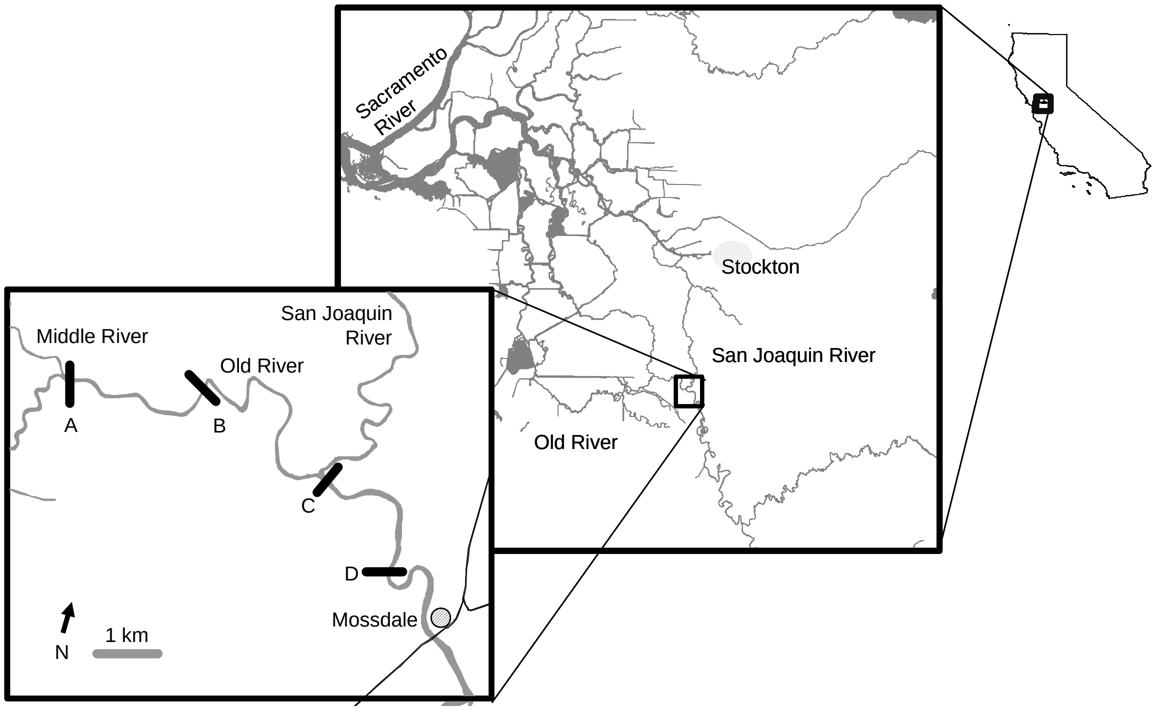
The South Delta Improvements Program was developed in 1990 to achieve two objectives. One objective was to increase water levels, improve circulation patterns and improve water quality for local agricultural diversions in the south Delta. The other objective was to improve operational flexibility of the State Water Project (SWP) to help reduce fishery impacts and improve fishery conditions. To meet these objectives, a plan was designed to have four permanent barriers placed at key locations throughout the south Delta. The South Delta Temporary Barriers Project was implemented to study the effectiveness of temporary barriers in obtaining the objectives of the permanent barriers.

A temporary barrier was designed for the head of Old River to meet the fishery objectives. The barrier is constructed where Old River diverges from the San Joaquin River, just downstream of Mossdale. This barrier is built in the spring to block the passage of out-migrating San Joaquin River juvenile Chinook salmon (*Oncorhynchus tshawytscha*) into Old River which leads to the SWP and Central Valley Project export facilities. However, similar to 2005, the spring Head of Old River Barrier (HORB) was not constructed in 2006 due to San Joaquin River flows in excess of 5,000 cfs. Because the HORB was not constructed, there was no fish entrainment monitoring. As an alternative to the entrainment monitoring, the Department of Fish and Game (DFG) towed a Kodiak trawl in Old River during the Vernalis Adaptive Management (VAMP) test period. The Old River Kodiak Trawl (ORKT) was conducted in a similar manner to the Mossdale Kodiak Trawl (MKT) which is conducted year-round on the San Joaquin River. Both trawls sampled for juvenile salmon during the first three weeks of May. Comparison of salmon catch between the two trawls may provide insights into salmon migration from the San Joaquin River into Old River.

Methods and Results

The ORKT and MKT used similar sampling gear and protocols. Fish were collected using a Kodiak trawl towed between two boats. Trawling took place in Old River, starting approximately two miles downstream of the head; and in the San Joaquin River, upstream of the head of Old River (Figure 3-1). The beginning of the 2006 ORKT sample site was about 1.3 km downstream of the end of the 2005 sample site. The Kodiak trawl is 19.8 m long, made of variable mesh (ranging from 1.27 cm stretch mesh at the cod-end to 5.08 cm mesh at the mouth), and has a mouth opening of 1.83 m by 7.62 m. The effective sampling area of the net was estimated at 12.5 m^2 (USFWS 2003). All trawling was done during daylight hours, starting around 0800 hrs. Typically, the MKT and ORKT started and ended within a half hour of each other. The Kodiak trawl was towed against the current for 20 minutes. Although the boats and net faced upstream, the high flows carried the boats and net downstream. Due to the extremely high flows, only two tows were completed before the ORKT net was retrieved and reset upstream. For the ORKT, a total of 14 tows per day, five days a week, were conducted from May 3 through May 19. During this same time period, the MKT conducted 15 tows per day, seven days a week.

Figure 3-1. Map of the 2006 Kodiak trawl sample locations on Old and San Joaquin Rivers. The Old River Kodiak trawl sampled between A and B, and the Mossdale Kodiak trawl sampled between C and D.



For the ORKT, all fish were counted and measured (fork length) to the nearest millimeter. All salmon were checked for a clipped adipose fin or spray dyed color-mark. Salmon with a clipped adipose fin were sacrificed for CWT reading. For this comparison of the MKT and ORKT salmon catch, CWT salmon refers to all salmon with a clipped adipose fin. Because the number of salmon with a clipped adipose fin and no CWT is small, this should not significantly change the results. The unmarked salmon catch represents both hatchery and naturally spawned salmon. A flow meter was used to estimate the volume of water sampled. All sample statistics are reported as the mean ± standard deviation unless otherwise noted. The average volume of water sampled per tow by the MKT (11,213 ± 1,241 m^3) was greater than the ORKT (7,279 ± 912 m^3).

The ORKT caught 243 fish, representing 10 species, in 186 tows during 13 days of sampling in Old River. The most abundant species was Chinook salmon followed by Threadfin shad (Table 3-1). Of the 211 salmon caught, 130 were unmarked, 54 were classified as CWT, and 27 had a color-mark. No delta smelt (*Hypomesus transpacificus*), four steelhead (*Oncorhynchus mykiss*), and one splittail (*Pogonichthys macrolepidotus*) were caught. The MKT caught 959 fish, representing 13 species, in 196 tows during the same 13 days of sampling in the San Joaquin River. The most abundant species caught was Chinook salmon followed by threadfin shad (Table 3-1). Of the 855 salmon caught, 547 were unmarked, 238 were classified as CWT, and 70 had a color-mark. No delta smelt, two steelhead, and 11 splittail were caught. A two sample t-test (degrees of freedom (df) = 964, Probability (P) = 0.03, t statistic = 2.17) indicated fork lengths for salmon (unmarked and CWT pooled) were significantly different between the MKT caught salmon (100.8 ± 8.2 mm) and the ORKT caught salmon (102.3 ± 8.0 mm).

As part of the VAMP salmon survival studies, roughly 50,000 CWT salmon were released at Mossdale on May 4 and 75,000 on May 19. On May 5, the ORKT caught four

CWT salmon and the MKT caught three CWT salmon from the May 4 VAMP release. Additionally, the MKT caught eight more May 4 VAMP salmon over the next two weeks. No CWT salmon were caught by the ORKT or the MKT from the May 19 release. CWT salmon catch was the highest on May 17 in the San Joaquin River (Figure 3-2) and on May 18 in Old River (Figure 3-3). The highest unmarked catch occurred on May 18 in both rivers. To estimate salmon vulnerability to the Kodiak trawl, groups of color-marked salmon were released upstream of the MKT and ORKT on May 4, 11 and 18. On each of these dates, approximately 5,000 fish were released at the Mossdale boat ramp and approximately 2,000 fish were released at the head of Old River. The MKT caught marked fish from all three Mossdale releases while the ORKT caught marked fish from the first and last Old River releases and from all three of the Mossdale releases (Table 3-2).

Table 3-1. The raw abundance and composition of fishes caught in the Kodiak trawl in Old River (ORKT) and in the San Joaquin River (MKT) for trawls conducted weekdays, May 3-19, 2006. Chinook salmon catch is divided into CWT salmon, unmarked salmon, and color-marked salmon. Note: ORKT conducted 182 tows and the MKT conducted 196 tows.

Species	ORKT	MKT
Black Crappie	1	
Bluegill	5	
Brown Bullhead	1	
Common Carp	2	14
Goldfish		1
Golden Shiner		1
Inland Silverside		2
Redear Sunfish	1	2
Red Shiner		4
Sacramento Pikeminnow		2
Sacramento Sucker		1
Splittail	1	11
Steelhead	4	2
Threadfin Shad	13	61
White Catfish	4	3
Chinook Salmon	**211**	**855**
CWT Salmon	54	238
Unmarked Salmon	130	547
Color-Marked Salmon	27	70
Total	**243**	**959**

Figure 3-2. The total number of salmon by category (color-marked, coded wire tagged, and unmarked) caught in daily five hour Kodiak trawling sessions (150,000 m^3) in the San Joaquin River.

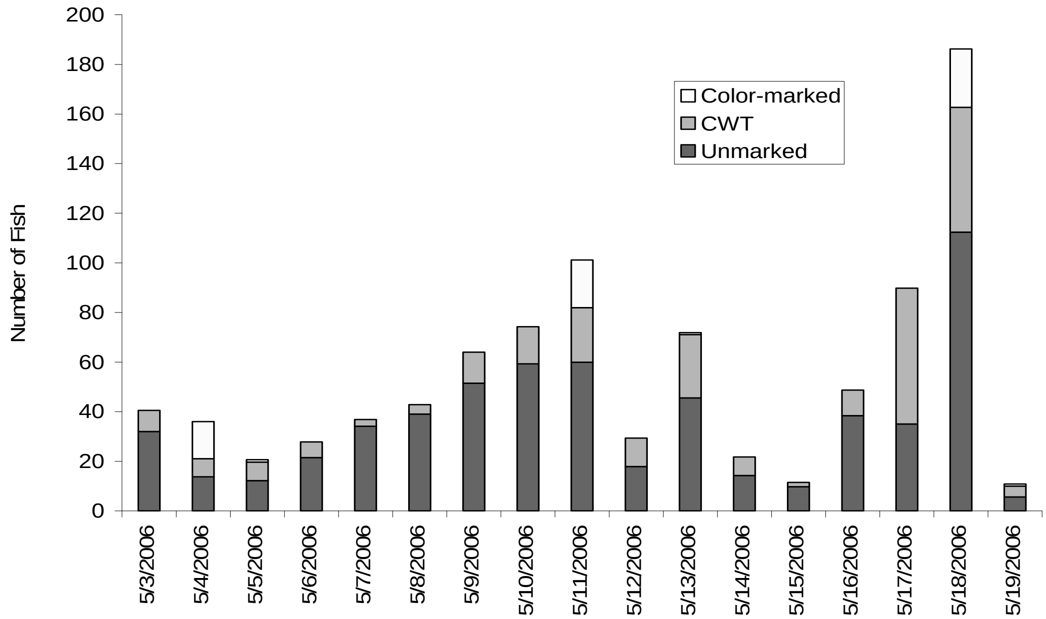


Figure 3-3. The total number of salmon by category (color-marked, coded wire tagged, and unmarked) caught in daily five hour Kodiak trawling sessions (150,000 m^3) in the Old River. An "X" indicates no samples were collected on that date.

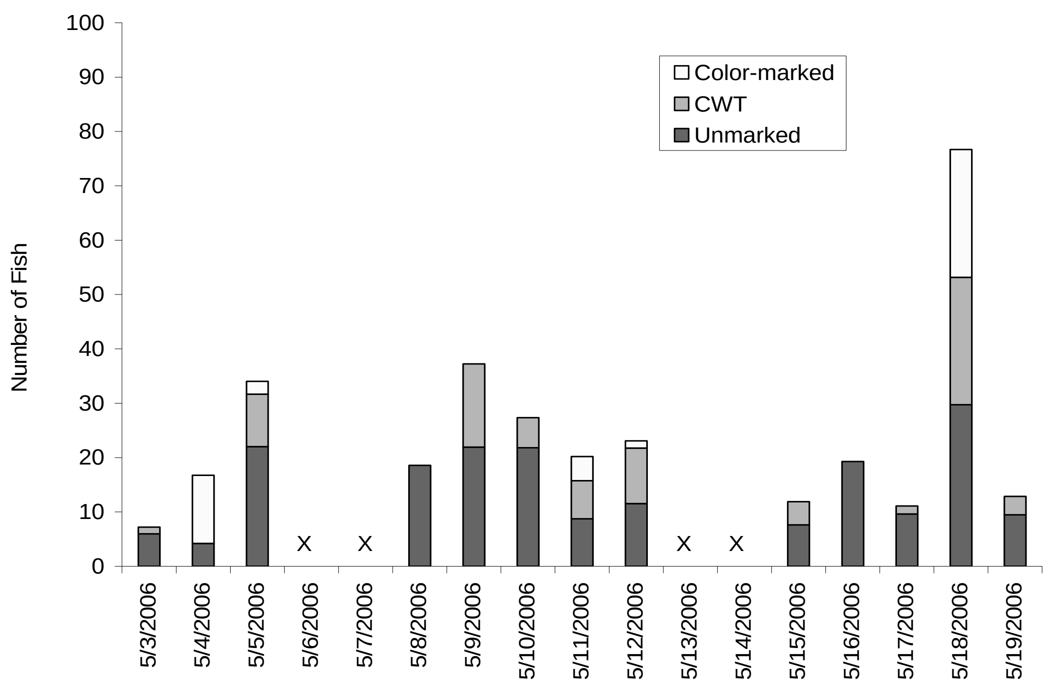


Table 3-2. Color-marked salmon vulnerability results for the Mossdale and Old River Kodiak trawls. The catch in parenthesis for the Mossdale releases indicates the number of salmon caught by the ORKT. Abundance is the color-marked salmon abundance estimate based on flow method. Percent is how close the abundance estimate is to the actual number of marked salmon released.

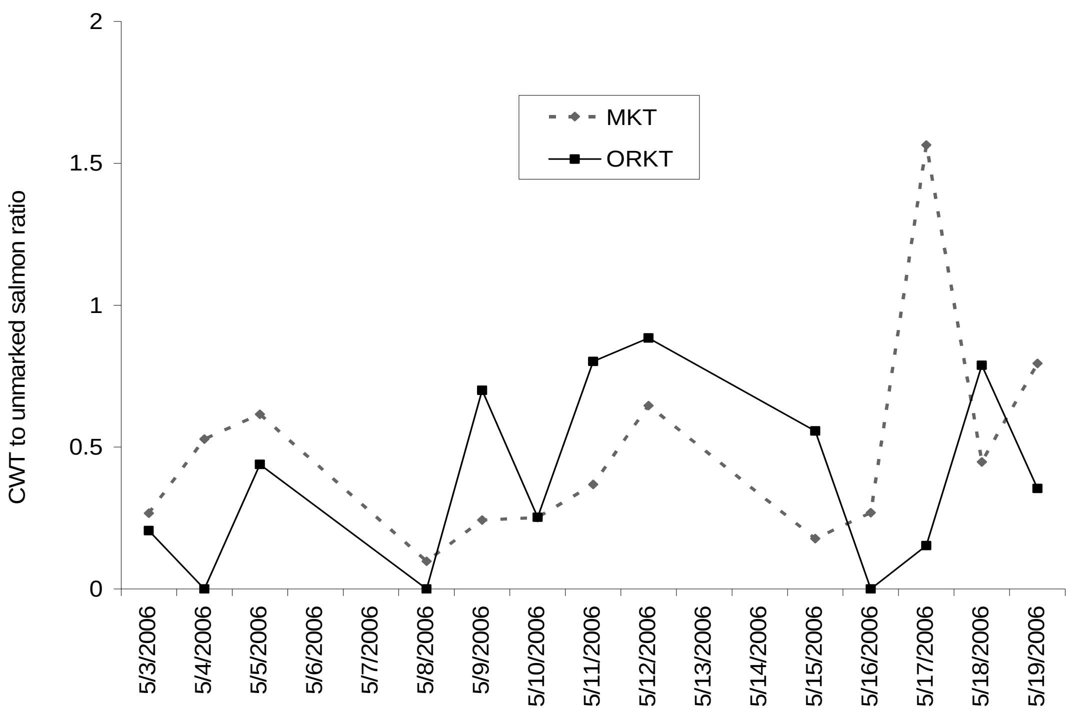
Mossdale Kodiak Trawl

Date	Released	Tows	Minutes	Catch	Vulnerability	Abundance	Percent
5/4/2006	4,998	11	220	17 (3)	0.0034	1,261	25%
5/11/2006	4,999	13	260	25 (4)	0.0050	1,529	31%
5/18/2006	4,990	4	80	25 (8)	0.0050	1,774	36%
Average	4,996			22 (5)	0.0045	1,521	30%

Old River Kodiak Trawl

Date	Released	Tows	Minutes	Catch	Vulnerability	Abundance	Percent
5/4/2006	1,997	7	140	4	0.0020	296	15%
5/11/2006	1,978			0		0	
5/18/2006	1,989	5	100	5	0.0025	315	16%
Average	1,988			4.5	0.0023	203	15%

Figure 3-4. The ratio of CWT salmon to unmarked salmon caught in the Old River Kodiak trawl (ORKT) on Old River and the Mossdale Kodiak trawl (MKT) on the San Joaquin River.



Daily catch ratios of CWT to unmarked salmon were compared between trawls to determine if CWT salmon were migrating similarly to unmarked salmon into the Old River. The daily ratio of CWT salmon to unmarked salmon was similar between the ORKT and MKT (Figure 3-4). The daily ratios of CWT to unmarked salmon were converted to percentages (percent of the combined CWT and unmarked catch) and arcsine transformed before testing whether there was a significant difference between the ORKT and MKT. A paired two-tailed t-test (df = 12, P = 0.45, t statistic = 0.78) indicates no significant difference between the daily percent of CWT salmon caught in the ORKT and in the MKT.

Two different methods were used to calculate five-hour daily salmon abundance estimates in the San Joaquin River and Old River. These abundance estimates were used to estimate the percent of salmon migrating down Old River from the San Joaquin River. The abundance method based on flow (A_f) is calculated by multiplying salmon density, calculated from the Kodiak trawl, by river flow and trawling duration (equation 1). The abundance estimate based on vulnerability (A_v) is calculated by dividing the daily catch by the vulnerability estimate and standardizing the tow duration to 20 minutes (equation 2). For both methods, the 5 hour abundance estimates were standardized to 15 tows (5 hours of sampling) before they were compared to one another.

Equation 1:

A_f = Abundance estimate based on flow and density
D = fish density (fish/m^3)
F = river flow (m^3/s) during sampling
T = trawling duration (s)
i = i^{th} tow
n = last tow with fish

$$\mathbf{A_f = \sum_{i=1}^{n} D_i * F_i * T_i}$$

Equation 2:

A_v = Abundance estimate based on vulnerability
C = catch of Chinook salmon
V = vulnerability
T = tow duration (min)
i = i^{th} tow
n = number of tows

$$\mathbf{A_v = \sum_{i=1}^{n}(C_i/V)/(T_i/20)}$$

where:
V = vulnerability
Y = number of color-marked fish recaptured
X = number of color-marked fish released
N = number of releases
i = i^{th} release

$$\mathbf{V = \sum_{i=1}^{N}(Y_i/X_i)/N}$$

The color-mark releases suggest the MKT flow abundance estimates were underestimating salmon abundance by one third and the ORKT flow abundance estimates were underestimating salmon abundance by one sixth (Table 3-3). Overall, the vulnerability abundance estimates were much higher than the flow abundance estimates, especially for Old River. Based on the flow method, on a daily average, 31 ± 29 % of the unmarked salmon, 32 ± 37 % of the CWT salmon, and 21 ± 11 % of the Mossdale released color-marked salmon estimated to be in the San Joaquin River migrated down Old River. Based on the vulnerability method, 85 ± 87 % of the unmarked salmon, 78 ± 94 % of the CWT salmon, and 43 ± 17% of the Mossdale released color-marked salmon estimated to be in the San Joaquin River migrated down Old River.

Flow data for the head of Old River (OH1) and San Joaquin River below Old River near Lathrop (SJL) was obtained from the California Department of Water Resources. Like last year, estimated flow on the San Joaquin River above Old River was calculated by summing flows from OH1 and SJL. From May 3 through May 19, river flow was slightly higher down Old River than down the San Joaquin River (Figure 3-5). During trawling, the percentage of water flowing down Old River ranged from 51 % (11,596 cfs) to 57 % (13,651 cfs), and averaged 54 % (12,113 cfs) ± 1 % (193 cfs).

Table 3-3. Salmon abundance estimates in the San Joaquin River and Old River, for a 5 hour period, and the percent migrating down Old River. Abundance estimates are based on two different methods of calculation: Abundance based on flow (Af) and abundance based on vulnerability (Av). Flow is the percent of the San Joaquin River flowing down Old River.

Unmarked Salmon

	San Joaquin River		Old River		Percent down Old River		
Date	Af	Av	Af	Av	Flow	Af	Av
5/3/2006	2,713	8,052	273	1,898	54%	10%	24%
5/4/2006	1,163	3,355	189	1,423	53%	16%	42%
5/5/2006	1,026	2,684	983	8,601	53%	96%	320%
5/8/2006	3,170	9,171	795	6,167	53%	25%	67%
5/9/2006	4,124	13,644	931	7,116	53%	23%	52%
5/10/2006	4,721	15,433	924	7,591	53%	20%	49%
5/11/2006	4,958	15,727	362	2,847	53%	7%	18%
5/12/2006	1,385	4,250	480	3,795	54%	35%	89%
5/15/2006	737	2,460	312	2,372	54%	42%	96%
5/16/2006	2,925	8,947	804	6,167	55%	27%	69%
5/17/2006	2,660	9,394	400	2,847	55%	15%	30%
5/18/2006	8,450	26,841	1,227	8,065	55%	15%	30%
5/19/2006	418	1,342	393	2,847	55%	94%	212%
Average					54%	31%	85%
Std dev					1%	29%	87%

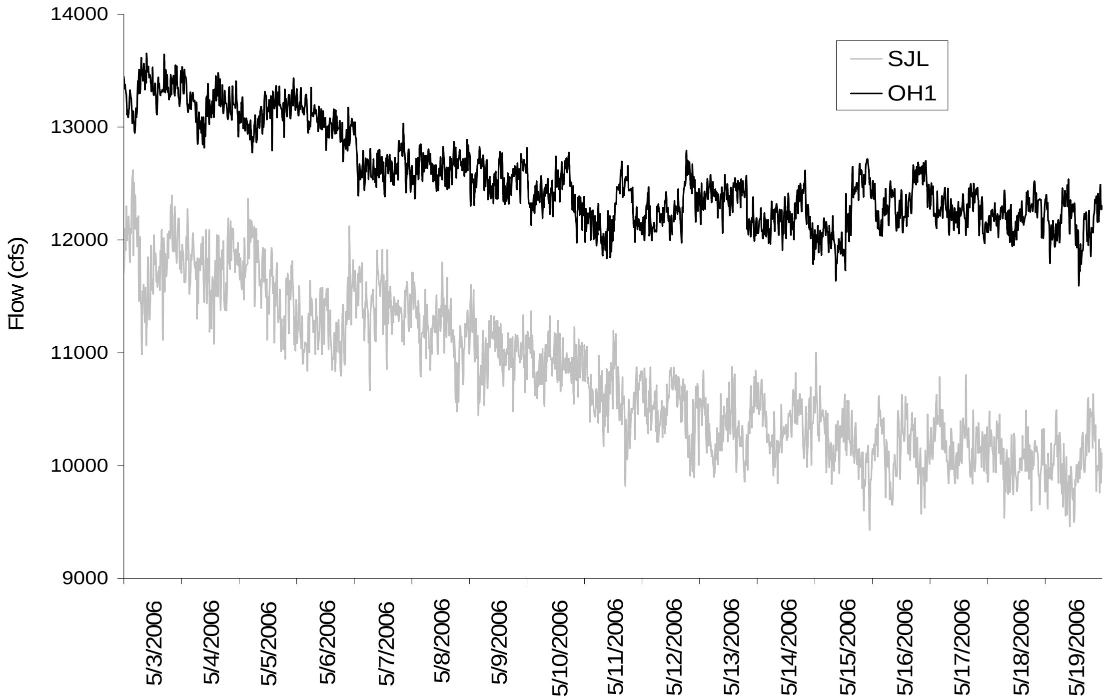
CWT Salmon

	San Joaquin River		Old River		Percent down Old River		
Date	Af	Av	Af	Av	Flow	Af	Av
5/3/2006	724	2,237	56	474	54%	7%	21%
5/4/2006	614	1,566	0	0	53%	0%	0%
5/5/2006	631	1,789	432	3,345	53%	66%	187%
5/8/2006	308	895	0	0	53%	0%	0%
5/9/2006	1,001	3,579	652	5,219	53%	63%	146%
5/10/2006	1,189	3,802	234	1,898	53%	19%	50%
5/11/2006	1,827	5,871	290	2,372	53%	15%	40%
5/12/2006	894	2,908	424	3,321	54%	46%	114%
5/15/2006	131	447	174	1,423	54%	128%	318%
5/16/2006	787	2,460	0	0	55%	0%	0%
5/17/2006	4,162	14,539	61	474	55%	1%	3%
5/18/2006	3,780	11,631	967	6,167	55%	25%	53%
5/19/2006	332	1,118	139	949	55%	40%	85%
Average					54%	32%	78%
Std dev					1%	37%	94%

Color-marked

	San Joaquin River		Old River		Percent down Old River		
Date	Af	Av	Af	Av	Flow	Af	Av
5/4/2006	1,261	3,802	226	1,328	53%	18%	35%
5/11/2006	1,529	5,592	173	1,771	53%	11%	32%
5/18/2006	1,774	5,592	591	3,542	55%	33%	63%
Average					54%	21%	43%
Std dev					1%	11%	17%

Figure 3-5. Flow at the head of Old River (OH1) and near Lathrop on the San Joaquin River (SJL) during the 2006 Kodiak trawl survey.



Discussion

Despite high flows on Old River, which delayed the initial start date by two weeks, trawling went reasonably well. The delayed start limited our sampling to 13 days. Overall, the ORKT caught fewer fish and fewer fish species than the MKT. In contrast to 2005, very few splittail were caught in either Kodiak trawl. For both trawls, salmon were caught throughout the monitoring period and consisted of least 85 % of the total catch. Statistically, salmon caught in the ORKT were on average larger than salmon caught in the MKT; however, the couple of millimeter difference in length is probably not biologically significant and should not affect the catch comparison between trawls. A relatively small proportion of the VAMP CWT salmon released at Mossdale were caught by either Kodiak trawls. The Mossdale VAMP salmon releases were intentionally delayed to mid afternoon to avoid immediate capture by the Kodiak trawls. Interestingly, half of the CWT salmon caught by the ORKT and roughly 30 % of the CWT salmon caught by the MKT were fish released for the Merced River Lower Survival Studies on April 26. These CWT salmon were caught throughout the two and half weeks both gear were simultaneously sampling.

Direct comparisons between ORKT and MKT are difficult for a variety of reasons. Biases that can affect catch include the habitat (channel width, depth, and flow are not the same between and within the sample sites); the sporadic and uneven distribution of migrating salmon; boat and crew differences affecting how the Kodiak net is towed; and MKT and ORKT flow meters might have different calibrations which would effect water volume calculations. Using the ratio of CWT to unmarked salmon in each trawl minimizes some of these biases and other sampling differences. Although abundance estimates are calculated for both the Old and San Joaquin River, they will only be used to provide general insights to salmon migration into Old River.

The daily ratio of CWT to unmarked salmon was similar between the San Joaquin River and Old River. Like year 2005, CWT and unmarked salmon were migrating proportionally down Old River at the same rate. It appears the marking and subsequent release of CWT salmon in the tributaries does not affect their outmigration relative to the unmarked fish when they reach the Delta. However, there might be a difference for in-Delta releases of color-marked salmon. It appears color-marked salmon migrate down Old River at a lower rate overall than the unmarked and CWT salmon. However, when comparing salmon caught only on the three color-marked release days (May 4, 11 and 18), color-marked salmon migrate down Old River at a slightly higher rate than the unmarked and CWT salmon. If color-marked fish releases were conducted everyday, they will probably show the same range in variability as the unmarked salmon migrating down Old River.

Salmon abundance in the San Joaquin River and Old River was calculated using two different methods. As in 2005, salmon abundance was calculated by multiplying salmon density by river flow and trawling duration. In 2006, abundance estimates were also calculated using the vulnerability study results. Salmon abundance estimates for the two different methods gave vastly different results. Therefore, the average daily percentage of salmon calculated to be heading down Old River varied dramatically between the two methods. The color-marked vulnerability studies suggest the ORKT was underestimating salmon abundance to a larger degree than the MKT. The color-marked flow abundance estimates indicate the ORKT was only half as efficient as the MKT in catching juvenile salmon. The flow abundance estimates also tend to underestimate abundance when salmon are not evenly distributed in the water column. The vulnerability estimates likely give a better abundance estimate because they are based on net efficiency and the assumption that color-marked salmon distribute themselves similarly to the unmarked salmon migrating down the river.

The daily percentage of CWT and unmarked salmon heading down Old River is similar on most days. However, there is variability in the percentages among sampling days. Although flow in the San Joaquin River and Old River was relatively constant during the monitoring period, the variability around the mean for salmon migrating down Old River is large. If salmon always migrated in proportion to the flow split, and if we sampled consistently among days, we would expect low variability among the daily percentages of salmon migrating down Old River. The large observed variability could be due to the natural variability in salmon migration compounded by trawling biases and the extrapolated abundance estimate calculations.

As a general insight into salmon migration into Old River, average salmon abundance estimates were compared at different flows for three different years of Kodiak trawling. Based on the 1995, 2005 (San Joaquin River Group Authority 2006) and 2006 salmon abundance estimates for the San Joaquin and Old Rivers, it appears a higher percentage of salmon migrate down Old River at higher flows. When flow on the San Joaquin River upstream of the split was around 8,000 cfs (in 2005), 59 ± 51 % of the salmon went down Old River. At flows around 18,000 cfs (in 1995), 67 ± 13 % of the salmon headed down Old River. At flows around 23,000 cfs (2006), 78 ± 71 % of the salmon went down Old River. It must be noted that there is a lot of variability around the means and the overall relationship is probably not statistically significant. Also, differences in sampling location, sampling procedures and salmon abundance calculations among years contribute additional variability which further confounds the results.

If salmon truly head down Old River at a higher rate at higher flows, then the hydrology in front of the split with Old River might be a contributing factor. At higher flows, it appears the main current in the San Joaquin River is pushed towards the western bank and down Old River. As observational evidence, on May 4, 2006, while trawling in Old River, we noticed a steady ribbon of water hyacinth floating with the current. At the end of the day, on our trip back to the Mossdale boat ramp, we noticed that all the water hyacinth was heading down Old River and nothing was continuing down the San Joaquin River. The continuous ribbon of hyacinth revealed that the bend in the San Joaquin River, just upstream of the head of Old River, pushed the main current to the western side of the river and straight down Old River. Anything floating with the main current or west of the main current went down Old River.

Summary

Salmon were the most abundant species caught during the 13 days of Kodiak trawling in the San Joaquin River and Old River. Five-hour salmon abundance estimates were calculated for each river using two different methods. It appears abundance estimates based on vulnerability gives a better estimate than those based on density and flow. On an average daily basis, it appears about three-quarters of the salmon in the San Joaquin River migrated down Old River. During this time period, a little more than half of the San Joaquin River flow was heading down Old River. Although the daily variability in the data is large, it appears that in May 2006, salmon were going down Old River at a higher rate than water flow. The hydrology at the San Joaquin River and Old River split might be a contributing factor for increased salmon migration down Old River at higher flows. Any salmon following the main current will probably head down Old River. More research into the hydrology of this area will provide better insights into salmon migration down Old River.

References Cited

San Joaquin River Group Authority, 2006. 2005 Annual Technical Report on the Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan. January 2006. 129 pgs.

USFWS. 2003. Abundance and Survival of Juvenile Chinook Salmon in the Sacramento-San Joaquin Estuary. 1999 Annual Progress Report. Sacramento-San Joaquin Estuary Fisheries Resources Office, U.S. Fish and Wildlife Office, Stockton, California. 68 pgs.

Chapter 4. Salmon Smolt Survival Investigations

One of the primary objectives of the VAMP study, in addition to providing enhanced protection of juvenile Chinook salmon emigrating from the San Joaquin River system, is to determine the effects of San Joaquin River flows, SWP and CVP water exports, and HORB placement on survival of Chinook salmon smolts emigrating from the San Joaquin River through the Delta. As mentioned in previous chapters, the HORB was not installed in 2006. Therefore the VAMP study design was modified in 2006 to accommodate this change. This section describes the methods used to conduct the Chinook salmon smolt survival investigations and provides calculated survival indices, absolute survival estimates, and combined differential recovery rates for coded-wire tagged (CWT) Chinook salmon smolts released during the VAMP 2006 test period.

Merced River Fish Hatchery Coded-Wire Tagging

Merced River Fish Hatchery (MRH) supplied 200,000 CWT Chinook salmon smolts for the VAMP 2006 study. This was lower than requested due to lower than average adult returns to the hatchery and use of many of the MRH fish available for tributary studies. Salmon were coded wire tagged and marked with an adipose fin clip by a private contractor in March and April. Groups of fish were generally held separately by tag code, for approximately 27 days before release. Salmon were tagged with one of eight distinct tag codes. MRH examined sub-samples of tagged salmon to obtain estimates of mean size at release and CWT retention rates. CWT retention is typically high and all salmon from the sub-samples without a detected tag were sacrificed to verify the accuracy of the CWT detection process and to determine if these fish contained an undetected, non-magnetized tag. No sub-sampled fish were found to contain non-magnetized tags. Average tag retention documented by MRH was 97% and ranged from 94% to 100% (Table 4-1).

California Department of Fish and Game (Region 4) calculated the effective number released (ER) by tag code by first subtracting the pond loss at the hatchery (HL) from the total number tagged (TM) to obtain the hatchery release number (HR) (Table 4-1). Mortalities from the quality control (QCL), loading (LL) and transporting (TL) processes were then subtracted from the HR to obtain the number released at the site (SR). The number released at the site (SR) was then corrected for the tag retention rate (TRR) to obtain the number of fish with tags released at the site (ST). Finally, the fish with tags in the net pens (PT) that were sacrificed were subtracted from the site release with tags (ST) to obtain the effective release number (ER). The following formula restates how the effective number of fish released in each VAMP group was calculated.

$$HR = TM - HL$$

$$SR = HR - QCL - LL - TL$$

$$ST = SR * TRR$$

$$ER = ST - PT$$

Table 4-1. Chinook Salmon Smolt Release Data for VAMP, 2006

				Mortalities									
Release Site	CWT Code	Release Date	Total Marked TM	Hatchery Loss (HL)	Hatchery rel. (HR)	Quality Control (QCL)	Load (LL)	Transport/ Plant (TL)	# Released at Site (SR)	Retention (TRR)	# Released at Site with tags (ST)	Fish in net pens w/ tags (PT)	Effective Release (ER)
Mossdale	06-47-13	5/4/06	25,992	92	25900	32	21	2	25,845	0.97	24,946	243	24,703
Mossdale	06-47-14	5/4/06	25,841	92	25749	34	27	3	25,685	0.96	24,534	219	24,315
Dos Reis	06-47-16	5/5/06	26,018	61	25957	25	27	1	25,904	1.00	25,904	302	25,602
Jersey Point	06-47-15	5/8/06	27,240	90	27150	30	23	3	27,094	0.98	26,417	225	26,192
Mossdale	06-47-21	5/19/06	25,917	49	25868	29	1	1	25,837	0.98	25,320	215	25,105
Mossdale	06-47-22	5/19/06	25,996	58	25938	38	6	1	25,893	0.94	24,225	217	24,008
Mossdale	06-47-23	5/19/06	25,765	43	25722	28	4	2	25,688	0.99	25,303	237	25,066
Jersey Point	06-47-24	5/22/06	25,941	51	25890	26	636	0	25,228	1.00	25,102	197	24,905
									Average	0.97			

VAMP Fish Releases

CWT salmon were released at three sites on five dates for the 2006 VAMP experiment (Table 4-2). CWT salmon with different tag codes were held separately at the hatchery and trucked in discrete tag lots to each release location. Releases occurred at Mossdale, Dos Reis, and Jersey Point for the first set of releases and at Mossdale and Jersey Point for the second set of releases. Transport and water temperatures at the time of release are listed in Table 4-2. The mean size of the fish released in each of the VAMP groups is also shown in Table 4-2.

Table 4-2. Chinook salmon smolt release data for VAMP 2006.

Release Date	Release Site	Tag Code	Effective Number Released	Size at release (in mm)	Transport Temperature (°F)	River Temperature (°F)
Release 1						
4-May-06	Mossdale	06-47-13	24703	80	53	64
4-May-06	Mossdale	06-47-14	24315	77	53	64
5-May-06	Dos Reis	06-47-16	25602	79	53	64
8-May-06	Jersey Point	06-47-15	26192	80	53	66
Release 2						
19-May-06	Mossdale	06-47-21	25105	89	55	67
19-May-06	Mossdale	06-47-22	24008	88	55	67
19-May-06	Mossdale	06-47-23	25066	89	55	67
22-May-06	Jersey Point	06-47-24	24905	87	55	67

Mossdale is located on the San Joaquin River upstream of the Head of the Old River (HOR). For the first release, approximately 50,000 CWT salmon with two different tag codes were released at Mossdale. For the second release approximately 75,000 CWT salmon with three different tag codes were released at Mossdale.

Dos Reis is located downstream of the HOR and was used as a release site in 2006 to help assess the mortality of marked salmon from the Mossdale release diverted into Old River. Just over 25,000 CWT salmon of one tag code were released during the first release. No releases were made at Dos Reis during the second set of releases.

Two releases of approximately 25,000 each were made at Jersey Point with one tag code per release. CWT salmon were released on a flood tide at Jersey Point to increase fish dispersion throughout the channel before they migrated downstream past Antioch and Chipps Island (recovery sampling stations). Releases at other locations did not incorporate the tides for determining release times.

During the VAMP period in 2006, San Joaquin River flows were so high that part of the flow was diverted into Paradise Cut (a flood bypass). Paradise Cut flow leaves the San Joaquin River upstream of Mossdale, but downstream of Durham Ferry. To better compare results to other years, when San Joaquin flow was not diverted into Paradise Cut, the upstream release site was changed from Durham Ferry to Mossdale in 2006.

The study design in 2006 was intended to 1) estimate survival between Mossdale and Jersey Point under two different export levels and 2) determine if there was a difference in survival for smolts released at Mossdale versus those released at Dos Reis. The group released at Mossdale would have some of the group presumably diverted into upper Old River while those released at Dos Reis would generally stay on the mainstem San Joaquin River. Two sets of releases were made at Mossdale and Jersey Point to measure survival through the Delta at two exports levels, under similar and high San Joaquin River flow levels (approximately 25,000 cfs). Average daily exports were targeted to be 1500 cfs for the two weeks following the first release at Mossdale and 6000 cfs during the two weeks following the second Mossdale release. The number released for the first Mossdale group was reduced from 75,000 to 50,000 to provide 25,000 fish to be released at Dos Reis. It was anticipated, even with the low release numbers, that recovery numbers would be sufficient from both Mossdale and Dos Reis since survival has been relatively high in the past during similar high flow years. With the anticipation that survival might be lower under higher exports the Mossdale release numbers were kept at 75,000 for the second Mossdale release resulting in no Dos Reis release during the second set of releases.

Water Temperature Monitoring

Water temperature was monitored during the VAMP 2006 study using individual computerized temperature recorders (e.g., Onset Stowaway Temperature Monitoring/Data Loggers). Water temperatures were measured at locations along the longitudinal gradient of the San Joaquin River and interior Delta channels between Durham Ferry and Chipps Island – locations along the migratory pathway for the juvenile Chinook salmon released as part of these tests (Appendices A and B). As part of the 2006 VAMP monitoring program additional temperature recorders were deployed in the south and central Delta (Appendix A) to provide geographic coverage for characterizing water temperature conditions while juvenile salmon emigrate from the lower San Joaquin River through the Delta.

Water temperature was recorded at 24-minute intervals throughout the period of the VAMP 2006 investigations. Water temperatures were also recorded within the hatchery raceways at the MRH coincident with the period when juvenile Chinook salmon were being tagged and held. These temperature recorders were later transported with the juvenile salmon released at Mossdale (Appendix A).

Results of water temperature monitoring within the MRH showed that juvenile Chinook salmon were reared in, and acclimated to, water temperatures of approximately 10°- 12° C (50°-54° F) prior to release into the lower San Joaquin River (Figures 4-1 and 4-2). Results of water temperature monitoring at Durham Ferry, Dos Reis, and Chipps Island during the April-May fall-run Chinook salmon smolt emigration from the San Joaquin River through the Delta are shown in Figures 4-3, 4-4, and 4-5. The water temperature logger deployed at the Mossdale release site could not be relocated and may have been lost to vandalism. Water temperature monitoring showed that water temperatures throughout the lower San Joaquin River and Delta (Appendix A) were higher than those at the hatchery, which is usually always the case. Water temperatures measured within the lower San Joaquin River and Delta (Figures 4-4 and 4-5; Appendix A) generally increased over time and may have reduced survival of emigrating juvenile Chinook salmon released as part of the VAMP 2006 investigations.

Figure 4-1. Water Temperature Monitoring Merced River Fish Hatchery to Mossdale, Apr. 1-May 6

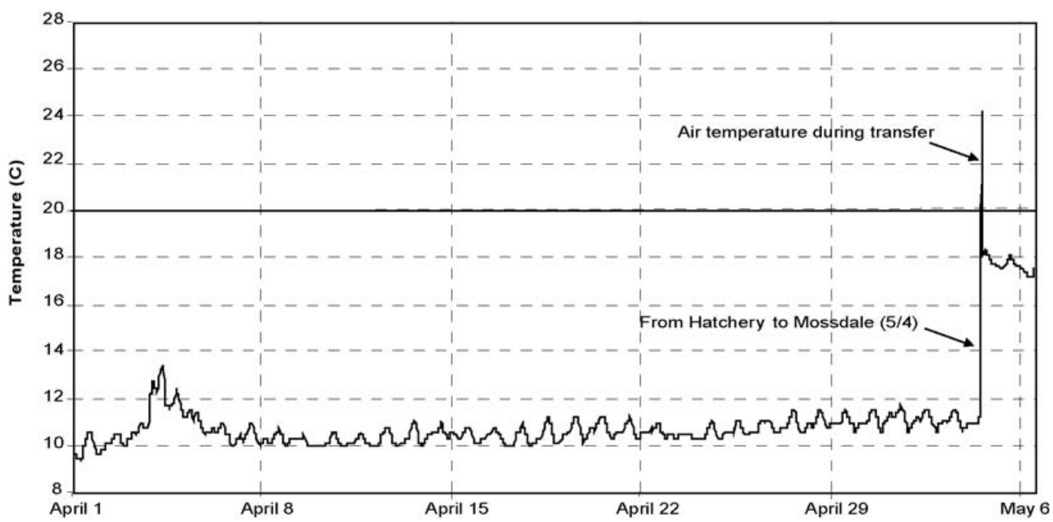


Figure 4-2. Water Temperature Monitoring Merced River Fish Hatchery to Mossdale, Apr. 1-May 20

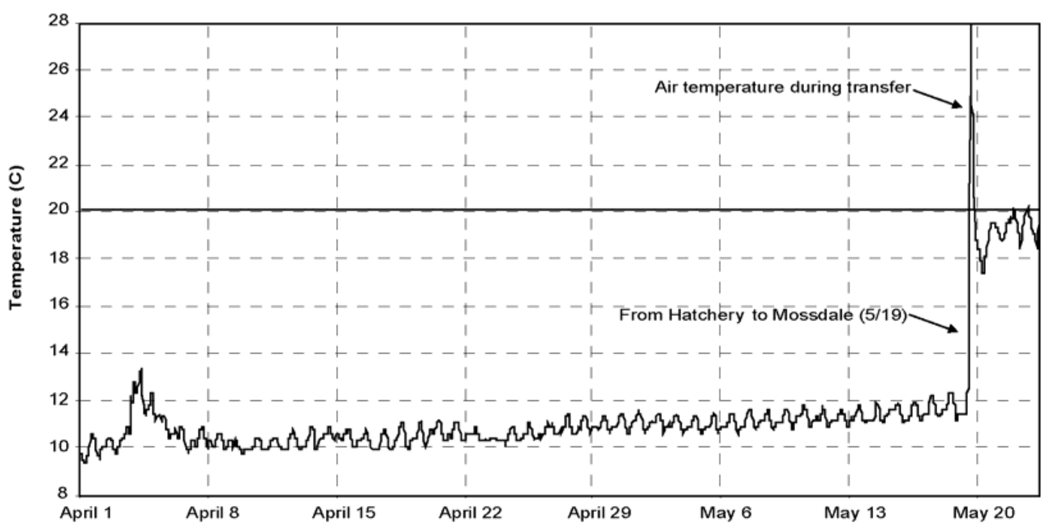


Figure 4-3. Water Temperature Monitoring Site 1-Durham Ferry

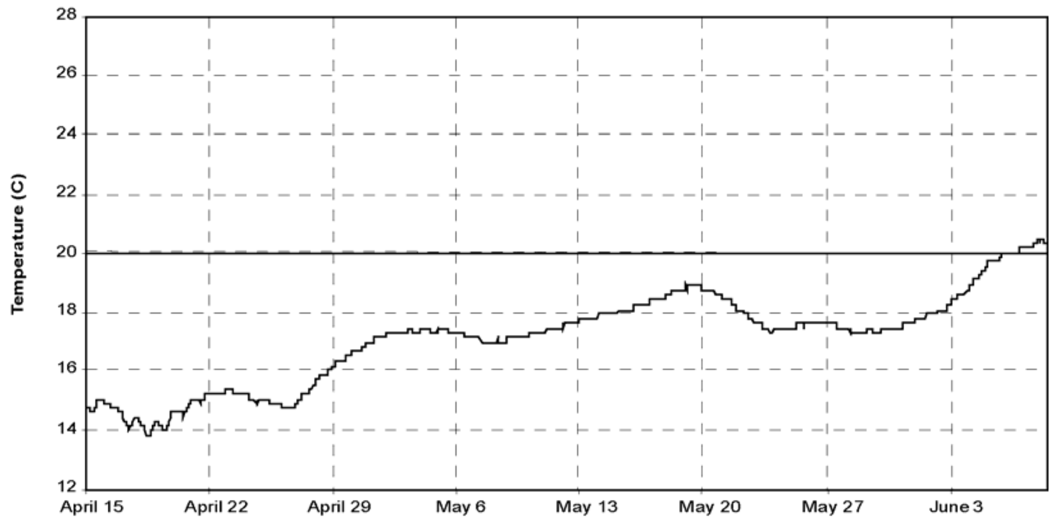


Figure 4-4. Site 3-Dos Reis Water Temperature Monitoring

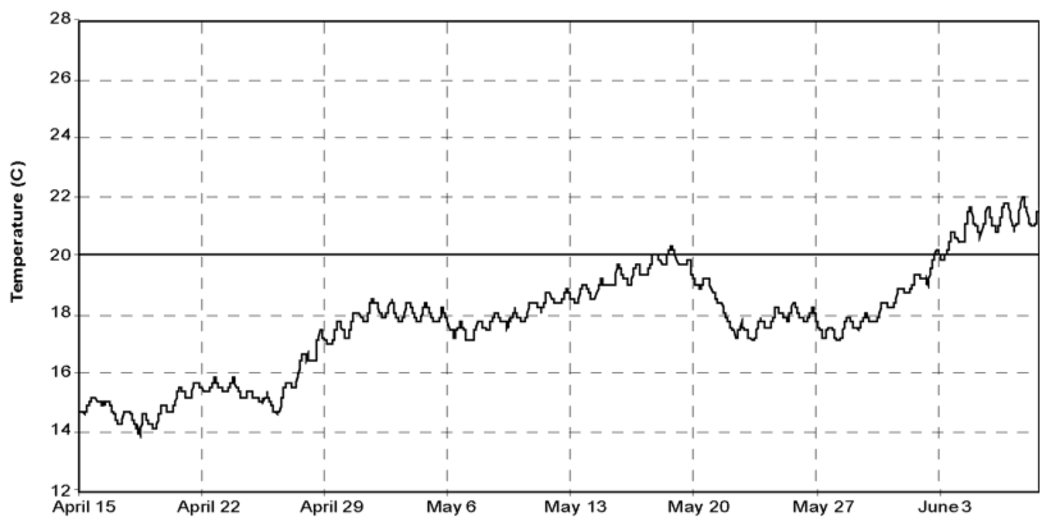
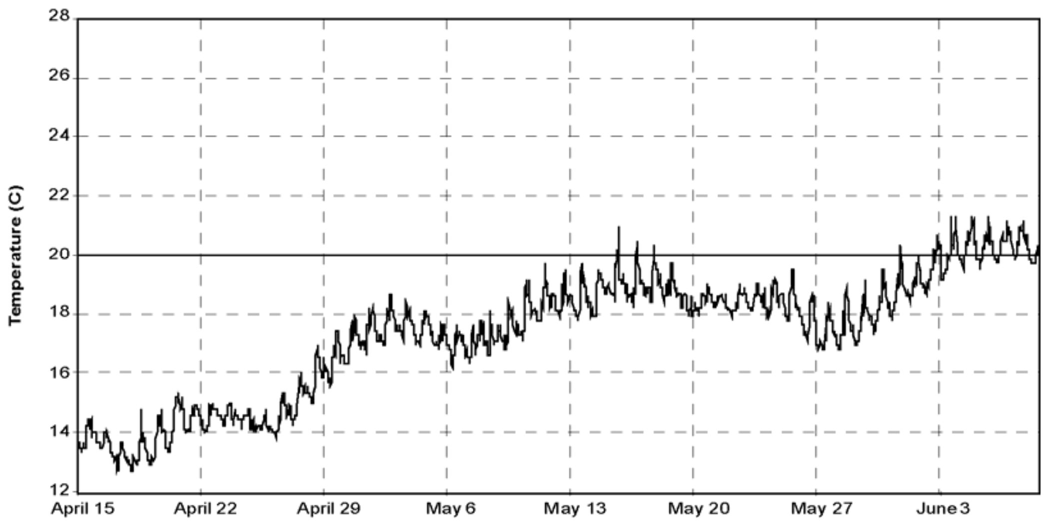


Figure 4-5. Site 10-Chipps Island Water Temperature Monitoring



Short-Term Survival Study

A short term survival study was conducted as part of VAMP to determine if handling, transport, and release affected immediate (short-term) and 48-hour survival and general condition. A subset of approximately 225 CWT salmon were removed from the MRH truck and placed in net pens (volume ~ $1m^3$; mesh size ~3 mm) before the remaining fish were released. Samples from each tag group were held in separate net pens.

Once placed into the pens, sub-samples of 25 fish from each pen were examined for swimming vigor then euthanized for measuring and documenting general condition. Each fish was measured (fork length to nearest 1 mm), weighed (to the nearest 0.1 g) and examined qualitatively in the field for percent scale loss, body color, fin hemorrhaging, eye quality, and gill coloration. Table 4-3 identifies the criteria used to define normal and abnormal conditions for these characteristics. Additionally, quality of adipose fin clip was documented. The sub-sampled fish were taken to the U.S. Fish and Wildlife Service, Stockton office (STFWO), for verification of tag code. After 48-hours post release, an additional 25 fish from each pen were measured, weighed, and examined for condition, as described above. The remaining fish from each pen were examined for mortalities, euthanized, counted, measured, weighed, and returned to the STFWO for additional tag code verification.

Table 4-3. Characteristics assessed for Chinook salmon smolt condition and short-term survival.

Character	Normal	Abnormal
Percent Scale Loss	Lower relative numbers based on 0-100%	Higher relative number based on 0-100%
Body Color	High contrast dark dorsal surface and light sides	Low contrast dorsal surface and sides, coppery color
Fin Hemorrhaging	No bleeding at base of fins	Blood present at base of fins
Eyes	Normally shaped	Bulging or with hemorrhaging
Gill Color	Dark beet red to cherry red colored gill filaments	Gray to light red colored gill filaments
Vigor	Active swimming (prior to anesthesia)	Lethargic or motionless (prior to anesthesia)

Sub-samples of fish in the net pens immediately after release were generally in good condition (Appendix A). All fish were swimming vigorously before being euthanized. Mean scale loss ranged from 3% for the second Mossdale release to 7% for the second Jersey Point release (average of all locations = 5.5%). Body color and gill color were normal for all fish examined except the second Jersey Point release. These fish were held for an additional 2 hours in the truck due to a flat tire; subsequently, body and gill color appeared pale. Fin hemorrhaging was observed in 4% of fish from the first Mossdale and second Jersey Point releases. Partial fin clips were observed at all sites and ranged from 8% to 16%.

Short-term survival (48-hours post-transport) was high (100%) within the net pens. Fish retained in the net pens for the 48-hour post release examination were swimming vigorously and generally in good condition (Appendix A). Mean scale loss was (7%) and ranged from 5% to 12.5% after each of the 48-hour trials. Fish from all releases, except the second Jersey Point release had fin hemorrhaging. Fin hemorrhaging ranged from 4% to 16%. Fish from the second Jersey Point release had a high occurrence of abnormal body color (84%). No abnormal eye quality was detected in any fish. Pale gills were detected in 3% of fish from the second Mossdale release and 16% from the second Jersey Point release. No other fish had abnormal gill coloration. These data indicate that the fish used for the VAMP 2006 experiment were in good condition both initially and after 48 hours; and that handling, transport, and release should not have affected their survival.

Tag code discrepancies were found to have occurred between two tag codes used in the second set of releases; one of the mixed tag codes (06-47-23) was from the Mossdale release (May 19th), and the other was from the May 22nd Jersey Point release (06-47-24). The mixing was discovered when one of the 25 fish from the Mossdale net pen had a tag code associated with the Jersey Point release. To further evaluate the extent of the mixing, all fish kept from each of eight net pens were dissected to obtain the tags and identify tag codes. For the one Mossdale net pen, a total of 7 fish out of 212 contained tags with the Jersey Point tag code (06-47-24). For the Jersey Point net pen group, 32 of 222 were found to have a Mossdale tag code (06-47-23). In further discussion with Fish and Game it was determined that the mixing occurred when a screen at the hatchery was changed that separated the tag groups in the raceway. There was no evidence of mixing in the remaining six tag codes.

Health and Physiology

On April 25 2006, a subsample of 60 CWT juvenile Chinook salmon from tagged lots used in the 2006 VAMP study, were brought from the MRH to the U.S. Fish and Wildlife Service California-Nevada Fish Health Center (CA-NA FHC). Kidneys from these fish were collected aseptically for viral assay, culture of systemic bacteria and imprint smears to determine if *Renibacterium salmoninarum* was present. Posterior kidney from 20 salmon was processed to evaluate *Tetracapsuloides bryosalmonae* infection and kidney inflammation. This parasite has been detected in Merced River salmon for several decades (Hederick et al., 1986) and causes Proliferative Kidney Disease (PKD). A total of 14 of 60 kidney imprints contained low numbers of bacteria that resembled *R. salmoninarum*. While the fish were asymptomatic for Bacterial Kidney Disease (BKD), the 23% detection rate indicates that MRH juvenile Chinook contained a high number of *R. salmoninarum* infected fish. *R. salmoninarum* infections have been documented for MRH Chinook juveniles in previous years. It is unclear whether such infection later develops into clinical disease and is a health problem for the population.

In addition to examining MRH 2006 VAMP salmon prior to release, selected salmon recovered at Chipps Island were also examined for the presence of PKD. A subsample of 407 adipose fin clipped Chinook juveniles were collected in the Chipps Island trawl between 5 May and 18 June 2006. Kidney samples were collected from these fish by field personnel from the Stockton Fish and Wildlife Office. Imprints from 66 of these fish, which contained tags with VAMP tag codes, were screened for *T. brysalmonae*. The parasite *T. brysalmonae* was not detected in Chipps Island imprints, however, a number of imprints were observed to have been improperly fixed. If kidney imprints are collected in the future, it may be necessary to use rapid methanol fixation or provide additional training to field personnel. Based on the inability to detect *T. brysalmonae* in both histological and cytological sample types, this strongly suggests that the MRH juvenile Chinook population was not infected in 2006. A full report is available in Foott and Stone (2006).

Release Number Correction

The release number for the 2nd Jersey Point group has been corrected because of the tag code mixing at the hatchery, explained above. Information from the mixed Mossdale tag lot (6-47-23 tag code) has not been used for any analyses in this report. Only the two unmixed Mossdale tag codes were used from the 2nd release. We have corrected the Jersey Point release number based on the assumption that the proportion of those mixed in the total group is the same as the proportion mixed in the net pens. Without this assumption, there is no basis for correcting the release numbers. While this assumption is reasonable, there is no way of testing it.

The number of fish actually released at Jersey Point with a 6-47-24 tag code was estimated by subtracting those with the same tag code that were mistakenly released at Mossdale (925) from the effective release number (Table 4-4). We have assumed that the estimated number of survivors to Jersey Point (19) of the 925 released at Mossdale would have a negligible effect on our estimates of survival or recovery rate. The number of survivors was estimated by multiplying the number estimated to be released at Mossdale (925) by the survival rate to Jersey Point of the other (two unmixed) Mossdale tag groups released on the same day (Table 4-4). The estimated number of 06-47-24 tags released at Mossdale was obtained by multiplying the effective release number of the Jersey Point group (06-47-24) by the proportion of the tag code in the Mossdale net pen relative to the total in both net pens (Jersey Point and the one mixed Mossdale net pen). Numbers were standardized so that equal weight was given to both net pens, although due to rounding this adjustment did not change the number of tags estimated (7) with a 6-47-24 code in the Mossdale net pen. The proportion (0.0371) of 06-47-24 tags in the Mossdale net pen was estimated by dividing the standardized number found in the Mossdale net pen (7) by the standardized total in both net pens (197). The corrected effective release (CER) of the 06-47-24 tag code released at Jersey Point was estimated at 23980.

Table 4-4. Calculations to correct tag code mixing between 6-47-23 and 6-47-24 for VAMP studies in 2006

Net Pen Location	Net Pen Total	CWT Code 06-47-23	CWT Code 06-47-24	Percentage 6-47-23 in Net Pen at Mossdale
Mossdale	212	205	7	96.70%
Adjusted net pen sample Mossdale	222	215	7	
Jersey Point	222	32	190	
CWT Code	**Number in Tag Code**	**Proportion of Tag Code Released at JP**	**Proportion of Tag Code Released at Moss**	
06-47-24	24905	0.9629	0.0371	
CWT Code	**Estimated Number Released at Mossdale**	**Corrected Number Released at JP CE**	**Estimated Survival Mossdale to JP**	**Mossdale Release Fish Surviving to JP**
06-47-24	925	23980	2%	19

Coded-Wire Tag Recovery Efforts

Coded-wire tagged salmon were recaptured at Old River, Mossdale, Antioch, Chipps Island, and the Federal (Central Valley Project (CVP)) and State Water Projects (SWP) (Figure 1-1). Juvenile Chinook salmon with an adipose fin clip caught at Antioch, Chipps Island and at the CVP and SWP fish facilities were sacrificed, labeled, and frozen for CWT processing by staff at Stockton Fish and Wildlife Office. DFG Region 4 staff processed CWT fish from Old River and Mossdale.

CWT processing consists of dissecting each tagged fish to obtain the 1-mm cylindrical tag from the snout. Tags are then placed under a dissecting microscope and the numbers are read and recorded in a database and archived. All tags were read twice, with any discrepancies resolved by a third reader. It should be noted that many CWT Chinook salmon are captured during the VAMP study; however a portion of these fish have been tagged for other studies and are not affiliated with the VAMP study. In order to identify tags related to VAMP, it is necessary to read all recovered tags.

Antioch Recapture Sampling

Fish sampling was conducted in the vicinity of Antioch on the lower San Joaquin River using a Kodiak trawl, similar to previous years (since 2000). The Kodiak trawl has a graded stretch mesh, from 2-inch mesh at the mouth to 1/2-inch mesh at the cod-end. Its overall length is 65 feet, and the mouth opening is 6 feet deep and 25 feet wide. The net was towed between two skiffs, sampling in an upstream direction. Trawls were performed near the left bank, mid-channel, and right bank to sample CWT salmon emigrating from the San Joaquin River. Each sample was approximately 20 minutes in duration.

All captured fish were transferred immediately from the Kodiak trawl to buckets filled with river water, where they were held for processing. Data collected during each trawl included: species identification and fork length for each fish captured, tow start time and duration, and location in the channel. Any fish mortalities or injuries were documented to comply with the Endangered Species Act permit requirements. Juvenile Chinook salmon with an adipose fin clip were retained for later CWT processing while other fish were released at a location downstream of the sampling site immediately after identification, enumeration, and measurement.

Sampling at Antioch each day between 5:30 a.m. and 9:00 p.m. began May 5 and continued through May 31. In all, 680 Kodiak trawl samples were collected, for a total of 13,520 tow minutes. During sampling, 3,147 unmarked juvenile Chinook salmon were captured; 110 salmon with a coded wire tag were collected: 52 from VAMP releases (Table 4-5) and 57 from other hatchery releases. In addition, 59 delta smelt, 8 unmarked steelhead, and 8 adipose fin clipped steelhead were caught during sampling.

Table 4-5 Chinook salmon smolt recovery information at Antioch, Chipps Island, and the fish facilities for VAMP 2006 releases. (11x17 table at end of chapter)

Chipps Island Recapture Sampling

Recovery efforts at Chipps Island were conducted using a mid-water trawl towed at the surface. The trawling net is 82 feet in length and has an opening that is 30 feet wide by 10 feet deep. Mesh size of the net is variable and ranges from 4-inch mesh at the mouth to 5/16-inch mesh at the cod end.

For VAMP 2006 trawling was conducted during two time periods per day, seven days per week from May 5, 2006 through June 17, 2006. Greater recoveries of Chinook salmon smolts have been reported during sunrise and sunset (Hanson Environmental, unpublished data).

Therefore, the first shift began during sunrise and the second shift was completed during sunset in an attempt to increase the recovery of Chinook salmon smolts and reduce the variability in calculated survival indices and recovery rates. Two shifts a day have been conducted during the VAMP period since 1998. Each shift consisted of ten 20-minute tows conducted in the north, middle, and south sections of the channel parallel to the shore. Generally, three tows are conducted in each section of the channel with the section of the channel selected randomly for the last tow. After six weeks, the majority of VAMP Chinook salmon smolts have migrated past Chipps Island, so sampling was subsequently reduced. Ten morning tows were continued seven days per week between June 18 and June 24; and three days per week after June 25.

All fish retained in the cod end of the net were placed in aerated water collected from the sample site. All Chinook salmon smolts with an adipose fin clip were labeled and retained for later CWT processing. All other fish were identified to species, enumerated, and released. The fork length of each individual was measured to the nearest mm. As mentioned previously, some salmon were also processed in the field to determine if *T. bryosalmonae* were present. CWT salmon released for the VAMP 2006 study were recovered from Chipps Island between May 8 and May 29, 2006 (Table 4-5). A total of 53 juvenile Chinook salmon with tag codes used in the VAMP 2006 study were recaptured at Chipps Island; the majority being released at Jersey Point.

During this same time period, the catch included 10,695 unmarked Chinook salmon; 944 CWT Chinook salmon from non-VAMP studies; 179 delta smelt; 80 Sacramento splittail; 6 marked steelhead; and 12 unmarked steelhead.

CVP and SWP Salvage Recapture Sampling

CVP and SWP fish facilities salvage fish on a continuous basis. To estimate the total number of fish salvaged, sub-samples (raw salvage) are collected approximately every two hours. Expanded salvage is a calculated by expanding the raw salvage by the time sampled and provides an estimate of the total number of fish salvaged. Expanded salvage does not take into account the loss of Chinook salmon smolts at the facilities from pre-screen predation, screening, handling, and trucking. Raw and expanded CVP and SWP salvage estimates are reported in Table 4-5.

During VAMP 2006, salvage and expanded salvage was very low. This result is surprising in that the HORB was not installed which has in the past increased the number of CWT salmon observed in salvage (Brandes and McLain, 2001).

Transit Time

Recoveries of VAMP 2006 smolts were made at Antioch between May 10 and May 29 and at Chipps Island between May 8 and May 29 (Appendix A). Recoveries were made at the CVP and SWP fish facilities between May 4 and May 19 (Table 4-5); a few days earlier than at the other recovery locations.

VAMP Chinook Salmon CWT Survival

Survival Indices

Survival indices were calculated for marked salmon released at Mossdale, Dos Reis and Jersey Point and recovered at Antioch and Chipps Island. Survival indices (SI) were calculated using the formula:

$$SI = (R / (ER*T*W))$$

where: R is the number recovered, ER is the effective number released, T is the fraction of time sampled, and W is the fraction of channel width sampled.

The fraction of the channel width sampled at Chipps Island (0.00769) was calculated by dividing the net width (30 feet) by the estimated channel width (3,900 feet). The fraction of the channel width sampled at Antioch (0.01388) was calculated in the same manner, with the net width being 25 feet and the channel width being 1,800 feet. The fraction of time sampled at both locations was calculated based on the number of minutes sampled between the first and last day of catching each particular tag code or group, divided by the total number of minutes in the time period. The fraction of time sampled for the VAMP 2006 release groups at Chipps Island was about 28%, while at Antioch it was about 40% (Table 4-5).

Survival indices were calculated for each tag code to provide a sense of the variability associated with the group survival index. To generate the group survival index, the recovery numbers and release numbers are combined for the tag codes within a release group.

Sampling at Antioch in 2006 was irregular between days (Appendix A) and potentially adds noise in estimating survival using the recoveries at Antioch. For instance, if the majority of the Mossdale group moves past Antioch on a day where more sampling occurs relative to the next day when the majority of Jersey Point fish pass, the Mossdale recovery rate would be potentially biased high relative to the recovery rate of the Jersey Point group. However, the timing of the Mossdale and Jersey Point groups past Antioch appears similar enough over the entire recovery period that there is probably no substantial bias however standardizing sampling effort between days could reduce the noise and variance associated with estimating survival (Appendix A). We will evaluate this source of noise in 2007.

Chinook Salmon Survival Estimates, and Differential and Combined Differential Recovery Rates

Survival indices are better put into context by evaluating absolute survival estimates and combined differential recovery rates (CDRR). Absolute survival estimates and CDRRs should be more robust for comparing survival between groups and years, since using ratios between upstream and downstream groups theoretically standardizes for differences in catch efficiency between recovery locations and years. As in past years, estimates of both absolute survival and CDRRs were calculated for CWT releases as part of VAMP 2006. The CDRR is similar to calculating absolute survival estimates, but does not expand estimates based on the fraction of the time and space sampled. The Differential Recovery Rate (DRR) is similar to the CDRR but only uses recoveries from one recovery location.

The CDRR and the absolute survival estimates should not be very different as (1) the fraction of the time sampled is similar between groups within a recovery location and (2) the fraction of space sampled at each recovery location is a constant. Neither would change the relative differences between groups. However, combining the recovery numbers from Antioch, Chipps Island and ocean fishery could result in different survival estimates between the two methods.

Absolute survival estimates (AS_i) are calculated by the formula:

$$\mathbf{AS_i = SI_u / SI_d}$$

where: SI_u is the survival index of the upstream group (Mossdale or Dos Reis),
SI_d is the survival index of the downstream group (Jersey Point) and
i is either Antioch or Chipps Island.

Although referred to throughout this document as absolute survival estimates they are more aptly described as standardized or relative survival estimates.

The combined differential recovery rate (CDRR) is calculated by the formula:

$$\mathbf{CDRR = CRR_u / CRR_d}$$

where: CRR_u is the combined recovery rate for the upstream group (Mossdale or Dos Reis),
CRR_d is the combined recovery rate for the downstream group (Jersey Point).

and the combined recovery rate (CRR) is estimated by the formula:

$$\mathbf{CRR = R_{C+A+O}/ER}$$

where: R_{C+A+O} is the combined recoveries at Antioch, Chipps Island and in the ocean fishery of a CWT group, and ER is the effective release number.

Recoveries are not available from each recovery location for all years so only those that are available have been used. For data obtained prior to 2000, no Antioch recoveries are available and for releases in 2004, 2005 and 2006 no ocean recoveries are available at this time.

This new approach of combining all recoveries to estimate survival was suggested by Dr. Ken Newman, statistician with the USFWS in Stockton. Since recovery rates in the past have been higher in the ocean fishery than in the Antioch and Chipps Island trawls, inclusion of the expanded ocean recoveries decreases the variance of the point estimates.

Standard errors were calculated for the CDRRs based on the Delta method and other methods developed by Ken Newman (K. Newman, personal communication). Plus or minus two standard errors are roughly equivalent to the 95% confidence intervals around the estimate. In comparing survival between reaches, the confidence intervals were used to determine if CDRRs were significantly different from one other. If the 95% confidence intervals overlapped, CDRRs were not considered statistically different from each other. If the 95% lower confidence level was less than zero it was truncated at zero, except in the case of the 95% confidence level around the difference in two point estimates.

Results

Individual and group survival indices to Antioch and Chipps Island of the CWT salmon released as part of VAMP 2006 are shown in Table 4-5. Survival indices have been reported to three significant digits, but we realize indices are not likely that precise. Survival indices were not corrected for the number of CWT fish recovered in DFG sampling in Old River. Survival indices estimated for smolts released at Mossdale and Dos Reis were relatively low in 2006, especially for the 2nd group released at Mossdale. Jersey Point survival indices were much higher for estimates based on Chipps Island recoveries (1.04 and 0.86 respectively) whereas they were lower when based on Antioch recoveries (0.19 and 0.12).

As in past years, survival indices were higher using the Chipps Island recoveries than when using the Antioch recoveries. Also as in the past, the raw recovery numbers at Chipps Island and Antioch were similar, but once recoveries were expanded for effort, survival indices were much lower at Antioch, indicating that the greater sampling at Antioch is not translating into additional recoveries.

Survival estimates and CDRR's in 2006 are reported in Table 4-6. Survival was generally high between Mossdale and Dos Reis (Figure 4-6), indicating no difference in survival under the low export condition from part of the group being diverted into upper Old River. Survival from Mossdale to Jersey Point was relatively low for both sets of releases, but lower for the second release when exports were higher (Figure 4-7). However the confidence levels around the difference in the point estimates, under the two different export levels, included zero, indicating the difference was not statistically significant at the $p<0.05$ level. (Figure 4-7). While there is general relative agreement between CDRR point estimates based on Chipps Island and Antioch recoveries versus those using the Chipps Island, Antioch and ocean recoveries (next section), the variance generally lessens once the ocean recoveries are incorporated (Figure 4-8). Thus future recoveries in the ocean fishery may increase the precision of the point estimate of the difference between the two test conditions in 2006 such that the 95% confidence interval would no longer include zero and be statistically significant.

Table 4-6. Absolute survival and combined differential recovery rates (CDRR) for VAMP 2006 releases.

Survival Reach	Release Date	Antioch Absolute survival	Chipps Island Absolute survival	CDRR
First release				
Mossdale to Dos Reis	4-May-06	1.67	0.67	0.94
Mossdale to Jersey Point	4-May-06	0.18	0.08	0.11
Dos Reis to Jersey Point	5-May-06	0.11	0.12	0.12
Second release				
Mossdale to Jersey Point	19-May-06	0.00	0.03	0.02

Figure 4-6. Combined Differential Recovery Rates (CDRR) (+ / -1 and 2 standard errors) of CWT smolts released at Mossdale (M) and Dos Reis (DR) and relative to those released at Jersey Point (JP) for the Dos Reis (DR/JP) and Mossdale (M/JP) first (1), second (2) release groups in 2006.

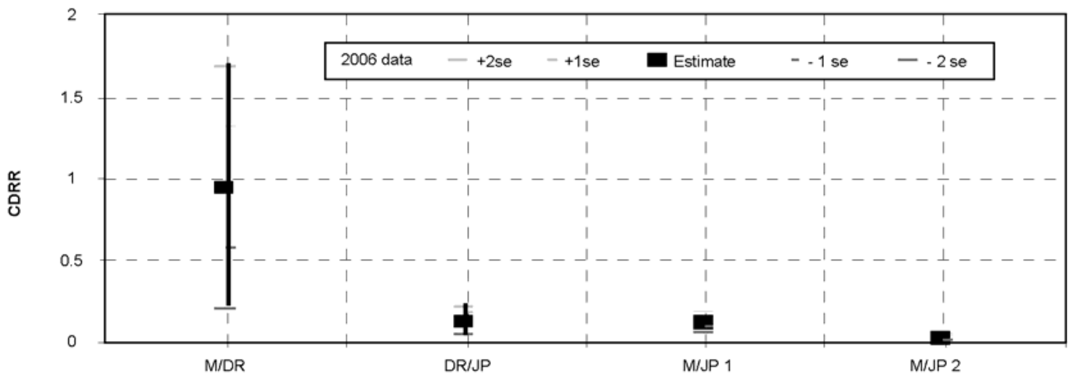


Figure 4-7. Combined Differential Recovery Rates (CDRR) (+ / -1 and 2 standard errors) of CWT smolts released at Mossdale (MD) relative to those released at Jersey Point for the first (1), second (2) release groups and the difference between the 1st and 2nd release groups at Mossdale in 2006.

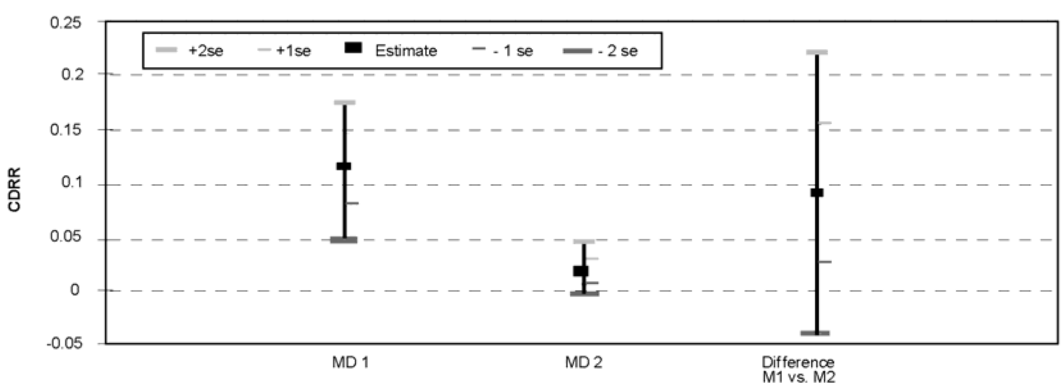
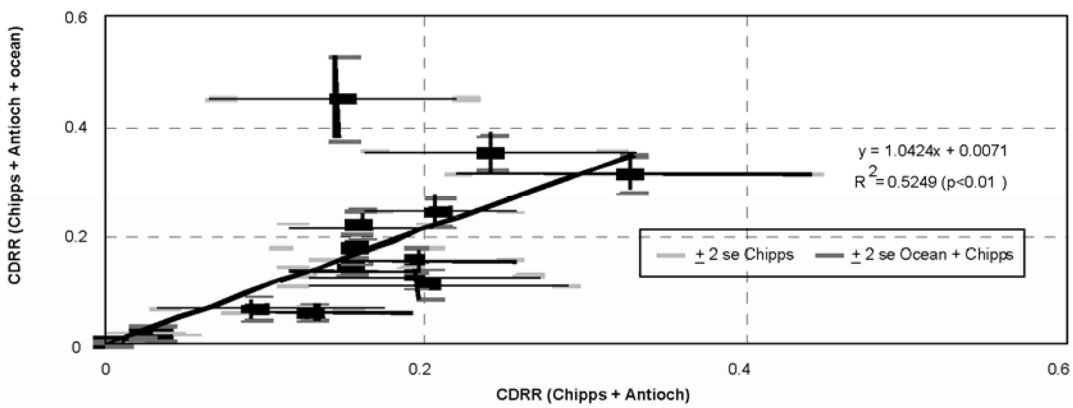


Figure 4-8. CDRR using Chipps Island and Antioch recoveries versus Chipps Island, Antioch and ocean fishery recoveries of the Mossdale or Durham Ferry and Jersey Point releases between 2000 and 2003.



Between the first and second release at Mossdale, temperatures at release increased by 3 degrees F (Table 4-2). This increase in water temperature could account for at least part of the differences observed in survival between the two groups. One additional issue, associated with water temperature was the 2 degrees F difference between the first Mossdale and Jersey Point releases, whereas the water temperature at the two locations for the second release was the same (Table 4-2). The lower temperature may have benefited the first Mossdale group and increased its survival somewhat relative to the Jersey Point group. While it is desirable to keep conditions as uniform as possible in these types of experiments, many of the factors are uncontrollable. Switching the export conditions between the two periods (and having the higher export condition first) would help alleviate some of these confounding issues, but due to logistical constraints could not be accommodated during this experiment.

Comparison with Past Years

Ocean Recovery Information

Ocean recovery data of CWT salmon groups can provide an additional source of recoveries for estimating survival through the Delta. The ocean harvest data may be more reliable due to the greater number of CWT recoveries and the extended recovery period.

Adult ocean recovery data are gathered from commercial and sport ocean harvest checked at various ports by DFG. The Pacific States Marine Fisheries Commission database of ocean harvest CWT data was the source of recoveries through 2004. The ocean CWT recovery data accumulate over a one to four year period after the year a study release is made as nearly all of a given year-class of salmon have been either harvested or spawned by age five. Consequently, these data are essentially complete for releases made through 2001 and partially available for CWT releases made from 2002 to 2004. Differential recovery rates (DRR) based on Chipps Island or ocean recoveries and combined differential recovery rates (CDRR) based on both Antioch and Chipps Island recoveries for salmon produced at the MRH are shown in Table 4-7. Absolute survival estimates based on Chipps Island and Antioch survival indices are also included. The earlier releases were made as part of south Delta survival evaluations (1996-1999) with the later releases associated with VAMP (2000-2004). Releases have been made at several locations: Dos Reis, Mossdale, Durham Ferry, and Jersey Point. The Chipps Island and Antioch survival estimates and combined differential (Antioch and Chipps Island recoveries summed) or differential recovery rates (Chipps Island recoveries only) are graphed in relation to the differential recovery rate using the ocean recovery information in Figure 4-9.

Table 4-7. Absolute survival estimates and differential recovery rates based on Chipps Island, Antioch, or ocean recoveries of Merced River Hatchery salmon released as part of South Delta studies between 1996 and 2004.

Release Year	San Joaquin River (Merced River Origin) TAG NO.	Release Number	Release Site	Release Date	Chipps Island Recovs.	Antioch Recovs.	Expanded Adult Ocean Recovs. (Age 1+ to 4+) Total	CHIPPS ISLAND	ANTIOCH	DRR or CDRR	OCEAN DRR
		Juvenile Salmon CWT Releases						Absolute Survival Estimates		Differential Recovery Rates	
1996	061110412	22,198	DOS REIS	1-May-96	2		3				
	061110413	25,414	DOS REIS	1-May-96	2		37				
	061110414	16,050	DOS REIS	1-May-96	1		8				
	061110415	31,208	DOS REIS	1-May-96	5		10				
	061110501	46,190	JERSEY PT	3-May-96	39		186				
	Effective Release	94,870	DOS REIS		10		58	0.120		0.125	0.152
	Effective Release	46,190	JERSEY PT		39		186				
1997	062545	48,973	DOS REIS	27-Apr-97	9		180				
	062546	53,483	DOS REIS	27-Apr-97	7		168				
	062547	51,576	JERSEY PT	2-May-97	27		356				
	Effective Release	102,456	DOS REIS		16		348	0.290		0.298	0.492
	Effective Release	51,576	JERSEY PT		27		356				
	062548	46,674	DOS REIS	8-May-97	5		90	0.300		0.283	0.477
	062549	47,534	JERSEY PT	12-May-97	18		192				
1998	61110809	26,465	MOSSDALE	16-Apr-98	25		60				
	61110810	25,264	MOSSDALE	16-Apr-98	31		39				
	61110811	25,926	MOSSDALE	16-Apr-98	32		58				
	61110806	26,215	DOS REIS	17-Apr-98	34		48				
	61110807	26,366	DOS REIS	17-Apr-98	25		35				
	61110808	24,792	DOS REIS	17-Apr-98	34		62				
	61110812	24,598	JERSEY PT	20-Apr-98	87		110				
	61110813	25,673	JERSEY PT	20-Apr-98	100		91				
	Effective Release	77,655	MOSSDALE		88		157	0.300		0.305	0.506
	Effective Release	77,373	DOS REIS		93		145	0.320		0.323	0.469
	Effective Release	50,271	JERSEY PT		187		201				
1999	062642	24,765	MOSSDALE	19-Apr-99	8		128				
	062643	24,773	MOSSDALE	19-Apr-99	15		135				
	062644	25,279	MOSSDALE	19-Apr-99	13		132				
	062645	25,014	DOS REIS	19-Apr-99	20		151				
	062646	24,841	DOS REIS	19-Apr-99	19		225				
	0601110815	25,101	JERSEY PT	21-Apr-99	34		334				
	062647	24,359	JERSEY PT	21-Apr-99	25		387				
	Effective Release	74,817	MOSSDALE		36		395	0.380		0.403	0.362
	Effective Release	49,855	DOS REIS		39		376	0.600		0.656	0.517
	Effective Release	49,460	JERSEY PT		59		721				
2000	06-45-63	24,457	DURHAM FERRY	17-Apr-00	11	11	246				
	06-04-01	23,529	DURHAM FERRY	17-Apr-00	7	6	215				
	06-04-02	24,177	DURHAM FERRY	17-Apr-00	10	10	232				
	06-44-01	23,465	MOSSDALE	18-Apr-00	9	14	207				
	06-44-02	22,784	MOSSDALE	18-Apr-00	9	16	174				
	06-44-03	25,527	JERSEY PT	20-Apr-00	24	50	649				
	06-44-04	25,824	JERSEY PT	20-Apr-00	41	47	704				
	Effective Release	72,163	DURHAM FERRY		28	27	693	0.310	0.190	0.242	0.364
	Effective Release	46,249	MOSSDALE		18	30	381	0.310	0.330	0.329	0.313
	Effective Release	51,351	JERSEY PT		65	97	1353				
	601060914	23,698	DURHAM FERRY	28-Apr-00	7	8	46				
	601060915	26,805	DURHAM FERRY	28-Apr-00	5	15	45				
	0601110814	23,889	DURHAM FERRY	28-Apr-00	10	8	70				
	0601061001	25,572	JERSEY PT	1-May-00	48	76	358				
	0601061002	24,661	JERSEY PT	1-May-00	30	76	230				
	Effective Release	74,392	DURHAM FERRY		22	31	161	0.190	0.140	0.156	0.185
	Effective Release	50,233	JERSEY PT		78	152	588				

Note: Ocean recoveries are based on data through 2005

Table 4-7 (cont.) Absolute survival estimates and differential recovery rates based on Chipps Island, Antioch, or ocean recoveries of Merced River Hatchery salmon released as part of South Delta studies between 1996 and 2004

Release Year	San Joaquin River (Merced River Origin) TAG NO.	Release Number	Release Site	Release Date	Chipps Island Recovs.	Antioch Recovs.	Expanded Adult Ocean Recovs. (Age 1+ to 4+) Total	CHIPPS ISLAND	ANTIOCH	DRR or CDRR	OCEAN DRR
		Juvenile Salmon CWT Releases						Absolute Survival Estimates		Differential Recovery Rates	
2001	06-44-29	23,351	DURHAM FERRY	30-Apr-01	14	28	95				
	06-44-30	22,720	DURHAM FERRY	30-Apr-01	22	30	158				
	06-44-31	22,376	DURHAM FERRY	30-Apr-01	17	18	111				
	06-44-32	23,022	MOSSDALE	1-May-01	17	18	122				
	06-44-33	22,191	MOSSDALE	1-May-01	14	15	106				
	06-44-34	24,444	JERSEY PT	4-May-01	50	156	470				
	06-44-35	24,993	JERSEY PT	4-May-01	61	173	556				
	Effective Release	68,447	DURHAM FERRY		53	76	364	0.340	0.170	0.212	0.256
	Effective Release	45,213	MOSSDALE		31	33	228	0.310	0.110	0.159	0.243
	Effective Release	49,437	JERSEY PT		111	329	1026				
	06-44-36	24,029	DURHAM FERRY	7-May-01	2	8	17				
	06-44-37	23,907	DURHAM FERRY	7-May-01	5	11	45				
	06-44-38	24,054	DURHAM FERRY	7-May-01	2	10	28				
	06-44-39	23,882	MOSSDALE	8-May-01	4	8	25				
	06-44-40	25,310	MOSSDALE	8-May-01	4	11	27				
	06-44-41	25,910	JERSEY PT	11-May-01	17	43	243				
	06-44-42	25,466	JERSEY PT	11-May-01	27	53	335				
	Effective Release	71,990	DURHAM FERRY		9	29	90	0.130	0.200	0.194	0.111
	Effective Release	49,192	MOSSDALE		8	19	52	0.190	0.180	0.201	0.094
	Effective Release	51,376	JERSEY PT		44	96	578				
2002	06-44-71	23,920	DURHAM FERRY	18-Apr-02	4	11	33				
	06-44-72	25,176	DURHAM FERRY	18-Apr-02	9	20	96				
	06-44-73	23,872	DURHAM FERRY	18-Apr-02	4	12	74				
	06-44-74	24,747	DURHAM FERRY	18-Apr-02	4	20	67				
	06-44-57	25,515	MOSSDALE	19-Apr-02	6	13	76				
	06-44-58	25,272	MOSSDALE	19-Apr-02	7	29	69				
	06-44-59	24,802	JERSEY PT	22-Apr-02	46	101	494				
	06-44-60	24,128	JERSEY PT	22-Apr-02	37	89	456				
	Effective Release	97,715	DURHAM FERRY		21	63	270	0.130	0.160	0.154	0.142
	Effective Release	50,787	MOSSDALE		13	42	145	0.150	0.210	0.194	0.147
	Effective Release	48,930	JERSEY PT		83	190	950				
	06-44-70	24,680	DURHAM FERRY	25-Apr-02	3	6	23				
	06-44-75	24,659	DURHAM FERRY	25-Apr-02	5	2	21				
	06-44-76	24,783	DURHAM FERRY	25-Apr-02	3	4	7				
	06-44-77	24,381	DURHAM FERRY	25-Apr-02	4	6	6				
	06-44-78	24,519	MOSSDALE	26-Apr-02	2	3	26				
	06-44-79	24,820	MOSSDALE	26-Apr-02	3	4	14				
	06-44-80	24,032	JERSEY PT	30-Apr-02	18	43	307				
	06-44-81	22,880	JERSEY PT	30-Apr-02	28	32	290				
	Effective Release	98,503	DURHAM FERRY		15	18	57	0.160	0.110	0.130	0.045
	Effective Release	49,339	MOSSDALE		5	7	40	0.110	0.090	0.094	0.064
	Effective Release	46,912	JERSEY PT		46	75	597				
2003	06-02-82	24,453	DURHAM FERRY	21-Apr-03	0	1	9				
	06-02-83	25,927	DURHAM FERRY	21-Apr-03	2	4	0				
	06-27-42	24,069	DURHAM FERRY	21-Apr-03	1	1	10				
	06-27-48	24,471	MOSSDALE	22-Apr-03	2	2	3				
	06-27-43	25,212	MOSSDALE	22-Apr-03	3	2	5				
	06-27-44	24,414	JERSEY PT	25-Apr-03	57	71	253				
	Effective Release	74,449	DURHAM FERRY		3	6	19	0.019	0.015	0.023	0.025
	Effective Release	49,683	MOSSDALE		5	4	8	0.048	0.015	0.035	0.016
	Effective Release	24,414	JERSEY PT		57	71	253				
	06-27-45	24,685	DURHAM FERRY	28-Apr-03	0	0	6				
	06-27-46	25,189	DURHAM FERRY	28-Apr-03	0	0	0				
	06-27-47	24,628	DURHAM FERRY	28-Apr-03	0	0	4				
	06-27-49	24,180	MOSSDALE	29-Apr-03	0	0	5				
	06-27-50	24,346	MOSSDALE	29-Apr-03	1	0	0				
	06-27-51	25,692	JERSEY PT	2-May-03	39	35	415				
	Effective Release	74,502	DURHAM FERRY		0	0	10			0.000	0.008
	Effective Release	48,526	MOSSDALE		1	0	5	0.010		0.007	0.006
	Effective Release	25,692	JERSEY PT		39	35	415				

Note: Ocean recoveries are based on data through 2005

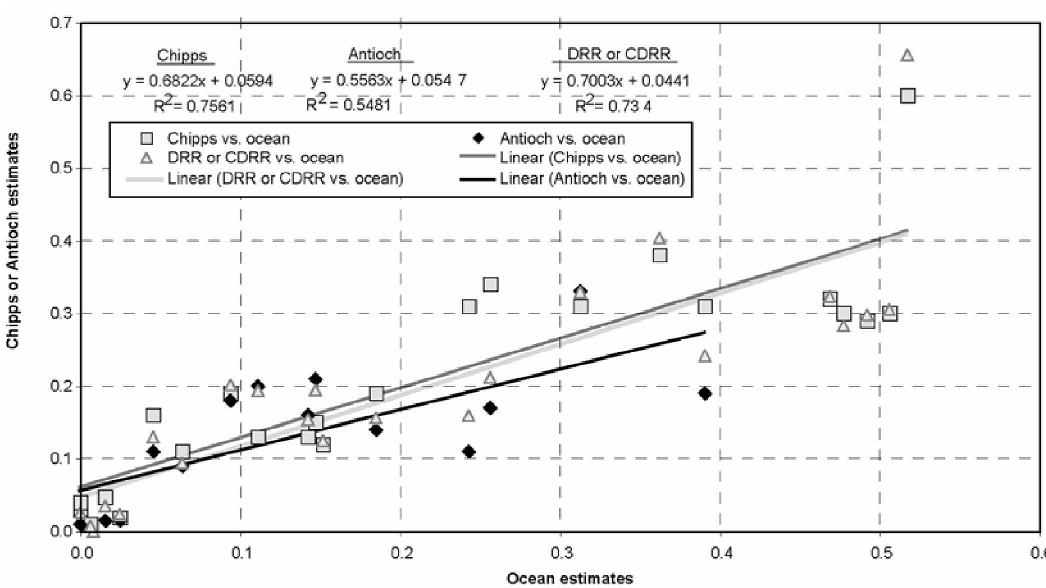
Table 4-7 (cont.) Absolute survival estimates and differential recovery rates based on Chipps Island, Antioch, or ocean recoveries of Merced River Hatchery salmon released as part of South Delta studies between 1996 and 2004

Release Year	San Joaquin River (Merced River Origin) TAG NO.	Release Number	Release Site	Release Date	Chipps Island Recovs.	Antioch Recovs.	Expanded Adult Ocean Recovs. (Age 1+ to 4+) Total	CHIPPS ISLAND	ANTIOCH	DRR or CDRR	OCEAN DRR
		Juvenile Salmon CWT Releases						Absolute Survival Estimates		Differential Recovery Rates	
2004	06-27-52	23,440	DURHAM FERRY	22-Apr-04	0	1	0				
	06-27-53	21,714	DURHAM FERRY	22-Apr-04	1	1	0				
	06-27-54	23,328	DURHAM FERRY	22-Apr-04	1	0	0				
	06-27-55	23,783	DURHAM FERRY	22-Apr-04	1	0	0				
	06-46-70	25,319	MOSSDALE	23-Apr-04	0	1	0				
	06-45-82	23,586	MOSSDALE	23-Apr-04	1	0	0				
	06-45-83	24,803	MOSSDALE	23-Apr-04	2	0	0				
	06-45-80	22,911	JERSEY PT	26-Apr-04	25	22	14				
	Effective Release	92,265	DURHAM FERRY		3	2	0	0.030	0.020	0.026	0.000
	Effective Release	73,708	MOSSDALE		3	1	0	0.040	0.010	0.026	0.000
	Effective Release	22,911	JERSEY PT		25	22	14				
2005	06-46-72	23,414	DURHAM FERRY	2-May-05	5	0	0				
	06-46-73	23,193	DURHAM FERRY	2-May-05	2	2	0				
	06-46-74	23,660	DURHAM FERRY	2-May-05	4	3	0				
	06-46-75	23,567	DURHAM FERRY	2-May-05	1	1	0				
	06-46-97	22,302	DOS REIS	3-May-05	1	1	0				
	06-46-98	24,149	DOS REIS	3-May-05	1	3	0				
	06-45-91	22,675	DOS REIS	3-May-05	1	3	0				
	06-45-88	22,767	JERSEY PT	6-May-05	32	31	0				
	Effective Release	93,834	DURHAM FERRY		12	6	0	0.099	0.049	0.069	
	Effective Release	69,126	DOS REIS		3	7	0	0.035	0.110	0.052	
	Effective Release	22,767	JERSEY PT		32	31	0				
	06-45-84	22,777	DURHAM FERRY	9-May-05	2	1	0				
	06-45-85	22,968	DURHAM FERRY	9-May-05	1	1	0				
	06-45-86	23,012	DURHAM FERRY	9-May-05	3	3	0				
	06-45-87	22,806	DURHAM FERRY	9-May-05	0	2	0				
	06-45-89	21,443	DOS REIS	10-May-05	3	5	0				
	06-45-90	23,755	DOS REIS	10-May-05	2	2	0				
	06-46-99	23,448	DOS REIS	10-May-05	1	0	0				
	06-47-00	23,231	JERSEY PT	13-May-05	38	27	0				
	Effective Release	91,563	DURHAM FERRY		6	7	0	0.044	0.094	0.051	
	Effective Release	68,646	DOS REIS		6	7	0	0.058	0.127	0.068	
	Effective Release	23,231	JERSEY PT		38	27	0				

Note: Ocean recoveries are based on data through 2005

Results of this comparative analysis of survival estimates and differential recovery rates for Chinook salmon produced in the MRH show: (1) there is general agreement between survival estimates and differential recovery rates based on juvenile CWT salmon recoveries at Chipps Island and adult recoveries from the ocean fishery (r^2=0.76), (2) there is less agreement with Antioch trawling which has fewer years of data, and (3) additional comparisons need to be made, as more data becomes available from VAMP releases for recoveries at Antioch, Chipps Island, and the ocean fishery.

Figure 4-9. Comparison of Antioch and Chipps Island survival estimates and differential or combined differential recovery rates compared to differential ocean recovery rates for 1996-2004.



Survival by Reach

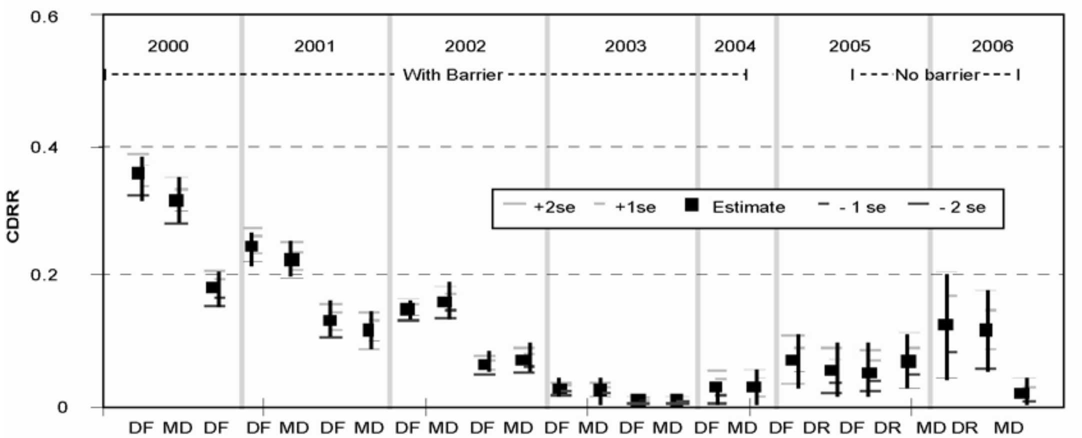
In this section, Chinook salmon smolt survival in different reaches of the San Joaquin River will be evaluated using several years of data. These analyses help our understanding of survival through the south Delta. Initially, survival in the entire reach (Durham Ferry and Mossdale to Jersey Point) will be discussed. The second reach discussed is from Durham Ferry and Mossdale to Dos Reis. And lastly, the reach between Dos Reis and Jersey Point will be discussed. In this section we will only use CDRR's as our estimate of survival. Combined recoveries from Chipps Island and the ocean fishery are available for releases made between 1985 and 1999, combined recoveries from Chipps Island, Antioch and the ocean fishery are available for releases made between 2000 and 2003 and releases made between 2004 and 2006 only have Chipps Island and Antioch recoveries available.

Survival between Durham Ferry or Mossdale and Jersey Point

Smolt survival between Durham Ferry and Mossdale and Jersey Point has been low since 2003 (Figure 4-10). Even the higher flows in 2005 and 2006 did not increase survival to levels we saw in 2000, when flows were 5700 cfs and the barrier was installed. The survival of the first Mossdale and Dos Reis releases in 2006 appeared higher than for the other years since 2003, although it was not always significantly different at the 95% confidence interval.

The health of the CWT fish in 2006 was relatively good and PKD infection did not seem to be a problem as it may have been in 2003-2005. None of the VAMP fish recovered at Chipps Island had evidence of infection in their kidneys by the parasite that causes PKD in 2006. However, kidney imprints detected some (23%) of the VAMP fish at the hatchery were infected with Bacterial Kidney Disease, although they did not show clinical signs of the disease.

Figure 4-10. Combined Differential Recovery Rates (CDRR) (+/- 1 and 2 standard errors) of CWT smolts released at Durham Ferry (DF), Mossdale (MD) and Dos Reis (DR) relative to those released at Jersey Point for the first and second release groups in 2000- 2006. Recovery rates include recoveries from the ocean fishery for releases made prior to 2004. Only one set of releases was made in 2004



Survival between Durham Ferry and Mossdale

No releases were made at Durham Ferry in 2006 thus comparisons of survival rates between Durham Ferry and Mossdale for this year cannot be made. However, survival between Durham Ferry and Mossdale has been measured from 2000 to 2003 and is generally high using the combined Chipps Island, Antioch and ocean recoveries (Table 4-8). Survival was estimated to be high between Durham Ferry and Mossdale in 2004 using Chipps Island and Antioch recoveries alone. Only one release group in 2002 indicated possible mortality between the two locations but confidence intervals around the two point estimates in 2002 did not indicate significant differences at the 95% confidence level even with the ocean recoveries included. Releases of marked fish at both sites will allow detection of mortality between Durham Ferry and Mossdale if mortality becomes great enough to detect in the future.

Table 4-8. Combined differential recovery rates (CDRR) with recoveries from Antioch, Chipps Island, and in the ocean fishery for VAMP fish released at Durham Ferry and Mossdale between 2000 and 2004. Survival is between Durham Ferry and Mossdale. Ocean recoveries are not yet available for the release made in 2004.

Year	CDRR		Standard Error + / - 2 SE
	Antioch +Chipps Island +Ocean Recovery	Antioch +Chipps Island	
2000	1.15		
2001	1.11		
2001	1.10		
2002	0.92		
2002	0.65		0.58-1.19
2003	1.09		
2003	1.08		
2004		1.00	

Survival between Mossdale and Dos Reis

In 2006, releases were made to assess the difference in survival between a group released at Mossdale (which include a portion of the group that migrated down upper Old River) and one group released at Dos Reis (those released on the main-stem San Joaquin River downstream of upper Old River) during the low export condition. Survival between Mossdale and Jersey Point and Dos Reis and Jersey Point was similar for this first set of releases in 2006 (Figure 4-6).

A pilot ultrasonic tagging study and trawling in Old River compared to that at Mossdale indicated that most salmon migrated through Old River in 2006. If most of the coded wire tagged fish released at Mossdale in 2006 also primarily migrated into Old River under low exports and high flows, survival was similar between the two routes (between Old River and Jersey Point and, between Dos Reis and Jersey Point).

Nine additional paired releases have been made at Mossdale (or Durham Ferry in 2005) and Dos Reis in past years without the HORB in place. Five of these pairs produced ratios of survival between Mossdale and Dos Reis that were significantly less than 1.0 ($p<0.05$), indicating that in some years there was a significant difference in survival between the two groups (Table 4-9). Differences in survival between the two locations could be from a high proportion of the fish entering upper Old River and experiencing higher mortality via that migratory pathway, or from high mortality on the mainstem San Joaquin River between Mossdale and Dos Reis. The average survival between Mossdale or Durham Ferry and Dos Reis without a barrier in place was 0.73 (Table 4-9).

Table 4-9. Combined Differential recovery rates (CDRR) for experimental fish released at Mossdale or Durham Ferry and Dos Reis between 1995-1999 and 2005-2006. 1995-1999 do not have Antioch recoveries. 2005 and 2006 do not have ocean recovery data available. Survival reach is between Durham Ferry or Mossdale and Dos Reis. Those shaded are significantly different (95% confidence interval) from 1.0.

Year	Date	Release site	Chipps + ocean CDRR	Chipps + Antioch CDRR	
1995	17-Apr	Mossdale	0.99		
1995	5-May	Mossdale	0.31		
1995	17-May	Mossdale	0.44		
1996	30-Apr	Mossdale	0.37		
1998	16-Apr	Mossdale	1.05		
1998	23-Apr	Mossdale	0.42		
1999	19-Apr	Mossdale	0.69		
2005	2-May	Durham Ferry		1.32	
2005	9-May	Durham Ferry		0.75	
2006	4-May	Mossdale		0.94	
Average for all years					**0.73**

Only once were releases made at Mossdale and Dos Reis with the HORB in place. That was in 1997 and the point estimate of survival between the two locations was 1.29 using combined Chipps Island and ocean recoveries. These data reinforce that the temporary HORB on average provides protection to juvenile salmon migrating from the San Joaquin basin by reducing or preventing these fish from being drawn into upper Old River. It also indicates there was no detectable loss between Mossdale and Dos Reis with the barrier in place. If there truly is substantial mortality occurring now from predation in a hole on the San Joaquin River just downstream of upper Old River, as the ultrasonic data suggests in Chapter 6, we may consider releasing fish at Dos Reis and Mossdale when the barrier is in place in the future to assess this potential mortality source.

Survival between Dos Reis and Jersey Point

Survival in the reach from Dos Reis to Jersey Point in 2006 was much lower than survival from Mossdale to Dos Reis and similar to that between Mossdale and Jersey Point. This indicated that most of the mortality of the coded wire tagged salmon released at Mossdale occurred downstream of Dos Reis in 2006.

There have been 16 experiments where releases have been made at Dos Reis and Jersey Point, with three of these made in 1997 with the HORB in place. The remaining data was gathered without the barrier in place between 1989 and 1991, 1995 and 1999 and during 2005 and 2006. CDRRs ranged between 0.05 and 0.79 and averaged 0.28 (Table 4-10). These historical data also indicate that the reach between Dos Reis and Jersey Point has the highest mortality. Additional data obtained in 1991, indicated that the highest salmon smolt mortality (lowest survival per mile) on the San Joaquin River between Dos Reis and Jersey Point occurred between Empire Tract and the mouth of the Mokelumne River, although mortality between Dos Reis and Stockton, and between Stockton and Empire Tract was also high (Brandes and McLain, 2001).

Table 4-10. Combined differential recovery rates (CDRR) using recoveries from Chipps Island and the ocean fishery or Chipps Island and Antioch to estimate survival between Dos Reis and Jersey Point between 1989 and 2005. Stock is either Feather River (FR) or Merced River (MR). The barrier was usually not installed (n) except in 1997(y).

Year	Date	Fish Stock	Barrier	CDRR Ocean + Chipps	CDRR Chipps + Antioch	
1989	20-Apr	FR	n	0.19		
1990	16-Apr	FR	n	0.05		
1990	2-May	FR	n	0.07		
1991	15-Apr	FR	n	0.12		
1995	17-Apr	FR	n	0.79		
1996	1-May	FR	n	0.11		
1996	1-May	MR	n	0.15		
1998	17-Apr	MR	n	0.40		
1998	24-Apr	FR	n	0.54		
1999	19-Apr	MR	n	0.53		
1997	29-Apr	FR	y	0.36		
1997	29-Apr	MR	y	0.48		
1997	8-May	MR	y	0.47		
2005	3-May	MR	n		0.05	
2005	10-May	MR	n		0.06	
2006	5-May	MR	n		0.12	
Average all years						0.28

Table 4-11. Ratio between CDRR of marked smolts released at Dos Reis (DR) and Upper Old River (UOR) between 1985 and 1990.

Year		Ratio	SE	+ 2 SE	- 2 SE
1985		0.99	0.01	1.00	0.97
1986		1.90	0.07	2.04	1.76
1987		2.48	0.13	2.74	2.22
1989		0.96	0.21	1.37	0.54
1989		4.35	1.08	6.50	2.20
1990		1.70	0.53	2.77	0.63
1990		3.17	1.05	5.28	1.07
	Mean	2.22		2.68	1.76

Survival between Old River and Jersey Point

No data has been gathered since 1990 to assess the differential survival for smolts migrating through upper Old River compared to those migrating on the mainstem San Joaquin River and released at Dos Reis. It has previously been published that survival appeared to be about twice that for smolts migrating down the mainstem San Joaquin versus those migrating down upper Old River, however differences were not statistically significant (Brandes and McLain, 2001).

In reanalyzing the data, using CDRR's, four of the seven years tested showed the 95% confidence interval around the ratio was significantly greater than 1.0 indicating the survival for smolts released at Dos Reis in those years was higher than for those released in upper Old River. (Table 4-11). The average ratio (Dos Reis to upper Old River) obtained by combining Chipps Island and ocean recoveries was similar to that reported in the past at 2.2 (Table 4-11). Confidence intervals around the mean of the ratio also indicated that the mean was significantly greater than 1.0, and survival was on average significantly higher for smolts released at Dos Reis compared to those released into upper Old River.

The Role of Flow, Exports and the Head of Old River Barrier on Smolt Survival Through the Delta

San Joaquin River flow and flow relative to exports between April 15 and June 15 was correlated to adult escapement in the San Joaquin basin 2 1/2 years later (SJRG 2003). Both relationships were statistically significant ($p<0.01$) with the ratio of flow to exports accounting for slightly more of the variability in escapement than flow alone ($r^2 = 0.58$ versus $r^2 = 0.42$; SJRG 2003). These relationships were updated, refined to only include escapement from the San Joaquin tributaries and split between HORB and non-HORB years (SJRG, 2006) and still suggest that adult escapement in the San Joaquin basin is affected by flow in the San Joaquin River at Vernalis and flow relative to CVP and SWP exports during the spring months when juveniles migrate through the river and Delta to the ocean. These relationships serve as conceptual models of how smolt survival could vary with flows and exports.

VAMP was designed to further define these relationships by testing how San Joaquin River flows (7,000 cfs or less) at Vernalis and exports (1,500 to 3,000 cfs) at the SWP and CVP, with the HORB, affect smolt survival through the Delta. The HORB is assumed to improve survival based on studies conducted between 1985 and 1990 (Brandes and McLain,

2001) and discussed previously. The HORB barrier could not be installed during the VAMP in 2005 and 2006 as San Joaquin River flows exceeded 5,000 cfs during the scheduled installation period. Flows also exceeded maximum levels for operation of the HORB (7,500 cfs) in 2005 and 2006.

Survival of juvenile Chinook salmon emigrating from the San Joaquin River system has been evaluated within the framework established by the VAMP since the spring of 2000. The installation of the HORB is part of the VAMP experimental design when flows do not exceed 5,000 cfs. This year was the second year since 2000 that the HORB has not been installed and operated during the VAMP experiment, due to high flows. However, similar survival tests both with and without the HORB were conducted prior to 2000. The results of these earlier tests were also used to help define the relationships between flow and exports on smolt survival with and without the HORB in place.

Role of flow on salmon survival

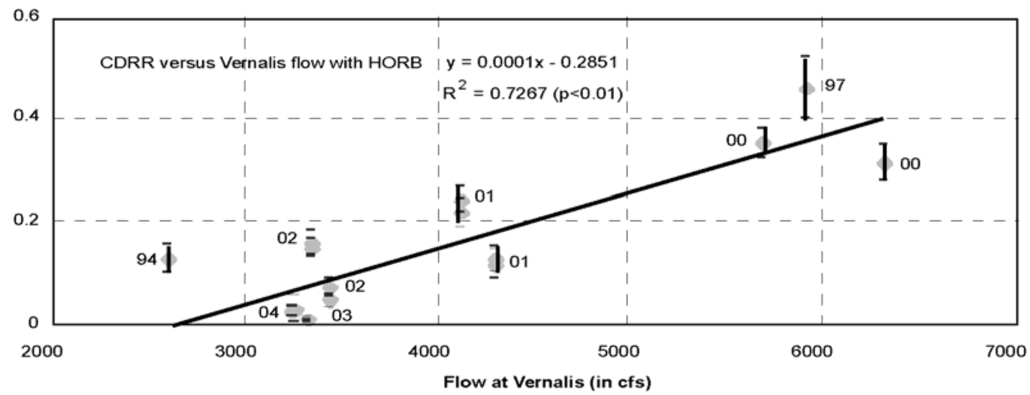
To assess the relationship between San Joaquin River flows at Vernalis and smolt survival with and without the HORB survival (CDRRs), using recoveries from Chipps Island, Antioch and the ocean (if they were available), between Durham Ferry and/or Mossdale and Jersey Point from 1994- 2006 were plotted against San Joaquin River flows at Vernalis. Flows at Vernalis were 10 day averages for each release starting on the day of the Mossdale release or the day after the Durham Ferry release. Ten day averages were used to represent the flow variable since after 10 days most of the fish are far enough downstream (with some already recovered) that the flow at Vernalis is probably no longer important for that particular group migrating to Chipps Island. Flow data was obtained through DWR’s DAYFLOW for past years (updated January 2004). San Joaquin flows downstream of Old River (SRL) between 1995 and 2004 were obtained from DWR from a model that simulated historical flows using DSM2 (T. Smith, DWR Personal Communication). SRL flow for 1994 was based on subtracting estimates of average daily flow in upper Old River from flow at Mossdale to obtain San Joaquin flows downstream of upper Old River. Average flows downstream of Dos Reis were for the 10 days starting on the day after the Dos Reis release. SRL and other flow and export data for 2005 and 2006 was obtained from Chapters 2 and 4 of this and last years (SJRG, 2006) annual report.

Role of flow with HORB on Salmon Survival

In the 2005 VAMP report (SJRG, 2006), it was reported that the CDRRs using the Chipps Island and Antioch recoveries of the Mossdale and Durham Ferry groups relative to the Jersey Point groups did increase with Vernalis flow with the HORB in place ($p<0.01$) (SJRG, 2006). It was also reported that the relationship between Vernalis flow and DRR using the ocean data with the HORB was also positive and statistically significant ($p<0.01$) (SJRG, 2006). The ocean data had fewer data points because recoveries were not yet available for the 2003-2005 releases.

For this year’s evaluation, we have combined recoveries from Antioch, Chipps Island and in the ocean fishery to obtain one point estimate based on recoveries made to date from all three recovery locations. The relationship between these point estimates and San Joaquin River flow at Vernalis with the HORB in place is statistically significant ($p<0.01$) with flow accounting for 73% of the variability in survival (Figure 4-11).

Figure 4-11. CDRR (point estimates of survival) plus and minus 2 standard errors using Chipps Island, Antioch and ocean recoveries, for groups released at Mossdale or Durham Ferry and Jersey Point in 1994, 1997, 2000-2004 and average flow at Vernalis in cfs for 10 days starting the day of the Mossdale release or the day after the Durham Ferry release with HORB in place. Ocean recoveries are not yet available for 2004 releases.



Role of flow without HORB on Salmon Survival

Without the HORB in place, there was no clear relationship between the DRR/CDRR's and flow using the Chipps Island, Antioch and ocean recoveries for the Mossdale and Durham Ferry releases relative to the Jersey Point releases (Figure 4-12). The 2005 and 2006 data were much lower than what previous results had been at similar flow levels. It is not surprising that more variability is associated with smolt survival at any given flow at Vernalis without the HORB since the flow and proportion of marked fish moving into HOR varies more without the HORB.

To explore this issue further, we evaluated a group of test fish that were released on the mainstem San Joaquin River downstream of the head of Old River. The CDRR's of smolts released at Dos Reis relative to those released at Jersey Point were compared to estimates of San Joaquin flow downstream of the HOR. Most of the data were gathered when there was no HORB, but three data points (obtained in 1997) were gathered when the HORB was operating. The data indicated a weak relationship between survival and flow, but 2005 and 2006 were potential outliers (Figure 4-13). The relationship without these two years of data was highly significant and showed that survival from Dos Reis to Jersey Point did increase with San Joaquin River flows downstream of the HOR ($p<0.01$ level) (Figure 4-14). It is unclear why 2005 and 2006 experiments resulted in such low survival compared to that observed in the past, although survival has been extremely low and lower than expected since 2003. It appears this trend has continued in 2005 and 2006 without the HORB in place, even though flows were higher.

Figure 4-12. CDRR using combined Chipps Island, Antioch and ocean recoveries between Mossdale or Durham Ferry and Jersey Point and average flow at Vernalis in cfs for 10 days starting the day of the Mossdale release or the day after the Durham Ferry release without the HORB in place. Data in 2005 and 2006 only include recoveries from Antioch and Chipps Island.

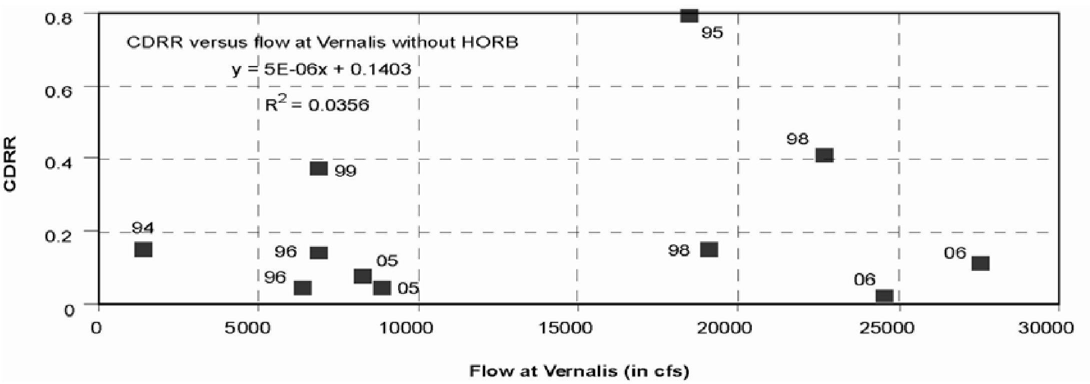


Figure 4-13. Survival between Dos Reis and Jersey Point (with recoveries at Chipps Island and the ocean fishery) with and without the HORB and estimated/modeled San Joaquin flows downstream of Old River between 1989-1991, 1995 -1999, 2005 and 2006. 1997 data was gathered with the HORB in place. 2005 and 2006 data only has Chipps Island and Antioch recoveries available at this time.

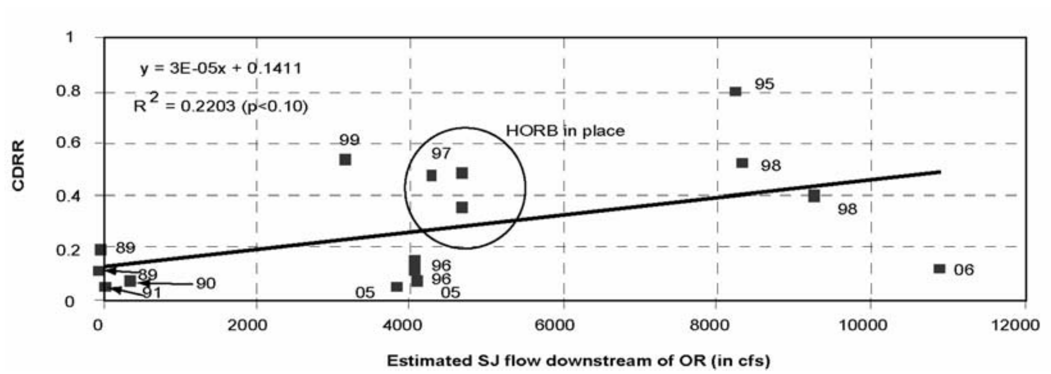
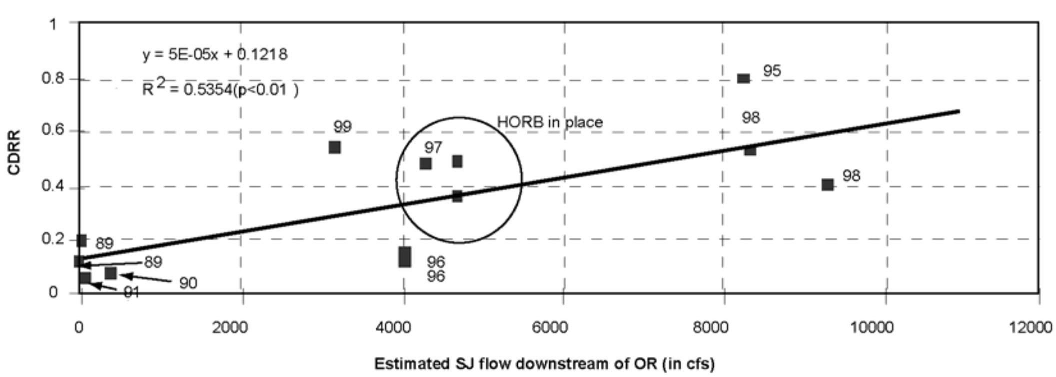


Figure 4-14. Survival between Dos Reis and Jersey Point (with recoveries at Chipps Island and the ocean fishery) with and without the HORB and estimated/modeled San Joaquin flows downstream of Old River between 1989-1991, 1995-1999, 2005 and 2006. 1997 data was gathered with the HORB in place. 2005 and 2006 data has not been included.



The Role of Exports on Survival

Another goal of the VAMP program is to identify the role of exports on juvenile salmon survival through the Delta. VAMP limits CVP+SWP exports to between 1,500 and 3,000 cfs depending on the flow target, because of its dual protective purpose for naturally spawned juvenile salmon and to meet the terms of the delta smelt biological opinion. Prior to 1994, exports were generally much greater during this period. The VAMP design includes examining the role of exports with the HORB at flows of 7,000 cfs by experimenting at exports of 1,500 and 3,000 cfs. As conditions have not yet provided a 7,000 cfs flow with a HORB to test either export level, assessing the role of exports with a HORB is limited at this time.

In years when the HORB could not be installed it was recommended in the VAMP framework agreement to limit exports to either 1,500 or 3,000 cfs to make better comparisons with and without the HORB. In 2005, there was an attempt to measure survival with combined SWP/ CVP pumping at 1,500 cfs for two weeks and then measure survival again at 3,000 cfs, but it was not implemented as one of the parties did not initially adjust pumping as proposed. In 2006, export levels were 1500 and 6000 cfs at high San Joaquin River flows (~25,000 cfs) for the two sets of VAMP releases. We were able to recommend such an experimental design because flows were deemed high enough to provide adequate protection for delta smelt even with the 6000 cfs exports. Results suggest the higher exports resulted in lower salmon smolt survival, but additional tests, especially with the higher export period, are needed to confirm this apparent benefit. Additional tests of this type may help us better identify the role of exports on smolt survival without the HORB in place.

Role of exports with HORB

The San Joaquin River flow relative to exports does not appear to explain the variability in smolt survival as well as flow alone from data obtained with the HORB in 1994, 1997 and between 2000 and 2004 (Figure 4-15). The flow/ export variable is the 10-day mean for the ratio. Previous reports (SJRG 2006) have represented the ratio as the 10-day average of flow divided by the 10-day average of the export rate. One potential explanation for these results is that level of exports were low and did not vary enough during these experiments to provide a sufficient difference to be detected in our measurements of smolt survival. Exports ranged between 1,450 and 2,350 cfs during these experiments which is much lower than those incorporated into the adult escapement relationships. Another complication is that exports and San Joaquin River flows were correlated with higher exports observed during times of higher flows (Figure 4-16). It is also likely the relationship of exports to smolt survival is different with the HORB in place than when it is absent. While some of the juveniles that contributed to adult escapement may have benefited from the HORB in a few of the years, the HORB was not installed during the majority of the years incorporated into the adult relationships.

The next step would be to conduct a survival experiment at flows of 7,000 cfs with the HORB and vary exports (1,500 and 3,000 cfs) to better define the export effect on smolt survival with the HORB in place. Experimenting at flows of 7000 with a 1500 exports would help decouple the effects of flows and exports with the HORB in place (Figure 4-16).

Figure 4-15. CDRR using Chipps Island, Antioch (2000-2004 only) and ocean recoveries (1994, 1997, 2000-2003), for groups released at Mossdale or Durham Ferry and Jersey Point and average flow at Vernalis/Exports in cfs for 10 days starting the day of the Mossdale release or the day after the Durham Ferry release with the HORB in place.

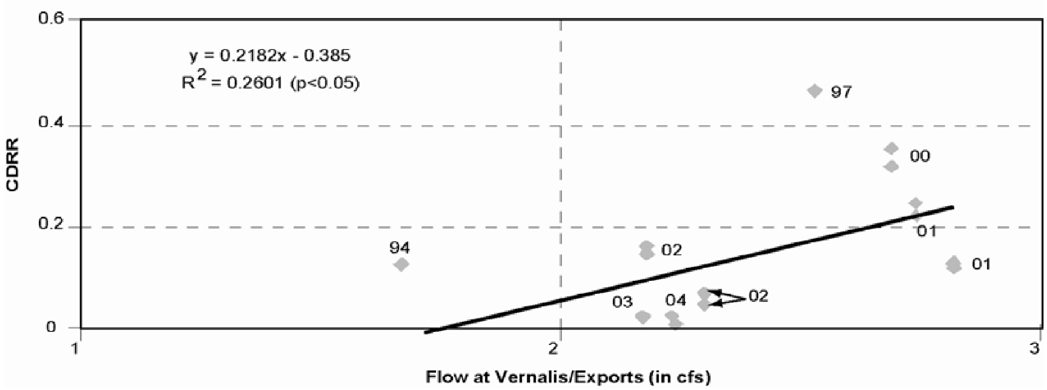
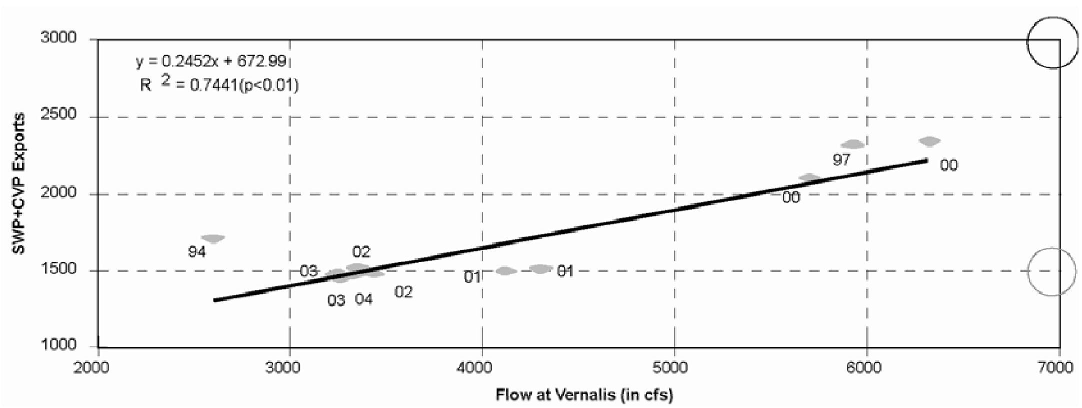


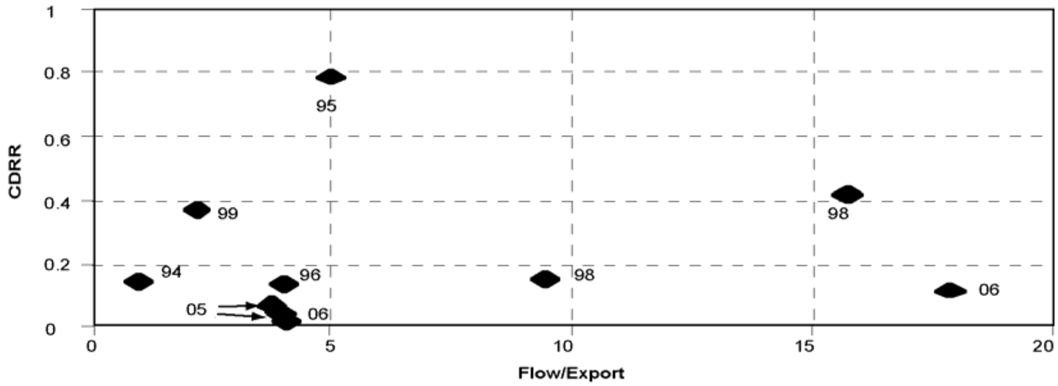
Figure 4-16. The relationship between flow and exports during VAMP tests with the HORB in place.



Role of exports without HORB

The role of exports on smolt survival without the HORB in place is also difficult to identify at this time. As mentioned earlier, there was not a clear relationship between smolt survival and flow without the HORB (Figure 4-12). Regressions between the CDRR from Mossdale and Durham Ferry to Jersey Point using Chipps Island, Antioch and ocean recoveries also do not show a clear relationship with flow/export ratios (Figure 4-17). This is counter to our conceptual model based on the better relationship of flow/ exports and San Joaquin basin escapement 2 1/2 years later than that when using flow alone. Similar limitations, to those with HORB, occur with this data. Exports have been limited to between 1400 and 3700 cfs, with the exception of 6000 cfs for the second experiment conducted in 2006. Conducting experiments as we did in 2006, where exports varied and flows were relatively constant may help us sort out the role of exports when the HORB is absent.

Figure 4-17. CDRR for fish released at Mossdale and Durham Ferry relative to Jersey Point between 1994-1996, 1998, 1999, 2005 and 2006 versus the mean Vernalis Flow/Export ratio for the 10 days after release without the HOR barrier.

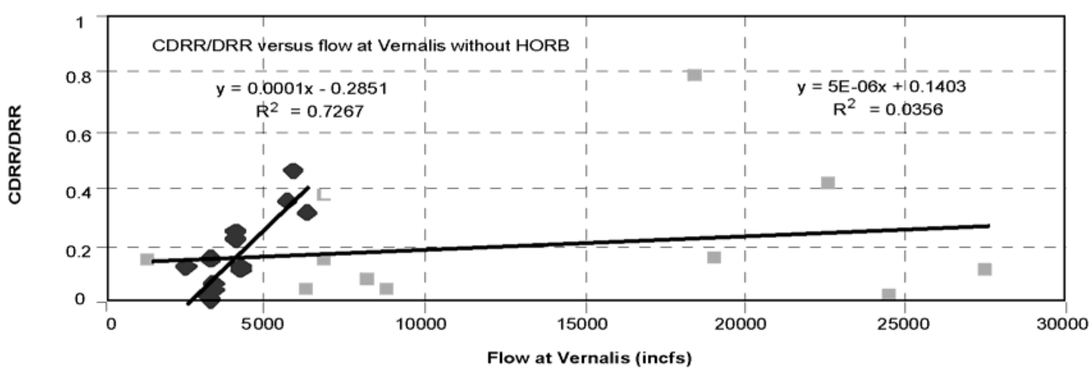


The Role of the HORB on survival through the Delta

One obvious result of the HORB on survival through the Delta has been the lower rate of salvage (and direct loss) for fish released at Durham Ferry and Mossdale when the HORB is installed. If one assumes densities are equal, direct loss should increase as exports increase. In 2006 very few individuals from either Mossdale group were salvaged in 2006. This could be a result of the extremely high flows present in 2006. In contrast, several hundred of the Durham Ferry group, were salvaged in 2005 indicating a higher direct loss in 2005 compared to that in 2006.

Comparing the CDRRs with and without HORB data using the recoveries from Chipps Island, Antioch, and the ocean fishery, appears to indicate that there may be on average value in installing the HORB at flows between about 4,000 and 7,000 cfs (Figure 4-18).

Figure 4-18. CDRR using combined Chipps Island, Antioch and ocean recoveries between Mossdale or Durham Ferry and Jersey Point and average flow at Vernalis in cfs for 10 days starting the day of the Mossdale release or the day after the Durham Ferry release with and without the HORB in place between 1994-2006. Data in 2004, 2005 and 2006 only include recoveries from Antioch and Chipps Island.

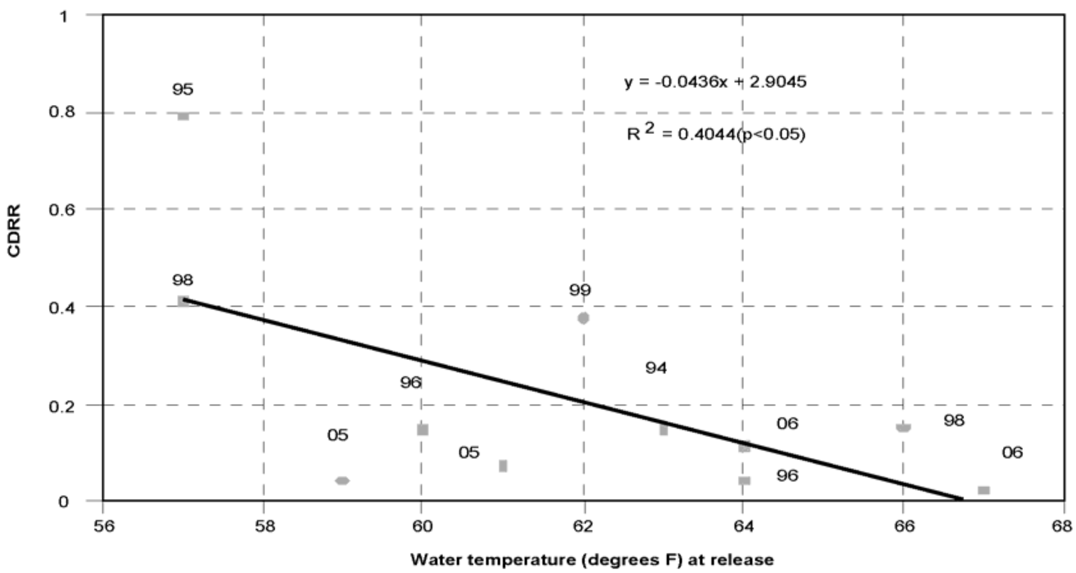


The role of temperature on smolt survival

One parameter that appears to be confounding identification of the role of exports and flow is water temperature. Without the HORB, survival from Mossdale or Durham Ferry to Jersey Point was highest in the years that had the lowest temperature at release (Figure 4-19). Water temperature at release was highest for the second group released in 2006

(Figure 4-19). Water temperature at release has also been shown to be an important factor in survival for smolts migrating through the Delta from the Sacramento basin (Newman, 2003).

Figure 4-19. Combined Differential Recovery Rate (CDRR) for smolts released at Durham Ferry and Mossdale relative to those released at Jersey Point without the HORB versus water temperature at release site for smolts released at Durham Ferry and Mossdale.



Relationship of flow and exports to adult escapement 2 1/2 years later

The relationships between flow and flow/export ratio to escapement 2 1/2 years later have been shown in previous reports (SJRG, 2003 and SJRG, 2006). These data have been updated to include the most recent escapement (to 2005) and flow (to 2003) data (Figures 4-20 and 4-21). These revised and updated escapement data were obtained from the USFWS Anadromous Fish Restoration Program's website at http://www.delta.dfg.ca.gov/afrp. The flow/ export variable was also modified to reflect the mean of the daily ratios between April 15 and June 15. The previous relationship (SJRG, 2006) was based on the ratio of the average flow and export values for the two month period.

In determining whether flow or flow/exports was better at predicting escapement 2 1/2 years later, Ken Newman conducted a K-fold cross validation where K=5. Essentially this analysis breaks the data down into five random groups and uses data not used to fit the model to validate the model. In this analysis, Ken found that the total absolute prediction error was about 15% less using the model that incorporated the flow/export variable, indicating that it better predicts the data than the model using flow alone.

The benefit of examining these adult relationships is that there are more data gathered over a broader range of conditions than with smolt survival under the VAMP framework. These adult relationships would indicate that as you increase flows and decrease exports relative to flows there should be corresponding increases in smolt survival and adult escapement 2 1/2 years later. It is not surprising that there is some uncertainty and noise in these relationships because the escapement data does not incorporate the varying age classes within annual escapement, the impact of declining ocean harvest in recent years and the imprecision in the escapement estimates.

Figure 4-20. Vernalis flows (April 15-June 15) versus escapement 2 1/2 years later in years with and without the HORB between 1951 and 2003.

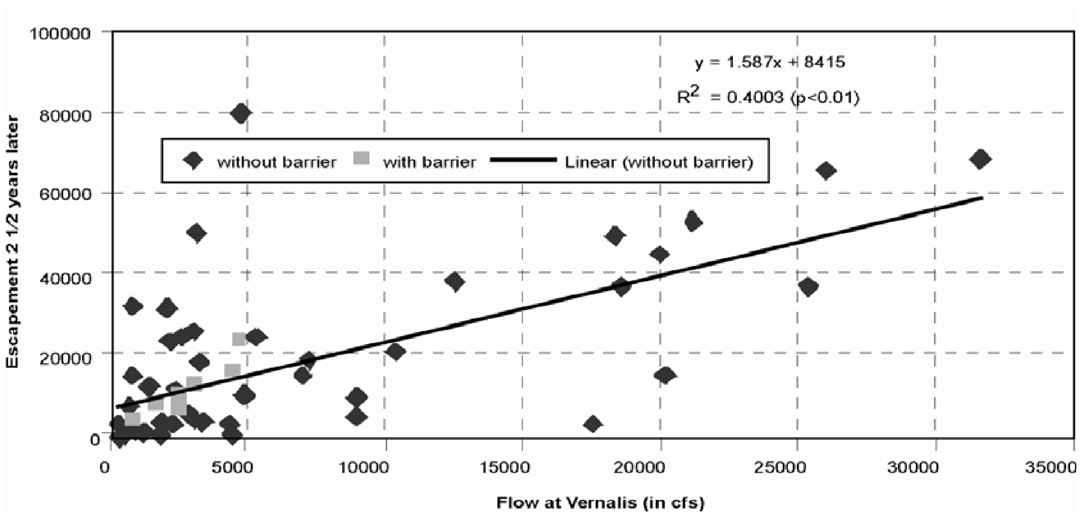
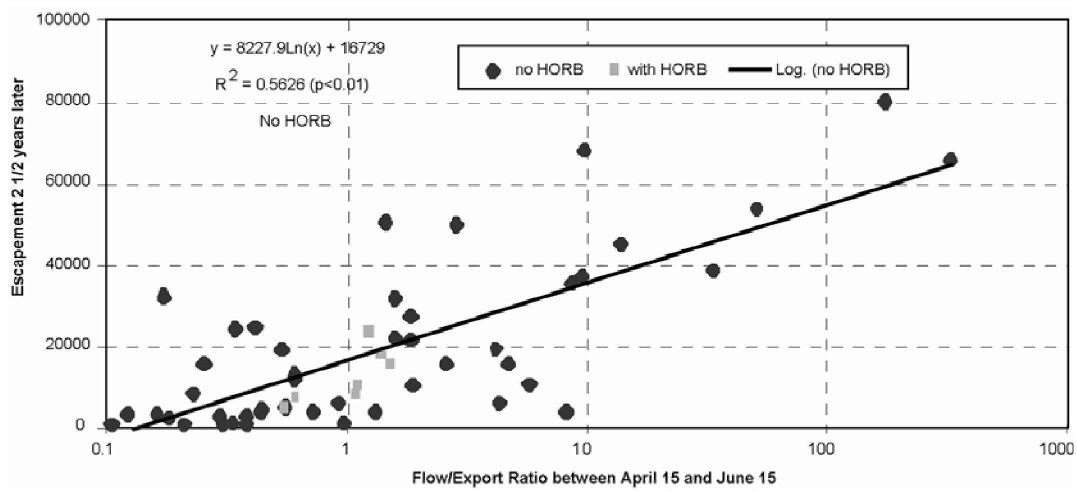


Figure 4-21. Vernalis flow/export ratio versus adult escapement 2 1/2 years later in years with and without the HORB in place between 1951 and 2003.



Summary

The smolt survival data obtained without the HORB do not show a clear relationship to flow, especially with the 2005 and 2006 data included. With the HORB in place we have demonstrated statistically significant relationships between smolt survival and flow at Vernalis and flow/exports, although exports are correlated to flow. The relationship between the survival of the Dos Reis groups relative to the Jersey Point groups indicate that survival will improve generally as flows increase for smolts migrating downstream on the main stem San Joaquin River. The role of exports on smolt survival within the VAMP (with HORB) and without a HORB is more difficult to define based on the limited data. To identify the role of exports with a HORB it is imperative that we measure survival with export rates at 1,500 and 3,000 cfs with San Joaquin River flows of 7,000 cfs. Experiments like those conducted in 2006 can help assess the role of exports without the HORB. It is unclear why smolt survival between 2003 and 2006 has been so low.

San Joaquin River Salmon Protection

One of the VAMP objectives is to provide improved conditions to increase the survival of juvenile Chinook salmon smolts produced in the San Joaquin River tributaries during their downstream migration through the lower river and Delta. It is hypothesized that these actions to improve conditions for the juveniles will translate into greater adult abundance and escapement in future years than would otherwise occur without the actions.

To determine if VAMP has been successful in targeting the migration period of naturally produced juvenile salmon, catches of unmarked salmon at Mossdale and in salvage at the CVP and SWP facilities were compared prior to and during the VAMP period.

Unmarked Salmon Recovered at Mossdale

The typical time period for VAMP (April 15 to May 15) was chosen based on historical data that indicated a high percentage of the juvenile salmon emigrating from the San Joaquin tributaries passed into the Delta at Mossdale during that time. In 2006, the VAMP period was delayed until May 1 due to flood conditions. The average catch per 10,000 cubic meters per day of unmarked juvenile salmon caught in Kodiak trawling at Mossdale during January through June is shown in Figure 4-22. Unmarked salmon do not have an adipose clip and can be juveniles from natural spawning or unmarked hatchery fish from the MRH. Unmarked smolt releases in 2006 at MRH were as follows: 65,000 on May 26, 75,000 on June 2, and 60,000 on June 4. There were less unmarked juvenile salmon passing Mossdale during the low export period than during the higher export period of VAMP (Figure 4-22). If results from this years VAMP are representative of survival for unmarked fish migrating through the Delta from Mossdale, those migrating during the latter half of May may have survived at a lower rate than those migrating earlier in the month. The size of the juvenile salmon captured in the Mossdale trawl during January through June is shown in Figure 4-23.

Figure 4-22. Average daily densities of unmarked salmon caught in the Mossdale Kodiak trawl.

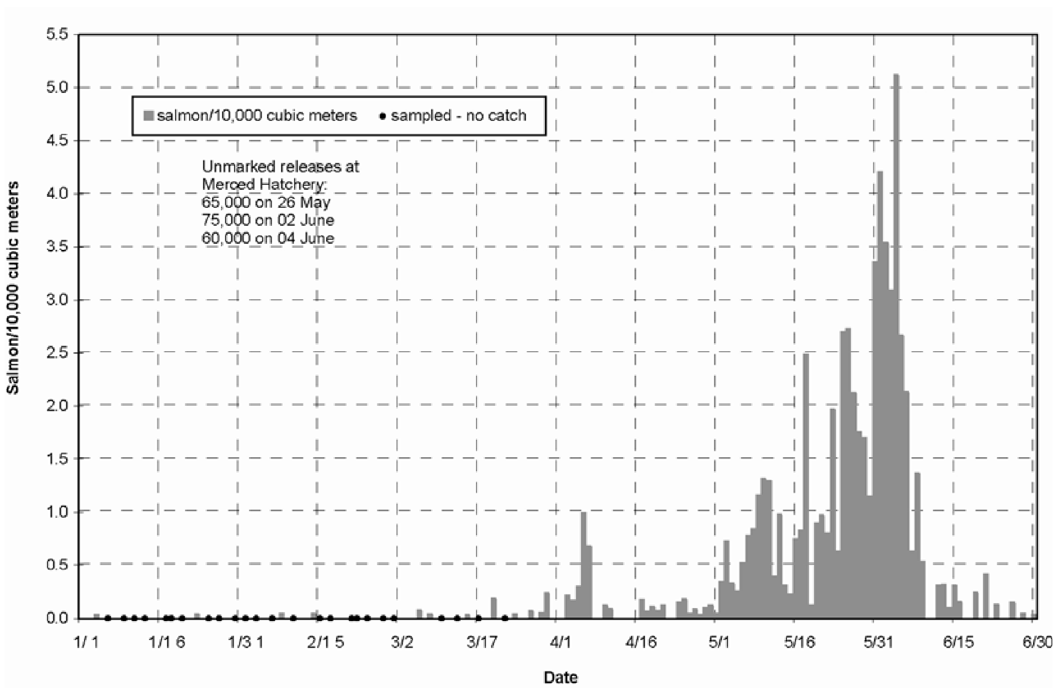
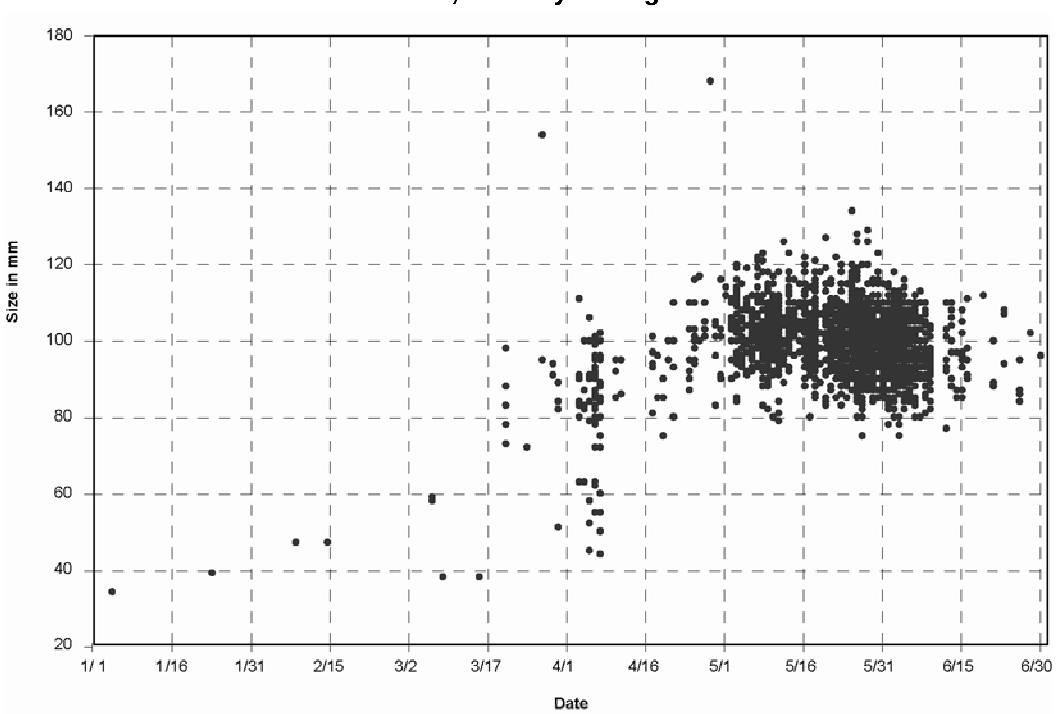


Figure 4-23. Mossdale Kodiak trawl individual daily forklengths of unmarked juvenile Chinook salmon, January through June 2006



Salmon Salvage and Losses at Delta Export Pumps

Fish salvage operations at the CVP and SWP export facilities capture juvenile salmon and transport them by tanker truck to release sites in the western Sacramento-San Joaquin Delta. The untagged salmon are potentially from any source in the Central Valley. It is not certain which unmarked salmon recovered are of San Joaquin basin origin, although the timing of salvage and fish size can be compared with Mossdale trawl data and CWT recovery data for MRH smolts at the salvage facilities to provide some general indications as to the origin of the unmarked fish. However, 2006 had extended San Joaquin River flood conditions and no temporary spring barriers. It was estimated by DWR that nearly all water in the Clifton Court Forebay (CCF) of the SWP during mid-March through June was from the San Joaquin River (SJR); SJR water was also predominant in CCF during January to mid-March (based on Real Time Data and Forecasting Project Water Quality Weekly Reports from DWR Office of Water Quality). It may be assumed that CVP water sources were similar in 2006.

The estimated salmon losses at the CVP and SWP are based on expanded salvage and an estimate of screen efficiency and survival through the facility and salvage process. The CVP pumps divert directly from the Old River channel and direct losses are estimated to range from about 50 to 80% of the number salvaged. Four to five salmon are estimated to be lost per salvaged salmon at the SWP because of high predation rates in Clifton Court Forebay. The SWP losses are therefore about six to eight times higher, per salvaged salmon, than for the CVP. The loss estimates do not include any indirect mortality in the Delta due to water export operations or additional mortality associated with post-release predation.

Density of salmon encountering both of the export and fish salvage facilities off Old River is represented by the combined salvage and loss estimated per acre-foot of water pumped. The DFG and DWR maintain a database of daily, weekly, and monthly salvage data.

The number and density of juvenile salmon that migrated through the system, the placement of the HORB, and the amount of water pumped by each facility are some of the factors that influence the number of juvenile salmon salvaged and lost. Density is an indicator of when concentrations of juvenile salmon may be more susceptible to the export facilities and salvage system. Additionally, salvage efficiency is lower for smaller-sized salmon (fry and pre-smolts), so their salvage numbers and estimated losses are underrepresented.

The weekly data covering the period of April 30 to May 27 approximated the 2006 VAMP period. A review of weekly data for January through June indicates that the highest CVP salvage and losses occurred in June, with the last half of May having increasing values (Figure 4-24). Highest SWP salvage and losses were also in June with a lesser peak from late March to early May (Figure 4-25). Salmon densities based on combined salvage and loss estimates at both facilities were highest in June, with an earlier peak from late March to early May, mainly at the SWP (Figure 4-26). CVP densities were also relatively high in the second half of May (Figure 4-26). The June CVP and SWP peaks occurred during a period of declining flow at Vernalis (Figure 4-27).

The size distribution of unmarked salmon during January through June in the Mossdale trawl (Figure 4-23) generally overlaps with the size distribution of those salvaged at the fish facilities (Figure 4-28, Source E. Chappell, DWR). Based on comparisons with Mossdale data, it appears that some salmon salvaged prior to VAMP could have been from the San Joaquin basin (Figure 4-22).

Results of these analyses showed that the 2006 VAMP test period coincided with part of the peak period of San Joaquin River salmon smolt emigration. The largest daily peak of the production passing Mossdale occurred after VAMP ended (June 3).

Figure 4-24. 2006 CVP estimated salmon salvage and loss

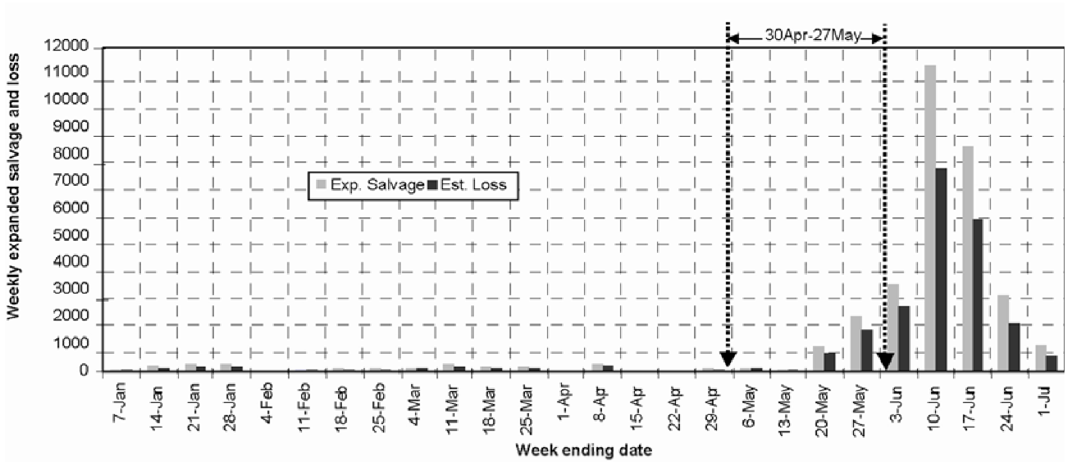


Figure 4-25. 2006 SWP estimated salmon salvage and loss

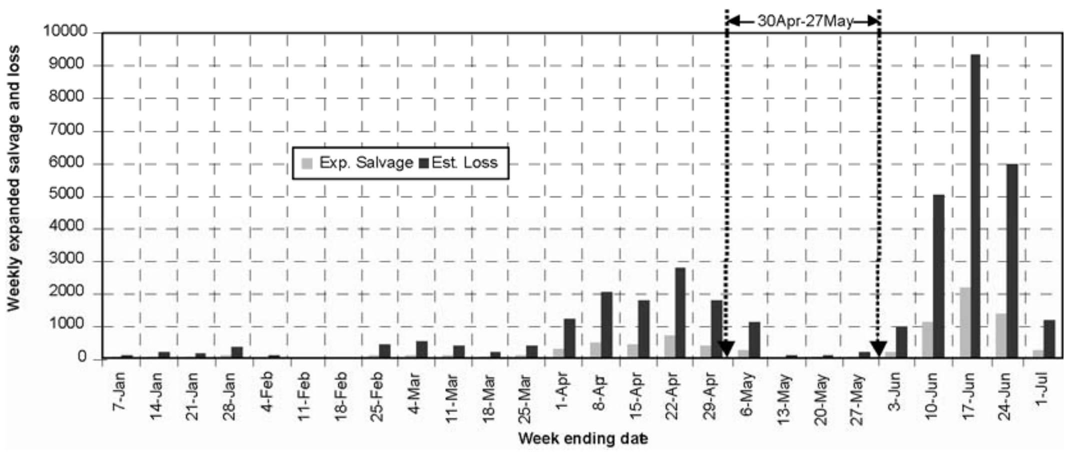


Figure 4-26. 2006 SWP & CVP Combined salvage and loss density

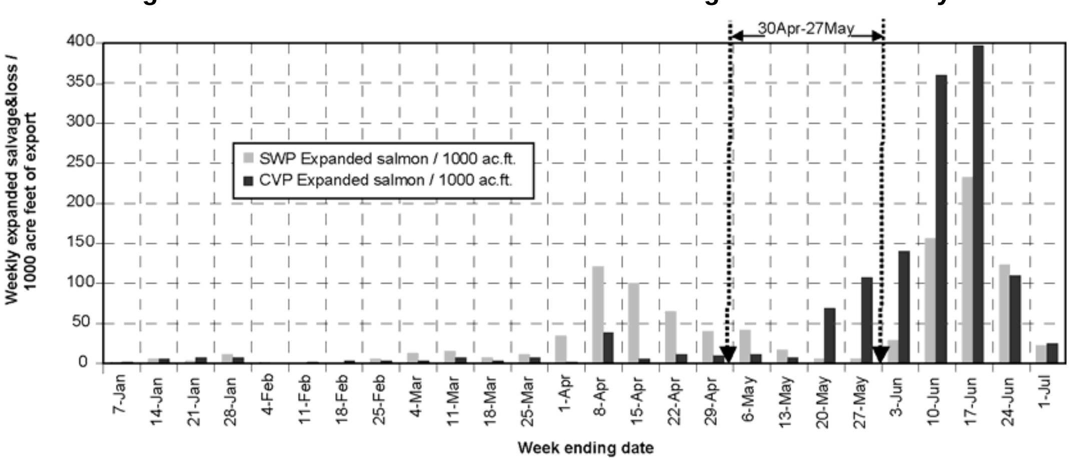
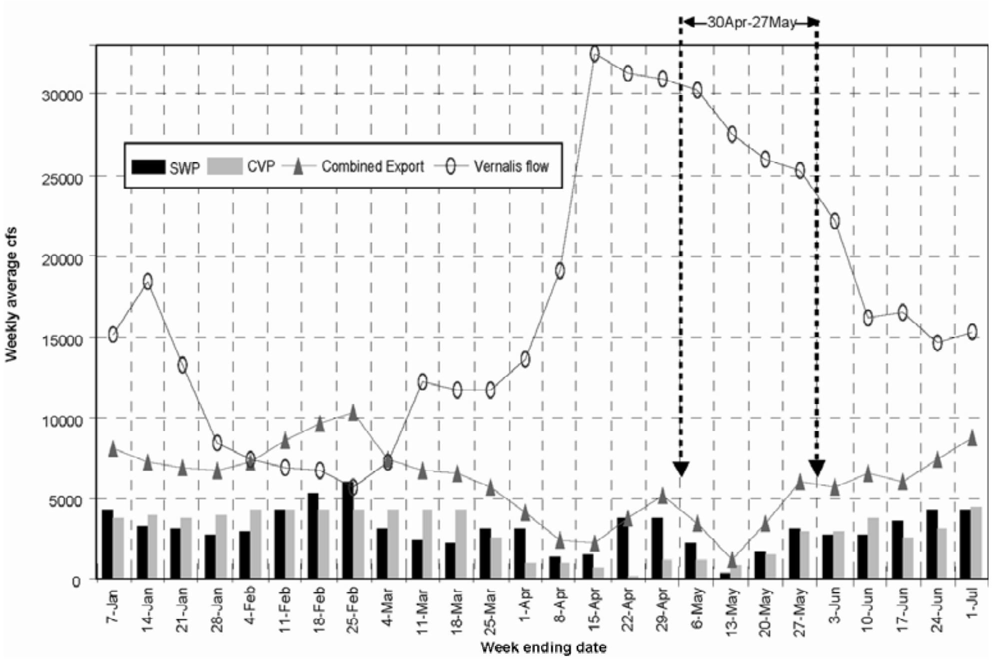


Figure 4-27. 2006 weekly export rates and Vernalis flow



Summary and Recommendations

The CDRRs measured for the first group released in 2006, under low exports, appeared higher than those obtained in 2003-2005 and for the 2006 group released under higher exports and higher temperature.

The health of the fish used in 2006 was generally good, but it is uncertain whether detection of Bacterial Kidney Disease (BKD) in a proportion of the fish may have affected their survival through the Delta.

There are significant relationships between smolt survival and San Joaquin River flow at Vernalis and flow/exports with the HORB, although exports and flows are correlated in the data. These relationships are found when combining all of the recoveries available (Chipps Island, Antioch and ocean fishery) for the Durham Ferry and Mossdale groups relative to the Jersey Point groups. There does not appear to be a clear relationship to flow when the HORB is absent. There is however, a statistically significant relationship between SJR flow/exports and adult escapement 2 1/2 years later.

To better determine relationships of smolt survival to exports and flow, certain conditions should be targeted during the remaining years of VAMP and in years when the HORB cannot be installed. Two of the conditions that need to be tested with the HORB are at exports at 1500 and 3000 cfs with San Joaquin River flows at 7000 cfs. In addition, the 7000 cfs flow and the 1500 export condition would be especially valuable in decoupling the effects of flow and exports with the HORB in place. More experiments, like those in 2006, should be conducted when the HORB cannot be installed to further refine and define the survival relationships to flow and exports without the HORB in place. If exports are to vary within a year, further consideration should be given to doing the high export rate with low temperatures first, to decouple the trend of higher flows, low exports and low temperatures for the first release and lower flows, higher exports and higher temperatures for the second release. Conducting field experiments where many parameters vary together, make isolating the role of a single variable more difficult.

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Figure 4-28. Observed Chinook salvage at the SWP and CVP Delta Fish Facilities, August 2005 through July 2006. (11x17 figure)

Chapter 5. Barrier Effects on SWP and CVP Entrainment

Introduction

In 2006, DWR used modeling to assess the effect of the TBP on Delta fish entrainment. The hydrodynamic particle tracking model (PTM) used nine particle injection sites within the south and central Delta (Figure 5-1) to represent local fish populations at risk of entrainment in the south Delta. Despite limitations of this modeling tool (i.e. a lack of behavior, mortality, vertical movement and growth on particles, etc.), simulations of particles injected into the Delta infer direct entrainment risk by tracking their passive movements in relation to State Water Project (SWP) and Central Valley Project (CVP) water diversions. The percentage of particles entrained into the Clifton Court Forebay (CCF) and the Tracy fish collection facility represents the likelihood of fish entrainment at the SWP and CVP south Delta export facilities.

Methods

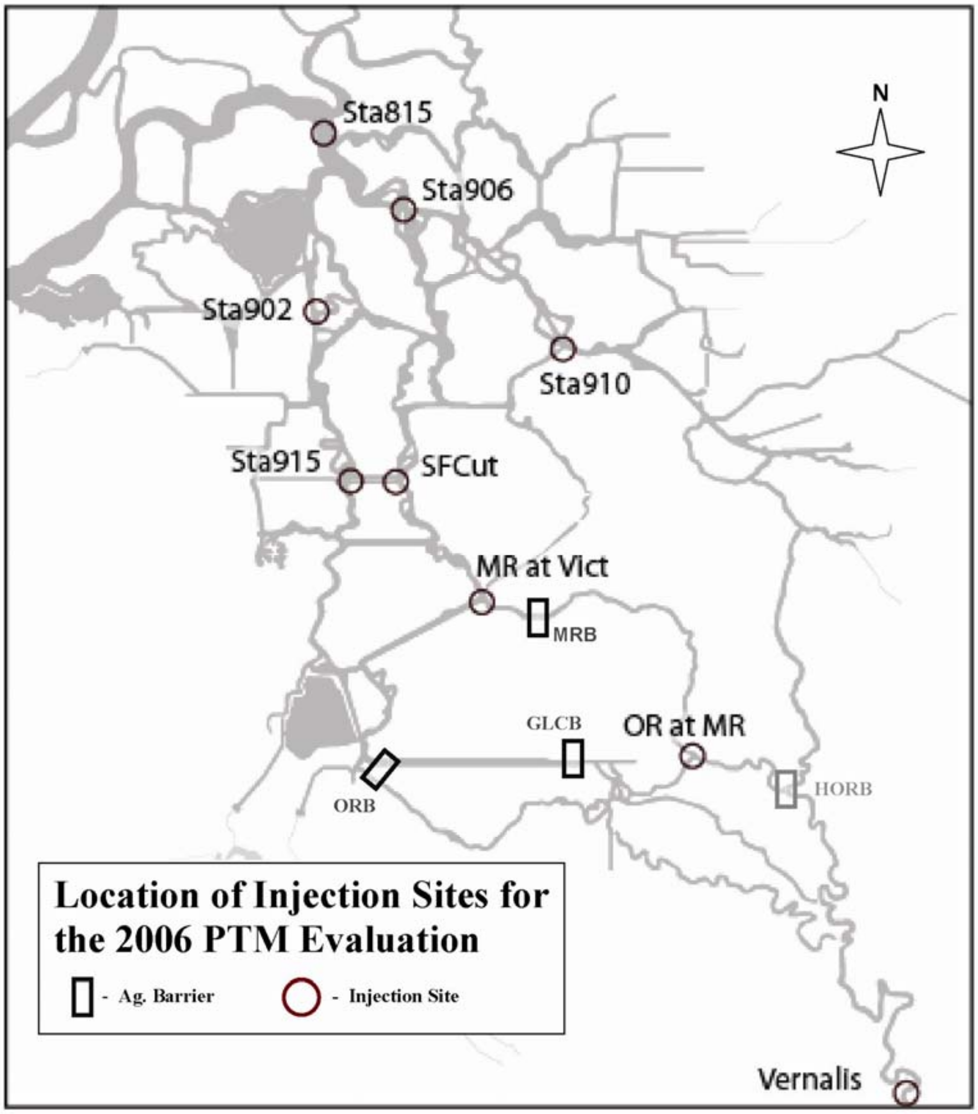
Modeling

DWR modeled daily injections using historic flow conditions for the 2006 calendar year, which included installation and operation of the TBP operating period (historic simulation) (Suits 2006c,d). Modelers next ran a modified simulation assuming no barrier installation. The Spring and Fall Head of Old River Barrier (HORB) was not installed in 2006.

The PTM continuously simulated transport and fate of particles throughout the modeling period. Particle fate was broken down into the following destination components: 1) downstream of Chipps Island; 2) entrained onto Delta islands; 3) entrained by the SWP (south Delta only); 4) entrained by the CVP; 5) entrained into Contra Costa Canal; and 6) remaining in Delta channels. A 90-day model run following injection provided sufficient time for fate determination (Suits, 2006c,d). The models provided output data per fate as percentages of the total number of particles released for each injection site and date. The difference between the modified and historic modeling runs allowed us to examine the effect of the barriers on entrainment utilizing the change in percent particle entrainment per injection (fingerprint fate)

CCF inflow and project export pumping data were provided by DWR (Amritpal Sandhu, 2006) and were reviewed for potential influence on particle entrainment.

Figure 5-1. South and central Delta, particle injection sites and South Delta Temporary Barriers (Old River Barrier, Grant Line Canal Barrier, Middle River Barrier, Head of Old River Barrier) and particle injection sites used in the 2005 PTM study.



Analysis

Total percentage of daily-injected particles entrained by the SWP and CVP after 90 days are prescribed to the occurrence of flow conditions conducive to real fish entrainment. Variation in this measure is likely due to changing hydrology, including relationships among Delta inflow, CVP pumping, CCF inflow and numerous small diversions, and to changing geometry, such as the installation, removal, and operational changes of one or more of the temporary barriers. Simulated entrainment differences at the project facilities will eventually help to infer specifically, which changes in operation of the agricultural temporary barriers contributed to changes in total fish entrainment at the project facilities.

For each injection point and particle fate, percent daily historic entrainment was subtracted from percent daily modified entrainment (% modified - % historic). The time series was broken down into a dozen overlapping periods defined by major hydrologic and geometric configurations in the south and central Delta (Table 5-1). The period average difference in percent daily entrainment represents a measure of barrier-induced entrainment risk. Table 5-1 lists these data for specific periods. A positive (+) value indicates that average daily entrainment for the modified simulation exceeds average daily entrainment for the historical simulation. Therefore, simulated entrainment was less with the barriers in place than without. A negative (-) result, therefore, indicates simulated entrainment is higher when the barriers are not in place.

Background noise was evaluated using the aforementioned method to calculate the greatest fingerprint value for the time series prior to installation of the first barrier (1/1-7/6/06). Since simulated hydrology was assumed to be equal for both runs during these two periods, the greatest daily difference observed represents the maximum amplitude of background noise resulting from the modeling process. The maximum difference was utilized as a test for evaluating significance for each injection site. This artificial error threshold was determined for combined SWP and CVP entrainment, and is included in Table 5-1. Period average daily percent differences were determined to be great enough to warrant further attention, when their values superseded the daily maxima (max diff) in background noise for the pre-barrier period, which exhibited greater maximum amplitudes for all stations.

Results

Period average daily percent difference in particle entrainment at the Tracy fish collection facility and at CCF represents the potential influence of the 2006 TBP operations on fish entrainment risk. Simulation results revealed that barrier operations generally had a directional effect (increase or decrease) on the entrainment of particles, depending on injection site. Of the nine injection sites modeled, the simulation of barrier operations on particles released from six of them correlated with a consistent directional change during periods when a net change in fingerprint occurred. Entrainment of particles released at stations MRatVict, Sta910, Sta906 and Sta902 was greater for all but one operating period during the historic simulation (barriers in-place). Station MRatVict exhibited the strongest footprints during the following periods: MRB Before GLCB (-1.2%; 7/7-7/19/06); Ag. Barrier (-1.0%; 7/7-11/21/06); and ORB Before GLCB (-2.7%; 7/17-7/19/06). These values surpassed the maximum noise threshold, as defined earlier, for this station (+/- 0.9%).

Table 5-1. PTM Fingerprinting; Difference in percentage of particles injected into the Delta daily and subsequently entrained by the SWP and CVP for each modeling condition (modified simulation - historical simulation), for the examined periods in 2006.

2006 Evaluation Period		Project Average Daily Percent Difference in Entrainment (Simulated) by Injection Site								
		Negative Fingerprint				Mixed Fingerprint			Positive Fingerprint	
Description (Maximum Diff.)	**Date**	**MRatVict**	**Sta910**	**Sta906**	**Sta902**	**SFCut**	**Vernalis**	**Sta915**	**Sta815**	**ORMR**
Pre-Barrier Period	1/1-7/6	0.0 (+/- **0.9**)	0.0 (+/- **1.0**)	0.0 (+/- **2.4**)	0.0 (+/- **1.7**)	0.0 (+/- **0.9**)	0.0 (+/- **2.0**)	0.0 (+/- **1.1**)	2.0 (+/- **44.5**)	0.0 (+/- **2.0**)
Full Modeling Period (max diff.)	1/1-12/31	-0.4	-0.3	-0.2	-0.3	-0.1	0.0	-0.1	1.5	1.2
VAMP Period	4/15-5/15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MRB Only Period	7/7-7/16	-0.7	-0.9	-1.0	0.0	0.2	-0.4	0.1	3.4	1.2
MRB Before GLCB Period	7/7-7/19 (7/17-)	**-1.2**	-0.9	-1.1	-0.1	-0.1	-0.3	0.2	3.0	1.3
Ag. Barriers Period	7/7-11/21	**-1.0**	-0.7	-0.4	-0.6	-0.3	0.0	-0.3	0.9	**3.1**
MRB Before ORB	7/7-7/16	-0.7	-0.9	-1.0	0.0	0.2	-0.4	0.1	3.4	1.2
ORB Install Onward Period	7/17-12/31 (7/7-, 7/20-)	-0.8	-0.5	-0.3	-0.5	-0.3	0.0	-0.3	0.9	**2.5**
ORB Before GLCB Period	7/17-19	**-2.7**	-0.9	-1.3	-0.7	**-1.2**	0.1	0.5	1.4	1.5
GLCB Install Onward Period	7/20-12/31	-0.8	-0.5	-0.3	-0.5	-0.3	0.0	-0.3	0.9	**2.5**
Post Barrier Period	11/22-12/31	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	1.5	0.0

Entrainment of particles injected at stations Sta815 and ORMR decreased for all operating periods, with the latter exhibiting notable footprints by exceeding the station's maximum noise threshold (+/- 2.0%) during the Ag. Barrier period (+3.1%; 7/7-11/21/06), the ORB Install Onward period (+2.5%; 7/17-12/31/06) and the GLCB Install Onward period (+2.5%; 7/20-12/31/06). Particle entrainment footprints for the remaining three injection sites (SFCut, Vernalis, Sta915) were mixed, indicating that barrier operations were not consistent in their effect on particles released from these locations. SFCut had the only fingerprint that surpassed its respective max difference threshold in this group, which occurred during the ORB Before GLCB period (-1.2%; 7/17-12/31/06).

Discussion

The PTM simulation results indicate that the installation and operation of the three agricultural temporary barriers is conducive to both greater and lower particle entrainment at the SWP and CVP south Delta facilities for 2006 conditions, depending on injection site location. Differences in entrainment between the two simulations were greatest (in opposite directions) at the MRatVict and ORMR stations.

Since many variables are involved in the entrainment of fishes in the south Delta, conclusions drawn from the relationship between historic conditions with barriers in place and particle entrainment was not extrapolated to actual fish entrainment. However, the results do indicate that the combined effects of barrier operation, associated hydrology, and concurring changes in particle entrainment fingerprinting seem likely to correlate with entrainment of fishes that tend to go with the flow of water, and most likely to similarly affect fishes with lower swimming performance. The latter group includes larval and juvenile fishes, as well as poor-swimming species like delta smelt, which utilize diel shifts in vertical position in response to tidal flows for mobility (Moyle, 2002). The relationships among these variables is not straight-forward and warrants further analysis by fisheries biologists.

SWP and CVP entrainment were not examined separately this year, due to a lack of staff time availability in preparing the data for this report.

Future PTM Ideas

Although the PTM design and evaluation used here helps to illustrate the entrainment of neutrally buoyant particles in a simulated environment, it lacks a method to relate such results to fishes in the real world. Other modelers have applied artificial behavior to particles by removing a degree of randomness from simulations. For delta smelt, an example might include forcing vertical diel shifts through a water column with variable flow rates at depth. A fisheries biologist could apply entrainment risk data calculated here to real-world populations occurring in the south and central Delta. These efforts are already being undertaken as part of the Delta Pelagic Organism Decline (POD) studies. Collaboration with other Department scientists would benefit our TBP monitoring responsibilities in the future.

Further evaluation should utilize the non-project particle fate components listed in the Modeling section of this report. This method could be applied to the historic record to evaluate particle entrainment over different water year types. Additionally, appropriate statistical analyses should be applied to the data in this report, which could determine whether causal relationships exist between the observed variables.

Resources

Moyle, Peter. 2002. Inland Fisheries of California. Berkeley and Los Angeles, California. University of California Press.

Sommer et. al., 2005. Sommer, Ted, Bob Suits, Michael Mierzwa and Jim Wilde. Draft, September 30, 2005. Evaluation of Residence Time and Entrainment using a Particle Tracking Model for the Sacramento-San Joaquin Delta. California Department of Water Resources. Sacramento, California. 32 pp.

Suits, Bob 7/6/06. [Suits 2006a] Memo from Bob Suits, Senior Engineer Delta Modeling Section, to Tara Smith, Chief of Delta Modeling Section, Bay-Delta Office, CA Department of Water Resources. Subject: Use of Particle Tracking Modeling to Generate Index of Entrainment Potential.

Suits, Bob 12/28/05. [Suits 2006b] Email correspondence from Bob Suits, Senior Engineer Bay-Delta Office, CA Department of Water Resources.

Suits, Bob 2/15/06. [Suits 2006c] Email correspondence from Bob Suits, Senior Engineer Delta Modeling Section, Bay-Delta Office, CA Department of Water Resources. Designed and implemented PTM simulations, and provided output data used in this chapter.

Suits, Bob 4/7/06. [Suits 2006d] Email correspondence from Bob Suits, Senior Engineer Delta Modeling Section, Bay-Delta Office, CA Department of Water Resources.

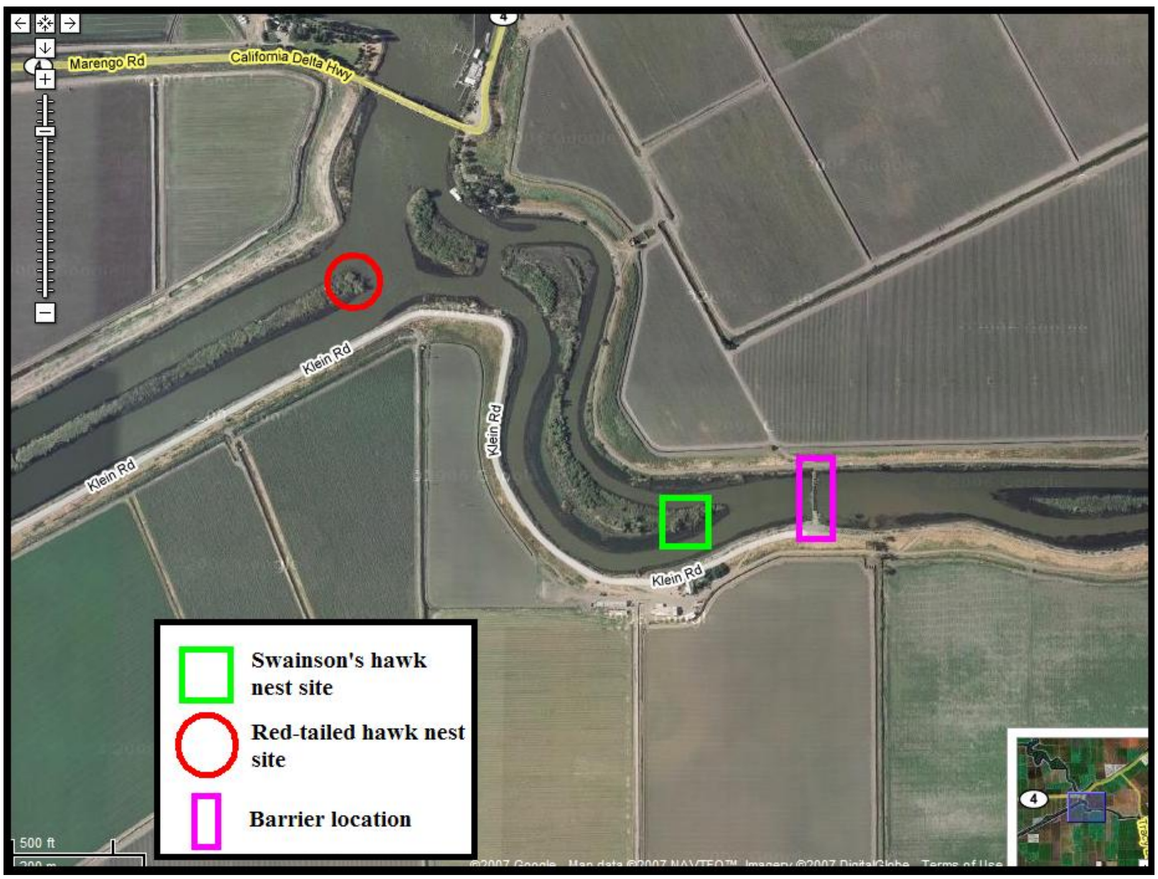
Chapter 6. 2006 Swainson's Hawk Monitoring

Swainson's hawk surveys were initiated around the Temporary Barrier construction and storage sites in late March 2006, though high flows in the Delta waterways delayed the construction of the agricultural barriers until July; the fish barrier was not installed. Because of the delay, by the time construction began, nesting had progressed at most nest sites near construction zones beyond the sensitive period of egg-laying and incubation, and chicks were, in most cases, weeks old. This reduced the likelihood of a nest abandonment and chick mortality. Nest success is listed at the specific construction sites below in order of occurring barrier construction.

Middle River Barrier

This barrier was scheduled for installation initiation on or about July 4. The site was first surveyed for Swainson's hawk nesting activity on March 23. At that time, the red-tailed hawks that normally nest at the confluence of Middle River and Victoria Canal were nesting there again (Figure 6-1). A pair of Swainson's hawks was first observed on 13 April in the trees on the in-stream island 200 yards downstream of the barrier location.

Figure 6-1. Swainson's hawk nest near Middle River Barrier

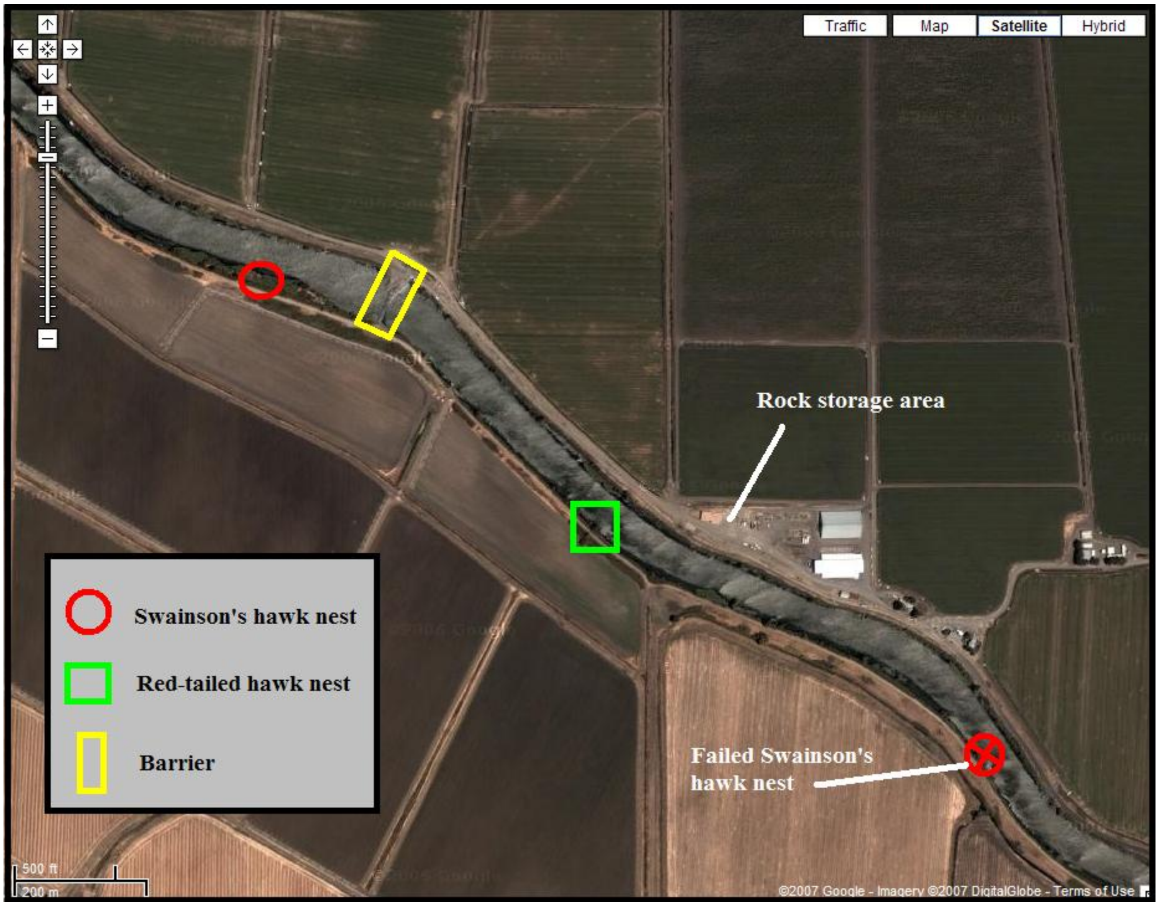


On 2 May, the female Swainson's hawk was observed incubating eggs in a willow on the island, and by the time construction was initiated, the pair had 3 chicks approximately 3 to 4 weeks old. There were no apparent effects on the chicks from construction, and two weeks later the young had fledged.

Old River at DMC Barrier

Swainson's hawks constructed nests at three sites near the barrier site and rock storage area (Figure 6-2). The first site was well upstream of both construction sites, just beyond the ½ mile limit; by 6 July, the 3 chicks raised at the nest were flying. The second site was 400 yards upstream of the rock storage area, where a pair had constructed a nest in a small alder the previous year, and appeared to do so again in 2006; by the time construction was initiated on the DMC barrier, the pair was no longer in the area and the nest was in disrepair, apparently damaged by strong winds. The third site was 250 yards upstream of the barrier site in a medium-size alder; there was one chick at the nest when construction began, and it fledged during construction. Two pairs of red-tailed hawks nested near the barrier as well.

Figure 6-2. Swainson's hawk nests near the DMC barrier site.



Grant Line Canal Barrier and Accessory Areas

Hawks nested (or constructed nests) at three locations near the Grant Line Canal barrier, haul road and Howard Road rock storage area (Figure 6-3). A red-tailed hawk nested in the rock storage area itself, as has happened previously. The young had fledged by the time the barrier's construction had begun. A pair of Swainson's hawks nested in a tree between Tracy Blvd and the haul road, just north of Clifton Court Road. That pair fledged 2 young, both of which were flying prior to the initiation of construction. A pair of Swainson's hawks constructed a nest about 300 yards upstream of the barrier site on Grant Line Canal, but by early July, the nest was empty and only the male was observed. The pair is assumed to have failed.

In all, Swainson's hawks fledged 6 young at 3 nests within ½ mile of barrier sites and their associated storage and construction zones. Two nests failed, but they failed prior to the initiation of construction activities. Barrier construction appeared to have no negative effects on Swainson's hawks in 2006.

Figure 6-3. Swainson's hawk nests at Grant Line Canal barrier.

Chapter 7. Water Elevations

The 2006 water elevation monitoring program included operation and maintenance of sixteen tide gauging stations near the barriers as shown in Figure 7-1. The 2006 monitoring program covers the period from January 2006 through December 2006, where stage is monitored at various stations with remote sensors.

Instrumentation recorded water surface elevation daily at fifteen-minute intervals. Later, the data records were retrieved and downloaded to a computer for subsequent analysis.

Data collected at these stations were used to determine effects of the barriers on the water surface elevations and circulation patterns in the South Delta. Circulation patterns are estimated using the water surface elevation data as an input to the hydrologic mathematical model (DWRSM2). Results of the model can be found in Chapter 9.

Figure 7-1. Tide Stations in the Southern Delta

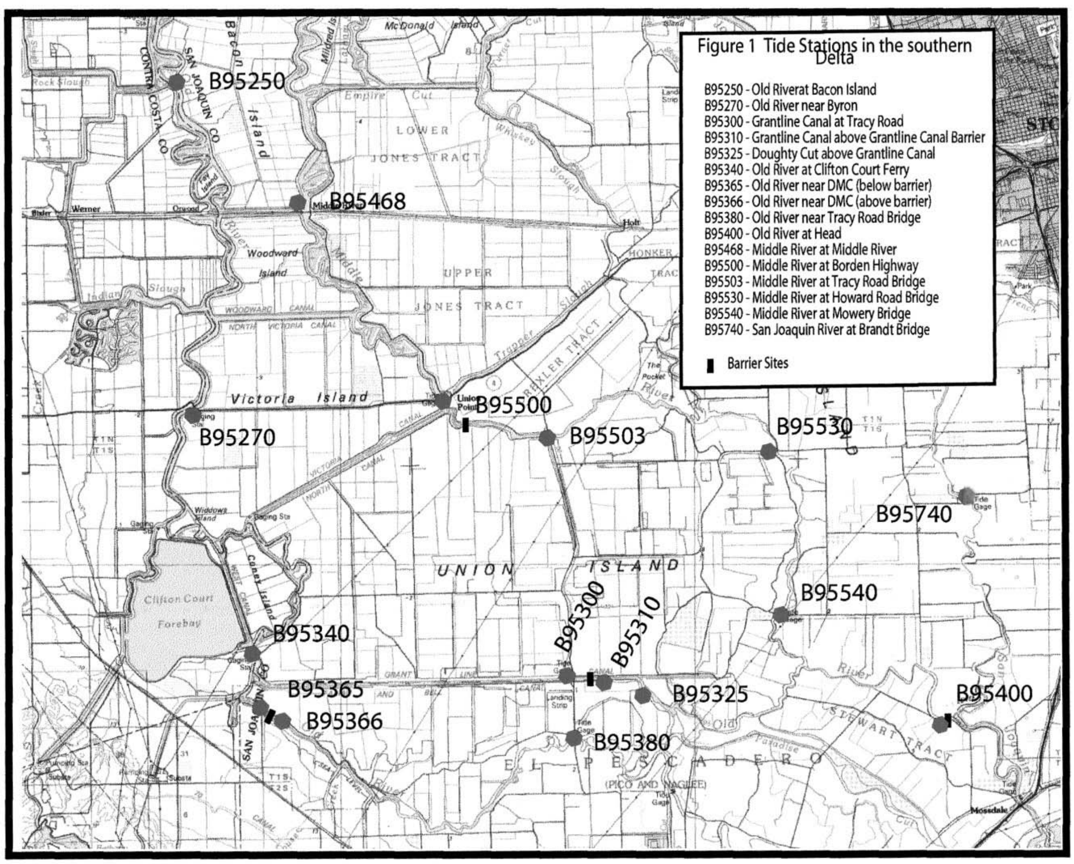
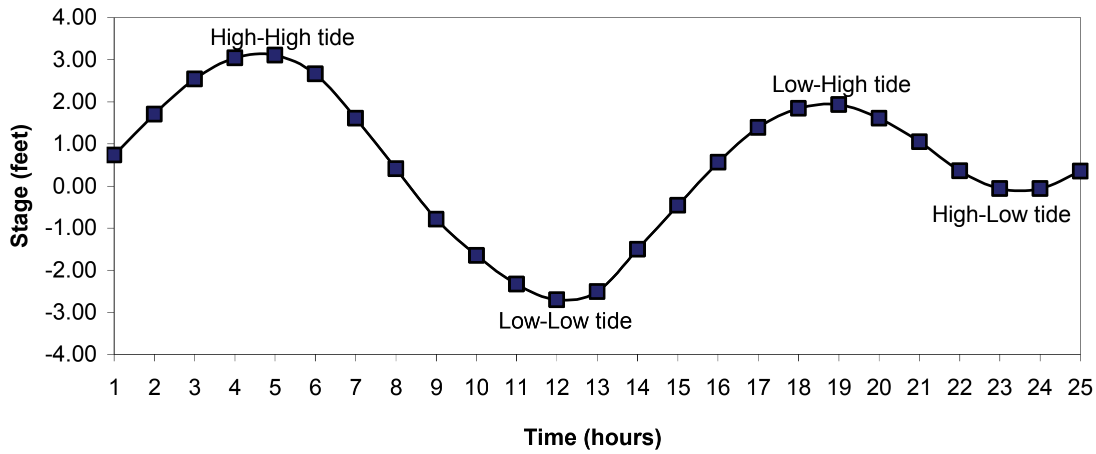


Figure 7-2. Tide stage variation along the Pacific Coast over a 25-hour cycle



Tides along the Pacific Coast exhibit a cycle of two high and two low tides over an approximately 25- hour period (Figure 7-2). These cycles vary in height throughout the day. Two elements make up a typical tidal curve.

- The tidal range is the difference between the highest and lowest tidal elevations.
- The daily inequality is the difference between the heights of successive high or low tides and the time between corresponding high or low stands of sea level.

A biweekly pattern of spring and neap tides is overlaid on top of the daily pattern. Additional patterns occur at longer intervals throughout the year.

Typically, farmers in the south Delta encounter pumping difficulties due to low water elevations during the irrigation season. One objective of the Old River at Tracy, Middle River, and Grant Line Canal barriers is to improve water elevations for agricultural diversions. This goal is achieved by installing barriers with culverts that restrict flow in the downstream direction during (receding) ebb tides, resulting in increased water levels upstream of the barrier. During periods of increasing (flood) tides, flap gates on the upstream ends of the culverts allow flow in the upstream direction. Sometimes during high flood tides water also flows over the barrier, thereby further increasing water levels upstream of the barrier. The increasing tide replenishes water being lost or diverted for agriculture irrigation and will maintain higher water levels during the next receding tide.

The agricultural barriers are constructed from rock with flap-gated culverts to allow flow in the upstream direction. Design of the three barriers varies slightly due to differences in upstream channel geometry.

The following are highlights of barrier installation effects:

- At low tide, water surface elevation upstream of the barrier is raised, but the elevation downstream remains nearly the same.
- Extreme high tide water surface elevations upstream of the barrier may be slightly delayed and reduced due to energy losses through the culverts.
- During ebb tides, culvert flap gates close and retain water behind the barriers.

Middle River Barrier

The Middle River Barrier is constructed to an elevation of +3.0 feet National Geodetic Vertical Datum (NGVD) and has six 48-inch diameter culverts. The center weir is 140 feet wide and constructed to an elevation of +1.0 foot NGVD (Figure 7-3). The center portion of the barrier is removed seasonally, while the culverts and the abutments remain in place year-round. Three culverts are located in the north abutment and three culverts are located in the south abutment.

The installation of Middle River (MR) barrier started on July 5, and was completed on July 8, 2006. The flap gates were tidally operational until November. For the 2006 operation, the MR agricultural barrier was allowed to remain until November 20, 2006. The MR barrier removal work began on November 17, and the barrier was fully removed by November 20, 2006.

Water level monitoring was conducted at two nearby tide recording stations, B95500 downstream of this barrier at Borden Highway (Highway 4) and at B95503 just upstream of the barrier.

Figure 7-4 shows the mean monthly high tides and mean monthly low tides upstream and downstream of the Middle River barrier from January 2006 to December 2006. The barrier was in operation between July and November 2006. Figure 7-4 shows an increase in mean monthly low water levels upstream of the barrier of one foot in June and July, over a foot from August through October, and about half foot in November because the barrier was breached on November 18, 2006. This was a positive effect for agricultural irrigators.

In 2006 the gaging station upstream of MR malfunctioned from 6/15/06 through 8/14/06; the stilling well piping was cleaned with a metal brush on 8/14/06 and the gaging station resumed proper functionality.

Figure 7-3. Middle River Barrier Profile

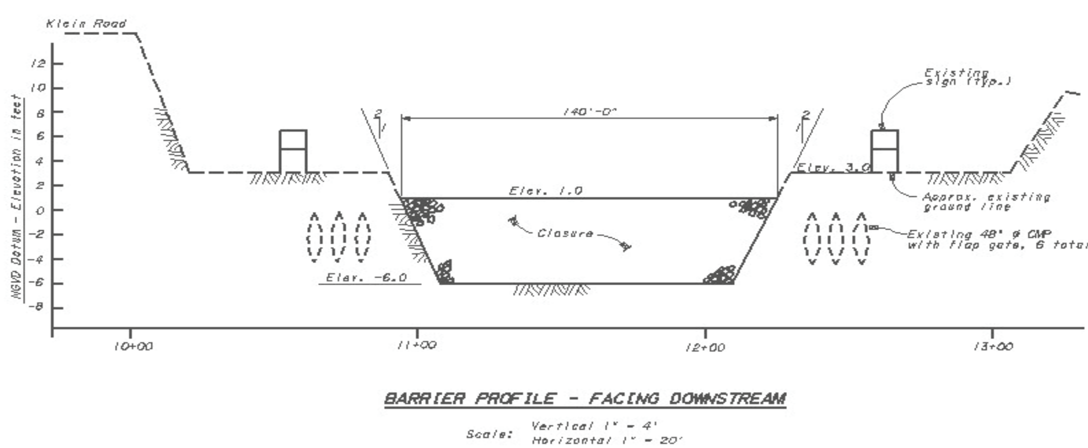
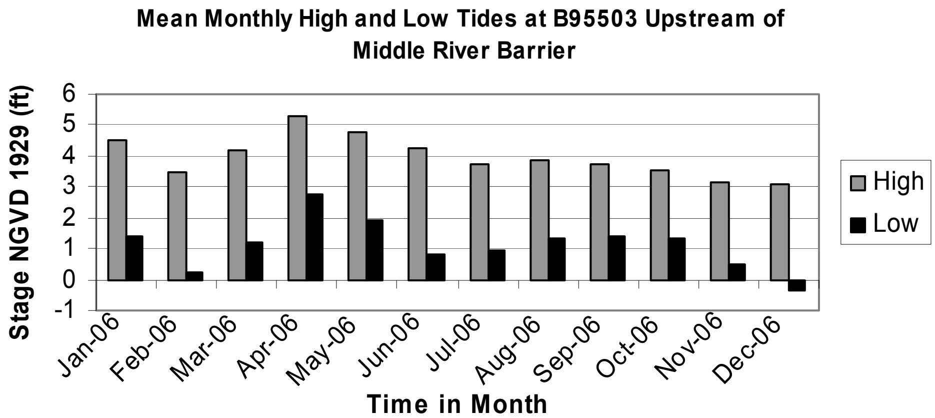
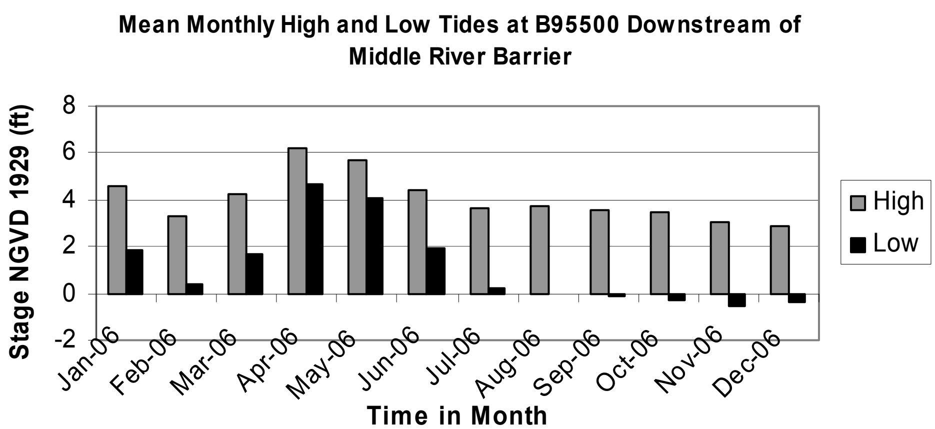


Figure 7-4. Water levels upstream and downstream of Middle River barrier





Old River at Tracy

The Old River at Tracy (ORT) barrier is constructed to an elevation of +4.0 feet NGVD and has nine 48-inch diameter culverts. The center weir is 75 feet wide and constructed to an elevation of +2.0 feet NGVD (Figure 7-5). The entire barrier structure is removed seasonally.

The ORT barrier was installed on July 7; it was closed by July 17, and the installation was completed by July 31, 2006. The flap gates were operational until November 13, 2006 when the removal of the barrier started. The barrier was fully removed by December 6, 2006.

Water level monitoring is conducted at two nearby tide stations, (1) B95365, downstream of the ORT barrier; and (2) B95366 upstream of the barrier. In 2006, both stations experienced an ongoing communication problem between the river and the stilling well resulting in an unreliable data for a certain periods of time at both locations. Station B95365 reported unreliable data during the period from 6/1/06 through 7/14/06. On 7/14/06 divers cleaned the piping for both stations and they started functioning normally again.

Figure 7-6 shows stages upstream and downstream of the Old River at Tracy barrier from January 2006 to December 2006. Figure 7-6 shows an increase in mean monthly low water levels on the upstream end of more than half foot in July; more than two feet from August through October, and approximately half foot in November.

Figure 7-5. Old River at Tracy barrier profile

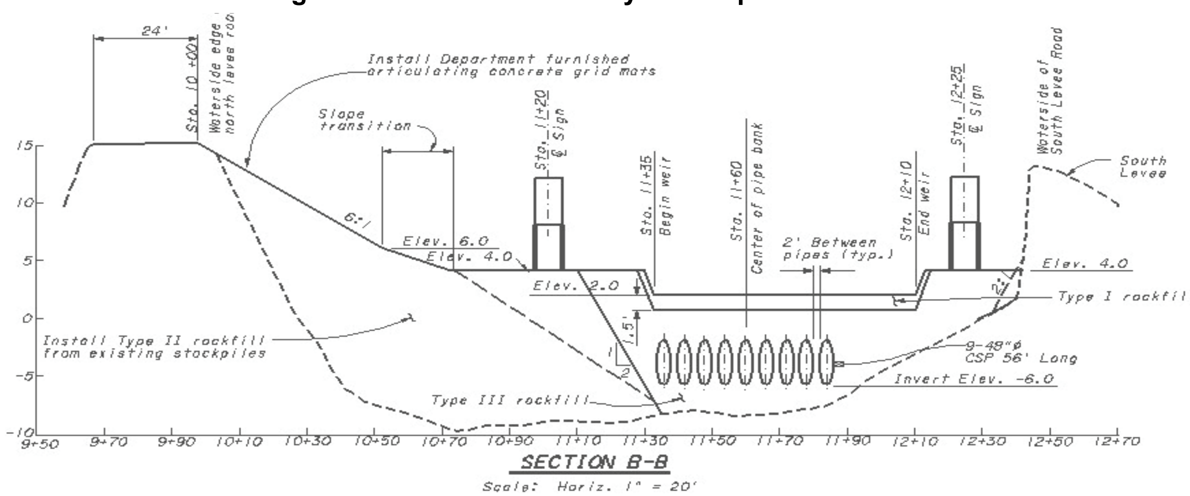
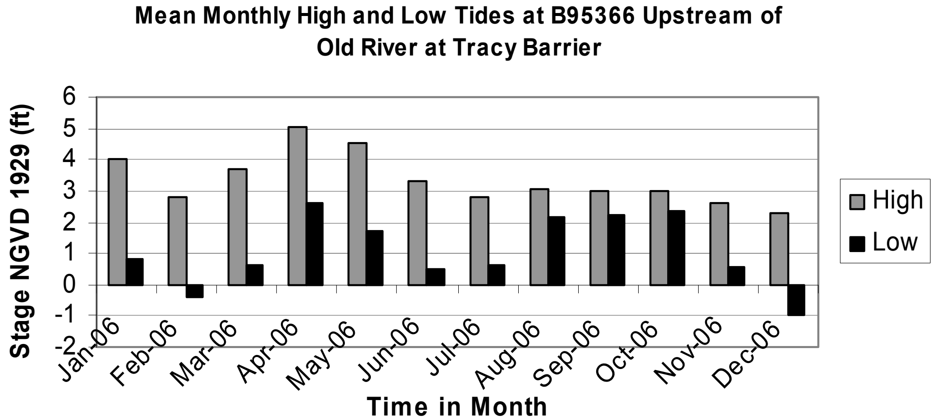
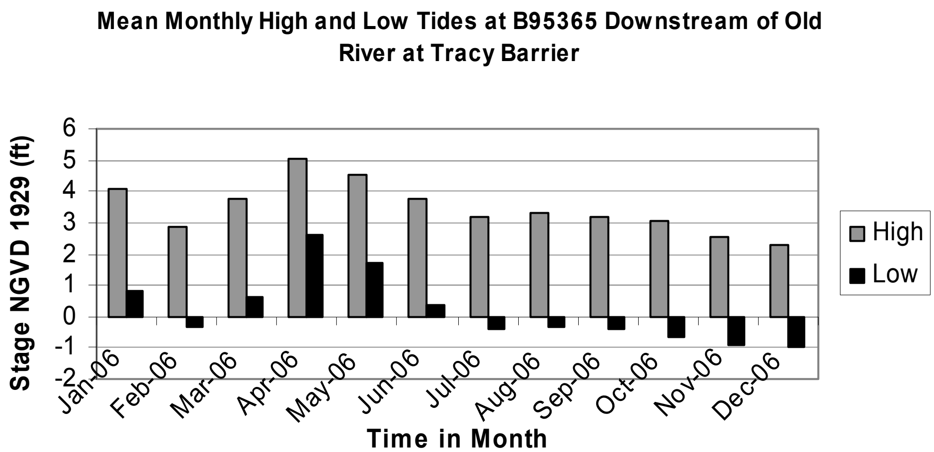


Figure 7-6. Water levels upstream and downstream of Old River at Tracy barrier





Grant Line Canal Barrier

The Grant Line Canal (GLC) barrier is constructed to an elevation of +4.0 NGVD and also has six 48-inch diameter culverts in the southern abutment of the barrier. The center weir is 140 feet wide and constructed to an elevation of +1.0 foot NGVD. In 2006, a 10 feet wide weir was operated on the southern abutment and the flashboards were adjusted on July 20 and October 1, 2006 to allow delta smelt passage (Figure 7-7). The culverts, fish passage weir and the southern abutment of the Grant Line Canal barrier are designed to remain in the channel year round. This will have less disruptive effects to the Swainson's hawk during the construction in spring.

The GLC barrier was installed between July 7 and July 26, 2006. Six flap gates were tied open until July 20, the day the middle portion of the barrier was closed. After July 20, the flap gates resumed normal tidal operation until November 21when the barrier was breached. The barrier removal work began on November 14, and was fully removed on December 6, 2006. Water level monitoring is conducted at two nearby tide recording stations: (1) B95300 just downstream of the barrier, and (2) B95325 Doughty Cut upstream of the barrier.

Figure 7-8 shows stages upstream and downstream of the GLC barrier from January 2006 to December 2006. Figure 7-8 shows an increase in mean monthly low water levels on the upstream end of more than half foot in July; more than two feet from August through October, and approximately half foot in November.

Figure 7-7 Grant Line Canal barrier profile

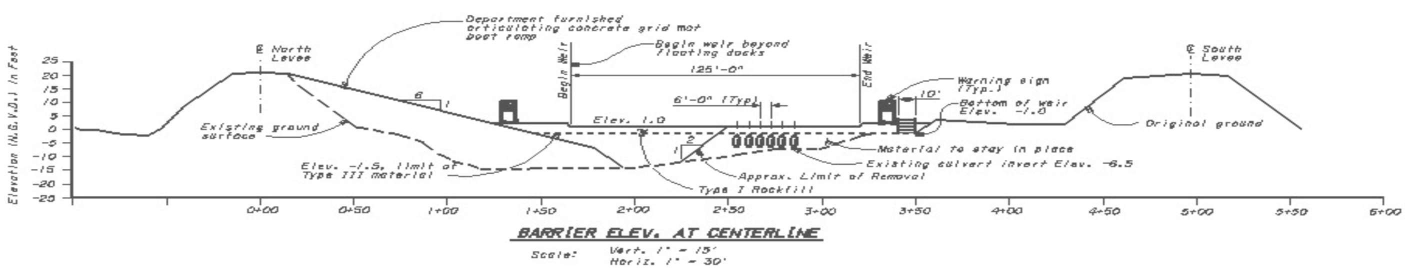
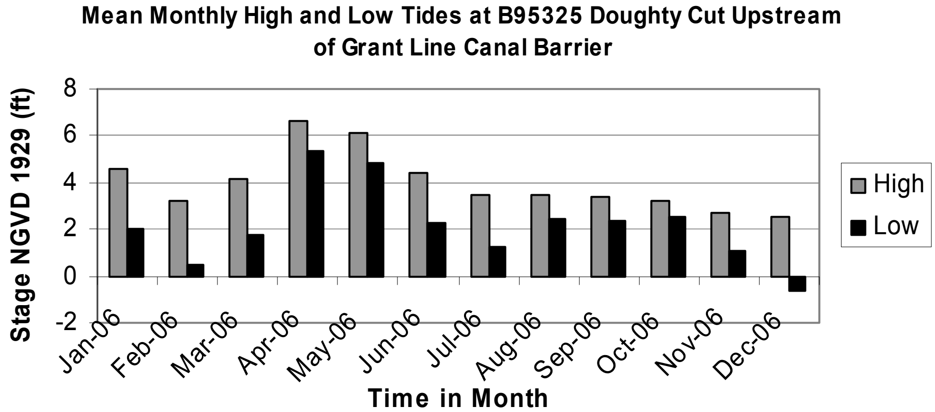
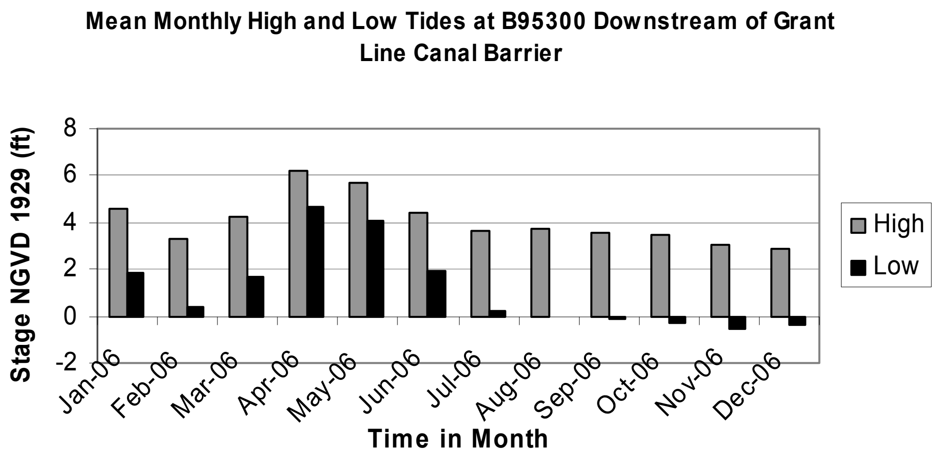


Figure 7-8. Water levels upstream and downstream of Grant Line Canal Barrier





Old River at Head Barrier

In 2006, the spring HORB was not constructed due to high flows on the San Joaquin River. In addition, the fall HORB barrier was not constructed also due to adequate dissolved oxygen levels in the San Joaquin River. Figure 7-9 shows the mean monthly high and low tides at station B95400 Old River at head gaging station from January through December 2006. The mean monthly low level was the lowest during the month of December an elevation of approximately one foot NGVD, and a maximum of 12 feet NGVD during the month of May 2006.

Figure 7-10 shows water level at station B95420 of Tom Paine Slough above the mouth, the mean monthly low level dipped below zero during the month of December and was well above 1 foot during the period from April through November. The highest was observed in April, a value of more than five feet NGVD.

Figure 7-10 also shows station B95421, Tom Paine Slough above the intake structure. This station reported unreliable or missing data during the periods of 1/1/06 to 1/4/06, 3/1/06 to 3/10/06, and 4/27/06 to 5/1/06.

Figure 7-10 also shows station B95425, Tom Paine Slough at Pescadero Pump Plant #6. The mean monthly low was a little over half foot during the month of December and the highest was observed in October, a value of more than two and half feet NGVD.

Figure 7-9. Water Levels downstream of Head of Old River Barrier

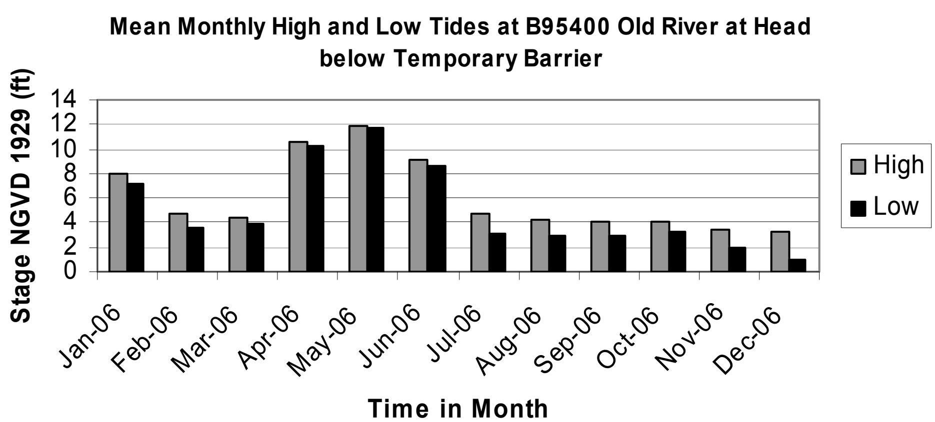
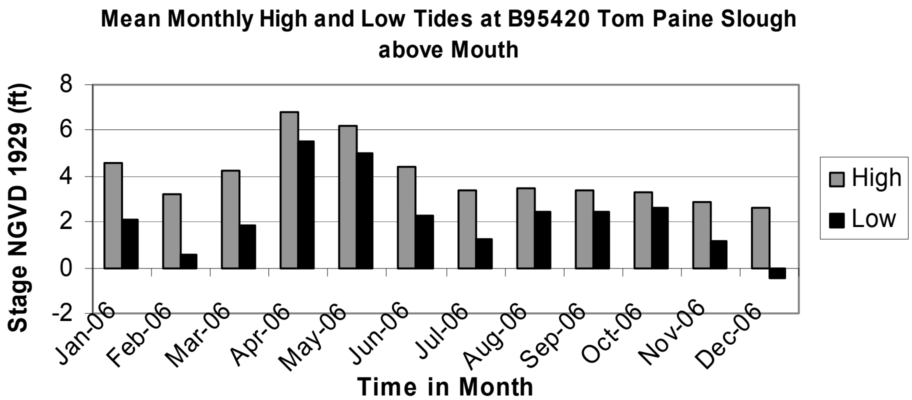
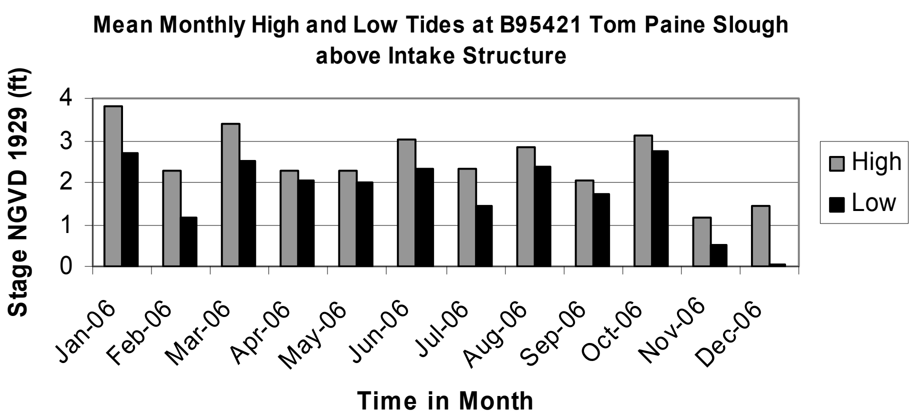
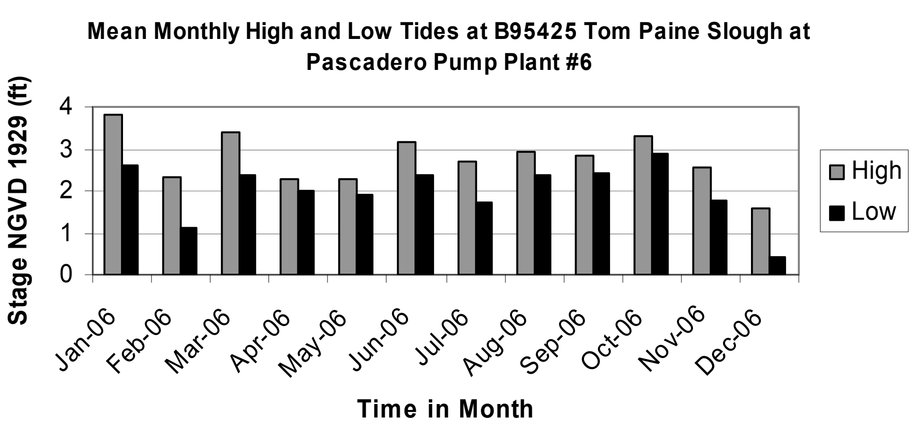


Figure 7-10. Water Levels at Tom Paine Slough above Mouth and above the Intake Structure and at Pump Plant #6







Chapter 8. Weekly Water Quality Sampling

Introduction

During the summer and fall of 2006, three temporary rock barriers were installed in the South Delta as part of the South Delta Temporary Barriers Project. The barriers were all installed on or before July 20th and removed by December 8th. (Barrier installations were scheduled for April 1st, but were not installed until July because of high San Joaquin River flows.) A fourth rock barrier, the Old River at Head Barrier, was not constructed in the spring or fall because of unseasonably high flows and favorable dissolved oxygen concentrations in the San Joaquin River.

The Department of Water Resources continued its discrete and continuous water quality sampling programs in 2006 to elucidate potential impacts of barrier installations and operations upon South Delta water quality, and for compliance with the Central Valley Regional Water Quality Control Board permit. Discrete water quality sampling was conducted bi-monthly while the temporary barriers were operational. Sampling commenced on August 9th and was completed on December 5th. Continuous monitoring was conducted during the entire calendar year by employing multi-parameter water quality instruments at eleven permanent sites. These stations provide continuous measurements of six water quality constituents. Continuous water quality data is discussed later in the chapter.

Discrete Water Quality Sampling

Changes to 2006 Discrete Monitoring

In 1998, Central District (District) initiated a pilot program to test the viability of using multi-parameter water quality instruments to potentially replace discrete dissolved oxygen monitoring at ten South Delta locations. The continuous water quality monitoring program began with two multi-parameter stations: Old River at Tracy Wildlife Association and Middle River at Howard Road. Four additional stations were installed between 2000 and 2003. The primary benefit of continuous monitoring is the amount of data generated in relation to discrete sampling. The multi-parameter instruments take readings every 15 minutes, which equals 672 readings per week versus one reading per week by discrete monitoring.

Data from six continuous water quality stations has provided the District with a more detailed representation of the dynamic water quality conditions in the South Delta. Due to the reliability and amount of high quality data generated from continuous monitoring, the District installed a multi-parameter water quality instrument at all 10 discrete dissolved oxygen sampling sites by the summer of 2006. Therefore, weekly dissolved oxygen sampling was terminated. However, grab samples for chlorophyll *a*, pheophytin *a*, ammonia, nitrite+nitrate, orthophosphate and organic nitrogen were still collected bi-monthly while the barriers were operational.

Sites

This section presents discrete data from ten sampling sites: one on the downstream side of each barrier, one on the upstream side of each barrier, excluding the Old River at Head, and an additional site located further upstream on each of the main river channels (Old River, Middle River, and Grant Line Canal). Figure 8-1 shows the location of the discrete sampling sites.

Barrier Locations

The Middle River barrier is upstream of the confluence of Middle River, Trapper Slough, and North Canal. The Old River near Delta Mendota Canal (DMC) barrier is eight miles northwest of the town of Tracy and about a mile east of the DMC intake at the Tracy Pumping Plant. The Old River at Head barrier is immediately downstream of the Old and San Joaquin River split. The Grant Line Canal (GLC) barrier is located approximately 400 feet upstream of the Tracy Road Bridge at the east end of the GLC.

The Middle River, Old River at DMC, and Grant Line Canal barriers were installed to improve water circulation and to increase and stabilize water levels in the South Delta during the agricultural season. The Old River at Head barrier was constructed to increase net downstream flows in the lower San Joaquin River to aid salmon smolt migration through the Delta to the Pacific Ocean.

Sampling Methods

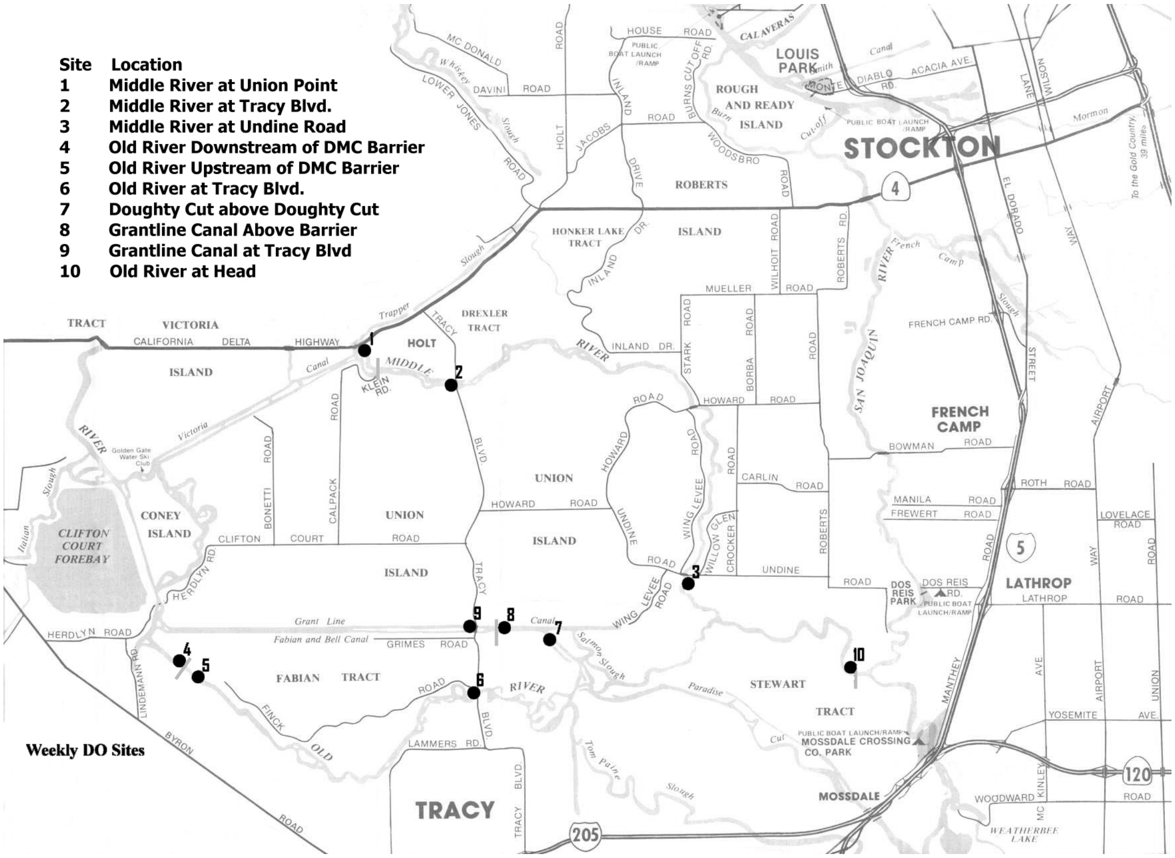
Water sampling was conducted bi-monthly on Tuesday morning between 5:00 AM and 9:00 AM for the entire operational period of the barriers. Grab samples were collected and filtered at each site for analysis at Bryte Lab. Constituents tested for were dissolved ammonia, dissolved nitrite + nitrate, dissolved organic nitrogen, dissolved orthophosphate, chlorophyll *a*, and pheophytin *a.* (See Table 8-1 below).

Table 8-1 Sampling methods and frequency of the water quality constituents measured at each of the 10 discrete water quality sampling sites.

Constituent	Lab Method[1]	Sampling Frequency
Dissolved Ammonia	EPA 350.1	Bi-Monthly
Dissolved Nitrite + Nitrite	Modified Standard Method 4500-NO3-F	Bi-Monthly
Dissolved Organic Nitrogen	EPA 351.2	Bi-Monthly
Dissolved Orthophosphate	Modified EPA 365.1	Bi-Monthly
Chlorophyll a	Standard Method 10200 H, Spectrometric Determination of Chlorophyll	Bi-Monthly
Pheophytin a	Standard Method 10200 H, Spectrometric Determination of Chlorophyll	Bi-Monthly

Dissolved Nitrite + Nitrate and Dissolved Orthophosphate Lab Methods Modified by DWR-Bryte Lab

Figure 8-1. Map of discrete water quality sites



Middle River Barrier

Middle River barrier construction commenced on July 5th and was completed on July 8th. Barrier removal started in mid November and was finished on November 20th. Monitoring of Middle River was conducted at three sites: 1) Undine Road Bridge (site 3) just downstream of the split between Middle and Old Rivers, 2) Tracy Road Bridge over Middle River (site 2), and 3) at Union Point (site 1) immediately downstream of the Middle River barrier. Figures 8-2 and 8-3 depict lab data for Middle River.

Chlorophyll *a*

Chlorophyll a concentrations can be used as a phytoplankton biomass indicator (APHA 1992). Phytoplankton (microscopic algae) occur as unicellular, colonial, or filamentous forms and are primarily grazed upon by zooplankton and other aquatic organisms (APHA 1992). The species composition and/or biomass of phytoplankton may be a useful tool in assessing water quality (APHA 1992). Algae can influence water quality by affecting: pH, dissolved oxygen, turbidity, the color, taste and odor of water, and under certain conditions, some species can develop noxious blooms.

During the summer chlorophyll a concentrations were higher upstream at the Undine Road site than at the downstream monitoring sites, while during the fall concentrations were relatively similar at all three sites. A maximum chlorophyll *a* concentration of 76.4 µg/L was recorded on August 9th at Undine Road. Chlorophyll *a* concentrations in the fall were less than 2.0 µg/L, with a minimum value of 0.41 µg/L measured on November 21st at Union

Point. Average chlorophyll a concentrations at Undine Road, Tracy Road, and Union Point were 11.7 µg/L, 3.3 µg/L, and 1.4 µg/L, respectively.

Pheophytin *a*

As phytoplankton populations decline, chlorophyll *a* degrades into byproducts. Pheophytin *a* is a degradation product of chlorophyll *a*. When phytoplankton are actively growing, the concentrations of pheophytin *a* are normally expected to be low in relation to chlorophyll *a*.

Pheophytin *a* concentrations were highest during the summer, especially at the upstream sites, and lowest during the fall. A maximum pheophytin *a* concentration of 20.4 µg/L was recorded on August 9th at Undine Road. Average pheophytin *a* concentrations at Undine Road, Tracy Road and Union Point were 5.4 µg/L, 2.7 µg/L and 1.2 µg/L, respectively. The pheophytin *a* values were congruent with the chlorophyll *a* concentrations measured in Middle River.

Ammonia

Ammonia is present naturally in surface and wastewaters (APHA 1992). It is produced largely by deamination of organic nitrogen containing compounds and is sometimes used by wastewater treatment plants to react with chlorine (APHA 1992). High ammonia concentrations in natural surface water may indicate contamination from effluent.

Measured ammonia concentrations in Middle River were similar throughout summer and fall, with one exception. On November 9th, a maximum value of 0.32 mg/L was recorded at Undine Road. The values at Tracy Road and Union Point on the same date were 0.04 mg/L and 0.06 mg/L. Mean ammonia concentrations ranged from 0.09 mg/L at Undine Road and Union Point to 0.10 mg/L at Tracy Road. A minimum ammonia concentration of 0.04 mg/L was recorded at both Undine Road and Tracy Road.

Figure 8-2. Middle River: chlorophyll *a*, pheophytin *a*, and ammonia discrete water quality data

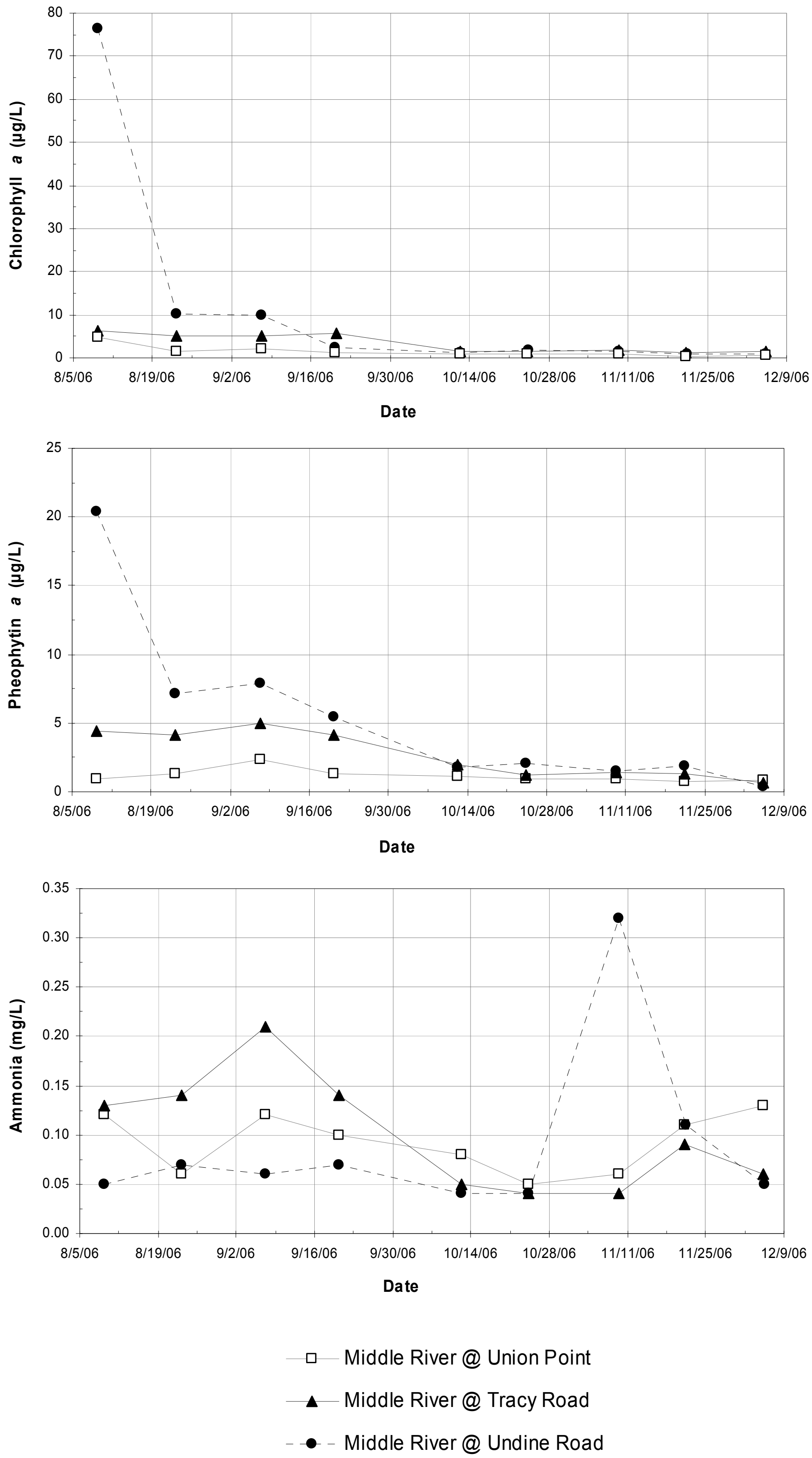
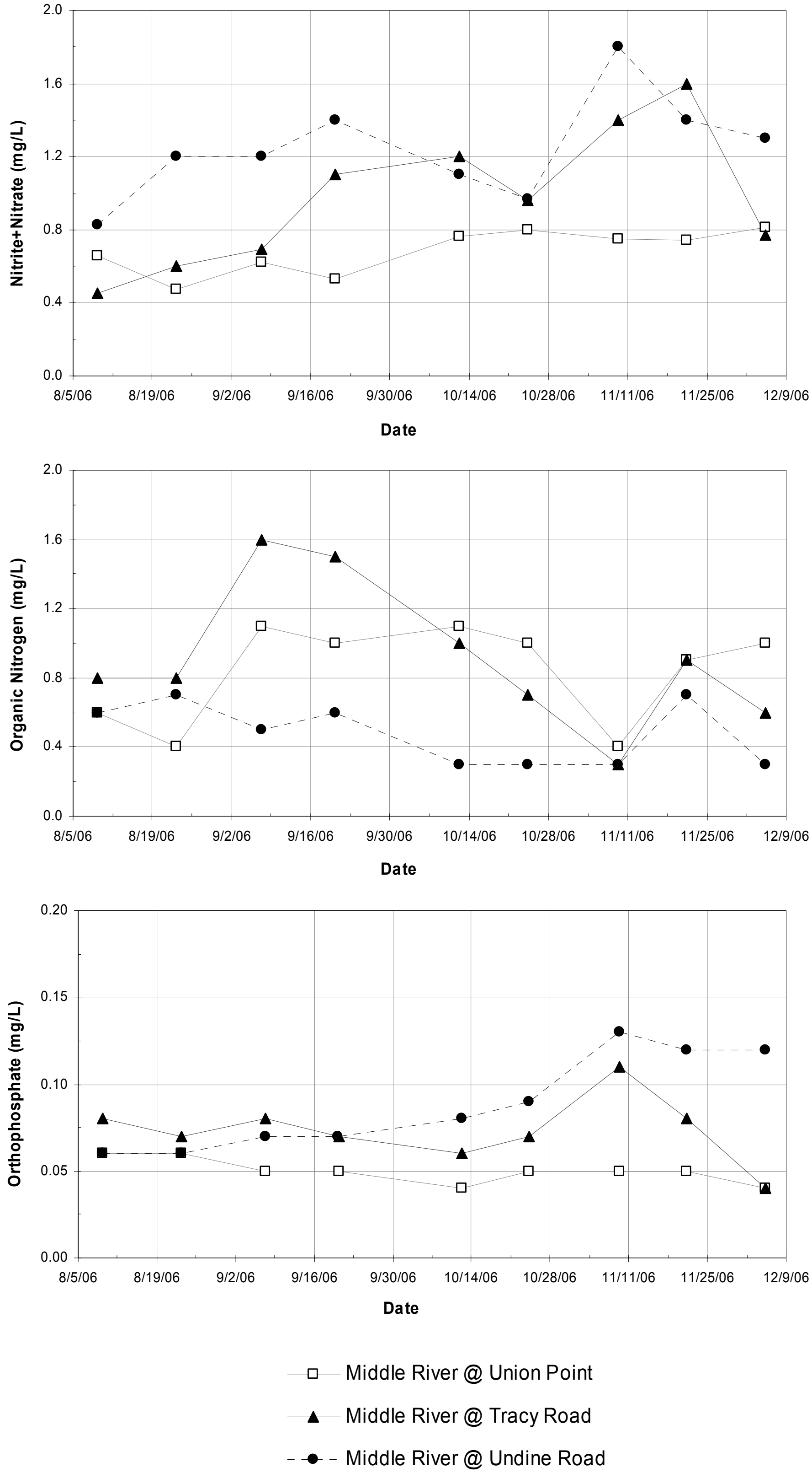


Figure 8-3. Middle River: nitrite + nitrate, organic nitrogen, and orthophosphate discrete water quality data



Nitrite + Nitrate

Total oxidized nitrogen is the sum of nitrate and nitrite nitrogen (APHA 1992). Nitrate is an essential nutrient for many photosynthetic autotrophs and can be a growth-limiting nutrient (APHA 1992). Nitrite is an intermediate oxidation state of nitrogen, both in the oxidation of ammonia to nitrate and in the reduction of nitrate (APHA 1992).

Nitrite-Nitrate concentrations were greater upstream at the Undine Road and Tracy Road sites during late summer and fall. Mean nitrite-nitrate concentrations were 1.24 mg/L and 0.97 mg/L at Undine Road and Tracy Road. Union Point had the lowest recorded nitrite-nitrate concentration in Middle River with an average of 0.68 mg/L. Nitrite-Nitrate values ranged from a minimum of 0.45 mg/L at Tracy Road to a high of 1.80 mg/L at Undine Road. The minimum value recorded at Undine Road was 0.83 mg/L and the maximum value recorded at Union Point was 0.81 mg/L.

Organic Nitrogen

Organic nitrogen is defined functionally as organically bound nitrogen in the trinegative oxidation state (APHA 1992). Organic nitrogen includes such materials as proteins and peptides, nucleic acids and urea, and numerous synthetic organic materials (APHA 1992).

Middle River organic nitrogen values ranged from 0.30 to 1.60 mg/L and were higher in early to mid September. The Undine Road site had the lowest measured organic nitrogen concentrations, with a mean of 0.48 mg/L. Organic nitrogen values were higher near the barrier with averages of 0.91 mg/L at Tracy Road and 0.83 mg/L at Union Point.

Orthophosphate

Phosphorus is essential to phytoplankton growth and can be a limiting nutrient for primary productivity. In cases where phosphate is a limiting factor, the discharge of raw or treated wastewater, agricultural drainage, and/or certain industrial wastes may stimulate the growth of photosynthetic micro- and macro- organisms in nuisance quantities (APHA 1992). Orthophosphates applied to agricultural or residential cultivated land, as fertilizers, are carried into surface water with storm runoff (APHA 1992).

Orthophosphate values were similar at all three sites during the summer, but were higher at the Undine Road site during fall. A maximum value of 0.13 mg/L was recorded on November 9th at Undine Road. Orthophosphate values at Union Point and Tracy Road tracked relatively closely averaging 0.05 mg/L and 0.07 mg/L. The mean concentration upstream at Undine Road was 0.09 mg/L. Values ranged from 0.04 to 0.06 mg/L at Union Point and from 0.04 to 0.11 mg/L at Tracy Road.

Several of the water quality constituents measured in Middle River showed differences between the stations (Union Point and Tracy Road) downstream and upstream of the barrier and the upstream station (Undine Road). Middle River at Undine Road had the highest chlorophyll *a*, pheophytin *a*, nitrite-nitrate, and orthophosphate values. Organic nitrogen concentrations were highest at the sites just upstream and downstream of the barrier. Union Point had the lowest chlorophyll *a*, pheophytin *a,* nitrite-nitrate, and orthophosphate concentrations.

Old River Barrier

Old River near DMC barrier construction commenced on July 7th and was closed on July 17th. Barrier removal started in early November and was finished on December 8th.

Monitoring of Old River was conducted at four sites: 1) Old River at Head (site 10), 2) Tracy Road bridge over Old River (site 6), 3) immediately upstream of the barrier in Old River near DMC (site 5), and 4) immediately downstream of the barrier in Old River near DMC (site 4). Figures 8-4 and 8-5 display the lab data for Old River.

Chlorophyll *a*

Chlorophyll *a* concentrations were comparable at all four sites, expect in early August. On August 9th, maximum values of 59.2 µg/L and 18.6 µg/L were recorded at Old River at Head and Tracy Road, respectively. Values upstream and downstream of the barrier on the same day were 7.26 µg/L and 4.97 µg/L. Median chlorophyll values ranged from 2.56 µg/L downstream of the DMC barrier to 6.57 µg/L at Tracy Road. A minimum chlorophyll *a* value of 1.06 µg/L was recorded on July 21st downstream of the DMC barrier.

Pheophytin *a*

Pheophytin *a* concentrations were higher during the summer when chlorophyll *a* concentrations were higher. A minimum concentration of 1.22 µg/L was recorded on November 21st downstream of the DMC barrier. A maximum of 14.2 µg/L was recorded at both Tracy Road and Old River at Head on August 23rd and August 9th, respectively.

Ammonia

Ammonia concentrations were highest at the Tracy Road site. Values at Tracy Road ranged from 0.11 to 0.24 mg/L, with a mean of 0.17 mg/L. Concentrations upstream at Old River at Head ranged from 0.02 to 0.11 mg/L, with a mean of 0.06 mg/L. The maximum measured ammonia concentration in Middle River was 0.24 mg/L, on August 23rd at Tracy Road. Average ammonia concentrations at the sites upstream and downstream of the DMC barrier were 0.11 mg/L and 0.08 mg/L.

Nitrite + Nitrate

Nitrite-nitrate levels were similar at all four monitoring locations and were higher in the fall. Average nitrite-nitrate concentrations ranged from 1.23 mg/L upstream of the DMC barrier to 1.31 mg/L at Tracy Road. Old River nitrite-nitrate concentrations ranged from a minimum of 0.80 mg/L on August 9th to a maximum of 2.0 mg/L on November 21st, both downstream of the DMC barrier.

Organic Nitrogen

Organic nitrogen concentrations were comparable at all four Old River sites. A minimum organic nitrogen concentration of 0.20 mg/L was measured at both the Old River at Head and Tracy Road sites and a maximum of 1.50 mg/L was recorded downstream of the DMC barrier. Mean organic nitrogen values ranged from 0.60 mg/L at Old River at Head to 0.78 mg/L at both Tracy Road and downstream of the DMC barrier.

Figure 8-4. Old River: chlorophyll *a*, pheophytin *a*, and ammonia discrete water quality data

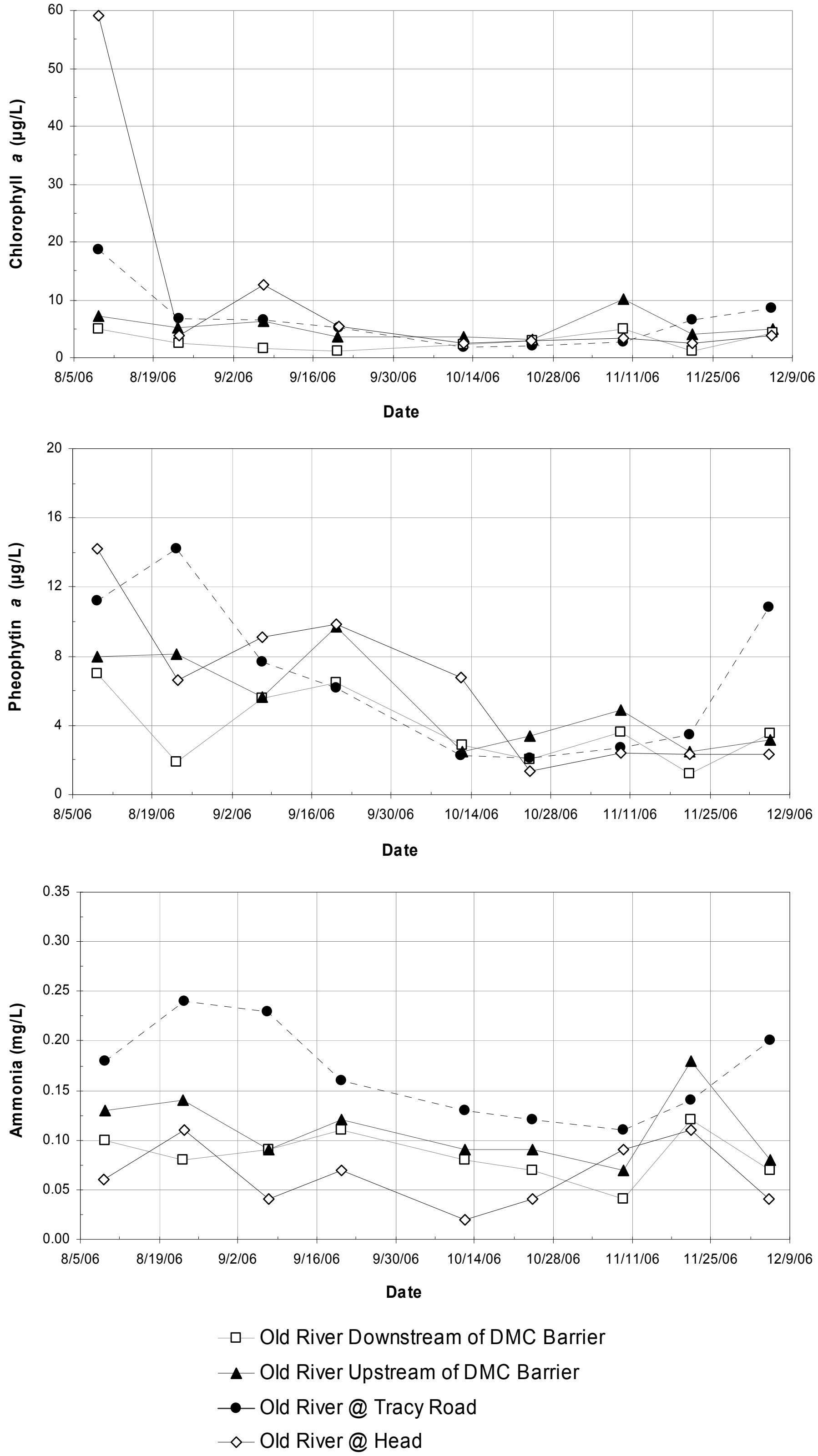
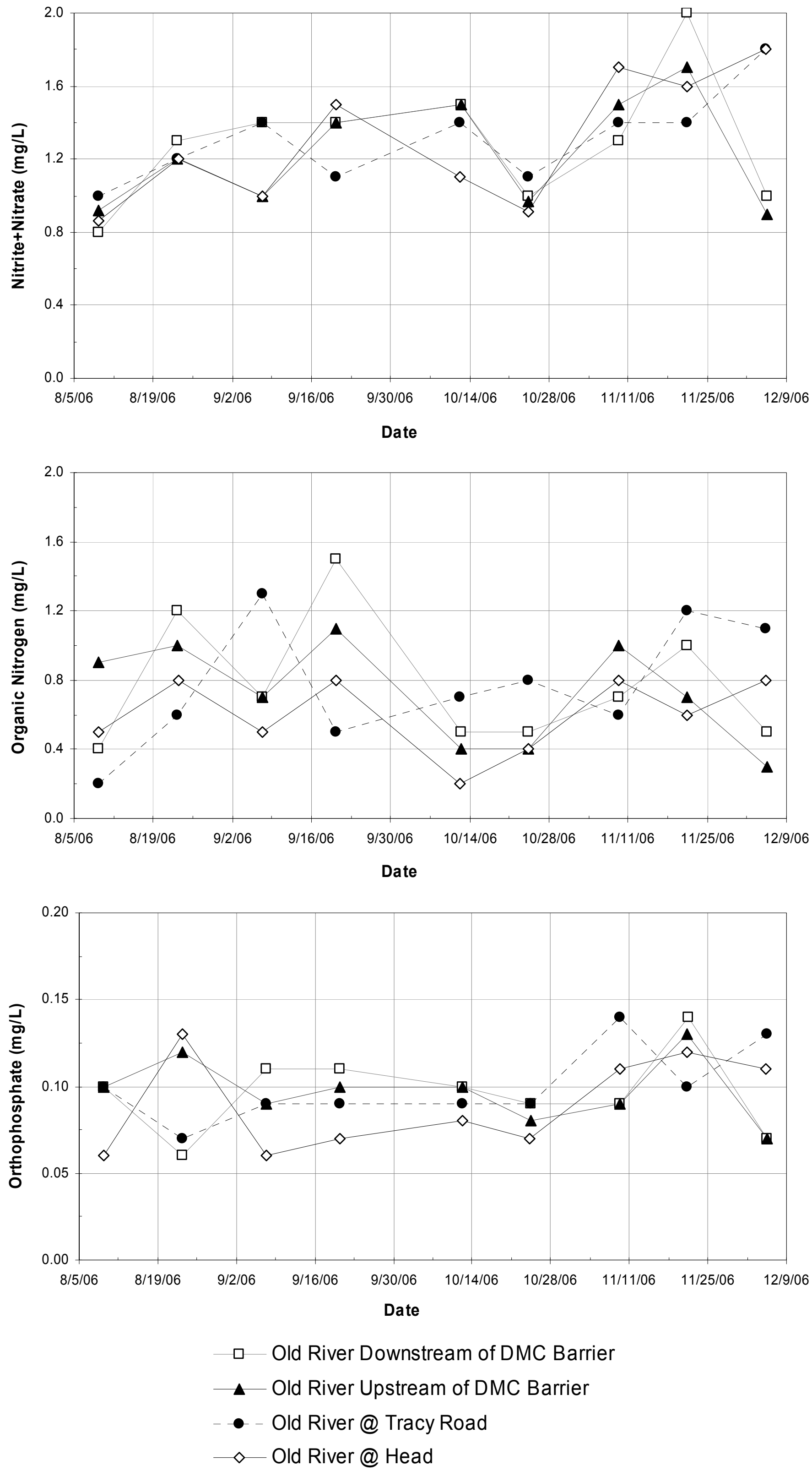


Figure 8-5. Old River: nitrite + nitrate, organic nitrogen, and orthophosphate discrete water quality data



Orthophosphate

Orthophosphate values ranged from 0.06 to 0.14 mg/L and tracked closely at the Old River sites during the summer and fall. Mean values ranged from 0.09 mg/L at the Head of Old River to 0.10 mg/L at the other three monitoring locations.

There were not any notable differences in the water quality constituents at the sites immediately upstream and downstream of the DMC barrier; however, water quality constituents did vary upstream at the Tracy Road and Old River at Head sites. Ammonia concentrations were higher at the Tracy Road site in comparison to the downstream sites near the DMC barrier and the upstream site, Old River at Head. Both the Old River at Head and Tracy Road sites had greater chlorophyll *a* and pheophytin *a* concentrations in early August compared to the sites just upstream and downstream of the DMC barrier.

Grant Line Canal Barrier

Grant Line Canal (GLC) barrier construction commenced on July 7th and was completed on July 26th. Barrier removal started in early November and was finished on December 6th. Monitoring of Grant Line Canal consisted of three sites: 1) in Doughty Cut immediately upstream of Grant Line Canal (site 7), 2) immediately upstream of the barrier (site 8), and 3) Tracy Road bridge over Grant Line Canal (site 9). Figures 8-6 and 8-7 show lab data for Grant Line Canal.

Chlorophyll *a*

Chlorophyll *a* concentrations followed the same general trend at the GLC sites. Algal biomass was highest in GLC from August through early September. Mean chlorophyll *a* values ranged from a high of 11.5 µg/L at GLC Above Barrier to a low of 7.8 µg/L at Tracy Road. A maximum concentration of 68.6 µg/L was recorded on August 9th above the GLC barrier. A minimum value of 0.57 µg/L was recorded on October 24th at Tracy Road.

Pheophytin *a*

Trends in pheophytin *a* concentrations were similar to those seen in chlorophyll *a* concentrations. A maximum pheophytin *a* value of 48.9 µg/L was measured on August 9th and a minimum of 1.28 µg/L was recorded on December 24th, both at Tracy Road.

Ammonia

Ammonia concentrations were lowest in October and highest in August and September. Ammonia concentrations ranged from 0.09 to 0.24 mg/L. The mean ammonia concentration at Doughty Cut was 0.15 mg/L. Mean values above the GLC barrier and at Tracy Road were similar to Doughty Cut, both with means of 0.16 mg/L.

Nitrite + Nitrate

Nitrite-nitrate values ranged from 0.88 to 2.00 mg/L and increased throughout the fall. Mean values ranged from 1.25 mg/L above the GLC barrier to 1.38 mg/L at Tracy Road. Nitrite-nitrate concentrations in GLC tracked closely and there was not much variation between sites.

Figure 8-6. Grant Line Canal: chlorophyll *a*, pheophytin *a*, and ammonia discrete water quality data

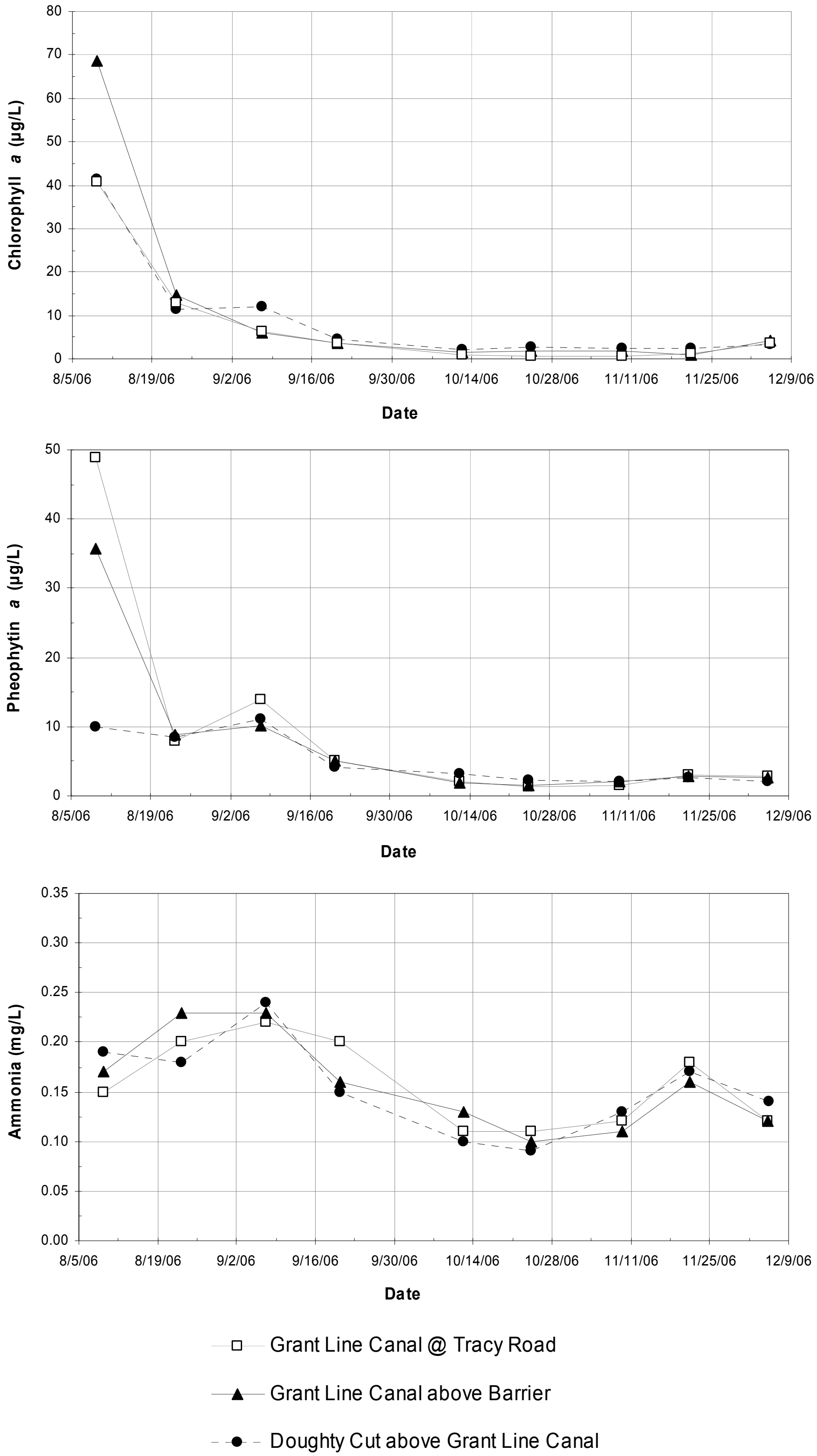
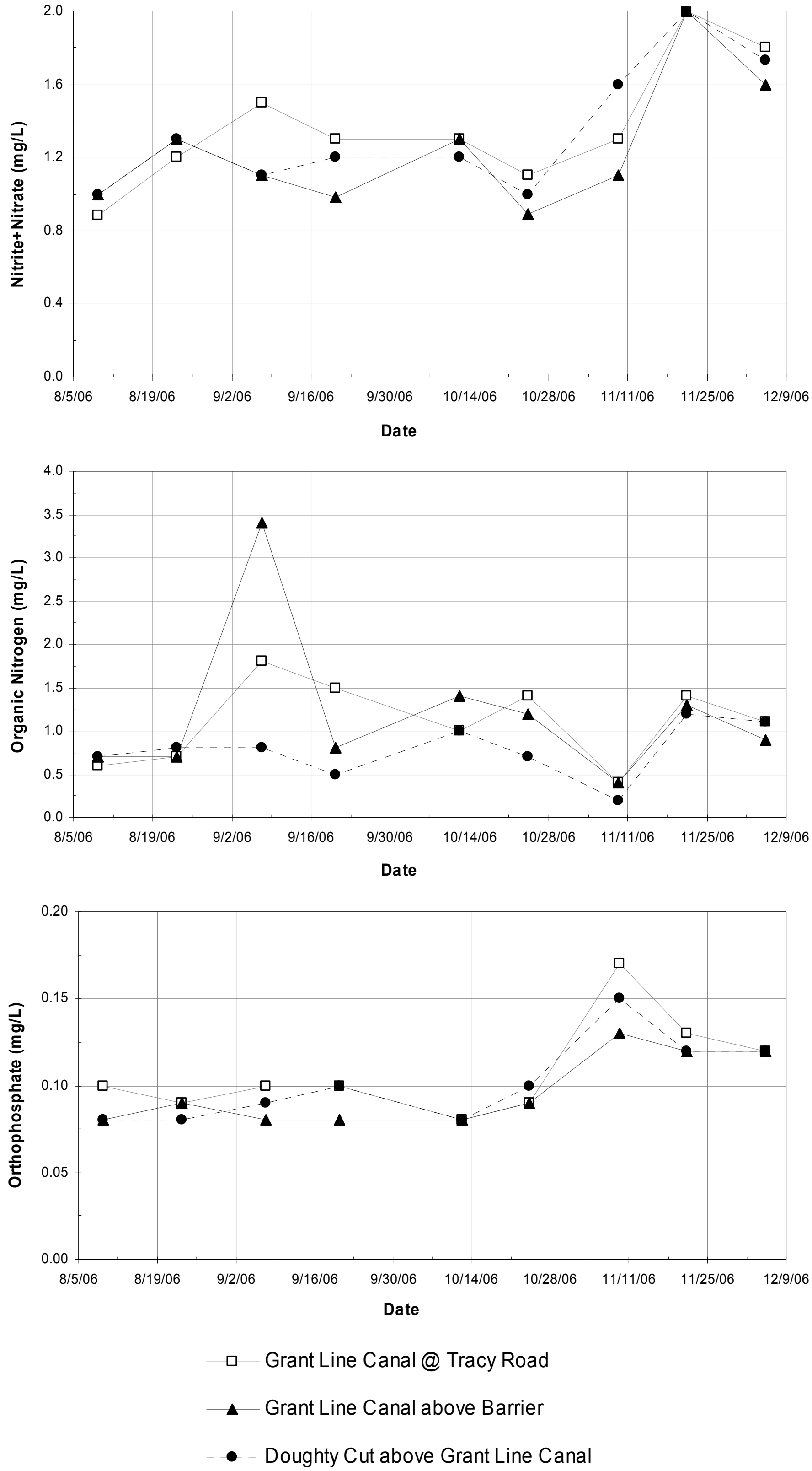


Figure 8-7. Grant Line Canal: nitrite + nitrate, organic nitrogen, and orthophosphate discrete water quality data



Organic Nitrogen

Organic nitrogen values ranged from 0.20 to 3.40 mg/L and did not vary much during the monitoring period, except on September 7th. On September 7th, values ranged from a low of 0.8 mg/L at Doughty Cut to a high of 3.4 mg/L above the GLC barrier. The mean organic nitrogen value at Doughty Cut was 0.78 mg/L. There were only minor differences in organic nitrogen concentrations near the barrier with mean values of 1.20 mg/L and 1.10 mg/L above the GLC barrier and at Tracy Road, respectively.

Orthophosphate

Orthophosphate values were similar at all three stations and increased from late October to mid November. GLC orthophosphate concentrations ranged from 0.08 to 0.17 mg/L. Mean values ranged from 0.10 mg/L at Doughty Cut and GLC Above Barrier to 0.11 mg/L at Tracy Road.

Water quality constituents measured at the three GLC sites tracked closely with each other and did not show any notable differences. Similar to the stations directly upstream and downstream of the DMC barrier, there were only minor differences in the constituents measured at the Grant Line Canal stations directly above (GLC Above Barrier) and below (Tracy Road) the barrier.

Continuous Water Quality Monitoring

Continuous monitoring to evaluate water quality impacts of barrier installations and operations in the South Delta was continued in 2006. This program was established for two reasons: first to determine the feasibility of collecting reliable time-series water quality data as opposed to weekly grab sampling data and second, to develop a dynamic understanding of water quality conditions affected by barrier installations, barrier operations, reservoir releases, forebay gate operations, SWP and CVP pumping operations, agricultural pumping and drainage, municipal effluent loading, hydrology, tidal fluctuations, Delta inflows, as well as other variables.

Continuous monitoring is capable of providing more information to identify variations and trends in water quality constituents over time, as more than 2900 data points (15-minute sampling frequency) can be gathered over a period of a month versus four or five data points from discrete sampling. Such a wealth of data can assist in making more informed decisions in the South Delta. This section presents data from eleven permanent continuous monitoring stations, which record water temperature, dissolved oxygen, pH, specific conductance, turbidity, and chlorophyll data.

Sites

Five new continuous monitoring sites were installed in 2006. These sites were added for three reasons: 1) to develop a better understanding of the water quality conditions directly upstream and downstream of the Middle River, DMC, and Grant Line Canal Barriers, 2) to discern water quality conditions in Grant Line Canal, and 3) to eliminate the need for discrete monitoring on a weekly basis. The District now operates and maintains eleven continuous monitoring stations in the South Delta: four in Middle River, four in Old River and three in Grant Line Canal. (See Figure 8-8 for site locations). Station coordinates are shown below in Table 8-2.

Figure 8-8. Map of South Delta Continuous Water Quality Monitoring sites

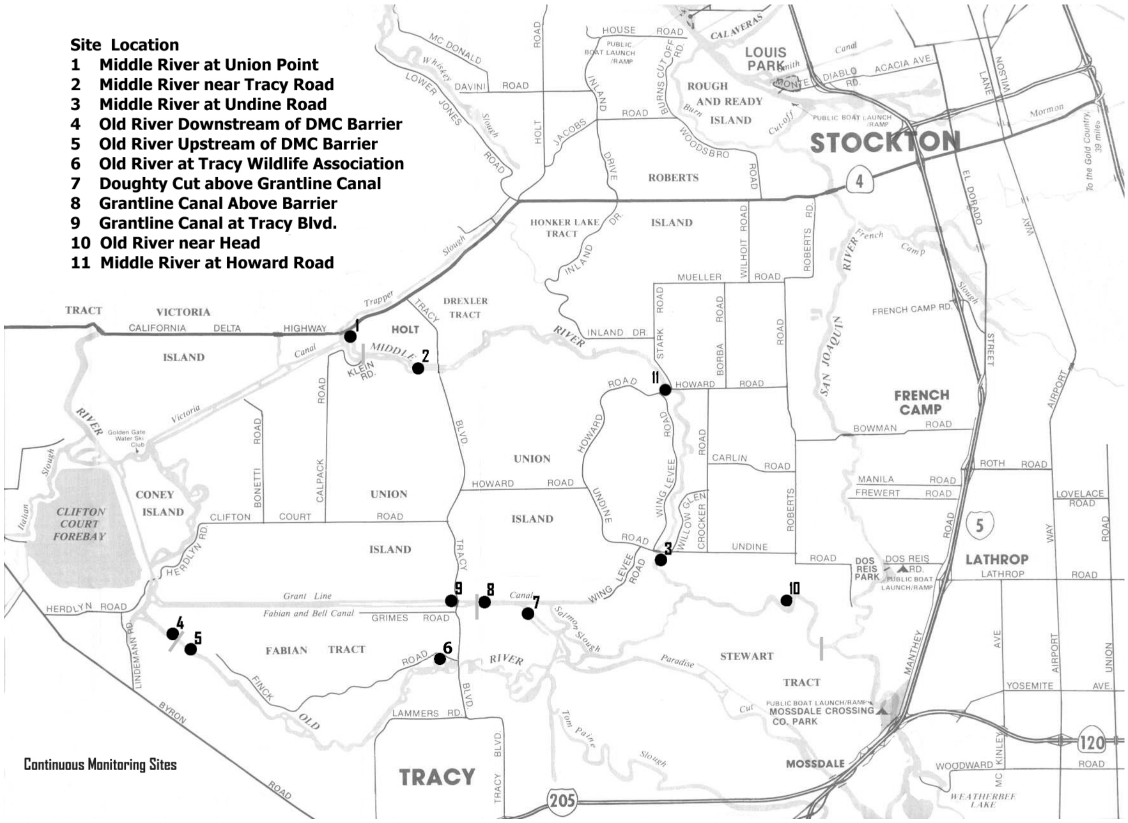


Table 8-2 Continuous Monitoring Station Coordinates

Continuous Monitoring Station	Latitude (N)	Longitude (W)	Year Established
Middle River at Undine Road (Undine Road)	37º 50' 2.4"	121º 23' 08.6"	2002
Middle River at Howard Road (Howard Road)	37º 52' 34.5"	121º 23' 0.1"	1999
Middle River near Tracy Road (Tracy Road)	37º 52' 52.8"	121º 28' 2.7"	2003
Middle River at Union Point (Union Point)	37° 53' 27"	121° 29' 18"	2006
Old River near Head	37º 49' 9.5"	121º 21' 37.2"	2001
Old River at Tracy Wildlife Association (TWA)	37º 48' 10.2"	121º 27' 26.8"	1999
Old River upstream of DMC Barrier	37º 48' 37"	121º 32' 32"	2000
Old River downstream of DMC Barrier	37° 48' 40"	121° 32' 38"	2006
Doughty Cut above Grant Line Canal (Doughty Cut)	37° 48' 53"	121° 25' 30"	2006
Grant Line Canal above Barrier	37° 49' 13"	121° 26' 42"	2006
Grant Line Canal at Tracy Road	37° 49' 12"	121° 27' 00"	2006

Instrumentation

Yellow Springs Instruments (YSI) 6600 “sondes” (continuous multi-parameter water quality monitoring instruments) were operated during the year to gather water quality data in the South Delta. YSI 6600 sondes are approximately two feet long and three and half inches in diameter. They are completely submersible and self-contained, operating on a minimum of 9 volts of battery power from 8 C-cell alkaline batteries. Deployment data are logged in each sonde’s internal memory. Sondes are capable of sampling at many different userspecified frequencies. During 2000, an hourly sampling frequency was used for all stations, approximately 732 samples per month. In 2001, the sampling frequency was changed to a fifteen minute interval, approximately 2920 samples per month.

A sonde can be powered by a new set of batteries from one to three months, depending on three factors: the number of parameters being monitored, the sampling frequency, and the water temperature. However, during the summer months biological growth can foul probes within a week. The dissolved oxygen sensor was the most susceptible to fouling, especially during the summer and fall. Thus, a sonde's deployment period can be limited either by operational style and/or ambient conditions within the water-body under study. In 2003, Central District staff shipped all 6600 sondes back to YSI for an upgrade to the new 6600 EDS (Extended Deployment System) model. The upgrade included a wiper that wipes the dissolved oxygen, pH and conductivity sensors, which reduces the amount of biological fouling on the probes. This has further ensured the collection of accurate and precise data.

For this project, a three-week deployment period was used year-round as our standard for exchanging out 6600 sondes in the South Delta. It is important to note however, that monitoring sites were visited weekly by Central District staff for routine maintenance and field verification of instrument operation. Field equipment used included a YSI-63 handheld unit that measured water temperature, pH, and specific conductance, a HACH Luminescent Dissolved Oxygen (LDO) handheld unit to check dissolved oxygen concentrations, and a HACH 2100P turbidimeter.

Sonde data can be downloaded in the field either by laptop computer or with a YSI-610 or YSI-650 interfacing hand-held unit. Typically, each sonde was exchanged in the field with a newly lab-calibrated instrument, then downloaded and post-deployed in the Central District lab. Post-deployments were performed to determine probe drift and biofouling errors by checking individual probe readings against calibration standards, to verify each probe's accuracy.

Installations

At each monitoring site, a sonde is vertically housed within a 4" diameter PVC pipe in the water column and suspended at a depth of approximately 3 feet. To discourage vandalism the pipes are covered at the top with an end-cap and locked shut with two Masterlocks through two 0.5"- diameter bolts. Installation pipes were drilled with 2.25" diameter holes along the length of the pipe and spaced approximately 8" – 10" on center. Four sets of holes are drilled longitudinally at 90º angles from each other. These holes allow ambient water to adequately contact the sonde sensors to ensure accurate data collection. At each site, the sonde installation pipe is either lag-bolted into an existing float structure (e.g. wooden boat dock), steel-banded to a pump platform durable enough to withstand long-term usage, or bracketed to a pile.

Continuous Monitoring Data

Water year 2006 (October 1st, 2005 – September 30th, 2006) was classified as a wet year for the San Joaquin Valley. Unimpaired runoff was 10.45 million acre-feet and runoff was greatest from April though July. For the Sacramento Valley water year 2006 was classified as a wet year and unimpaired runoff totaled 31.88 million acre-feet. San Joaquin River flows past Vernalis were highest from April to June averaging 24,700 cfs. (See Figure 8-9 for San Joaquin River at Vernalis flow and specific conductance data). (Flow during the same time period in 2005 averaged 10,232 cfs.) Flows were lowest from August through

December averaging about 3,022 cfs. Total daily exports for the Central Valley Project (CVP) and State Water Project (SWP) averaged 7,415 cfs from January to March. In April and May exports were the lowest during the year averaging 3,566 cfs and 3,704 cfs. (See Figure 8-10 for SWP and CVP total daily exports (cfs)). From June through December, daily exports averaged 10,236 cfs. (Note: All CVP and SWP pumping data is preliminary and has not been checked for accuracy.)

Middle River

Water Temperature

Temperature affects pH, specific conductance, the solubility of constituents such as dissolved oxygen, the rate of chemical reactions, and biological activity in water (Radtke et al., 2004). It is also probably the single most important factor affecting fish distribution both between and within estuaries seasonally, although temperature effects are closely tied to the effects of other variables (Moyle and Cech, Jr. 2000)

A maximum water temperature of 33.27 °C was recorded on July 25th at 15:45 PST at Tracy Road and a minimum of 5.52 °C was recorded on December 30th at 9:00 PST at Howard Road. (See Figure 8-11). Tables 8-3 and 8-4 provide a basic statistical summary of the 2006 water quality data collected for Middle River. A visual comparison of the 2006 water temperature plots for each of the four Middle River monitoring sites reveals similar trends. This would seem reasonable, as all four sites are located within 10 miles of each other and thus are subject to relatively similar meteorological conditions throughout the year. The finer perturbations of water temperatures at each site are related to site-specific conditions (water volume, flow, etc.). Temperature patterns at the Middle River sites followed seasonal trends, with the highest temperatures occurring in summer and the lowest in late fall and winter. Monthly mean temperatures were highest in July ranging from 24.29 °C at Undine Road to 26.52 °C at Middle River near Tracy Road and lowest in December ranging from 8.37 °C at Howard Road to 9.67 °C at Union Point. The mean temperatures for the monitoring period ranged from 16.13 °C at Undine Road to 18.18 °C at Union Point. It should be noted that the higher mean temperature at Union Point is primarily the result of not having a complete data set, since the station was not installed until February 23rd, 2006. Also, there is no April or May data at Howard Road because the site had to be reinstalled due to a broken pipe.

In 2005, water temperatures ranged from a minimum of 7.61°C (December) to a maximum of 29.58°C (July). Mean temperatures for the monitoring period ranged from 16.70 °C to 17.40 °C.

Figure 8-9. San Joaquin River at Vernalis: hourly flow and specific conductance data

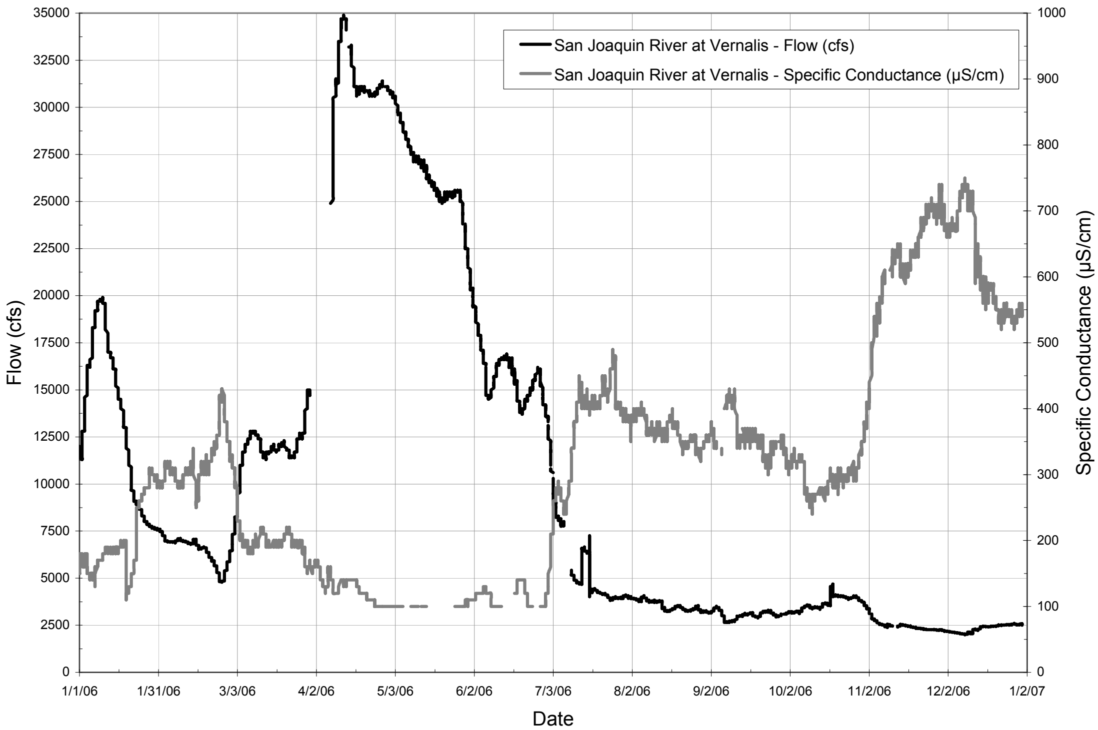


Figure 8-10. Total daily exports: State Water Project + Central Valley Project

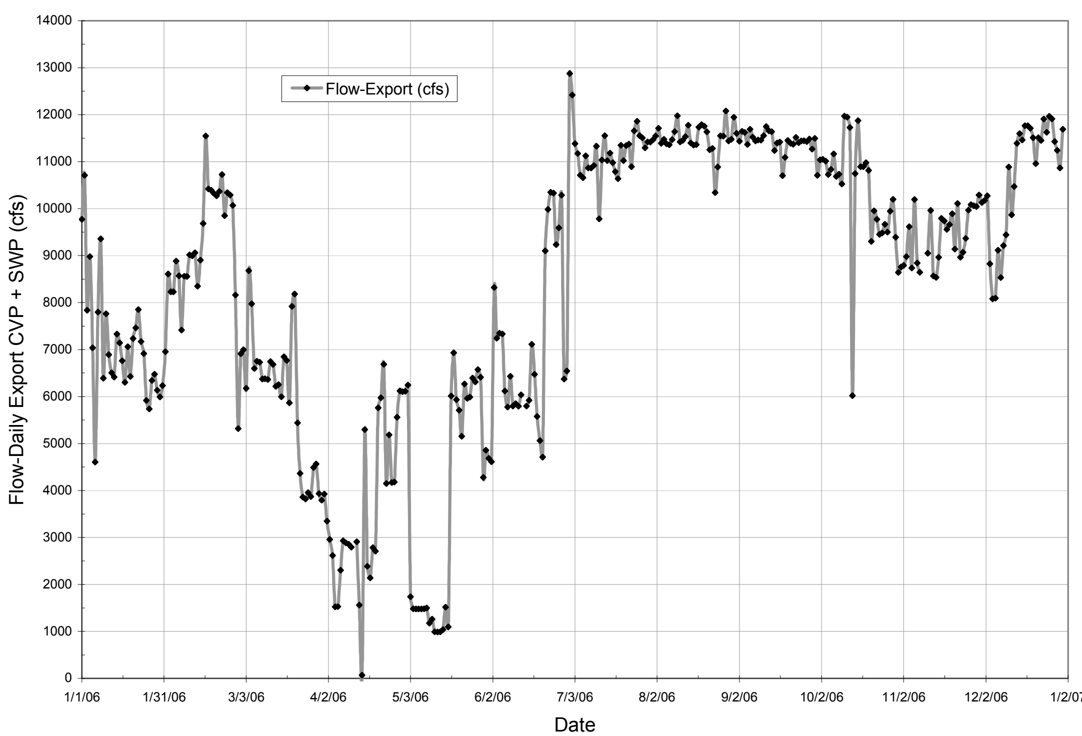


Figure 8-11. Middle River: water temperature data (15-minute intervals)

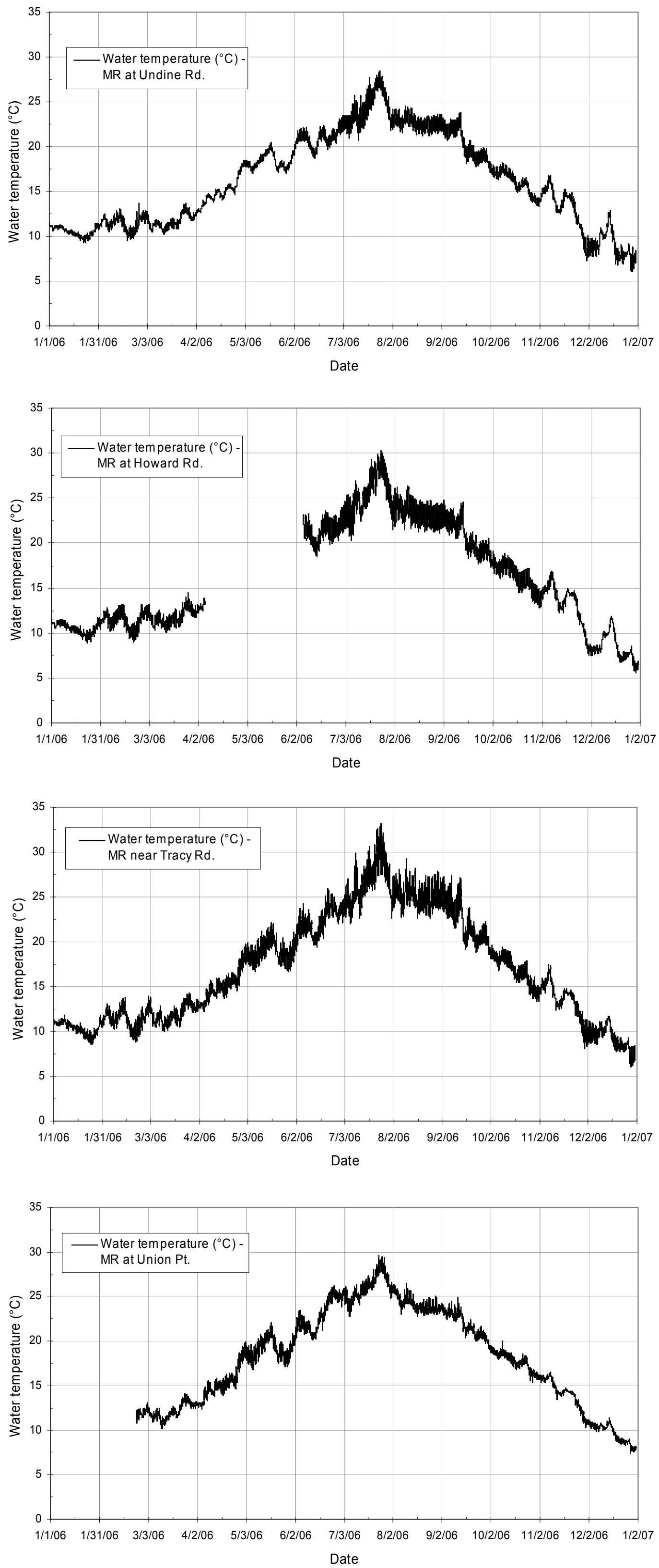


Table 8-3. Statistical summary of 2006 Middle River continuous water quality data: water temperature, dissolved oxygen and pH

Month	Water Temperature (°C)			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	11.54	11.75	11.76	-
Feb.	13.65	13.20	13.82	12.49
Mar	13.65	14.45	14.32	14.11
Apr	18.15	-	19.46	19.40
May	20.43	-	22.14	22.05
Jun	23.05	23.95	25.92	26.21
Jul	28.50	30.22	33.27	29.57
Aug	24.52	26.38	29.30	26.61
Sep	23.82	24.84	27.35	24.91
Oct	18.28	19.11	19.63	20.03
Nov	16.79	16.81	17.55	16.59
Dec	12.81	11.91	11.71	11.40
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	10.50	10.48	10.36	-
Feb.	11.39	11.40	11.28	11.81
Mar	11.63	11.73	11.94	12.14
Apr	14.67	-	14.87	14.96
May	18.31	-	18.89	19.11
Jun	20.75	21.21	22.19	22.71
Jul	24.29	25.54	26.52	26.04
Aug	22.67	23.42	25.01	24.18
Sep	20.48	20.93	22.20	21.95
Oct	16.13	16.40	16.95	17.84
Nov	13.50	13.46	13.69	14.32
Dec	8.97	8.37	9.24	9.67
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	9.27	8.95	8.59	-
Feb.	9.58	9.02	8.77	10.77
Mar	10.22	10.10	9.97	10.22
Apr	11.86	-	12.26	12.32
May	17.01	-	16.62	16.79
Jun	18.69	18.51	18.49	19.50
Jul	20.72	20.33	22.01	22.74
Aug	21.20	21.11	22.61	22.80
Sep	17.75	17.67	18.81	19.68
Oct	13.42	12.86	13.37	15.32
Nov	7.83	7.67	8.07	10.32
Dec	6.02	5.52	6.04	7.38
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	0.51	0.59	0.67	-
Feb.	0.77	0.93	1.02	0.33
Mar	0.74	0.86	0.92	0.81
Apr	1.31	-	1.49	1.49
May	0.75	-	1.18	1.04
Jun	0.93	1.17	1.44	1.79
Jul	1.88	2.16	2.26	1.29
Aug	0.75	1.15	1.19	0.84
Sep	1.65	1.83	2.01	1.25
Oct	1.23	1.40	1.45	0.93
Nov	1.90	1.96	1.72	1.44
Dec	1.37	1.39	1.25	1.02
2006 - Max.	28.50	30.22	33.27	29.57
2006 - Avg.	16.13	16.17	16.96	18.18
2006 - Min.	6.02	5.52	6.04	7.38
2006 - S.D.	5.08	5.93	5.90	5.35

Month	Dissolved Oxygen (mg/L)			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	11.80	12.05	11.25	-
Feb.	12.62	13.07	11.42	10.49
Mar	12.26	12.37	11.28	11.26
Apr	11.12	-	10.66	10.22
May	9.01	-	10.20	8.72
Jun	9.60	10.63	9.96	8.45
Jul	15.30	14.74	9.91	8.81
Aug	12.87	13.57	11.97	8.69
Sep	11.16	9.55	12.15	9.30
Oct	9.77	10.51	11.43	9.68
Nov	11.25	12.18	12.21	13.79
Dec	12.98	13.67	13.53	13.40
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	10.69	10.64	9.60	-
Feb.	10.90	10.98	9.40	10.01
Mar	11.12	11.23	10.19	10.35
Apr	8.06	-	8.48	8.20
May	7.49	-	7.77	7.73
Jun	8.19	8.50	7.46	6.70
Jul	9.60	8.45	6.62	6.45
Aug	9.15	9.26	5.96	7.32
Sep	8.77	8.19	7.93	7.60
Oct	8.83	9.15	9.06	8.40
Nov	8.85	9.29	9.93	10.42
Dec	10.48	11.54	11.30	11.03
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	9.03	9.32	7.95	-
Feb.	9.76	9.17	7.87	9.00
Mar	9.99	9.76	8.50	9.42
Apr	6.73	-	7.04	6.62
May	6.72	-	5.29	6.28
Jun	6.94	7.41	5.06	5.08
Jul	6.43	3.05	3.86	5.27
Aug	7.37	5.24	0.38	5.74
Sep	7.25	6.58	4.91	5.89
Oct	7.97	6.70	6.26	6.20
Nov	7.45	7.04	8.23	7.32
Dec	8.47	9.26	9.76	9.65
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	0.62	0.72	0.60	-
Feb.	0.51	0.80	0.78	0.25
Mar	0.44	0.42	0.45	0.28
Apr	1.16	-	0.76	0.86
May	0.58	-	0.66	0.33
Jun	0.30	0.47	0.90	0.77
Jul	2.02	1.86	0.99	0.44
Aug	1.20	1.74	1.59	0.40
Sep	0.71	0.66	1.11	0.45
Oct	0.42	0.61	0.84	0.47
Nov	0.59	0.99	0.85	0.94
Dec	0.86	0.75	0.53	0.92
2006 - Max.	15.30	14.74	13.53	13.79
2006 - Avg.	9.34	9.86	8.68	8.45
2006 - Min.	6.43	3.05	0.38	5.08
2006 - S.D.	1.47	1.54	1.77	1.67

Month	pH			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	7.76	7.65	7.53	-
Feb.	7.91	8.40	8.04	7.77
Mar	7.81	7.84	7.81	7.80
Apr	7.64	-	7.59	7.52
May	7.34	-	7.96	7.54
Jun	7.47	7.55	7.87	7.58
Jul	9.35	9.33	8.21	7.50
Aug	8.97	8.99	8.56	7.63
Sep	8.25	8.00	8.05	7.77
Oct	7.69	7.86	8.40	7.70
Nov	7.86	8.36	8.36	8.18
Dec	8.16	8.57	8.31	8.01
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	7.47	7.47	7.28	-
Feb.	7.68	7.73	7.51	7.52
Mar	7.65	7.56	7.56	7.59
Apr	7.27	-	7.31	7.29
May	7.16	-	7.31	7.18
Jun	7.32	7.27	7.15	6.93
Jul	7.64	7.52	7.15	7.09
Aug	7.95	7.72	7.24	7.33
Sep	7.67	7.58	7.44	7.39
Oct	7.49	7.58	7.65	7.48
Nov	7.58	7.74	7.84	7.62
Dec	7.77	8.11	7.81	7.65
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	7.20	7.37	7.11	-
Feb.	7.53	7.21	7.26	7.37
Mar	7.52	7.33	7.38	7.39
Apr	7.12	-	7.13	7.13
May	7.06	-	7.14	7.01
Jun	7.17	7.10	6.85	6.42
Jul	7.12	7.05	6.92	6.96
Aug	7.58	7.25	6.98	7.13
Sep	7.49	7.29	7.02	7.14
Oct	7.38	7.22	7.30	7.22
Nov	7.33	7.44	7.57	7.24
Dec	7.56	7.49	7.58	7.33
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	0.12	0.05	0.07	-
Feb.	0.08	0.19	0.16	0.10
Mar	0.07	0.08	0.06	0.06
Apr	0.13	-	0.12	0.08
May	0.06	-	0.08	0.09
Jun	0.06	0.09	0.15	0.20
Jul	0.65	0.58	0.14	0.07
Aug	0.34	0.35	0.22	0.08
Sep	0.15	0.14	0.18	0.11
Oct	0.04	0.11	0.17	0.07
Nov	0.08	0.22	0.17	0.15
Dec	0.10	0.16	0.11	0.12
2006 - Max.	9.35	9.33	8.56	8.18
2006 - Avg.	7.50	7.59	7.39	7.29
2006 - Min.	7.06	7.05	6.85	6.42
2006 - S.D.	0.35	0.33	0.27	0.25

Table 8-4. Statistical summary of 2006 Middle River continuous water quality data: specific conductance, turbidity and chlorophyll *a*

Month	Specific Conductance (µS/cm)			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	405.2	645.6	482.1	-
Feb.	511.2	737.8	564.8	459.4
Mar	384.4	566.5	579.0	523.3
Apr	215.2	-	292.3	305.9
May	129.0	-	174.3	192.0
Jun	173.7	224.0	228.2	249.8
Jul	534.6	822.7	422.8	246.2
Aug	446.4	711.0	552.4	320.6
Sep	469.2	620.4	539.0	361.3
Oct	381.2	566.0	445.0	345.9
Nov	796.6	865.8	695.0	584.6
Dec	797.8	918.8	664.2	495.1
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	245.2	269.9	292.6	-
Feb.	378.3	419.5	437.4	319.2
Mar	255.7	252.2	287.4	292.9
Apr	159.3	-	187.8	196.7
May	115.3	-	138.2	141.5
Jun	127.7	138.9	165.4	173.4
Jul	382.7	414.0	237.1	192.4
Aug	406.2	428.0	418.0	251.2
Sep	392.0	405.0	425.4	263.0
Oct	322.8	330.1	343.5	260.0
Nov	650.4	646.4	517.3	318.0
Dec	682.0	684.1	412.3	377.9
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	159.8	186.2	187.5	-
Feb.	313.0	301.2	314.5	283.4
Mar	199.3	177.0	192.0	208.0
Apr	125.1	-	135.2	134.6
May	103.1	-	115.9	114.3
Jun	100.3	106.6	125.5	135.4
Jul	124.5	135.4	140.1	151.4
Aug	364.4	370.5	231.4	209.5
Sep	336.8	343.5	262.4	235.0
Oct	275.0	277.4	276.6	239.9
Nov	359.6	352.7	309.0	255.9
Dec	577.0	400.1	341.0	328.3
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	62.9	68.0	66.3	-
Feb.	39.2	74.4	40.7	38.6
Mar	37.1	52.9	69.4	35.1
Apr	22.7	-	27.0	30.5
May	7.0	-	9.7	12.6
Jun	14.7	18.8	20.3	16.7
Jul	97.8	110.5	42.3	21.0
Aug	16.2	30.2	84.3	12.4
Sep	31.2	34.9	53.1	13.5
Oct	25.7	33.8	38.2	12.6
Nov	104.4	109.7	123.1	42.7
Dec	70.7	107.0	53.8	38.1
2006 - Max.	797.8	918.8	695.0	584.6
2006 - Avg.	343.0	399.7	320.9	248.1
2006 - Min.	100.3	106.6	115.9	114.3
2006 - S.D.	183.6	174.0	131.6	73.5

Month	Turbidity (NTU)			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	83.8	80.6	53.7	-
Feb.	64.5	15.6	47.7	21.3
Mar	57.5	58.7	40.2	27.3
Apr	148.1	-	65.7	49.6
May	35.6	-	45.2	28.9
Jun	80.9	58.7	111.4	30.3
Jul	169.8	152.9	122.4	56.9
Aug	41.4	137.8	183.8	170.4
Sep	60.4	141.8	179.4	22.4
Oct	44.6	25.3	53.2	13.7
Nov	106.2	83.6	176.9	174.5
Dec	195.1	115.5	150.5	41.3
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	21.2	19.6	14.5	-
Feb.	6.3	6.4	5.9	7.8
Mar	17.0	16.4	11.2	6.6
Apr		-	21.8	17.3
May	7.4	-	17.2	12.8
Jun	19.9	27.6	24.3	15.7
Jul	28.5	40.8	24.9	7.1
Aug	22.3	26.9	24.1	12.3
Sep	19.4	14.0	41.6	6.4
Oct	14.8	10.8	17.0	4.6
Nov	10.2	7.5	13.0	4.0
Dec	7.7	5.6	9.0	3.8
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	2.7	5.1	4.4	-
Feb.	2.1	3.0	1.0	3.3
Mar	8.7	6.5	4.5	0.9
Apr	2.1	-	7.2	4.3
May	3.6	-	7.2	5.3
Jun	7.8	12.2	11.5	6.8
Jul	13.8	16.6	7.9	-6.5
Aug	12.2	10.8	8.4	-6.4
Sep	10.2	7.8	7.8	2.2
Oct	7.5	6.2	7.3	1.4
Nov	3.5	3.8	2.3	1.5
Dec	2.0	2.9	2.6	1.2
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	12.6	13.0	9.4	-
Feb.	2.9	1.3	3.1	2.7
Mar	5.8	6.5	3.8	3.2
Apr	15.4	-	10.6	8.4
May	1.8	-	5.3	3.8
Jun	6.5	6.0	8.3	4.0
Jul	9.2	18.3	13.1	7.9
Aug	5.0	12.4	13.9	22.6
Sep	5.2	4.7	23.7	2.2
Oct	3.7	2.1	4.4	1.7
Nov	1.9	3.0	11.9	3.6
Dec	6.0	3.0	10.0	1.9
2006 - Max.	195.1	157.4	183.8	174.5
2006 - Avg.	16.1	17.3	18.5	9.0
2006 - Min.	2.0	2.9	1.0	-6.5
2006 - S.D.	10.1	13.6	14.2	9.1

Month	Chlorophyll a (µg/L)			
MAXIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	11.4	73.0	-	-
Feb.	25.2	18.5	10.1	7.3
Mar	18.8	22.4	14.1	21.3
Apr	41.3	-	24.0	9.5
May	30.7	-	16.1	26.9
Jun	42.2	33.2	73.0	38.8
Jul	218.2	168.4	74.9	39.8
Aug	95.2	89.2	96.9	182.3
Sep	49.2	30.9	95.5	58.5
Oct	19.2	9.3	39.8	24.6
Nov	13.7	23.9	59.4	16.7
Dec	28.0	24.7	33.6	15.1
AVERAGES	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	-1.3	4.5	-	-
Feb.	0.5	1.6	2.6	3.3
Mar	5.3	7.1	2.8	3.2
Apr	13.5	-	9.2	5.3
May	5.1	-	5.4	3.6
Jun	18.7	14.4	12.5	7.3
Jul	59.1	46.8	8.4	5.1
Aug	38.2	28.2	26.1	19.6
Sep	19.4	4.4	15.6	2.8
Oct	2.2	0.4	3.5	1.9
Nov	-8.3	1.1	3.5	1.2
Dec	-2.0	1.4	3.5	1.9
MINIMUMS	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	-8.4	-3.5	-	-
Feb.	-9.3	-5.4	-1.3	1.9
Mar	-11.6	-5.0	-1.7	1.1
Apr	-4.3	-	1.7	1.7
May	-6.6	-	1.2	1.4
Jun	3.1	3.1	3.7	2.7
Jul	8.6	8.9	-0.01	0.8
Aug	7.2	-0.8	2.0	0.2
Sep	1.3	-3.5	-0.01	0.5
Oct	-7.5	-6.2	-1.3	-1.6
Nov	-15.3	-5.0	-1.5	-0.9
Dec	-15.80	-5.00	-0.5	-1.4
STD. DEVS.	UNDINE	HOWARD	TRACY	UNION PT.
Jan.	2.7	3.8	-	-
Feb.	4.0	2.2	1.5	0.7
Mar	2.7	6.0	1.9	1.9
Apr	7.8	-	3.1	1.6
May	7.5	-	2.7	1.6
Jun	6.5	4.9	4.9	2.6
Jul	43.4	32.7	5.0	2.4
Aug	21.5	21.6	17.6	26.3
Sep	9.4	3.6	14.0	1.9
Oct	4.9	2.3	2.5	1.0
Nov	3.4	2.3	3.3	0.6
Dec	6.8	2.5	2.2	0.9
2006 - Max.	218.2	168.4	96.9	182.8
2006 - Avg.	12.8	11.2	8.4	5.1
2006 - Min.	-15.8	-6.2	-1.7	-1.6
2006 - S.D.	24.1	19.5	9.9	9.6

Dissolved Oxygen

One of the most important measures of water quality is the amount of dissolved oxygen (Masters 1996).

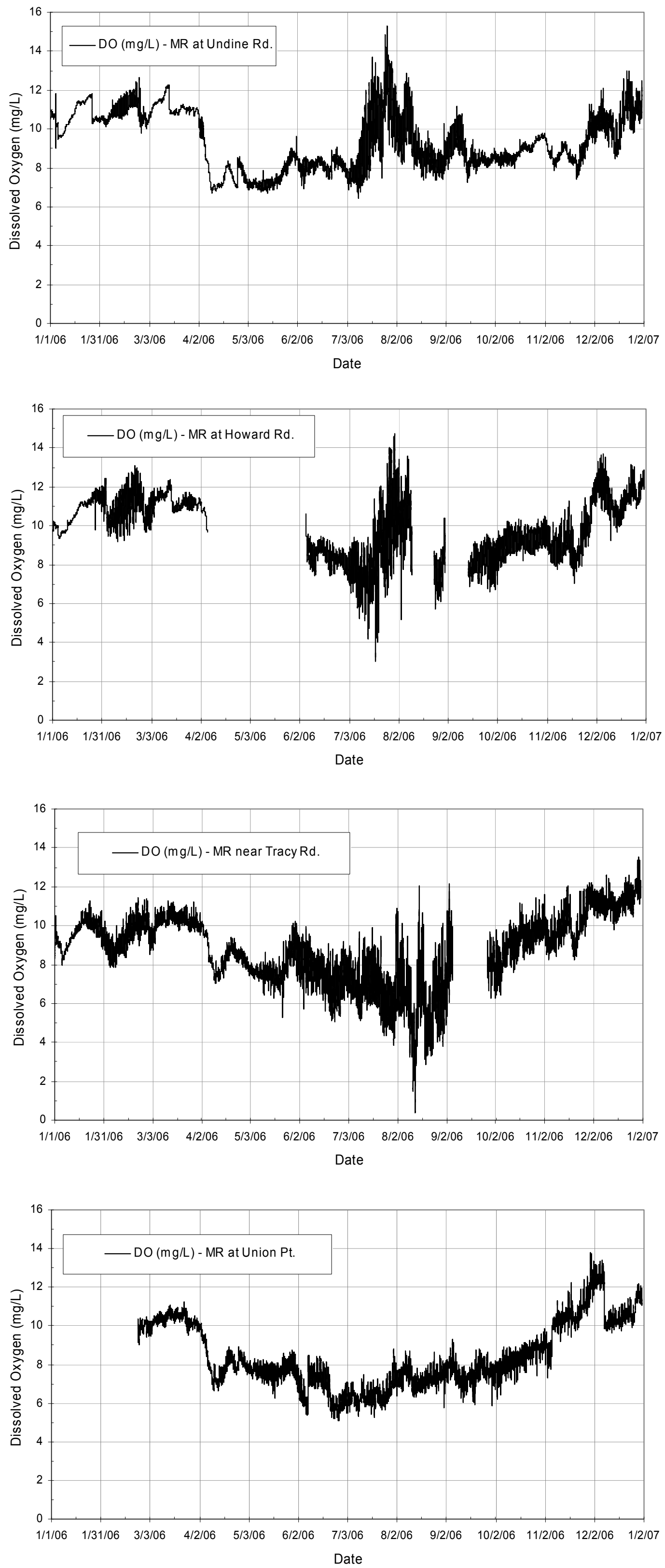
The USEPA has established National Ambient Water Quality Criteria for inorganic constituents, such as dissolved oxygen to protect freshwater aquatic life. However, there is considerable variability in dissolved oxygen tolerances among fish and other aquatic life. For a warm water system like the Delta, dissolved oxygen criteria for early aquatic life stages (embryos, larvae, and less than 30-day old juveniles) was set at 5 mg/L, and 3 mg/L for other life stages (older juveniles and adults). (Marshack 2000). Sources of dissolved oxygen in surface waters are primarily atmospheric reaeration and photosynthetic activity of aquatic plants (Lewis, 2005). Dissolved oxygen saturation is inversely related to water temperature (i.e. as water temperature increases, dissolved oxygen saturation decreases). Super saturated dissolved oxygen conditions can occur as a result of excess photosynthetic production of oxygen by phytoplankton and/or aquatic plants. The depletion of dissolved oxygen can occur by inorganic oxidation reactions or by biological or chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

Dissolved oxygen (DO) data for the Middle River sites during 2006 is plotted in Figure 8-12. A maximum DO concentration of 15.30 mg/L was measured on July 27th at 15:15 PST at Undine Road a minimum of 0.38 mg/L was recorded on August 13th at 7:00 PST at Tracy Road. There were 55 (Howard Road) and 916 (Tracy Road) instances where the sonde(s) recorded DO concentrations less than 5 mg/L. There were no DO concentrations below 5 mg/L at Undine Road or Union Point. The lowest monthly mean DO was 5.96 mg/L in August at Tracy Road and the highest was 11.54 mg/L in December at Howard Road. Overall, mean DO concentrations for Middle River ranged from 8.45 mg/L at Union Point to 9.86 mg/L at Howard Road.

During the late spring through early fall, DO concentrations showed marked diel variation at Undine Road, Howard Road and Tracy Road. During a typical summer day, DO concentrations reached a maximum in the late afternoon and a minimum during the early morning. Diel variation in dissolved oxygen concentrations is likely due to algal photosynthesis and respiration and water temperature variation. Supersaturated dissolved oxygen concentrations were observed in the summer at all of the Middle River sites, except Union Point. In the winter and fall there was less pronounced diel variation in DO values, which may be to due to the fact there is less daily variation in water temperature and generally, lower chlorophyll a concentrations (less algal biomass) during the colder months.

In 2005, DO concentrations were lower and there were more instances where dissolved oxygen readings were less than 5 mg/L than in 2006. There were 51 (Undine Road), 915 (Howard Road), and 3,271 (Tracy Road) instances were the sonde(s) recorded DO concentrations less than 5 mg/L. The higher dissolved oxygen concentrations recorded in 2006 were likely the result of unseasonably high flows in the San Joaquin River.

Figure 8-12. Middle River: dissolved oxygen data (15-minute intervals)



pH

pH is a measure of the hydrogen ion concentration [H+] of a solution. pH values range from 1 to 14 with values less than 7 considered acidic and values greater than 7 considered basic. Since the pH scale is logarithmic; a pH value of 7 is ten times greater than a pH value of 6 and one hundred times greater than a value of 5. Natural waters usually have pH values in the range of 4 to 9, and most are slightly basic (APHA 1992). The USEPA recommended criterion for pH is an instantaneous maximum between 6.5 and 9.0 (Marshack 2000).

Figure 8-13 depicts 2006 pH data in Middle River. Similar to water temperature and dissolved oxygen data, pH data at Undine Road and Howard Road exhibited greater diel fluctuations during summer through early fall and noticeably less during late fall and winter. This is likely a direct function of algal productivity, in that, as algae consume CO2 from water, they produce dissolved oxygen as a byproduct of photosynthesis. Less CO2 in the water drives the pH higher, as the water becomes more alkaline. pH values at Tracy Road tended to have greater diel fluctuation in the summer and fall versus spring and winter. There was no observable diel variation at Union Point. Recorded pH data ranged from a high of 9.35 on July 27th at 16:30 PST at Undine Road to a low of 6.42 on June 8th at 10:45 PST at Tracy Road. There were 207 and 126 pH values greater than 9.0 recorded at Undine Road and Howard Road. Maximum values of 8.56 and 8.18 were recorded at Tracy Road and Union Point. Mean pH values ranged from 7.29 at Union Point to 7.59 at Howard Road.

In 2005, pH values ranged from 6.73 to 9.01. There were four pH values greater than 9.0 recorded at Undine Road.

Specific Conductance

Conductivity is a measure of the ability of an aqueous solution to carry an electrical current (APHA 1992). Specific conductance values are temperature compensated to 25 ºC and can be used to estimate salinity and total dissolved solids. (Wagner et al., 2006) Specific conductance is of vital importance in the South Delta because the water is used for irrigation. High amounts of dissolved salts in irrigation water can result in crop damage and reduced yield. The USEPA recommended that the agricultural water limit for specific conductance not exceed 700 µS/cm (Marshack 2000).

Specific conductance data for the Middle River sites is shown in Figure 8-14. A maximum of 918.8 µS/cm was recorded on December 8th at Howard Road. The minimum recorded specific conductance was 100.3 µS/cm on June 27th at Undine Road. Mean values for the monitoring period ranged from 248.1 µS/cm at Union Point to 399.7 µS/cm at Howard Road. Howard Road had spikes in specific conductance throughout most of the year (see Figure 8-14) and had a higher mean value than either the upstream or downstream monitoring locations. This would seem to suggest that localized influences are affecting specific conductance in this area. The pronounced fluctuations in specific conductance at Middle River near Tracy Road from the summer through winter are likely due to tidal influences. Union Point had the lowest specific conductance values throughout the summer and fall.

Monthly mean values were the highest in November and December. The highest monthly mean specific conductance value was 684.1 µS/cm in December at Howard Road. From April through June there were higher San Joaquin River flows past Vernalis and decreases in SWP and CVP daily exports (Figures 8-9 and 8-10). Specific conductance readings decreased considerably during this period with mean values in April through June ranging from 115.3 µS/cm at Undine Road to 196.7 µS/cm at Union Point.

Figure 8-13. Middle River: pH data (15-minute intervals)

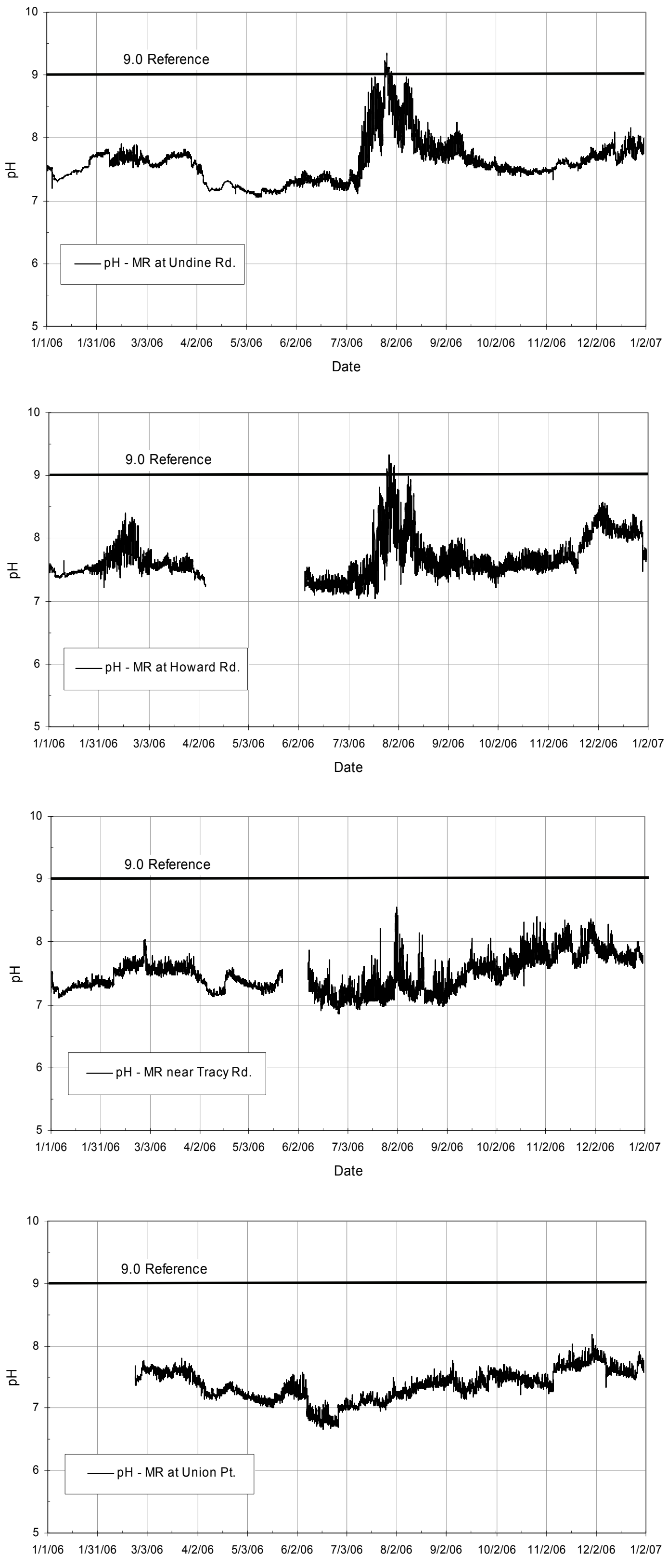
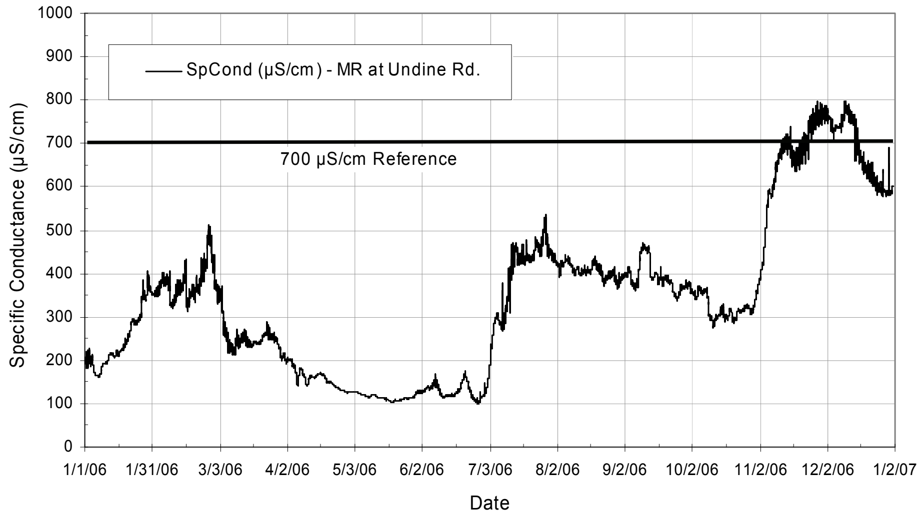
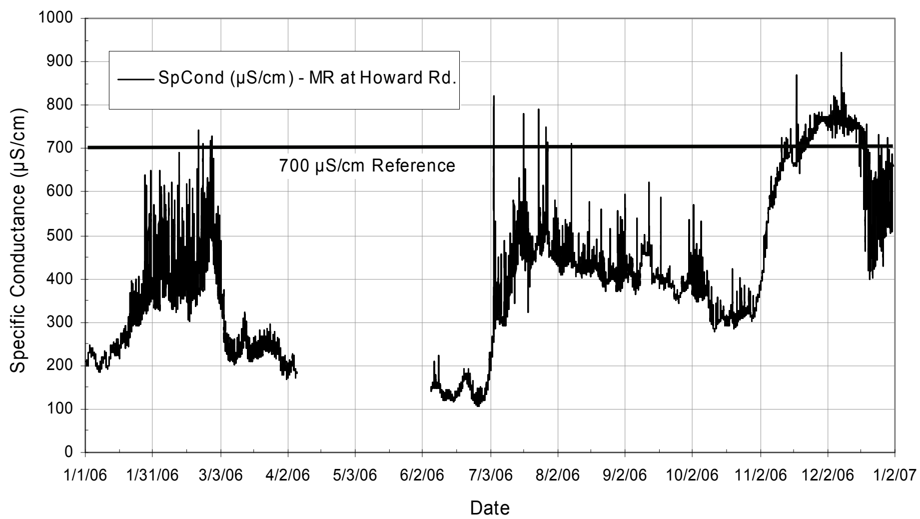
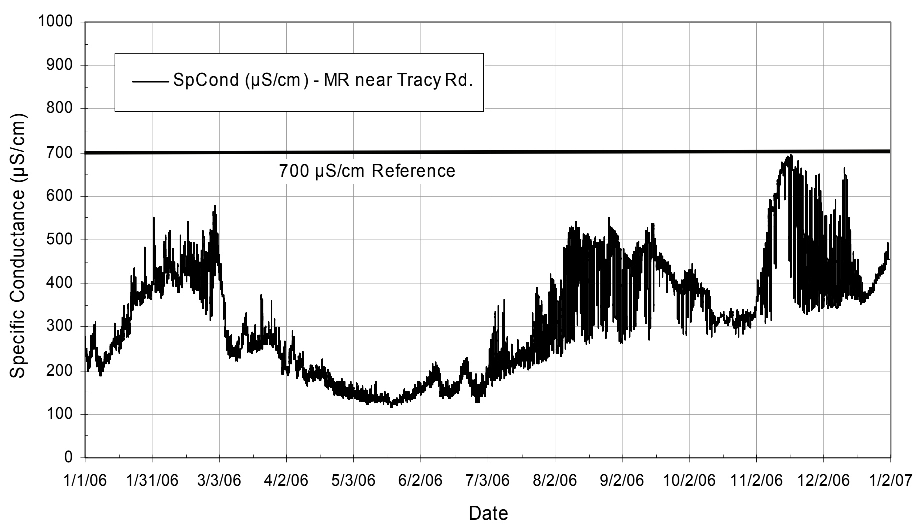


Figure 8-14. Middle River: specific conductance data (15-minute intervals)







Throughout the summer and winter specific conductance values began to rise, likely, in part due to lower San Joaquin River flows, CVP and SWP pumping, and agricultural pumping and return flows. While the barriers were operational the highest monthly mean was 650.4 µS/cm in November at Howard Road. From July through December the station below the Middle River Barrier (Union Point) had the lowest specific conductance values of the four monitoring stations. This may be due to the fact that at certain periods (i.e. in the months of July through December when San Joaquin River flow is low) during 2006 the source water for Union Point was Sacramento River water.

2005 specific conductance values ranged from a minimum of 100 µS/cm at Undine Road to a maximum of 1,664 µS/cm at Howard Road. The mean values for the monitoring period ranged from 483.5 µS/cm at Undine Road to 565.3 µS/cm at Howard Road.

Turbidity

Turbidity in water is caused by suspended matter, such as clay, silt, organic and inorganic matter, plankton, and other microscopic organisms (APHA 1992). Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (APHA 1992). In surface waters with reduced water clarity, phytoplankton and aquatic plant growth may be adversely affected because of reduced light penetration in the water column. Water clarity (turbid vs. clear) may affect predator-prey interactions of some aquatic species and highly turbid water may be harmful to aquatic life.

Figure 8-15 depicts turbidity data at the Middle River sites. Turbidity values ranged from a high of 195.1 NTU on December 13th at Undine Road to a low of -6.5 NTU on July 26th at Union Point. Generally, single turbidity spikes can be attributed to a foreign object, such as a leaf or fish passing before the optic sensors as the instrument is taking a reading. These anomalies are usually omitted if a single value is greater than 200 NTU; however, there are moments during the year where several continuous readings reveal a peaking-trend. Negative turbidity values usually occur as the result of clear water, probe drift and/or calibration error.

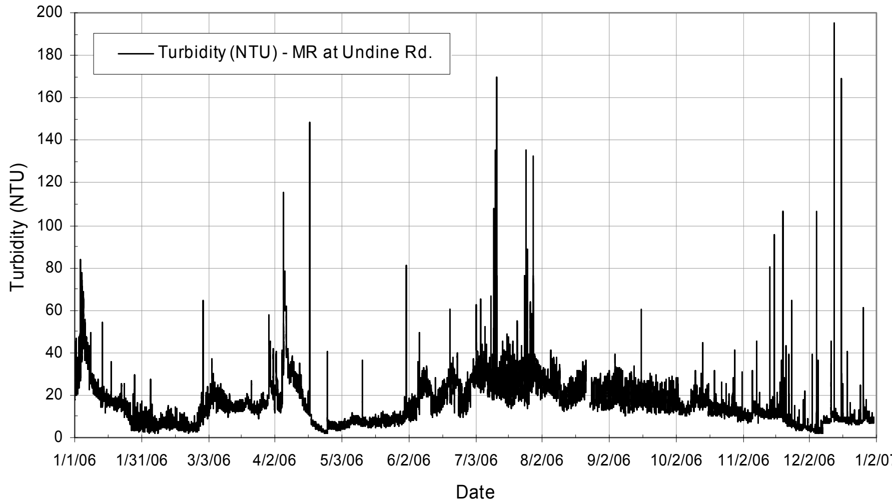
Mean turbidity values ranged from 9.0 NTU at Union Point to 18.5 NTU at Tracy Road. In February and December mean turbidity values were lowest, ranging from 3.8 NTU at Union Point to 9.0 NTU at Tracy Road. Summer turbidity readings were the highest, with mean values ranging from 7.1 NTU at Union Point to 40.8 NTU at Howard Road. The three upstream stations (Undine, Howard, Tracy) had greatly reduced water clarity in comparison to Union Point.

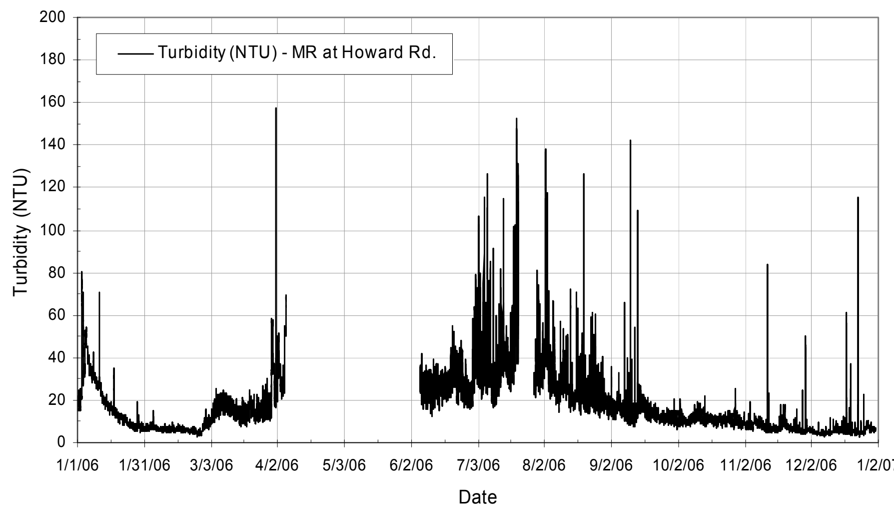
Mean turbidity values in 2005 ranged from 11.6 NTU at Tracy Road to 27.7 NTU at Undine Road. Turbidity values were high throughout the late winter, spring and summer and low in fall and early winter.

Chlorophyll

In 2006, chlorophyll sampling was implemented at all eleven South Delta monitoring locations. The YSI chlorophyll probe provides an estimate of chlorophyll concentrations by measuring fluorescence. To get a more precise representation of chlorophyll *a* concentrations in the South Delta, grab samples for chlorophyll were taken bi-monthly at each site for analysis at Bryte lab. Regression analysis was used to determine a relationship between continuous chlorophyll values from the YSI 6600 sonde and extracted chlorophyll *a* values.

Figure 8-15. Middle River: turbidity data (15-minute intervals)





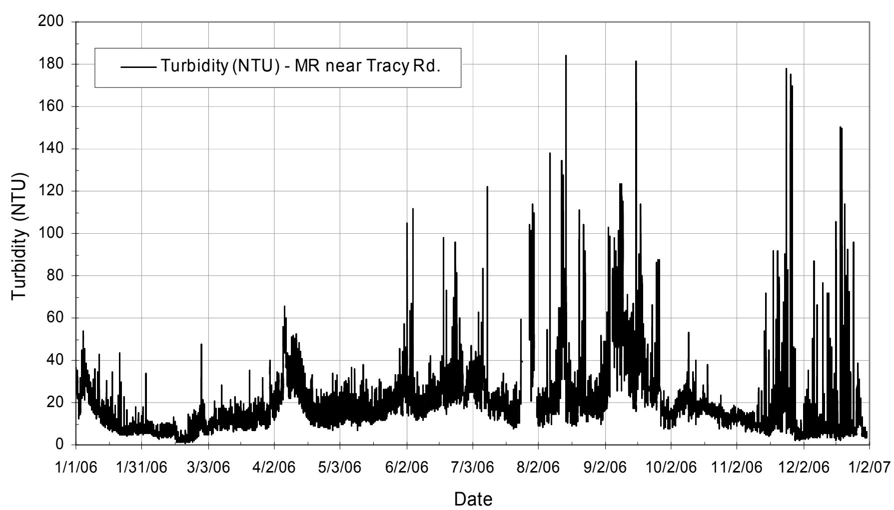


Figure 8-16 displays estimated chlorophyll *a* data for Middle River. Chlorophyll a concentrations ranged from a high of 218.2 µg/L on July 27th to a low of -15.8 µg/L on December 1st, both at Undine Road. The negative chlorophyll *a* minimum was due to low chlorophyll concentrations and the error associated with the relationship between extracted chlorophyll values and continuous chlorophyll values. Algal biomass as indicated by chlorophyll *a* concentrations was highest during the warm summer months of July and August, with monthly means ranging from 5.1 µg/L at Union Point to 59.1 µg/L at Undine Road. The lowest chlorophyll *a* concentrations were recorded in mid to late fall and winter. Overall, means ranged from 5.1 µg/L at Union Point to 12.8 µg/L at Undine Road.

Old River

Water Temperature

Water temperatures in Old River ranged from a maximum of 30.31 °C on July 18th at 15:45 PST to a minimum of 6.78 °C on December 30th at 2:30 PST, downstream and upstream of the DMC Barrier, respectively. (See Figure 8-17). Tables 8-5 and 8-6 provide a basic statistical summary of the 2006 water quality data collected for Old River. Temperature patterns at the Old River monitoring stations were similar to the Middle River stations previously discussed. July and August water temperatures were the warmest with means ranging from 22.54 °C to 25.66 °C, while December temperatures were the coldest averaging about 9.40 °C. Mean water temperature values during the monitoring period ranged from 16.14 °C at Old River near Head to 17.16 °C downstream of the DMC Barrier.

In 2005, water temperatures ranged from a minimum of 8.54°C (January) to a maximum of 27.49°C (July). Mean temperatures for the monitoring period ranged from 16.99 °C to 18.43 °C.

Dissolved Oxygen

Dissolved oxygen data for Old River is plotted in Figure 8-18. A maximum DO concentration of 15.90 mg/L was recorded on July 27th at 17:00 PST at Old River near Head and a minimum of 1.19 mg/L was recorded on July 26th at 1:30 PST upstream of the DMC Barrier. There were four (Old River near Head), one (TWA), 672 (upstream of DMC Barrier), and 420 (downstream of DMC Barrier) instances where the sonde(s) recorded DO concentrations less than 5 mg/L. The lowest monthly mean was 6.29 mg/L in July, upstream of the DMC barrier. Mean DO concentrations for Old River ranged from 8.41 mg/L upstream of the DMC barrier to 9.22 mg/L at Old River near Head.

Diel variation in DO concentrations was most pronounced during the summer through early fall, while in late fall and winter, there was less variation. Diel variation in dissolved oxygen concentrations is likely due to algal photosynthesis and respiration and water temperature variation. Mean DO concentrations were highest at all four sites during winter when oxygen solubility was the highest. Supersaturated DO concentrations were observed throughout the summer at Old River near Head and TWA, and to a lesser extent upstream and downstream of the DMC barrier.

In 2005, DO concentrations were lower and there were more instances where dissolved oxygen readings were less than 5 mg/L than in 2006. There were 24 (Old River near Head), 405 (TWA), and 2,404 (upstream of the DMC barrier) instances where the sonde(s) recorded DO concentrations less than 5 mg/L.

Figure 8-16. Middle River: estimated chlorophyll *a* data (15-minute intervals)

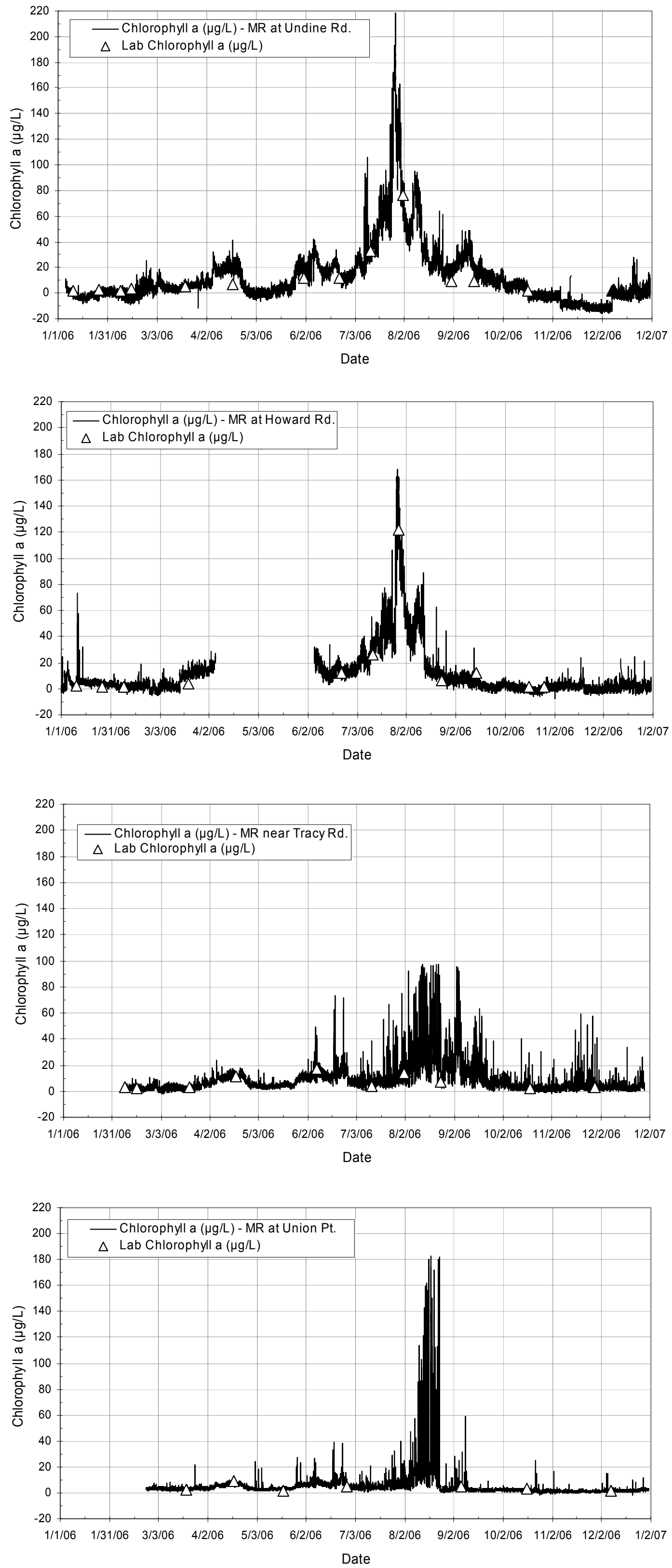
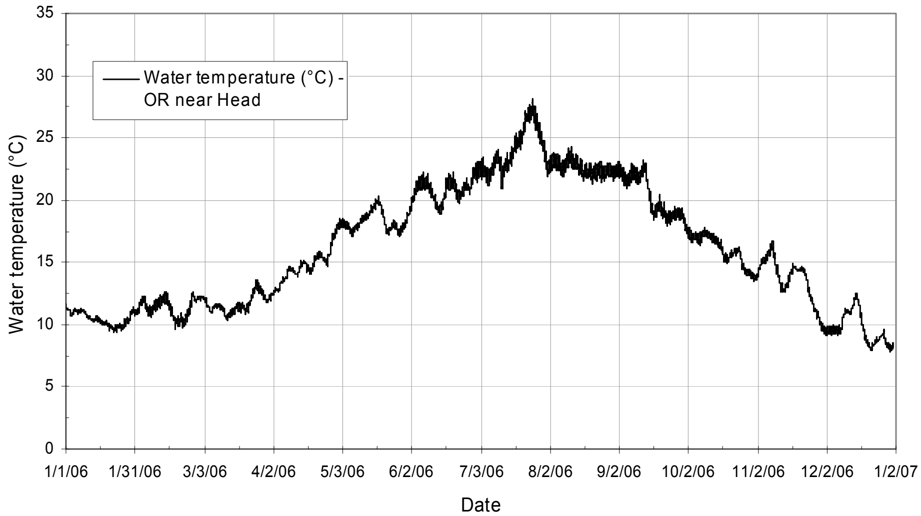
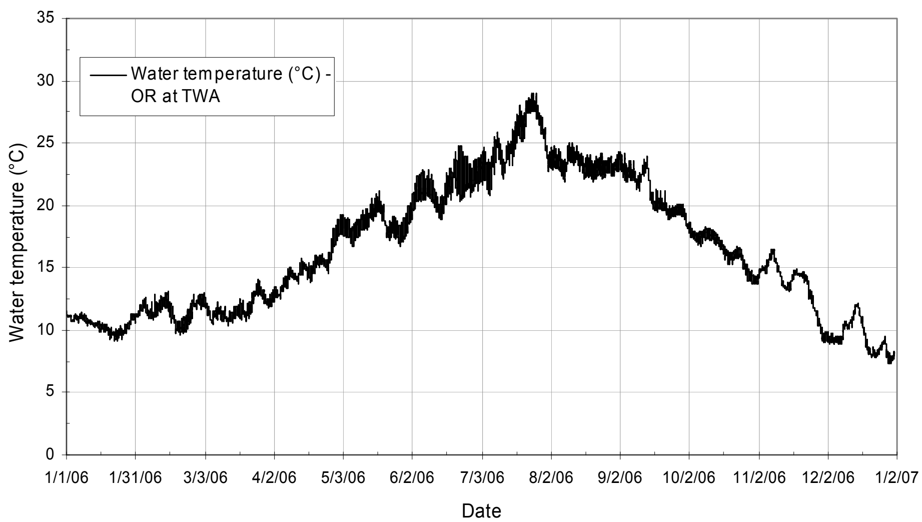


Figure 8-17. Old River: water temperature data (15-minute intervals)





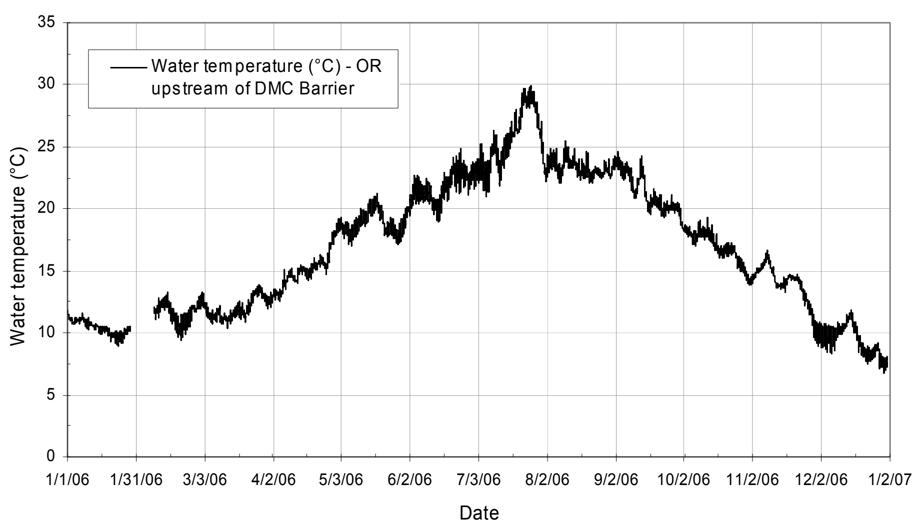


Table 8-5. Statistical summary of 2006 Old River continuous water quality data: water temperature, dissolved oxygen and pH

Month	Water Temperature (°C)			
MAXIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	11.64	11.56	11.81	11.38
Feb.	12.64	13.09	13.27	13.21
Mar	13.55	14.02	13.88	13.90
Apr	18.13	18.91	18.84	18.82
May	20.32	21.16	21.30	21.27
Jun	22.94	24.82	24.83	25.06
Jul	28.09	29.02	29.96	30.31
Aug	24.32	25.03	25.49	25.19
Sep	23.20	24.30	24.68	24.39
Oct	18.07	18.86	19.37	19.32
Nov	16.76	16.50	16.70	16.55
Dec	12.55	12.19	11.79	11.69
AVERAGES	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	10.49	10.45	10.41	10.13
Feb.	11.36	11.47	11.56	11.65
Mar	11.68	11.82	12.00	12.03
Apr	14.63	14.79	14.94	15.71
May	18.27	18.53	18.85	18.84
Jun	20.72	21.38	21.71	21.71
Jul	23.98	25.15	25.55	25.66
Aug	22.54	23.32	23.25	23.29
Sep	20.37	21.15	21.37	21.40
Oct	16.06	16.60	16.92	16.93
Nov	13.64	13.78	13.93	13.97
Dec	9.63	9.35	9.37	9.42
MINIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	9.39	9.12	8.97	9.10
Feb.	9.68	9.60	9.42	9.81
Mar	10.35	10.32	10.34	10.36
Apr	11.91	11.88	12.02	12.03
May	17.03	16.72	16.97	16.96
Jun	18.74	18.50	18.96	18.89
Jul	20.90	20.84	20.97	20.90
Aug	21.33	21.92	22.08	22.07
Sep	17.92	18.86	19.08	19.16
Oct	13.50	13.68	13.90	13.96
Nov	9.45	9.04	9.17	9.19
Dec	7.85	7.31	6.78	7.14
STD. DEVS.	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	0.52	0.57	0.55	0.51
Feb.	0.71	0.79	0.80	0.70
Mar	0.67	0.80	0.79	0.78
Apr	1.30	1.38	1.38	1.63
May	0.74	0.93	0.91	0.91
Jun	0.89	1.24	1.17	1.16
Jul	1.74	1.95	2.19	2.25
Aug	0.58	0.62	0.60	0.58
Sep	1.60	1.54	1.43	1.40
Oct	1.15	1.27	1.22	1.21
Nov	1.66	1.66	1.51	1.51
Dec	1.20	1.19	1.15	1.13
2006 - Max.	28.09	29.02	29.96	30.31
2006 - Avg.	16.14	16.51	16.84	17.16
2006 - Min.	7.85	7.31	6.78	7.14
2006 - S.D.	4.90	5.29	5.36	5.42

Month	Dissolved Oxygen (mg/L)			
MAXIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	10.24	10.72	11.00	10.51
Feb.	11.19	11.70	11.71	11.64
Mar	11.37	12.06	11.98	12.84
Apr	10.61	10.64	10.59	12.02
May	8.49	9.94	10.02	10.24
Jun	8.96	10.02	10.06	9.86
Jul	15.90	13.90	9.80	9.40
Aug	13.44	10.92	10.09	7.77
Sep	10.63	8.95	12.31	7.74
Oct	10.09	8.99	9.08	8.91
Nov	10.36	12.57	10.40	10.47
Dec	11.68	13.55	14.67	15.06
AVERAGES	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	9.59	9.79	9.63	10.08
Feb.	10.30	10.47	10.35	10.40
Mar	10.90	10.74	10.82	11.59
Apr	7.74	8.52	8.42	8.94
May	7.08	8.21	8.07	8.14
Jun	8.40	8.10	7.70	7.94
Jul	9.69	8.77	6.29	6.30
Aug	9.46	7.61	6.43	6.35
Sep	9.09	7.05	6.88	6.72
Oct	9.07	8.01	7.50	7.61
Nov	9.42	8.35	8.26	8.40
Dec	10.59	10.27	11.30	11.40
MINIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	8.45	8.23	8.11	9.68
Feb.	8.05	9.17	9.07	9.27
Mar	10.23	9.71	9.63	9.99
Apr	5.38	6.52	6.32	7.82
May	4.24	7.44	6.97	7.38
Jun	7.45	6.31	6.01	6.10
Jul	7.12	4.75	1.19	3.54
Aug	7.51	5.84	4.05	5.07
Sep	7.99	5.90	4.11	5.15
Oct	8.51	6.59	5.22	5.89
Nov	8.33	5.99	6.49	6.43
Dec	9.22	7.54	9.58	9.64
STD. DEVS.	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	0.45	0.66	0.56	0.16
Feb.	0.75	0.45	0.50	0.52
Mar	0.26	0.40	0.42	0.59
Apr	1.33	1.02	0.99	1.25
May	0.51	0.63	0.68	0.71
Jun	0.31	0.60	0.51	0.74
Jul	1.97	1.70	1.26	0.98
Aug	1.29	0.97	0.98	0.45
Sep	0.45	0.50	1.00	0.39
Oct	0.36	0.49	0.65	0.65
Nov	0.47	0.93	0.75	0.70
Dec	0.62	0.96	1.12	1.23
2006 - Max.	15.90	13.90	14.67	15.06
2006 - Avg.	9.22	8.82	8.41	8.56
2006 - Min.	4.24	4.75	1.19	3.54
2006 - S.D.	1.39	1.43	1.83	1.99

Month	pH			
MAXIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	7.93	7.63	7.64	7.80
Feb.	8.02	8.02	7.93	8.05
Mar	7.76	8.17	7.95	8.01
Apr	7.60	8.06	8.44	7.75
May	7.26	7.58	7.50	7.56
Jun	7.48	7.81	7.86	7.74
Jul	9.11	8.71	8.25	8.11
Aug	8.80	8.39	8.38	8.02
Sep	8.28	7.67	8.50	7.75
Oct	7.70	7.66	7.73	7.69
Nov	7.79	8.10	7.94	7.84
Dec	7.86	8.20	8.42	8.51
AVERAGES	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	7.69	7.48	7.36	7.58
Feb.	7.56	7.62	7.63	7.69
Mar	7.61	7.70	7.68	7.71
Apr	7.22	7.31	7.36	7.35
May	7.10	7.19	7.20	7.23
Jun	7.36	7.27	7.35	7.28
Jul	7.74	7.57	7.40	7.30
Aug	7.88	7.51	7.59	7.57
Sep	7.70	7.41	7.57	7.52
Oct	7.59	7.46	7.43	7.51
Nov	7.68	7.62	7.66	7.54
Dec	7.71	7.78	7.75	7.73
MINIMUMS	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	7.42	7.36	7.22	7.40
Feb.	7.42	7.39	7.32	7.38
Mar	7.49	7.44	7.49	7.47
Apr	7.05	7.12	7.21	7.17
May	6.92	7.05	7.07	7.08
Jun	7.08	7.04	7.10	6.94
Jul	7.27	7.07	7.04	6.89
Aug	7.47	7.16	7.32	7.39
Sep	7.35	7.28	7.32	7.35
Oct	7.33	7.32	7.23	7.34
Nov	7.55	7.40	7.40	7.31
Dec	7.55	7.47	7.37	7.39
STD. DEVS.	HEAD	TWA	ABOVE DMC	BELOW DMC
Jan.	0.15	0.06	0.10	0.07
Feb.	0.12	0.11	0.12	0.14
Mar	0.04	0.10	0.07	0.07
Apr	0.14	0.14	0.12	0.12
May	0.05	0.14	0.10	0.09
Jun	0.04	0.14	0.09	0.11
Jul	0.53	0.37	0.20	0.21
Aug	0.32	0.21	0.16	0.08
Sep	0.13	0.07	0.15	0.07
Oct	0.04	0.07	0.08	0.06
Nov	0.05	0.11	0.10	0.12
Dec	0.05	0.10	0.25	0.29
2006 - Max.	9.11	8.71	8.50	8.51
2006 - Avg.	7.50	7.46	7.46	7.47
2006 - Min.	6.92	7.04	7.04	6.89
2006 - S.D.	0.33	0.24	0.22	0.23

Figure 8-18. Old River: dissolved oxygen data (15-minute intervals)

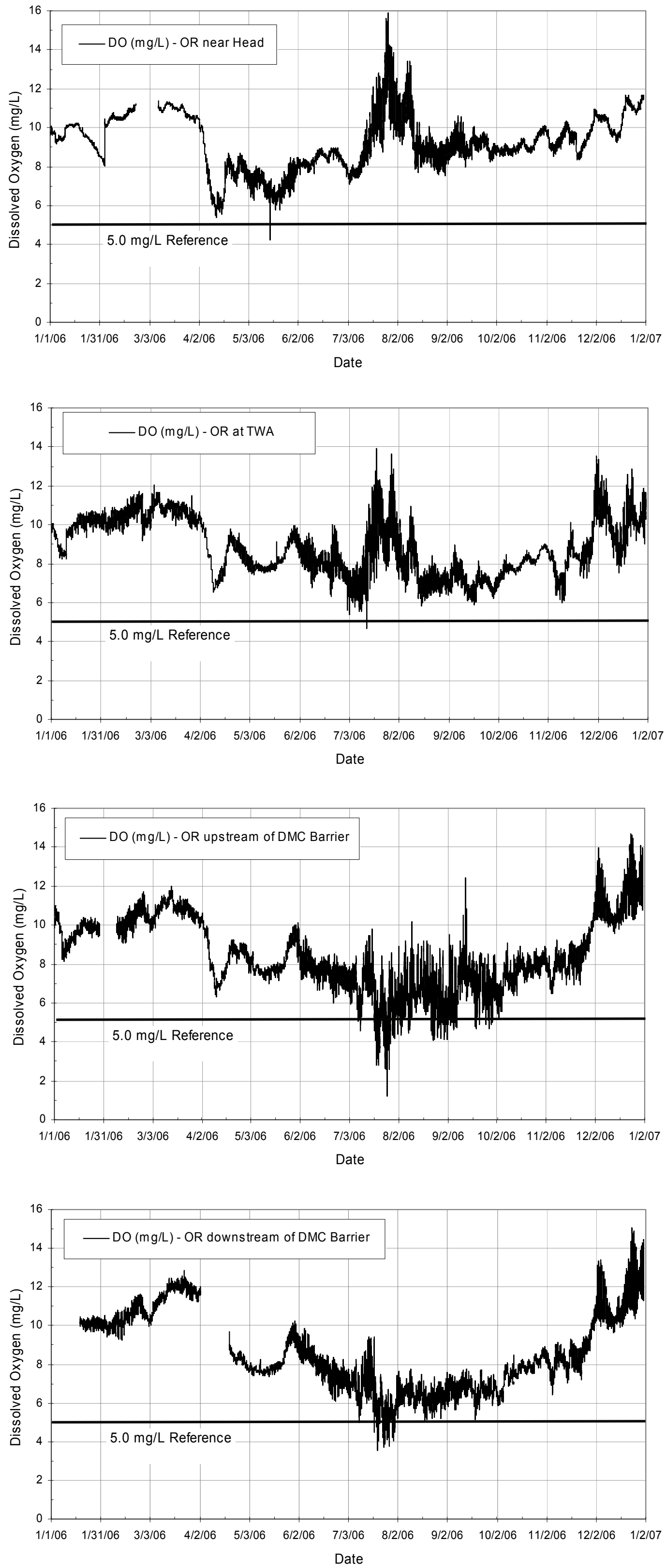


Table 8-6. Statistical summary of 2006 Old River continuous water quality data: specific conductance, turbidity and chlorophyll *a* (11x17 table at end of chapter)

pH

Figure 8-19 displays pH data in Old River. A maximum pH of 9.11 was recorded on July 27th at Old River near Head and a minimum of 6.89 was recorded on July 9th at 21:30 downstream of the DMC barrier. There were 72 pH values greater than 9.0 recorded at Old River near Head. There were no recorded pH values greater than 9.0 at the other three stations. Mean pH values in Old River ranged from 7.46 at TWA and upstream of the DMC barrier to 7.50 at Old River near Head.

In 2005, pH values ranged from 6.94 to 9.11. There were 30 pH values greater than 9.0 recorded at TWA.

Specific Conductance

Specific conductance data for the Old River monitoring sites is shown in Figure 8-20. A maximum of 1515.6 µS/cm was recorded on December 13th at TWA. The minimum recorded specific conductance was 98.7 µS/cm on June 27th at Old River near Head. Mean values for the monitoring period ranged from 346.7 µS/cm at Old River near Head to 431.2 µS/cm downstream of the DMC barrier. TWA had spikes in specific conductance throughout November and December with monthly mean values of 767.9 µS/cm and 804.7 µS/cm, higher than the upstream and downstream sites. This would seem to suggest that localized conditions are influencing specific conductance in this area. The fluctuations in specific conductance at the upstream and downstream DMC sites (especially in November and December) are likely to due to tidal influences.

Monthly mean conductivity values were highest in November and December. From April through June there were higher San Joaquin River flows past Vernalis and decreases (April and May only) in SWP and CVP daily exports (Figures 8-9 and 8-10). Specific conductance decreased considerably during this period, with means in April through June ranging from 116 µS/cm at Old River near Head to 203 µS/cm upstream of the DMC barrier. From early to mid July specific conductance values began to increase. Contributing factors to increased conductivity include: lower San Joaquin River flows, higher specific conductance values at Vernalis, CVP and SWP pumping, and agricultural pumping and return flows. Conductivity values remained relatively steady from mid July until early November, when values increased steadily until mid November.

2005 specific conductance values ranged from a minimum of 101 µS/cm to a maximum of 1,410 µS/cm. Mean values for the monitoring period ranged from 485.5 µS/cm at Old River near Head to 616.7 µS/cm at TWA.

Turbidity

Figure 8-21 depicts turbidity data in Old River. Turbidities ranged from a high of 198.8 NTU on May 3rd upstream of the DMC Barrier to a low of -0.9 NTU on December 8th downstream of the DMC barrier. The minimum value of -0.9 can be attributed to clear water and probe drift. Monthly mean turbidity values were highest in summer ranging from 14.5 NTU in August to 31.3 NTU in July, both upstream of the DMC barrier. The lowest readings occurred in winter with mean values ranging from 10.3 NTU in December upstream of the DMC barrier to 27.3 NTU in January at Old River near Head. In 2006, mean values ranged from 16.6 NTU downstream of the DMC barrier to 19.0 NTU at TWA.

Figure 8-19. Old River: pH data (15-minute intervals)

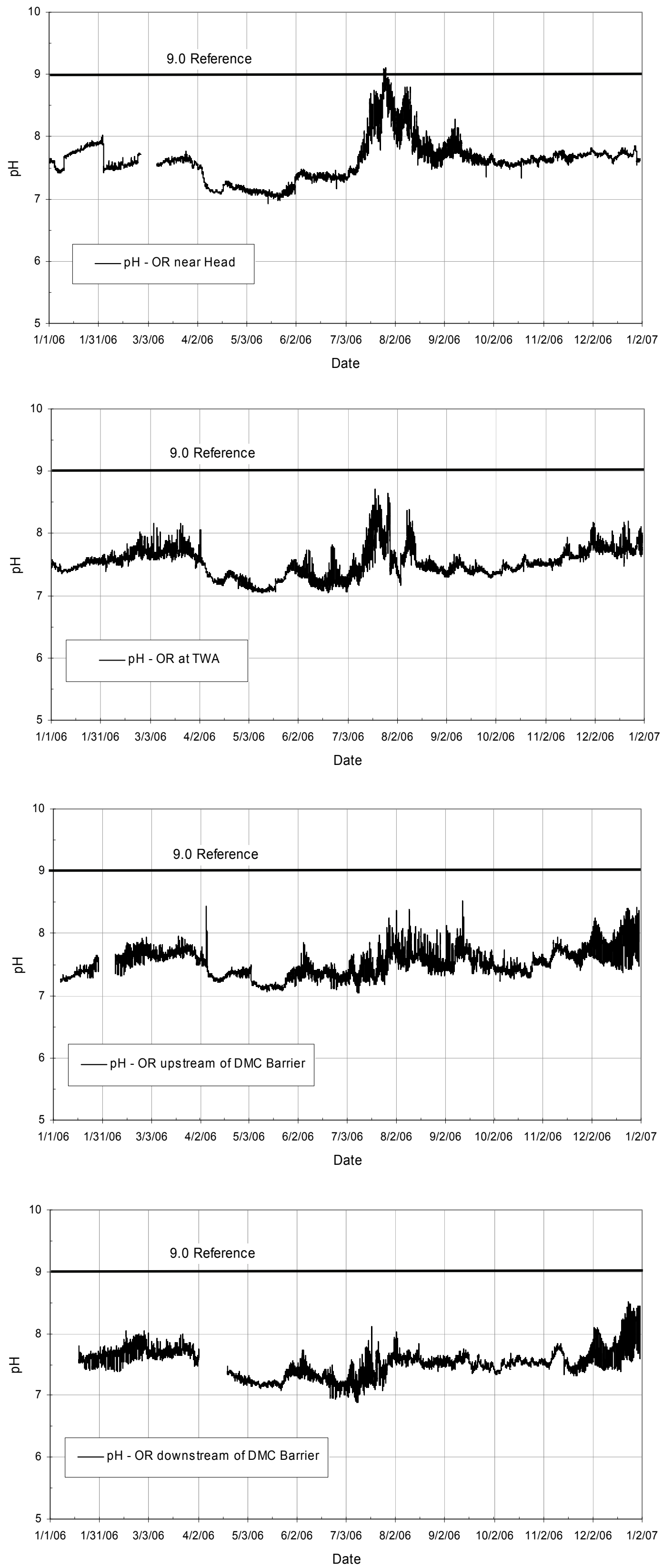


Figure 8-20. Old River: specific conductance data (15-minute intervals)

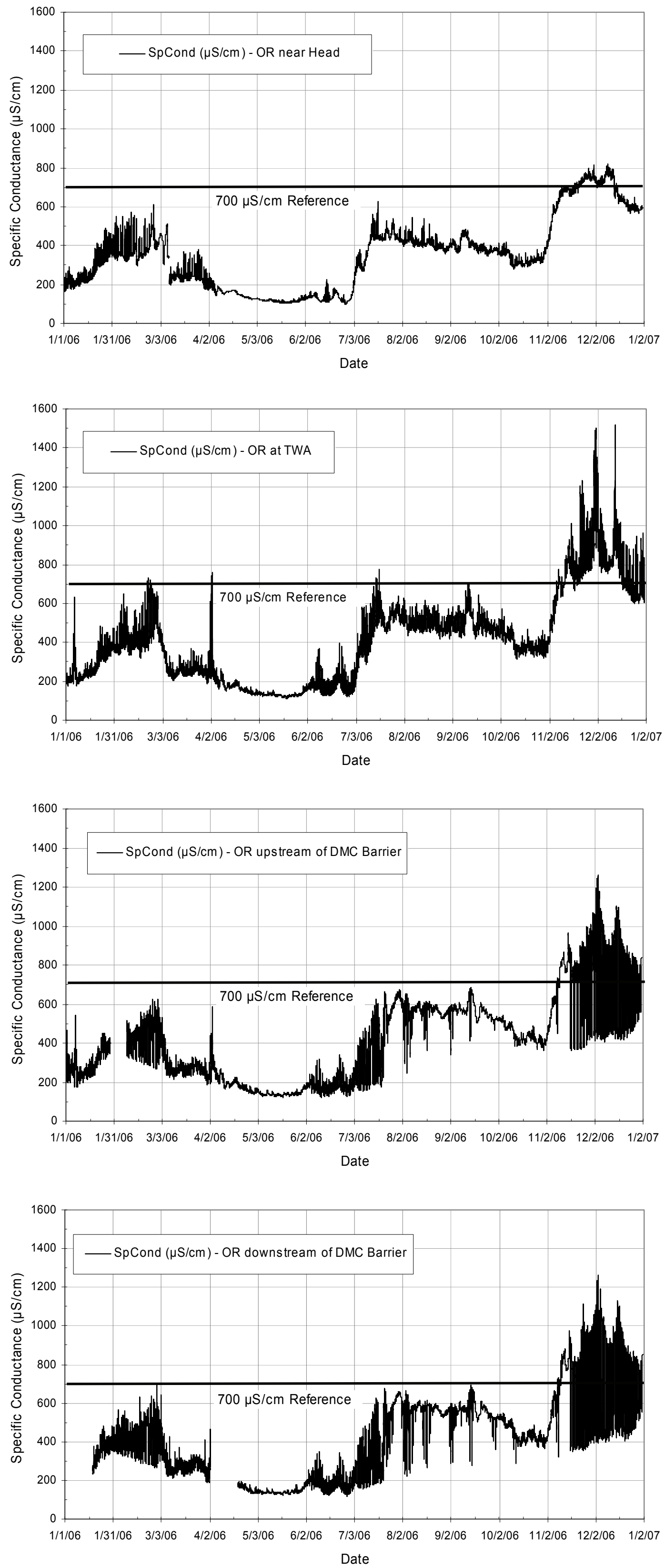
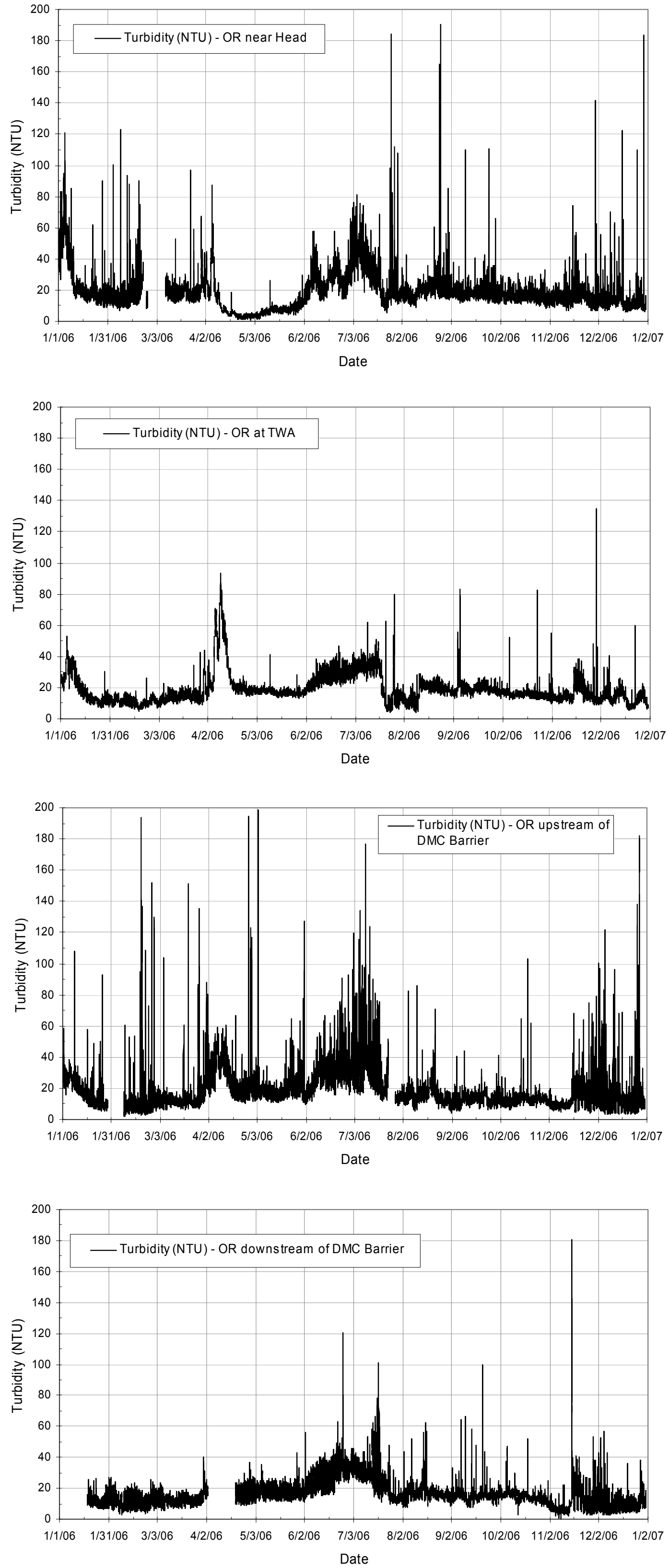


Figure 8-21. Old River: turbidity data (15-minute intervals)



Mean turbidity values in 2005 ranged from 16.6 NTU upstream of the DMC barrier to 28.7 NTU at Old River near Head. Turbidity values were high throughout the late winter and summer and low in fall.

Chlorophyll

Figure 8-22 displays estimated chlorophyll *a* data for Old River. Chlorophyll *a* concentrations ranged from a high of 207.3 µg/L on July 17th to a low of -8.3 µg/L on January 18th, both at TWA. The negative chlorophyll *a* minimum was due to low chlorophyll concentrations and the error associated with the relationship between extracted chlorophyll values and continuous chlorophyll values. Algal biomass as indicated by chlorophyll *a* concentrations was highest in July at Old River near Head and TWA with monthly means ranging from 20.9 µg/L to 63.1 µg/L. The estimated chlorophyll data for Old River near Head and TWA in Figure 8-22 shows a large algal bloom occurring throughout July and early to mid August. There were no distinguishable blooms during the summer upstream or downstream of the DMC barrier. The lowest chlorophyll *a* concentrations occurred in late winter and fall. Overall, means ranged from 7.4 µg/L downstream of the DMC barrier to 15.7 µg/L at Old River near Head and TWA.

Grant Line Canal

Water Temperature

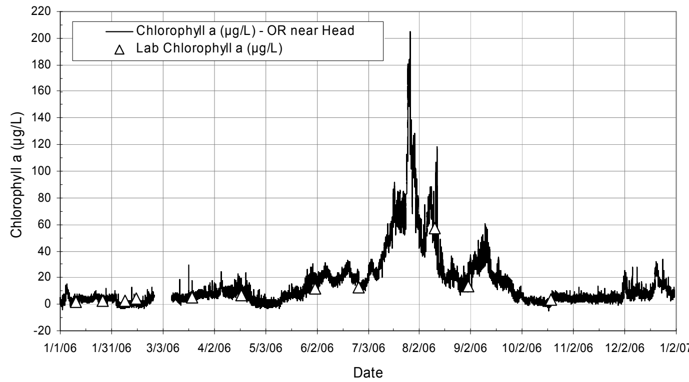
Water temperatures in Grant Line Canal ranged from a maximum of 29.29 °C on July 15th at 15:35 PST to a minimum of 7.51 °C on December 29th at 0:30 PST, above the GLC barrier and at Doughty Cut, respectively. (See Figure 8-23). Tables 8-7 and 8-8 provide a basic statistical summary of the 2006 water quality data collected for GLC. Temperature patterns at Grant Line Canal monitoring stations were similar to the Old River and Middle River stations previously discussed. July and August water temperatures were the warmest with means ranging from 22.77 °C to 24.51 °C, while December temperatures were the coldest averaging about 9.65 °C. Mean water temperatures during the monitoring period ranged from 17.41 °C at GLC at Tracy Road to 18.42 °C at Doughty Cut. **NOTE: The Grant Line Canal monitoring stations were not installed until spring (above Barrier and Tracy Road) and summer (Doughty Cut) of 2006.**

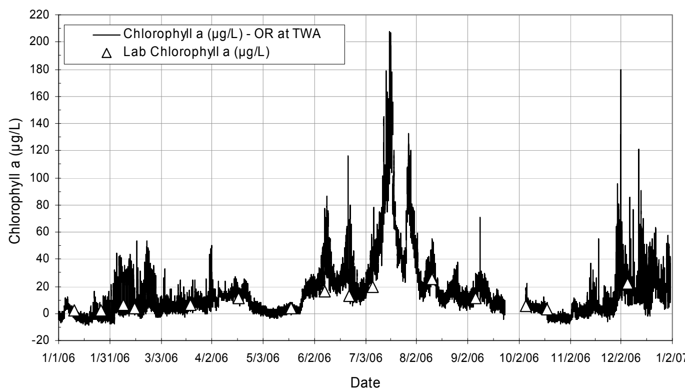
Dissolved Oxygen

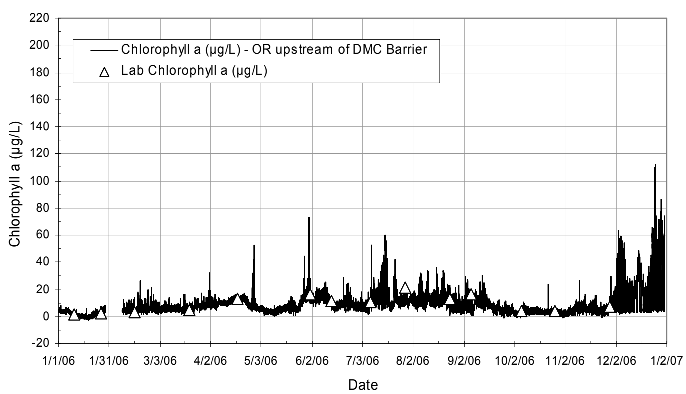
Dissolved oxygen data for Grant Line Canal is plotted in Figure 8-24. A maximum DO concentration of 15.46 mg/L was recorded on July 28th at 14:45 PST above the GLC barrier. A minimum DO concentration of 1.33 mg/L was recorded on July 17th at 19:30 PST at Doughty Cut. There were 98 instances at Doughty Cut where the sonde(s) recorded DO concentrations less than 5 mg/L. There were no DO concentrations less than 5 mg/L above the GLC barrier and at GLC at Tracy Road. The lowest monthly mean was 7.77 mg/L in September at GLC at Tracy Road. Mean DO concentrations for Grant Line Canal ranged from 8.84 mg/L above the GLC barrier to 9.05 mg/L at GLC at Tracy Road.

Diel variation in DO concentrations was most pronounced during the summer, while in spring and late fall/early winter, there was less variation. Supersaturated DO concentrations were observed throughout the summer at all three GLC stations. DO concentrations in GLC were very similar at the three monitoring locations, except in July at Doughty Cut.

Figure 8-22. Old River: estimated chlorophyll *a* data (15-minute intervals)







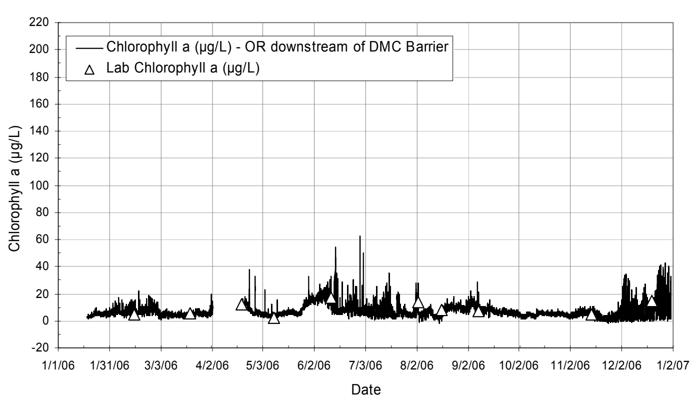


Figure 8-23. Grant Line Canal: water temperature data (15-minute intervals)

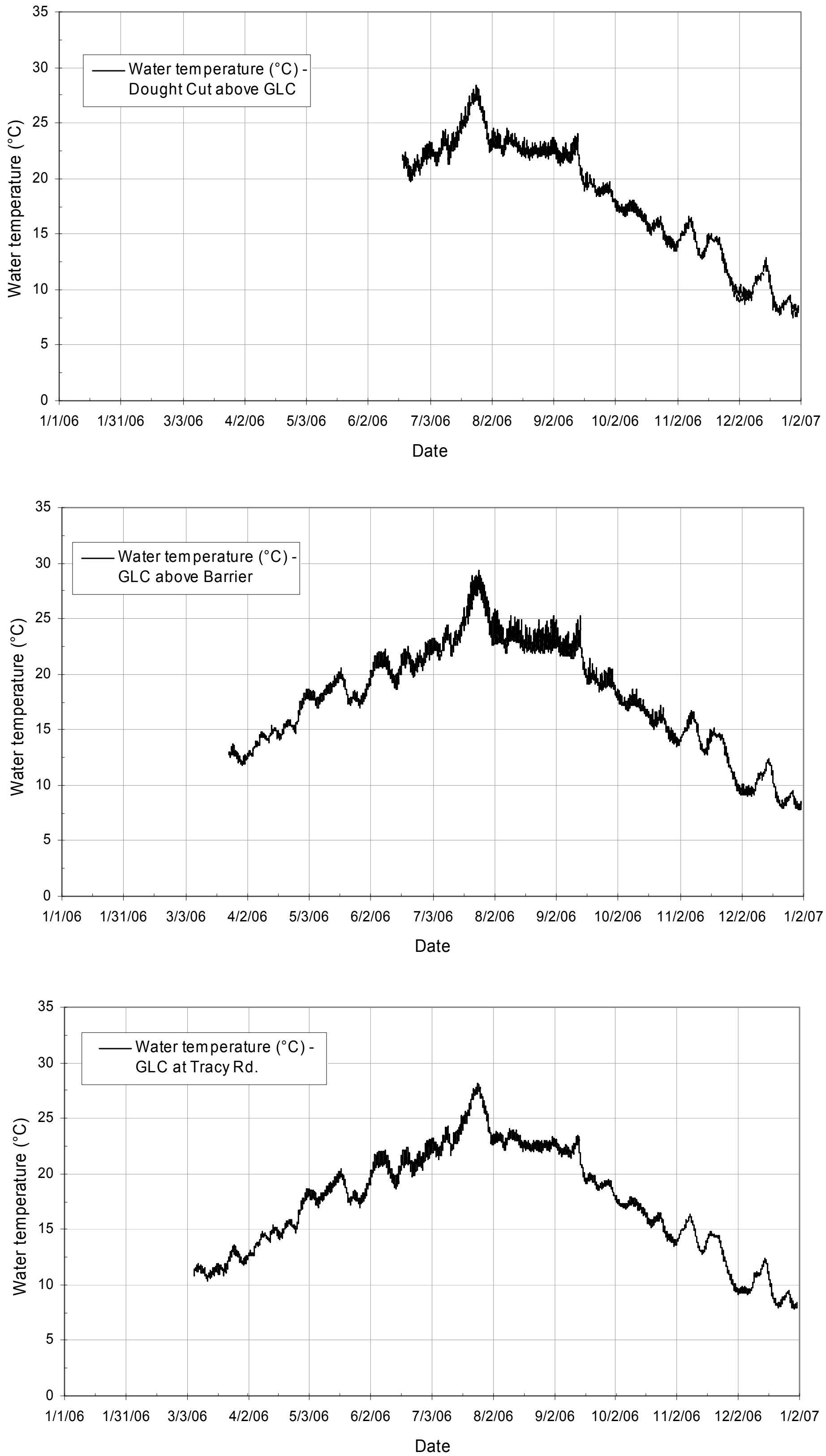


Figure 8-24. Grant Line Canal: dissolved oxygen data (15-minute intervals)

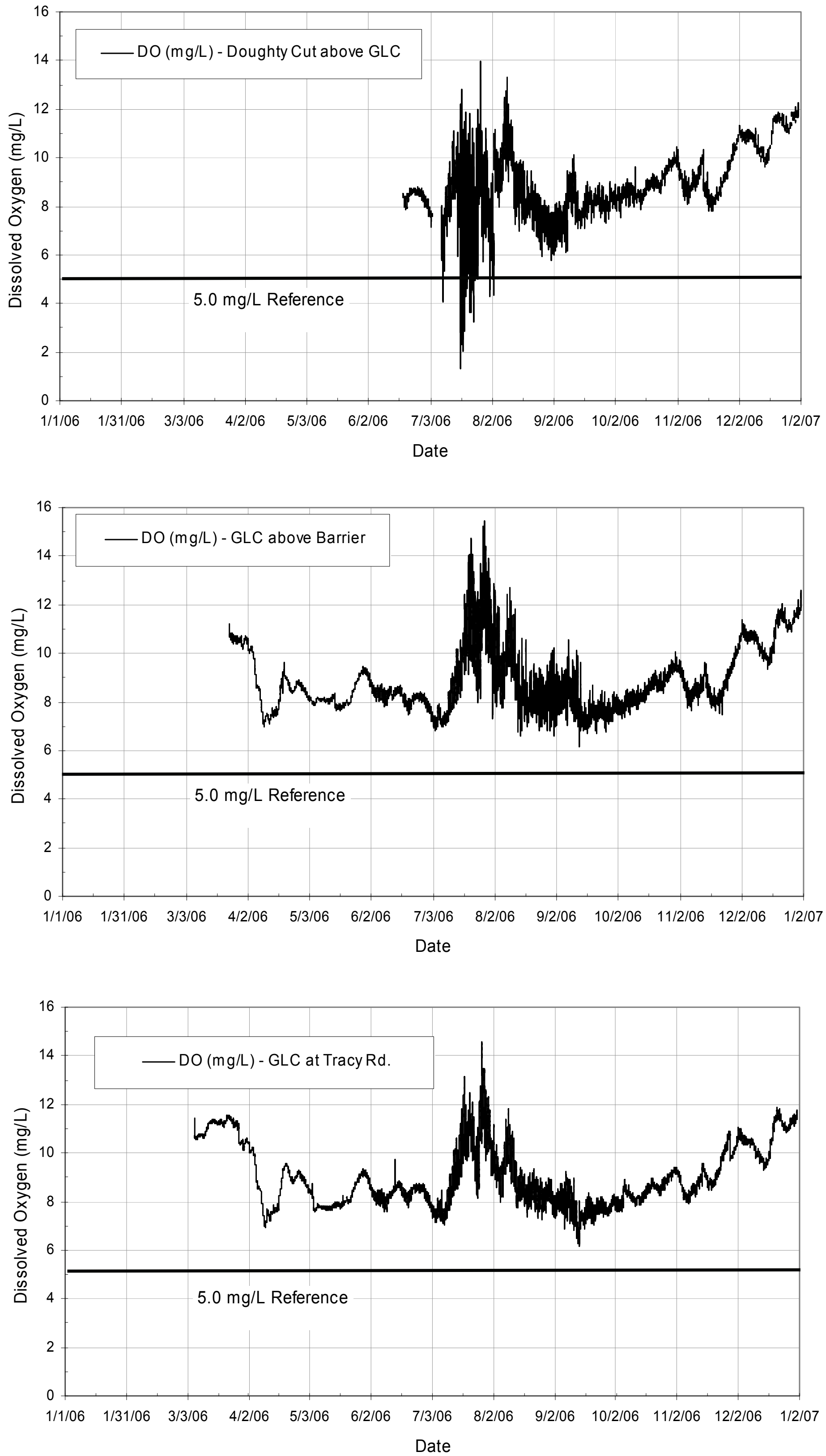


Table 8-7. Statistical summary of 2006 Grant Line Canal continuous water quality data: water temperature, dissolved oxygen and pH (11x17 table at end of chapter)

Table 8-8. Statistical summary of 2006 Grant Line Canal continuous water quality data: specific conductance, turbidity and chlorophyll *a* (11x17 table at end of chapter)

pH

Figure 8-25 displays pH data in Grant Line Canal. A maximum pH of 9.15 was recorded on July 28th at 14:45 PST and a minimum of 6.89 was recorded on July 8th at 12:00 PST, both above the GLC barrier. There were 78 pH values greater than 9.0 recorded above the GLC barrier. There were no recorded pH values greater than 9.0 at the other two stations. Mean pH values ranged from 7.45 at GLC at Tracy Road to 7.67 at Doughty Cut.

Specific Conductance

Specific conductance data for the GLC monitoring sites is shown in Figure 8-26. A maximum of 917 µS/cm was recorded on December 11th above the GLC barrier. The minimum recorded specific conductance was 104.2 µS/cm on June 27th at GLC at Tracy Road. Mean values for the monitoring period ranged from 444.5 µS/cm at Doughty Cut to 355.3 µS/cm at GLC at Tracy Road. Specific conductivity patterns were almost identical at all three GLC stations and Old River near Head (Compare Figures 8-20 and 8-26).

Turbidity

Figure 8-27 depicts turbidity data in GLC. Turbidities ranged from a high of 193 NTU on November 22nd, to a low of 4.7 NTU on December 20th, both above the GLC barrier. Monthly mean turbidity values were highest in summer ranging from 15.4 NTU in August above the GLC barrier, to 35.1 NTU in July at Doughty Cut. The lowest readings occurred in late fall/early winter, with mean values ranging from 11.2 NTU in December at GLC at Tracy Road to 16.8 NTU in November at Doughty Cut. In 2006, mean values ranged from 16.7 NTU at GLC at Tracy Road to 17.1 NTU at Doughty Cut and above the GLC barrier.

Chlorophyll

Figure 8-28 displays estimated chlorophyll *a* data for GLC. Chlorophyll *a* concentrations ranged from a high of 200 µg/L on July 27th to a low of -13.6 µg/L on October 5th, both above the GLC barrier. The negative chlorophyll *a* minimum was due to low chlorophyll concentrations and the error associated with the relationship between extracted chlorophyll values and continuous chlorophyll values. Algal biomass as indicated by chlorophyll *a* concentrations was highest in July and August above the GLC barrier and at GLC at Tracy Road, with monthly mean values ranging from 31.6 µg/L to 63.5 µg/L, both above the GLC barrier. The estimated chlorophyll data for above the GLC barrier and GLC at Tracy Road in Figure 8-28 shows a large algal bloom occurring throughout July and early to mid August. Chlorophyll data during most of July and August was lost at Doughty Cut due to probe fouling. The lowest chlorophyll *a* concentrations occurred in mid to late fall. Overall, mean values ranged from 11.7 µg/L at Doughty Cut to 18.0 µg/L above the GLC Barrier.

Conclusions

Water temperature readings in Middle River, Old River and GLC followed the same seasonal patterns. Temperature variation between the eleven continuous sites was likely due to site-specific localized differences (i.e. Middle River tends to be narrower and shallower than either GLC or Old River). Temperatures ranged from a minimum of 5.52 °C to a maximum 33.27°C, both at Middle River stations.

Figure 8-25. Grant Line Canal: pH data (15-minute intervals)

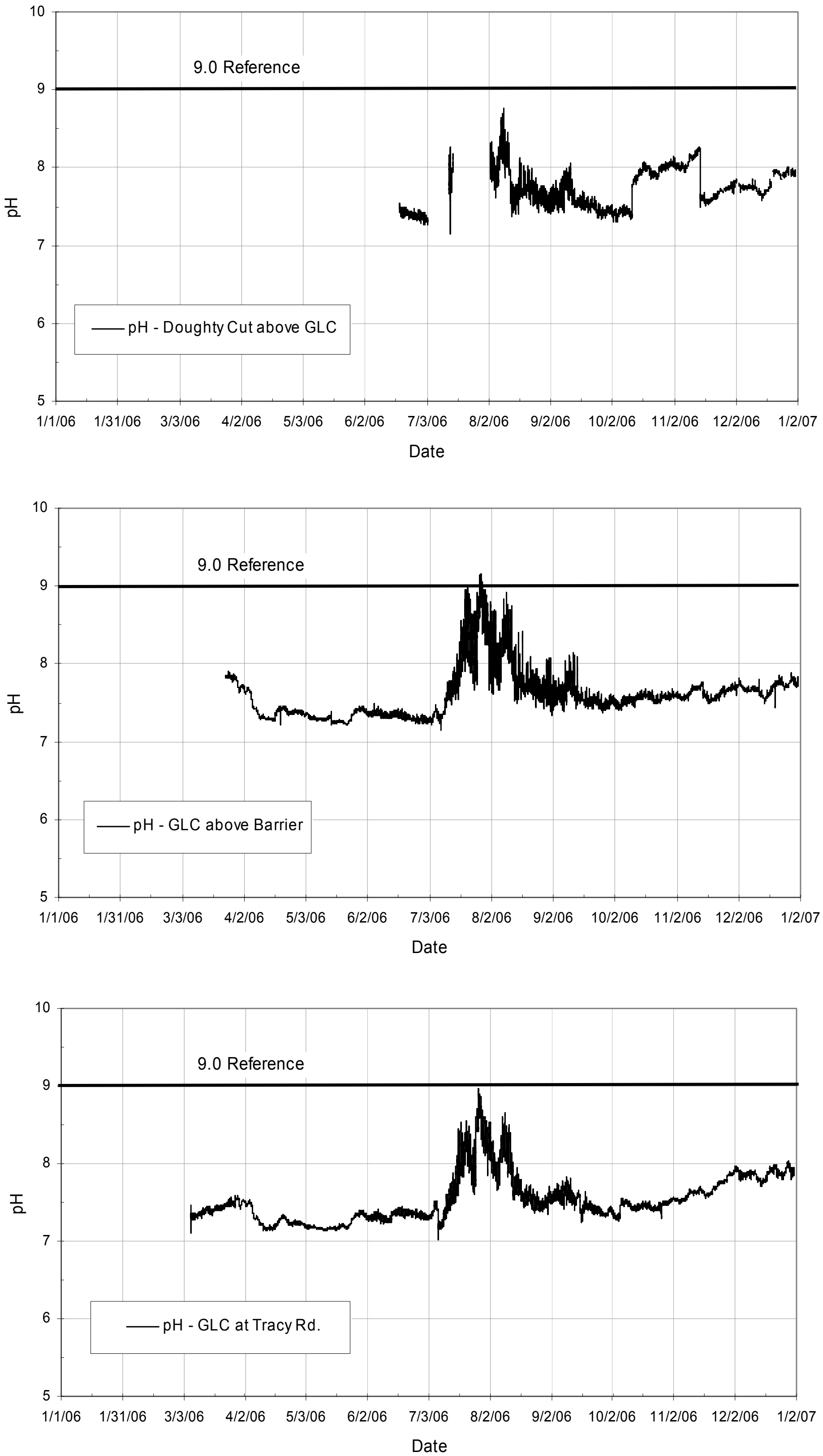


Figure 8-26. Grant Line Canal: specific conductance data (15-minute intervals)

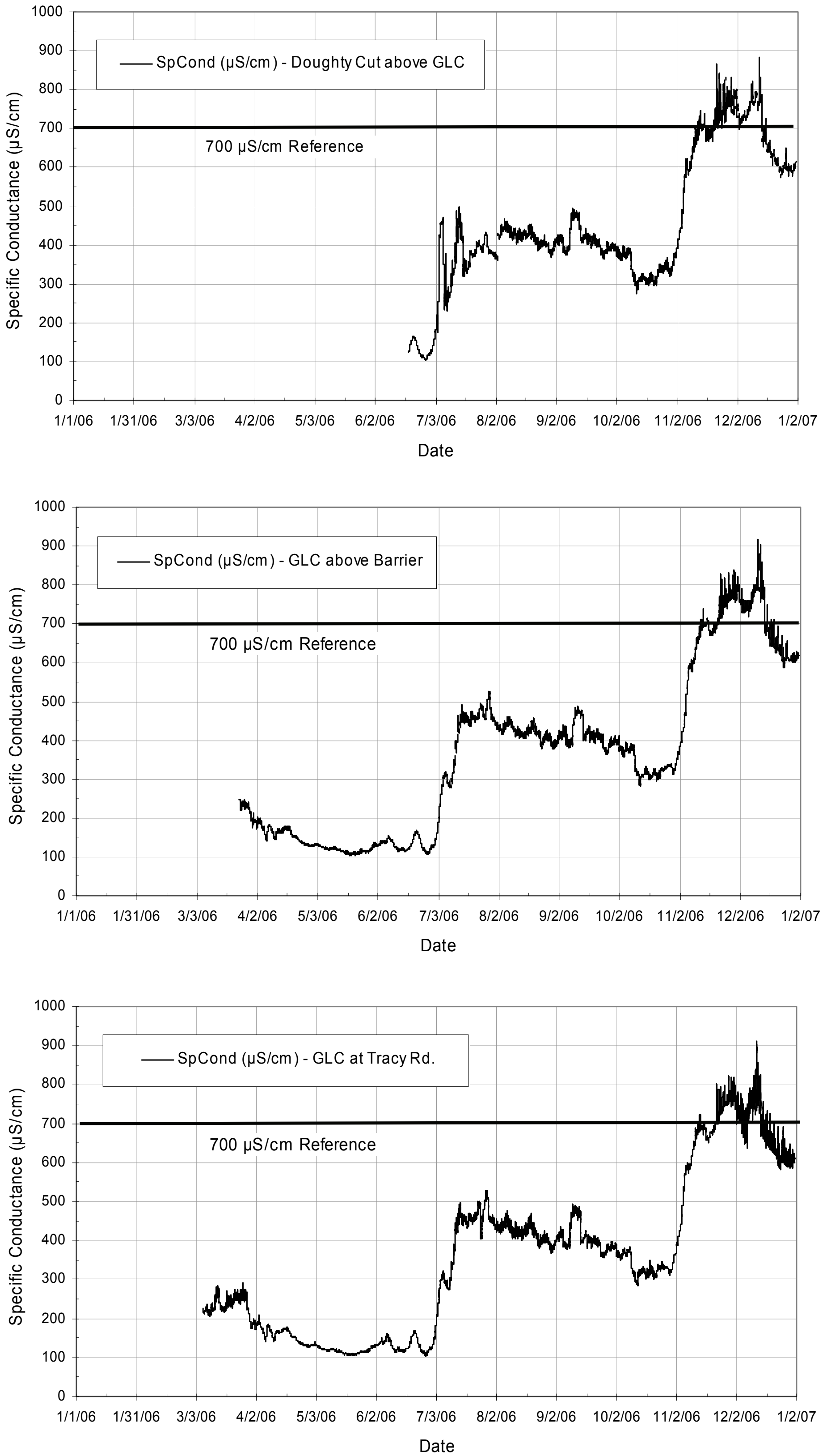
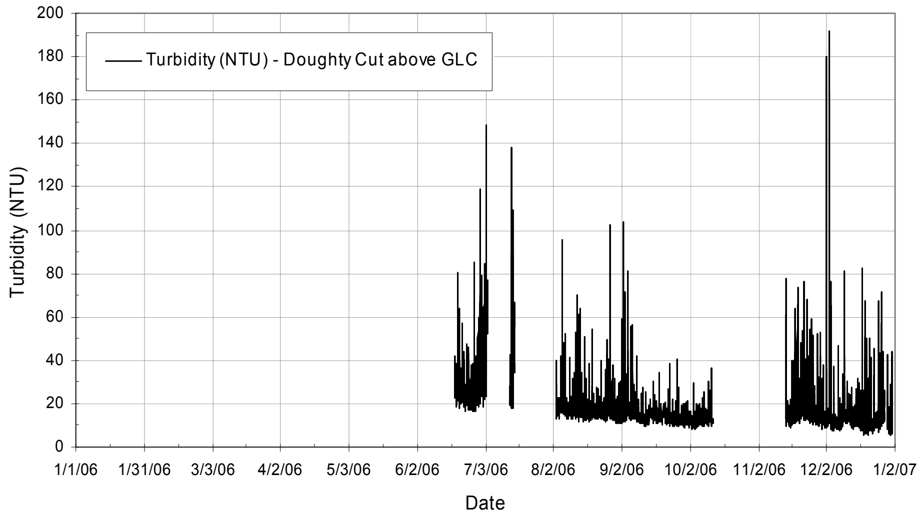
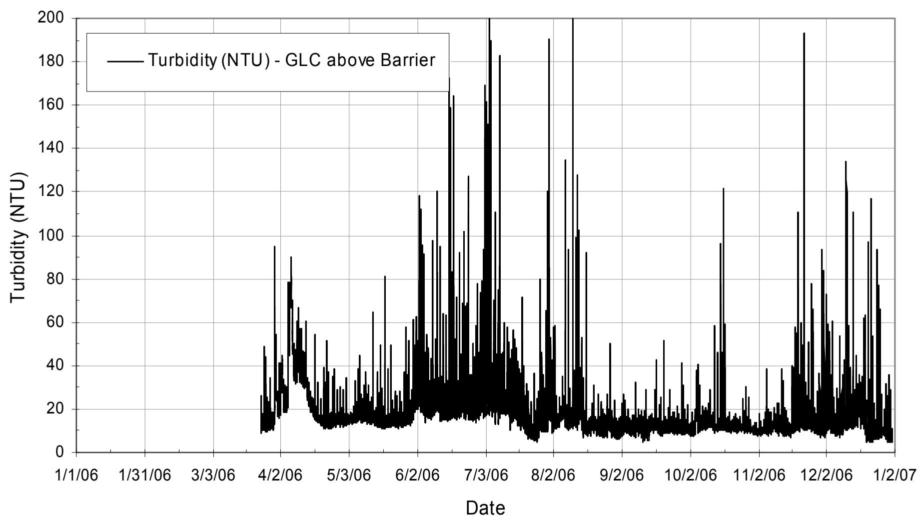


Figure 8-27. Grant Line Canal: turbidity data (15-minute intervals)





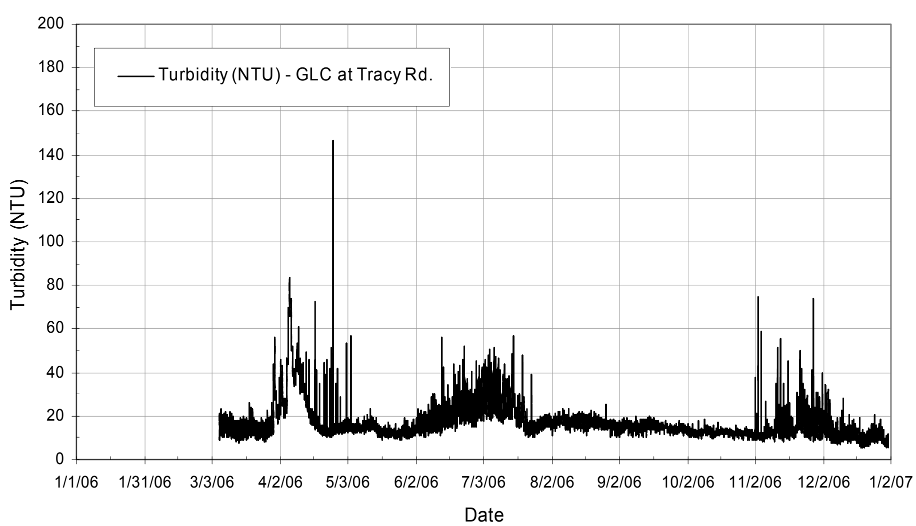
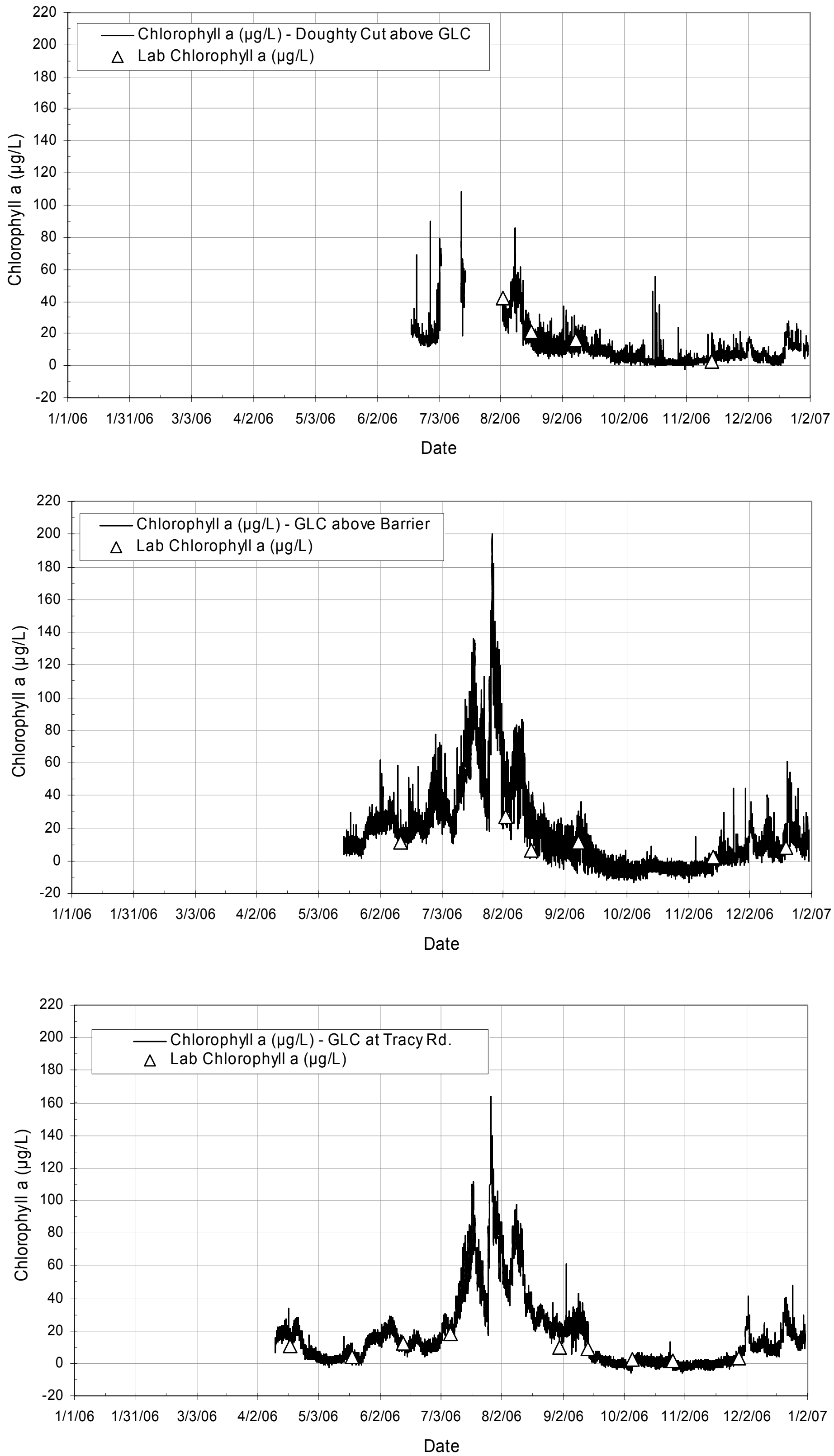


Figure 8-28. Grant Line Canal: estimated chlorophyll *a* data (15-minute intervals)



Dissolved oxygen concentrations were lowest during the summer and early fall in Middle River near Tracy Road and at the sites upstream and downstream of the DMC barrier. Contributing causes of low dissolved oxygen at these sites were: warm water temperatures (lower oxygen solubility), low San Joaquin River flows (high residence times), and high biochemical oxygen demand (oxygen consumption by microorganisms). At Middle River near Tracy Road and the DMC sites, there were a combined 1,954 instances where the sonde(s) recorded DO concentrations less than 5 mg/L. In contrast, there were only 158 readings below 5 mg/L at the other eight sites combined. In 2005, there were a combined 7,070 instances where the sonde(s) recorded DO concentrations less than 5 mg/L. The higher dissolved oxygen concentrations recorded in 2006 were likely the result of unseasonably high flows in the San Joaquin River.

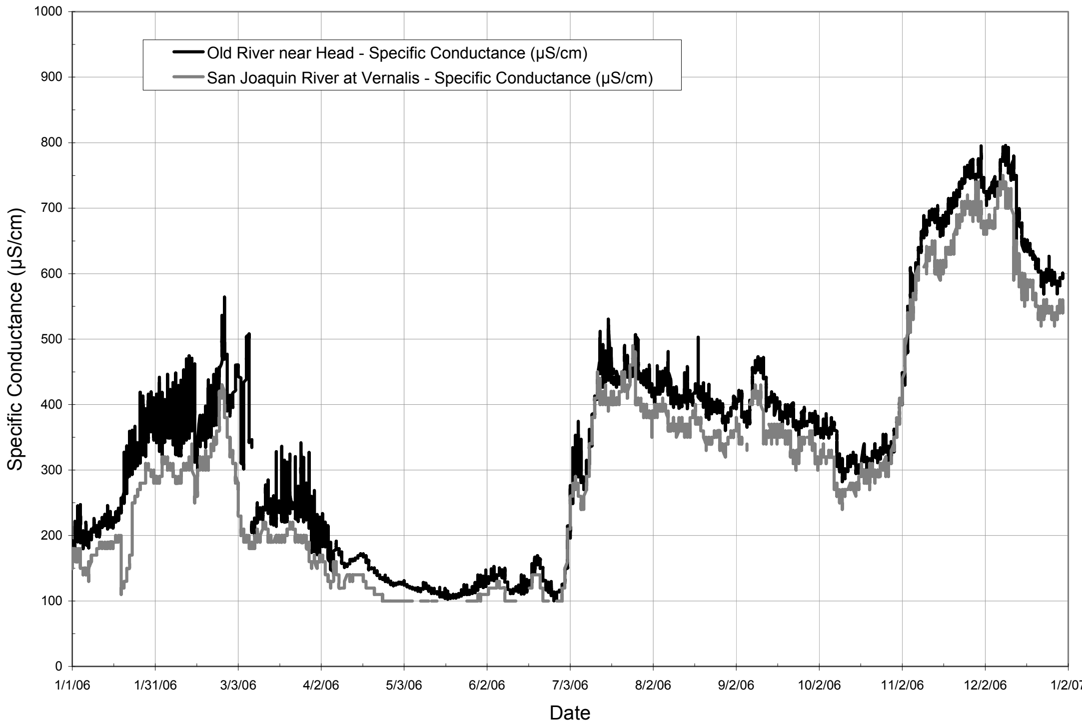
High summer DO concentrations at Old River near Head, TWA, Undine Road, Howard Road, and all three GLC sites are likely due to algal photosynthesis that resulted in supersaturated conditions. Favorable DO conditions at Middle River at Union Point are likely due to incoming freshwater from the Sacramento River during the summer and fall. (From July through December specific conductance values at Union Point are lower than any of the upstream stations) Overall, mean DO values ranged from 8.41 mg/L upstream of the DMC barrier to 9.86 mg/L at Howard Road.

pH values > 9.0 were recorded in Middle River (Undine Road and Howard Road), Old River (Old River near Head) and GLC (above GLC barrier). Each of the four stations had elevated pH values during July and August resulting from an algal bloom as indicated by estimated chlorophyll a concentrations. High pH values during the summer and fall are a direct function of algal productivity, in that, as algae consume CO2 from water, they produce dissolved oxygen as a byproduct of photosynthesis. Less CO2 (decrease in carbonic acid) in the water drives the pH higher, as the water becomes more alkaline. Stations with the lowest chlorophyll a concentrations, such as Union Point, had the lowest pH values. Mean pH values ranged from 7.29 at Union Point to 7.67 at Doughty Cut.

Middle River, Old River and GLC specific conductance values were lowest from April through June. Factors contributing to lower specific conductivity were: high San Joaquin River flows, low specific conductance values upstream at Vernalis, and decreased pumping (CVP and SWP exports). Conductivity values were highest in November and December as the result of lower San Joaquin River flows, higher conductance values upstream at Vernalis, CVP and SWP exports, runoff, as well as other variables.

Specific conductance patterns at Old River near Head are similar to values upstream at Vernalis, though conductance values at Old River near Head are slightly higher throughout most of the year. (See Figure 8-29). The downstream South Delta stations with conductivity levels equivalent to Old River near Head in 2006 were: Middle River at Undine Road, Doughty Cut, above the GLC barrier, and GLC at Tracy Road. Old River at TWA had the highest specific conductance readings in November and December with some values exceeding 1400 µS/cm. Middle River at Union Point had the lowest conductivity readings of the South Delta monitoring stations, likely because of incoming Sacramento River water during times of low San Joaquin River flow. Daily fluctuations in specific conductance ranging from 400 to 800 µS/cm, while San Joaquin River flow is low (< 2,500 cfs), indicate that tidal influences affect conductivity at the downstream sites (Middle River near Tracy Road and upstream and downstream of the DMC barrier). In 2006, mean specific conductance values ranged from 248.1 µS/cm at Union Point to 444.5 µS/cm at Doughty Cut.

Figure 8-29. Old River near Head and San Joaquin River at Vernalis: hourly specific conductance data



In general, turbidity at all eleven sites was lower from mid winter through early spring and in fall, and higher during early winter and summer. Turbidity readings during the summer were higher, partially, because of increased primary productivity (algal biomass), low San Joaquin River flows and agricultural pumping and return flows. Winter storms and runoff resulted in high turbidity readings in early January. The furthest sites downstream on both Middle River and Old River had the lowest turbidity readings for most of the year. High water clarity at these sites during the late spring through early fall may be attributed in part to lower algal biomass (lower chlorophyll *a* concentrations). The Middle River at Union Point site had the highest average water clarity (least turbid) during the 2006 sampling period. Turbidity values at Union Point averaged 9.0 NTU, about 7 NTU lower than at any other site. Mean turbidity readings at the other ten sites ranged from 16.1 NTU at Undine Road to 19.0 NTU at TWA.

Warm water temperatures and low San Joaquin River flows during the summer through early fall contributed to high primary productivity at six South Delta locations. An algal bloom, as indicated by estimated chlorophyll *a* concentrations, was observed from early July through mid August at: Old River near Head, TWA, Undine Road, Howard Road, above the GLC barrier, and GLC at Tracy Road. The observed algal bloom contributed to high turbidity values and supersaturated dissolved oxygen concentrations during the summer at these sites. Chlorophyll *a* concentrations were lowest at the downstream stations in Middle River (Tracy Road and Union Point) and Old River (upstream and downstream of the DMC barrier). Mean chlorophyll *a* concentrations ranged from 5.1 µg/L at Union Point to 18.0 µg/L above the GLC barrier.

Recommendations

The Middle River near Tracy Road and upstream and downstream of the DMC barrier monitoring sites had the most instances where the sonde(s) recorded DO concentrations less than 5.0 mg/L. These sites also have lower estimated chlorophyll *a* concentrations then the upstream sites, especially during the summer. A study could be done to elucidate the causes of low DO in these areas and to determine if phytoplankton are dieing off and/or settling out downstream near the barriers.

A study to discern the contributing factors to high specific conductivity values at and around Old River at TWA could also be undertaken. In comparison to the Old River near Head and GLC stations, conductance readings at TWA were up to 600 µS/cm higher in November and December.

Data Availability

Data is available upon request. Please email Shaun Philippart at sphilipp@water.ca.gov or call at (916) 651-0717.

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Chapter 9. Hydrologic Modeling

This chapter describes the details of the simulation of historical 2006 Delta hydrodynamic conditions as requested by the Temporary Barriers and Lower San Joaquin Section in DWR's Bay-Delta Office. The period of simulation is from January 1, 2006 to December 31, 2006.

To simulate the hydrodynamics, the Delta Modeling Section used DSM2-Hydro which is a one-dimensional open channel unsteady flow model based on a four-point finite difference solution of equations of momentum and continuity. The solution scheme has proven to be stable. The model network extends north to Sacramento River at I street, south to San Joaquin River at Vernalis, and west to Martinez where a 15-minute time history of stage input governs how the tide signal propagates into the Delta.

Boundary conditions

Flow and stage information required at model boundaries were downloaded from the IEP web site (www.iep.water.ca.gov) and from the California Data Exchange Center web site (cdec.water.ca.gov). The IEP database includes data collected by various agencies, including DWR and USGS. When duplicate data from more than one agency was available, they were assigned a priority order. As the first option, DSM2 uses data ranked at the highest priority, and then proceeds to those of lower priority if necessary. Priority was assigned based on data availability, quality of the data, and past experience. Input data, visually examined using plotting routines, was occasionally missing. In most cases, alternate sources of data filled any gaps.

Resulting key boundary conditions for 2006 are shown in Figures 9-1 through 9-4.

Figure 9-1. Daily average historical inflow from the Sacramento River, 2006.

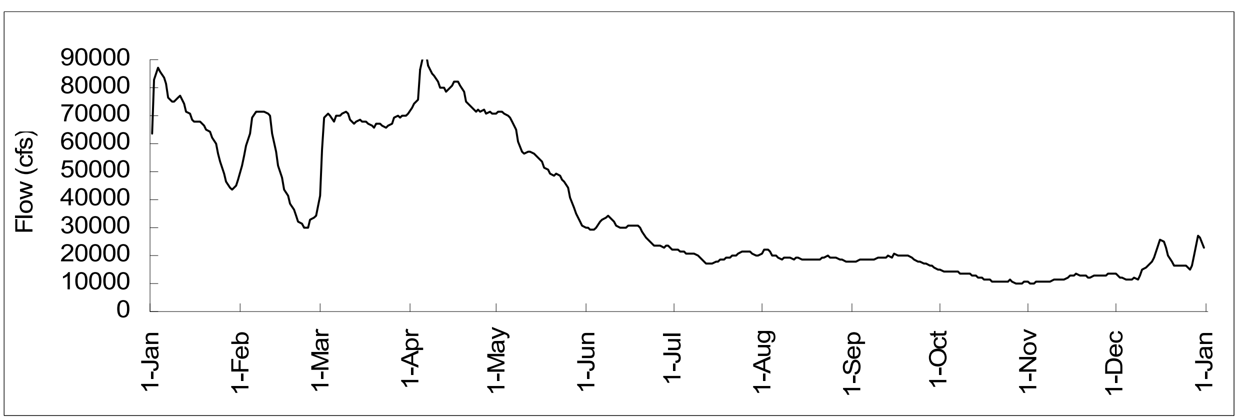


Figure 9-2. Daily average historical inflow from the Yolo Bypass, 2006.

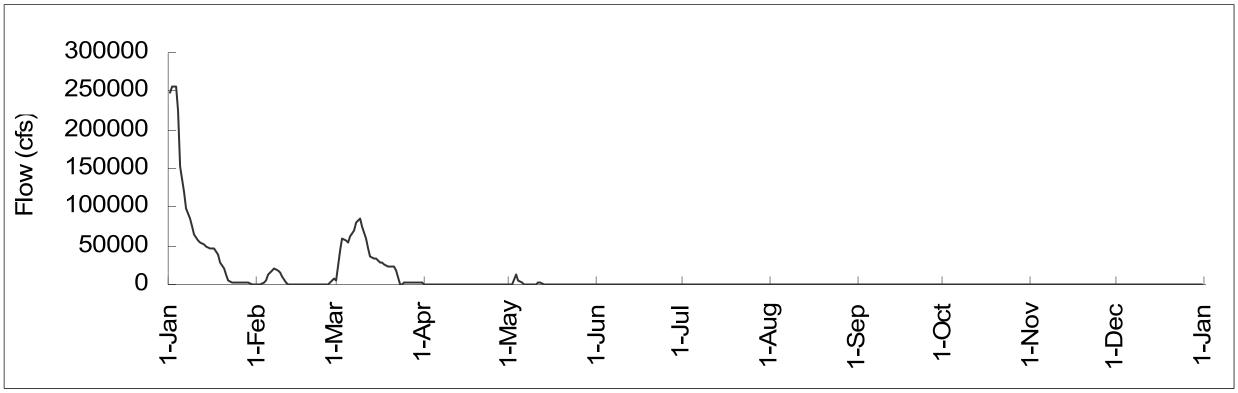


Figure 9-3. Daily average historical inflow from the San Joaquin River, 2006.

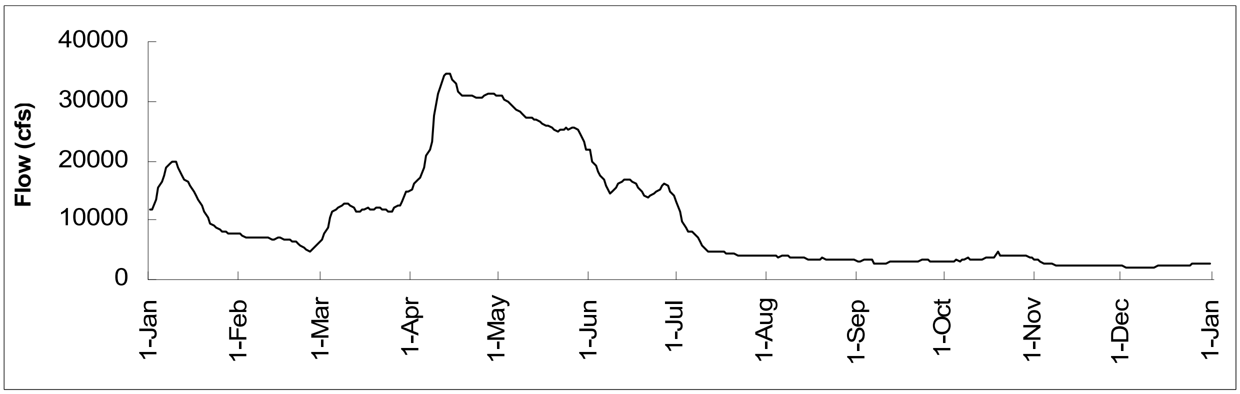
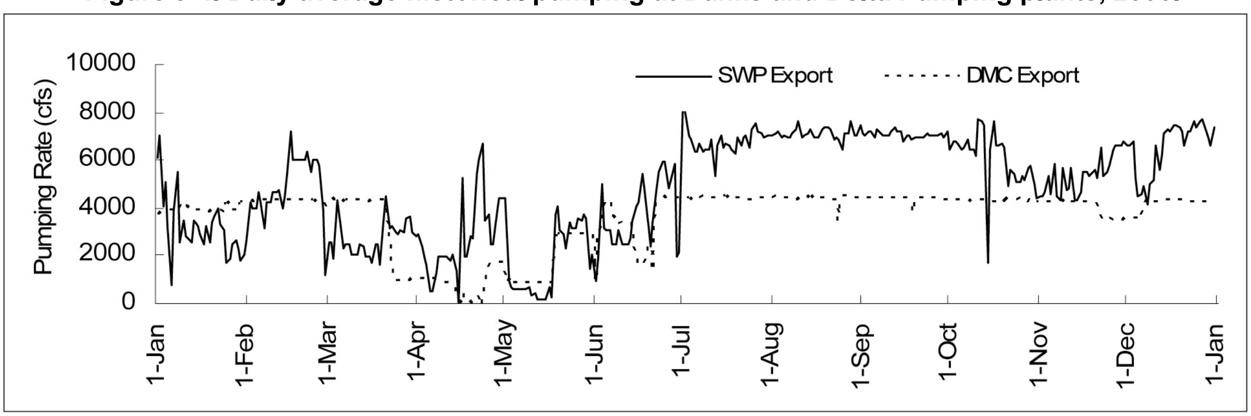


Figure 9-4. Daily average historical pumping at Banks and Delta Pumping plants, 2006.



Consumptive use

The Delta Island Consumptive Use (DICU) model provided an estimate of the amount of water diverted from and returned to Delta channels due to agricultural activities. Input to DICU model includes precipitation, pan evaporation data, and water year types. The water year type determines which of two possible cropping patterns in the Delta is assumed, which in turn contributes to the estimation of agricultural water needs.

Delta Structures

The relatively high San Joaquin River flows delayed installation of the temporary agricultural barriers until July and the spring and fall barriers at the head of Old River were not installed. While installation and removal of the temporary barriers may have taken days or weeks, the DSM2 simulation timed the actual installation and removal to effective dates and times, as inferred from 15-minute observed water levels. The table below describes the historical operation of all the South Delta Barriers.

Table 9-1. Historical south Delta barriers installation and removal, 2006

Barrier	Installation		Removal	
	Started*	Ended*	Started*	Ended*
Middle River	7/7/06	7/7/06	11/18/06	11/18/06
Old River near Delta Mendota Canal	7/17/06	7/17/06	11/16/06	11/16/06
Grant Line Canal	7/20/06	7/20/06	11/21/06	11/21/06
Old River @ Head (spring)	--	--	--	--
Old River @ Head (fall)	--	--	--	--
* As reported by Temporary Barriers Program, DWR				

The Delta Cross Channel gates were operated in 2006 as shown below.

Table 9-2. Historical Delta Cross Channel Operation for 2006.

Time Interval					
Date	Time		Date	Time	Status
1/1/2006	0000	-	6/30/2006	0800	closed
6/30/2006	0800	-	11/15/2006	0900	open
11/15/2006	0900	-	12/31/2006	2400	closed

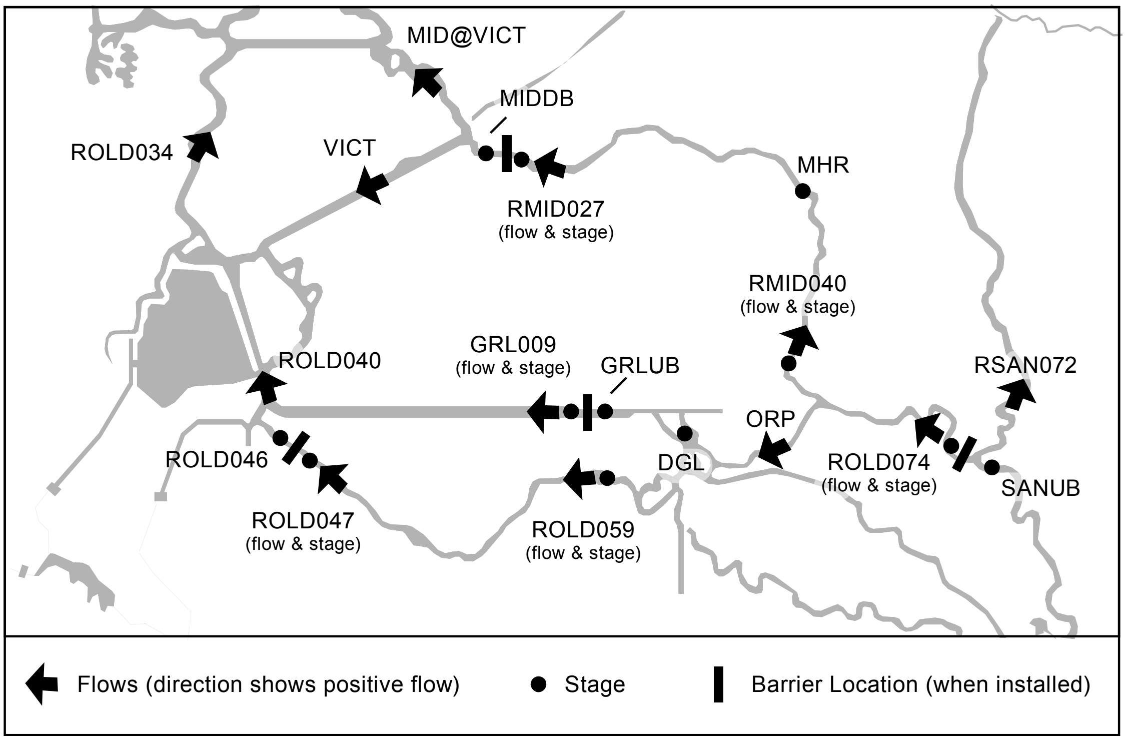
DSM2 Simulation of 2006 Hydrodynamics

In order to aid the interpretation of DSM2-simulated hydrodynamics, 2006 was partitioned into 26 periods corresponding to times for which significant Delta inflows and exports were fairly constant and south Delta barrier configurations were unchanging. The 26 periods and their characteristics are shown in the table below.

Table 9-3. Characteristics of intervals during 2006 for presentation of simulation results.

Period		Period Average Flows				Period Barrier Status			
		Sac R. + Yolo Bypass (cfs)	SJR (cfs)	DMC Pumping (cfs)	SWP Pumping (cfs)	MR	OR	GLC	ORH
JAN	1 - 6	290,280	14,431	3,807	4,350				
	6 - 21	122,693	16,008	3,913	3,210				
	22 - 31	48,214	7,607	4,236	1,996	--	--	--	--
FEB	1 - 14	71,975	7,030	4,319	4,134	--	--	--	--
	15 - 28	37,581	5,961	4,308	5,532	--	--	--	--
MAR	1 - 20	114,851	11,297	4,316	2,445	--	--	--	--
	21 - 31	73,905	12,570	1,329	3,240	--	--	--	--
APR	1 - 9	83,555	19,682	999	1,669	--	--	--	--
	10 - 20	80,147	32,536	403	2,160	--	--	--	--
	21 - 30	71,723	30,940	1,102	4,286	--	--	--	--
MAY	1 - 17	63,339	28,194	870	707	--	--	--	--
	18 - 31	42,639	24,903	2,814	3,099	--	--	--	--
JUN	1 - 21	31,201	16,567	2,815	3,145	--	--	--	--
	22 - 30	24,192	15,016	4,409	4,679	--	--	--	--
JUL	1 - 7	21,908	9,869	4,360	7,177	--	--	--	--
	7 -1 7	19,035	5,582	4,458	6,509	IN	--	--	--
	17 - 19	19,244	4,475	4,391	6,411	IN	IN	--	--
	19 - 31	21,149	4,052	4,363	7,029	IN	IN	IN	--
AUG	1 - 31	19,651	3,576	4,393	7,104	IN	IN	IN	--
SEP	1 - 30	18,766	3,059	4,371	7,075	IN	IN	IN	--
OCT	1 - 31	12,204	3,648	4,308	6,068	IN	IN	IN	--
NOV	1 - 15	11,033	2,674	4,265	4,841	IN	IN	IN	--
	16 - 17	13,253	2,471	4,259	5,506	IN	--	IN	--
	18 - 20	12,788	2,402	4,257	5,445	--	--	IN	--
	21 - 30	12,950	2,278	3,554	6,156	--	--	--	--
DEC	1 - 31	17,409	2,330	4,133	6,539	--	--	--	--

Figure 9-5. Locations where simulated Delta stages and flows for 2006 are presented.



Hourly simulated stage and flow data for each period were used to generate data for box plots which graphically show period minimum, maximum, 25% quartile, 75% quartile, and average values. By typical sign convention, negative flow values correspond to upstream flow. The locations where box plots of stage and flow are presented are shown in Figure 9-5 with arrows indicating assumed positive flow direction. The numerical values these graphs are based upon are presented in the appendix.

The distributions of simulated stages and flow for each of the 26 intervals are shown in Figures 9-6 and 9-7. Stage results are presented upstream and downstream of each barrier location and flows are presented throughout the south Delta in order to convey the general circulation patterns. Some of the minimum stages and average flows from the distributions of data in Figures 9-6 and 9-7 are shown in Figure 9-8 which graphically presents flow circulation and minimum water levels in the south Delta for periods of time with and without the barriers in 2006.

Discussion

The installation of the temporary barriers in 2006 significantly altered water levels in the south Delta. In July before the barriers were installed, minimum water levels in the vicinity of the barrier sites were significantly lower than were levels at sites not far upstream: approximately 1 foot lower in Middle River compared to the Howard Road site, approximately ½ foot lower in Old River compared to the Tracy Road site, and approximately ½ foot lower in Grant Line Canal compared to the Doughty Slough site. By July 20, all three temporary barriers were installed which raised minimum water levels just upstream of the barriers approximately 1½ feet in July and 2 to 3 feet in August through October. Minimum water levels upstream of the barriers were maintained. Before the barriers were installed, circulation patterns maximized bringing San Joaquin River-source water into the south Delta. After all three barriers were installed, the distributions of flow in the south Delta channels were somewhat narrowed (Figure 9-7), but period-average flows indicate generally similar flow splits in terms of percent of flow at the head of Old River, at the Old River-Middle River bifurcation, and in the relative amount of flow down Old River at Tracy Road compared to flow down Grant Line Canal (Table 9-4 and Figure 9-8). An important reason for the similar flow splits was the relatively high summertime flows in the San Joaquin River.

Table 9-4. DSM2-simulated flow splits in the south Delta over different periods in 2006.

Period	Barriers Installed	Average SJR flow (cfs)	SJR-OR Split OR flow (%)	SJR-OR Split SJR flow (%)	OR-MR Split OR flow (%)	OR-MR Split MR flow (%)	GLC-OR Split OR flow (%)	GLC-OR Split GLC flow (%)
Jun 1-21		16,567	53	47	90	10	18	82
Jun 22-30		15,016	53	47	91	9	17	83
Jul 1-7		9,869	53	47	93	7	15	85
Jul 7-17	MR	5,582	57	43	95	5	13	87
Jul 20-31	OR,MR,GLC	4,052	53	47	89	11	20	80
Aug 1-31	OR,MR,GLC	3,576	50	50	88	12	15	85
Sep 1-30	OR,MR,GLC	3,059	50	50	88	12	11	89
Oct 1-31	OR,MR,GLC	3,648	47	53	88	12	12	88

Note: SJR is San Joaquin River, MR is Middle River, OR is Old River, and GLC is Grant Line Canal. Values are based on ratios of period-average flows.

Figure 9-6. Box Plots showing distribution of DSM2-simulated stages for various periods during 2006.

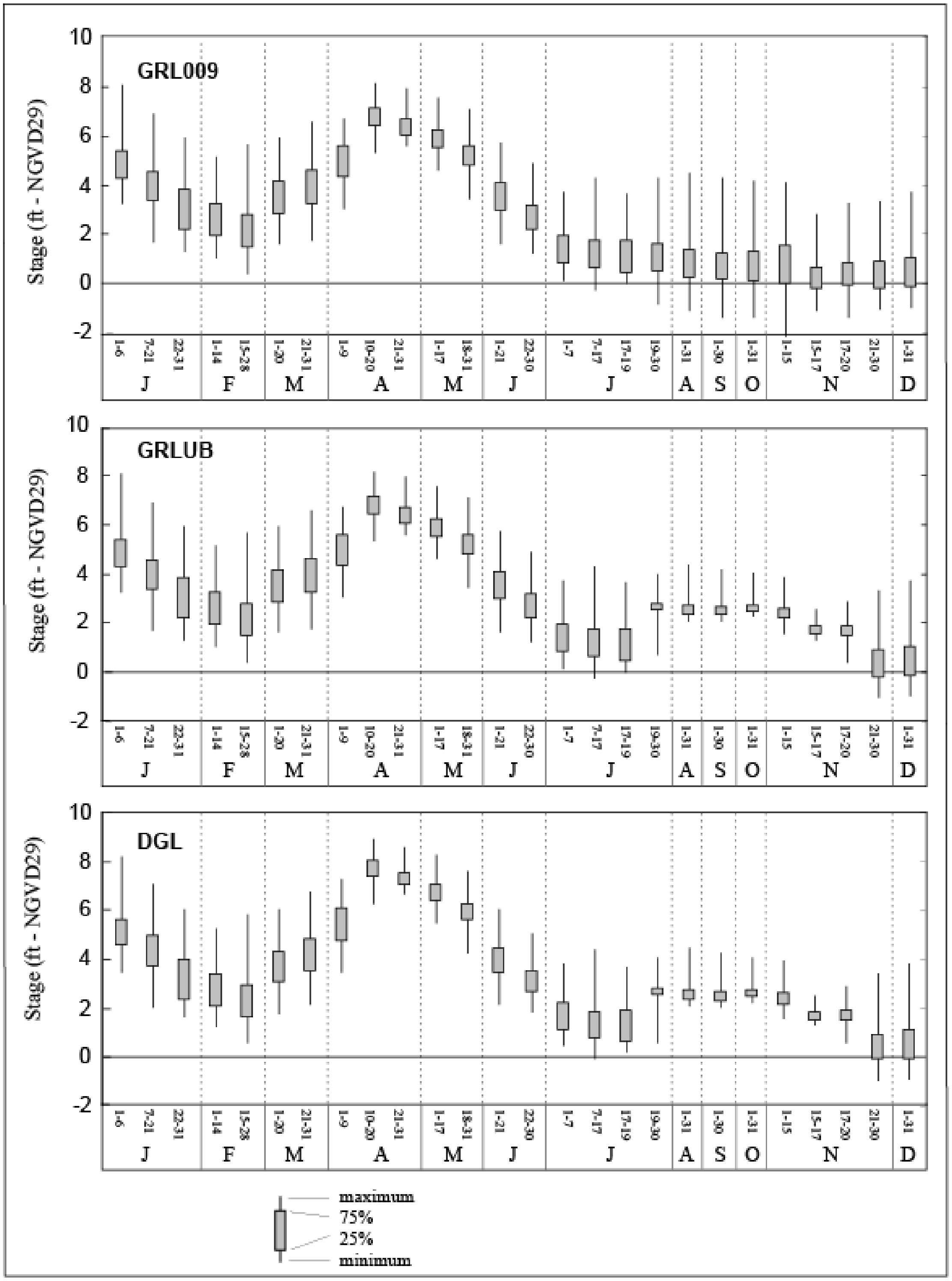


Figure 9-6 (cont.). Box Plots showing distribution of DSM2-simulated stages for various periods during 2006.

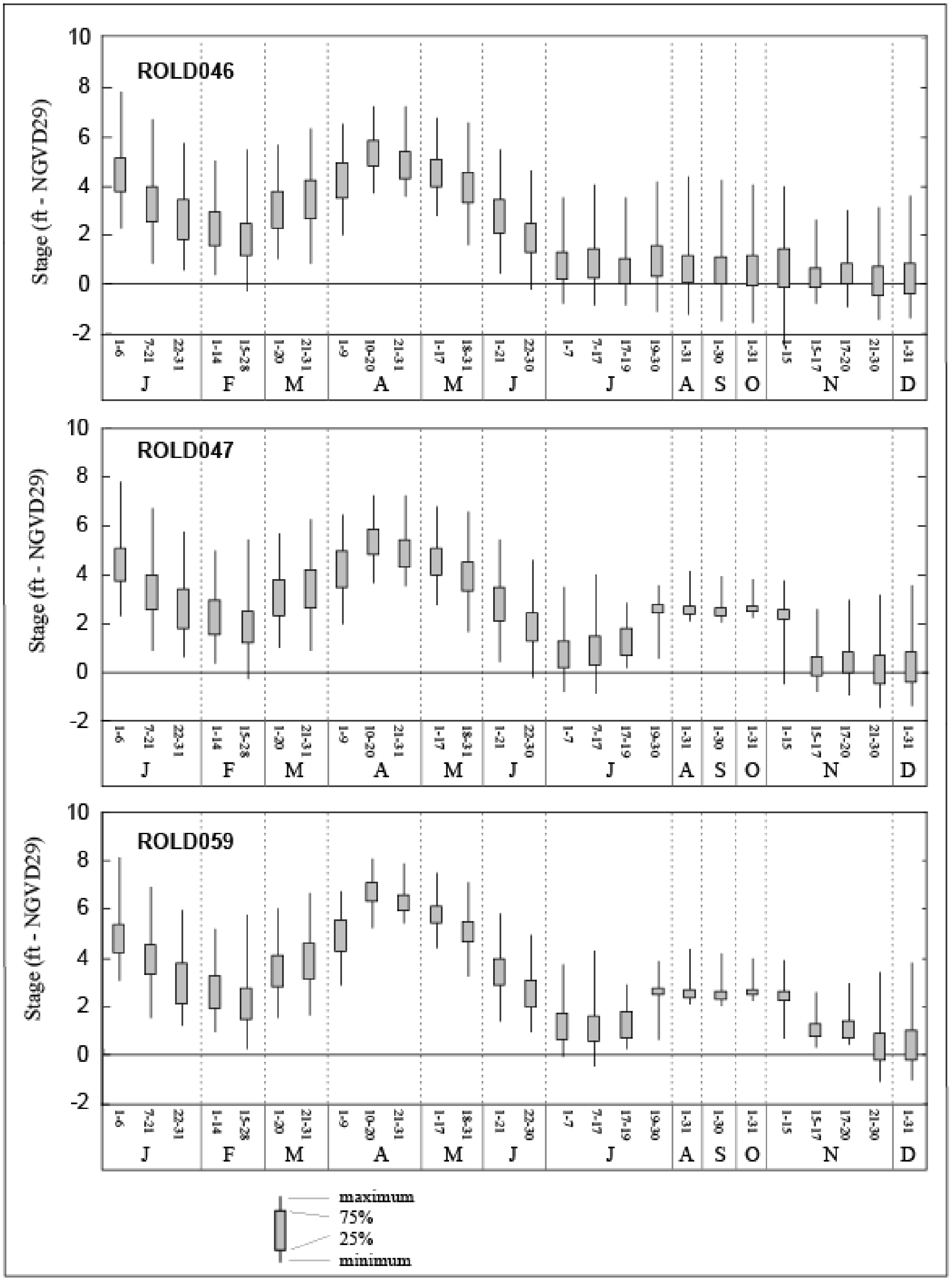


Figure 9-6 (cont.). Box Plots showing distribution of DSM2-simulated stages for various periods during 2006.

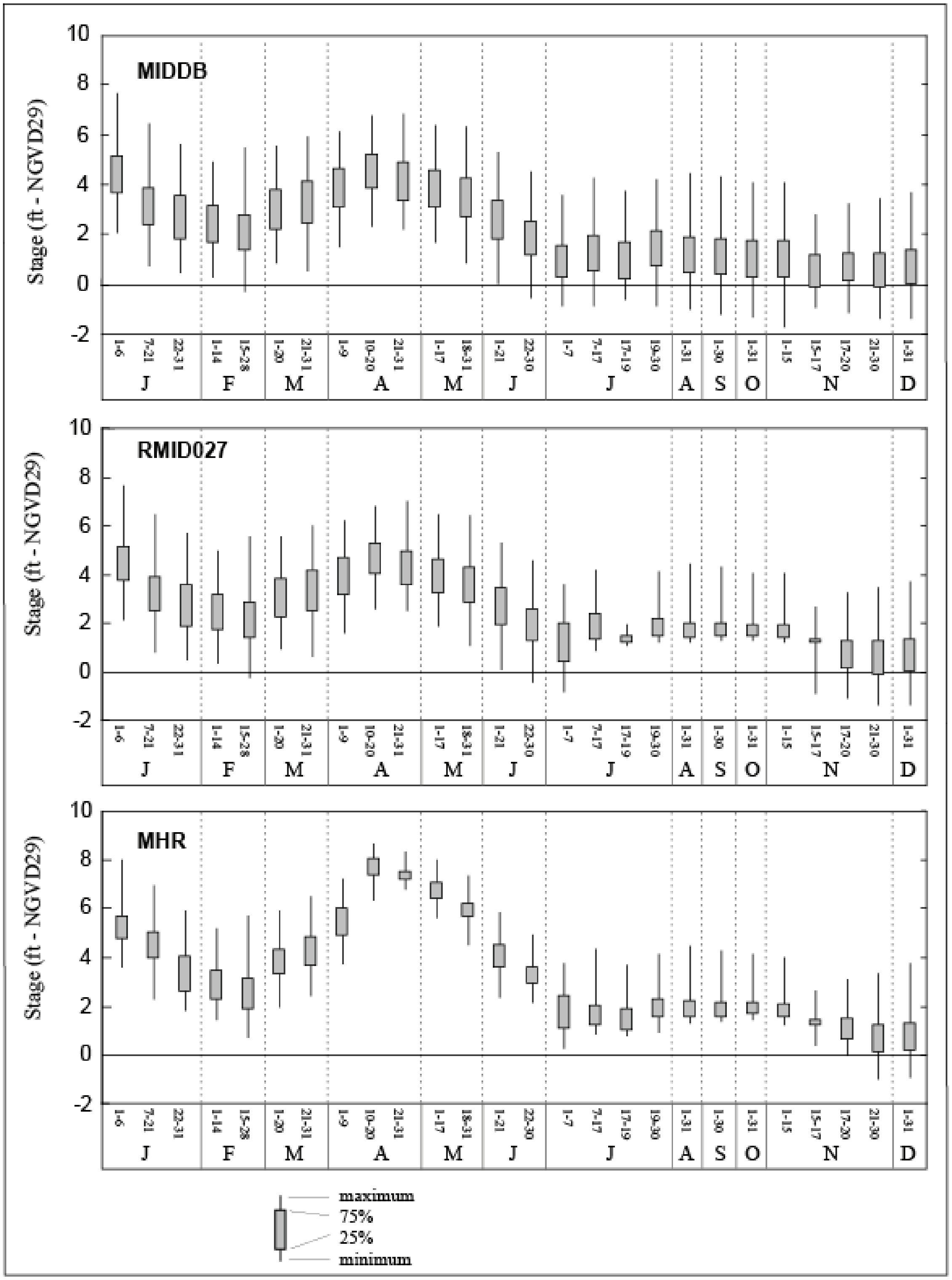


Figure 9-6 (cont.). Box Plots showing distribution of DSM2-simulated stages for various periods during 2006.

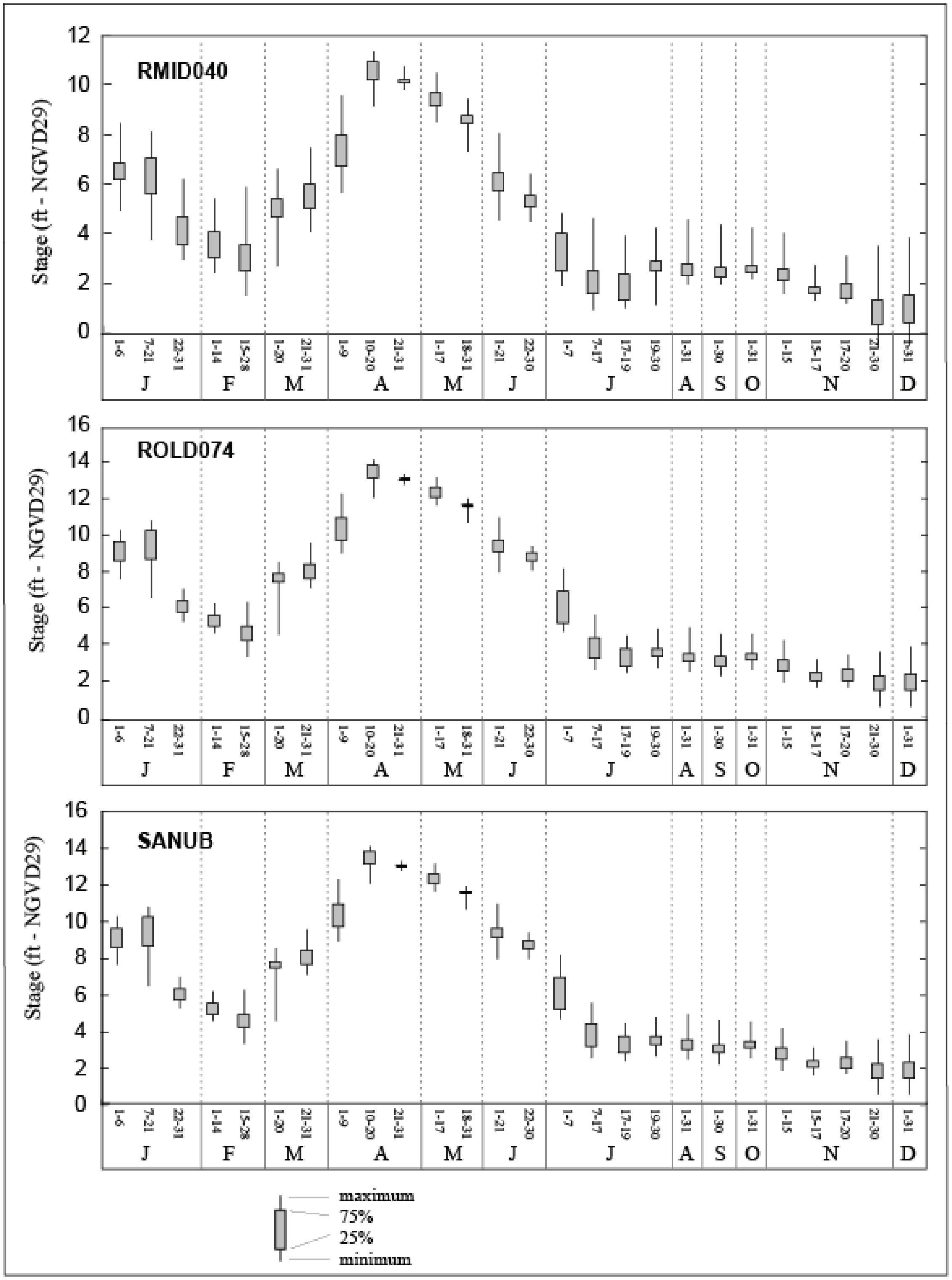


Figure 9-7. Box Plots showing distribution of DSM2-simulated flows for various periods during 2006.

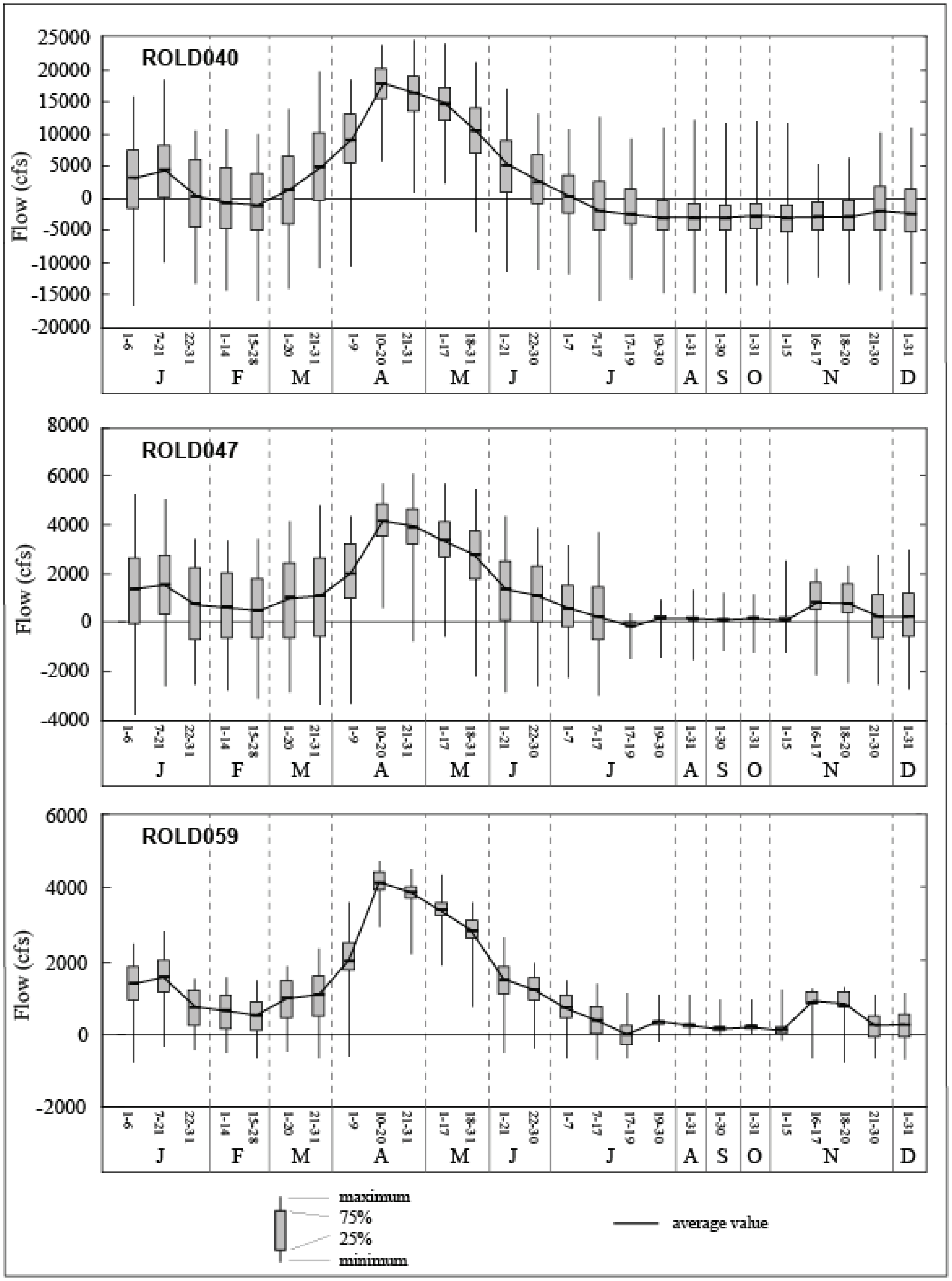


Figure 9-7 (cont.). Box Plots showing distribution of DSM2-simulated flows for various periods during 2006.

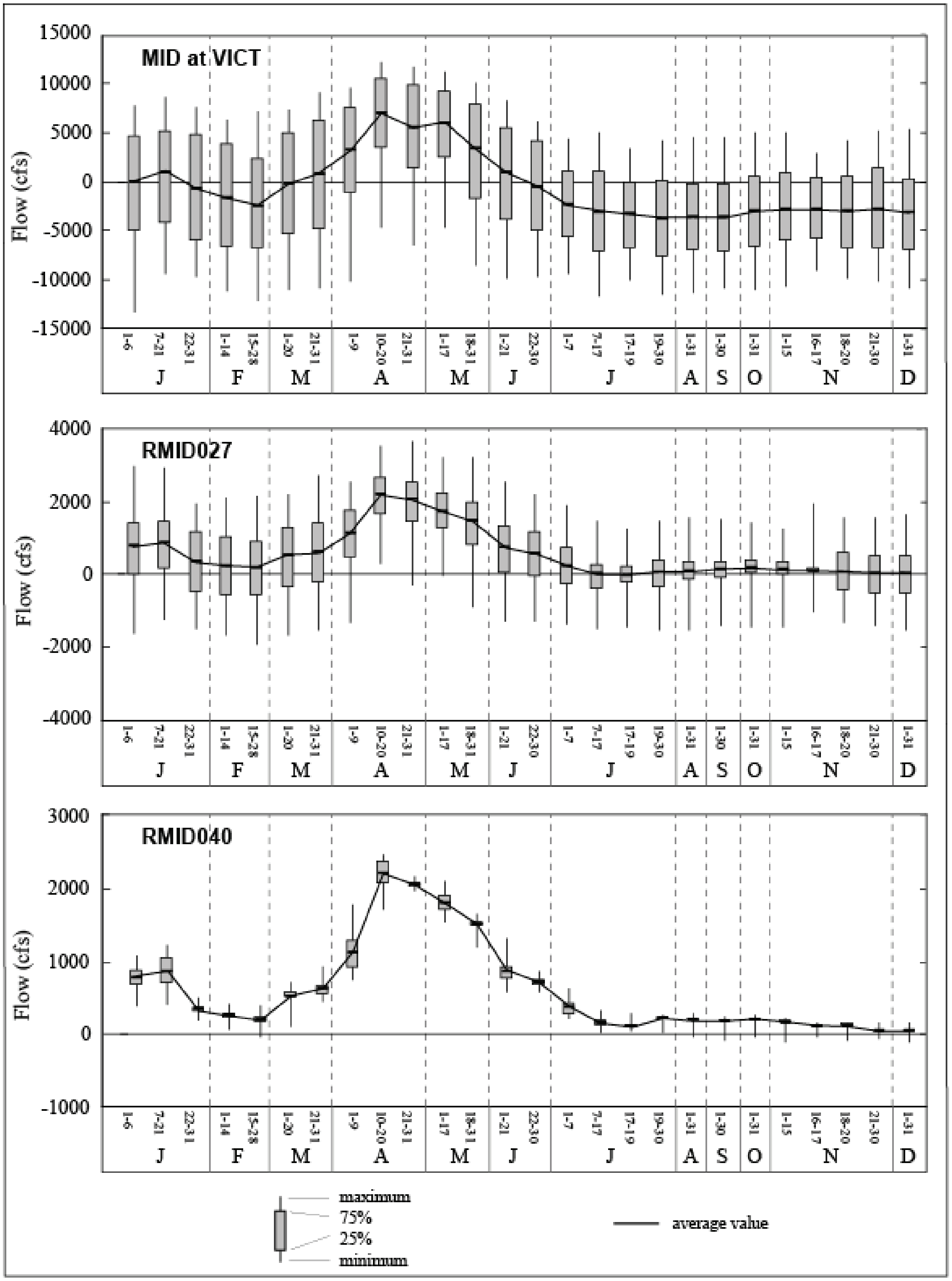


Figure 9-7 (cont.). Box Plots showing distribution of DSM2-simulated flows for various periods during 2006.

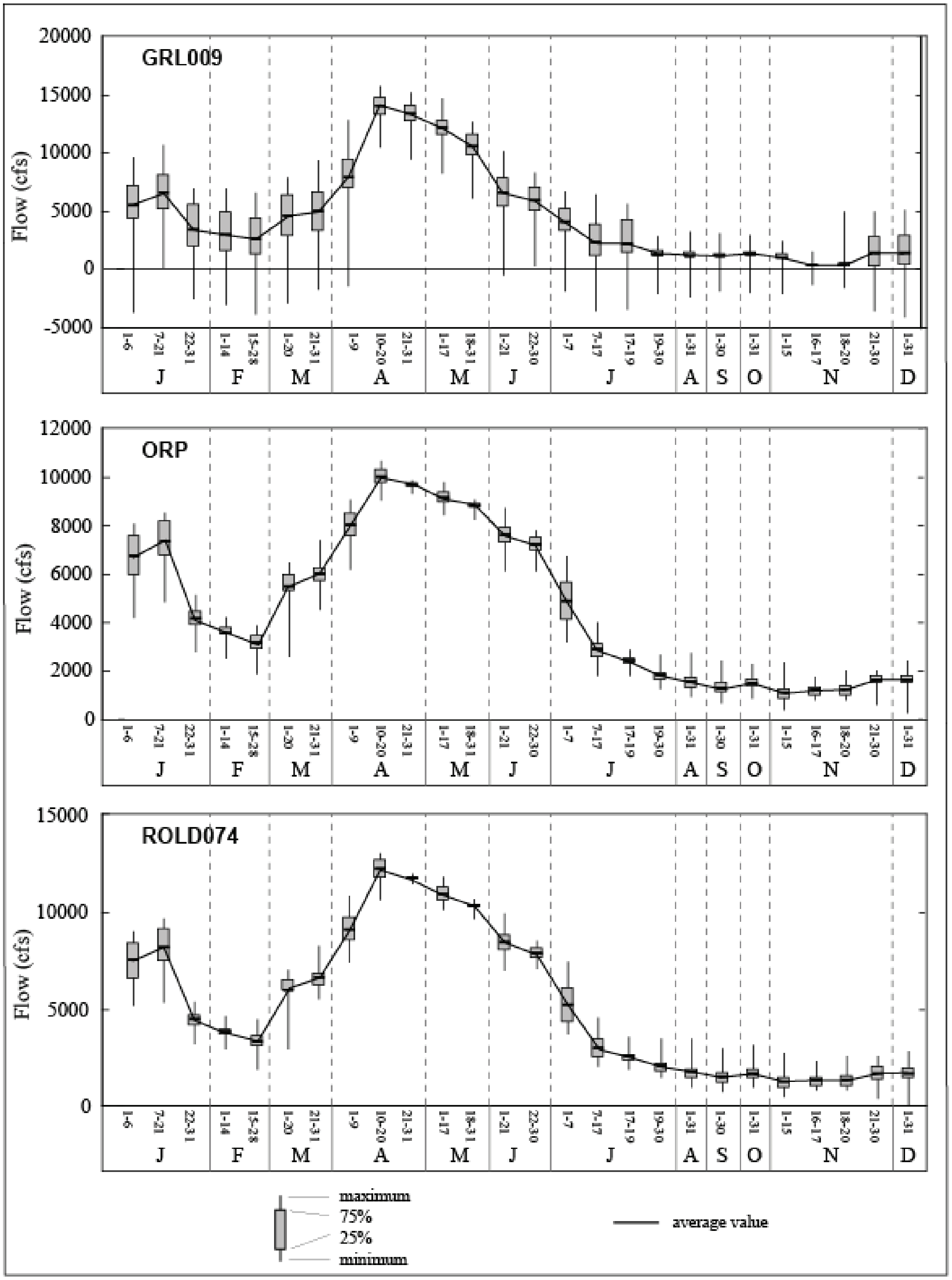


Figure 9-7 (cont.). Box Plots showing distribution of DSM2-simulated flows for various periods during 2006.

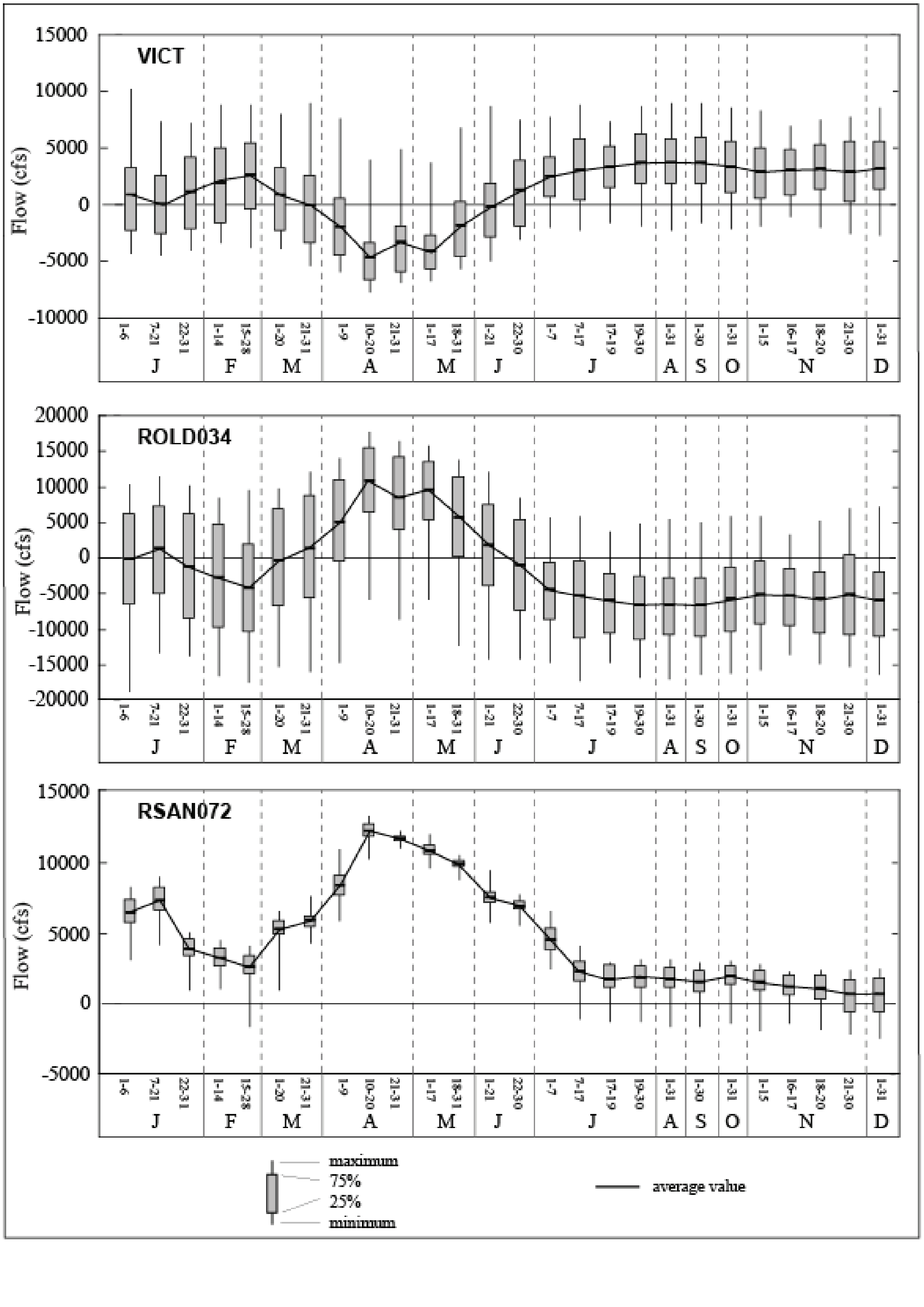


Figure 9-8. DSM2-simulated average flow patterns and minimum stages for 2006.

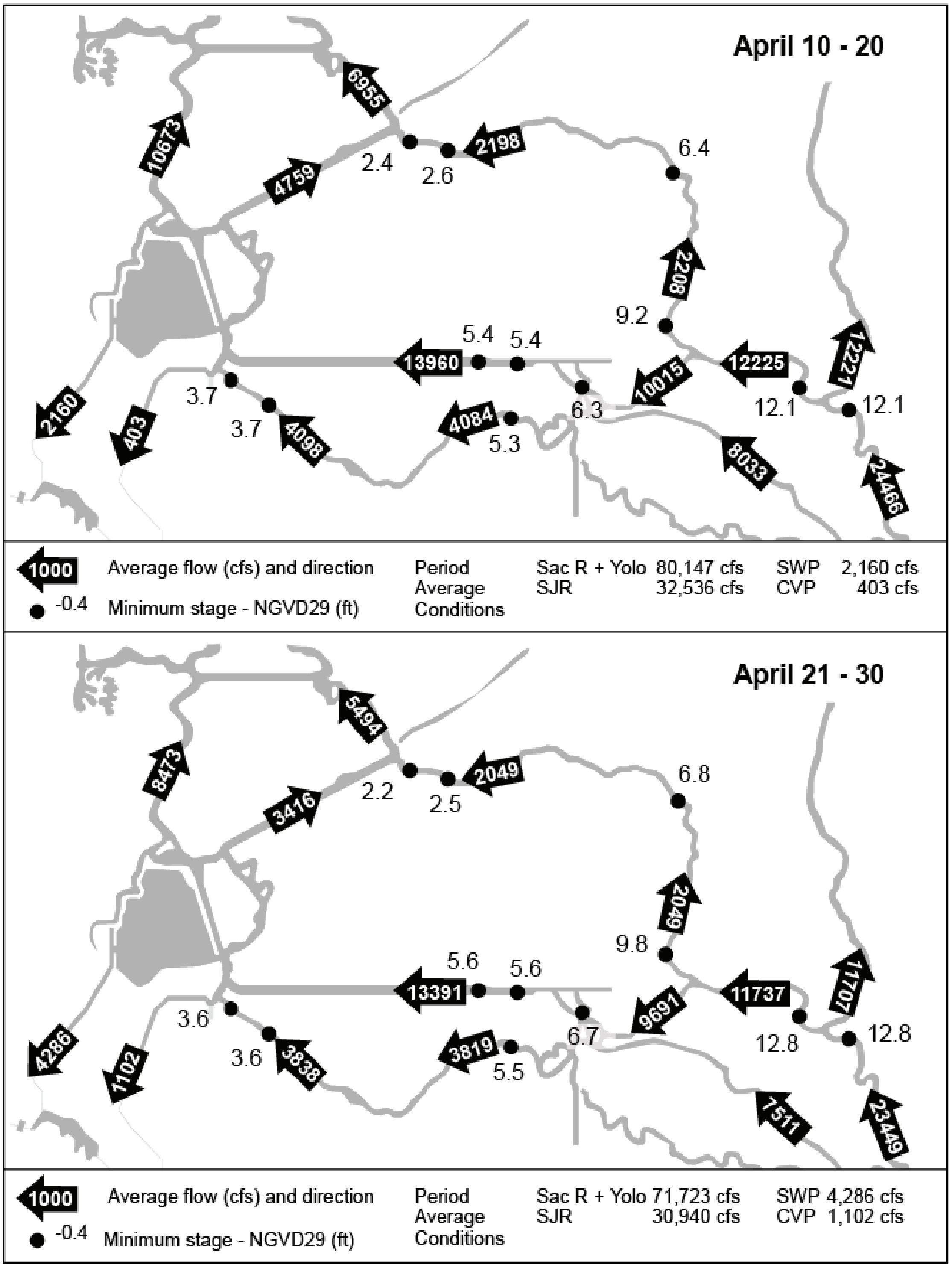


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.

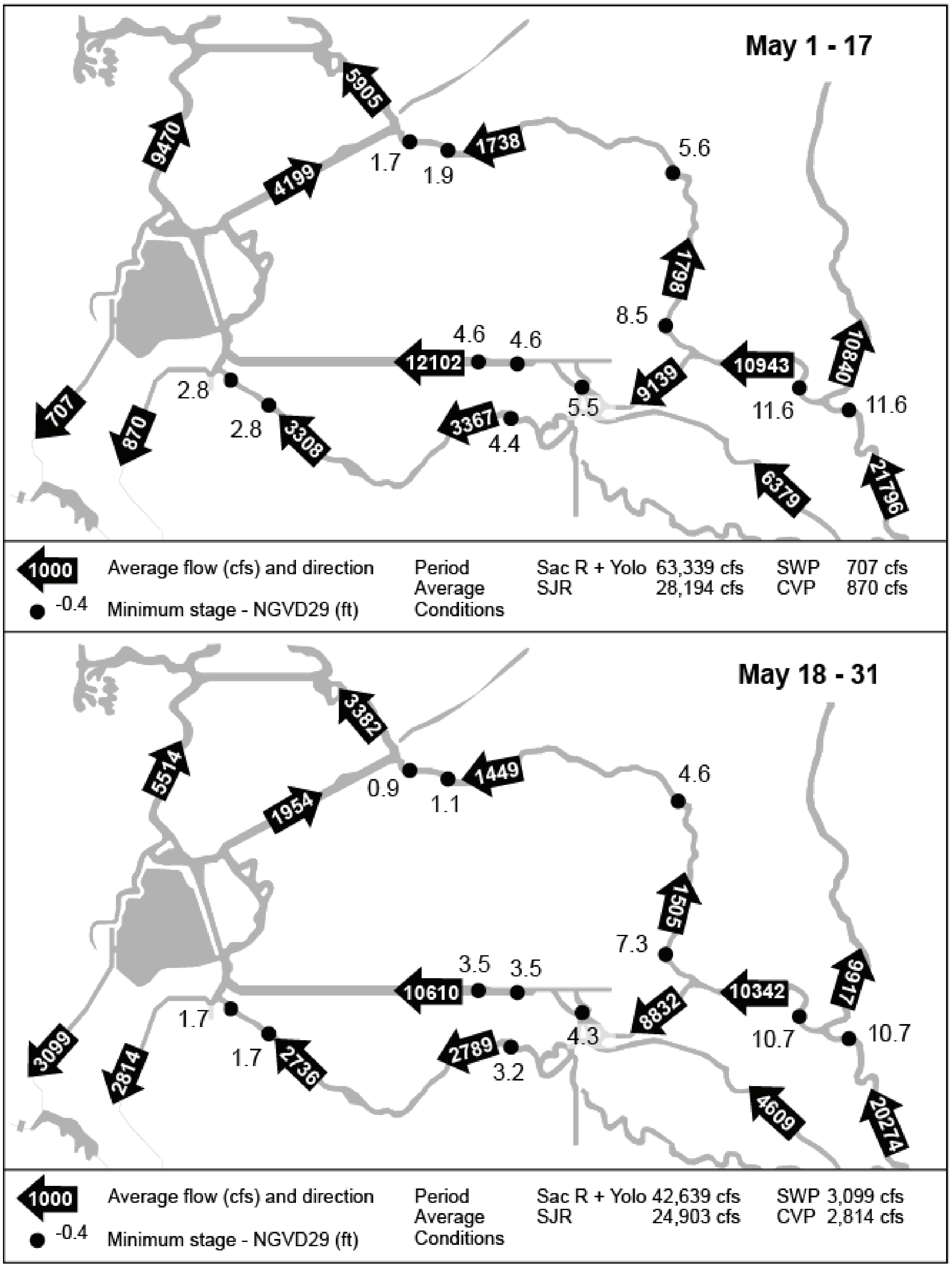


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.

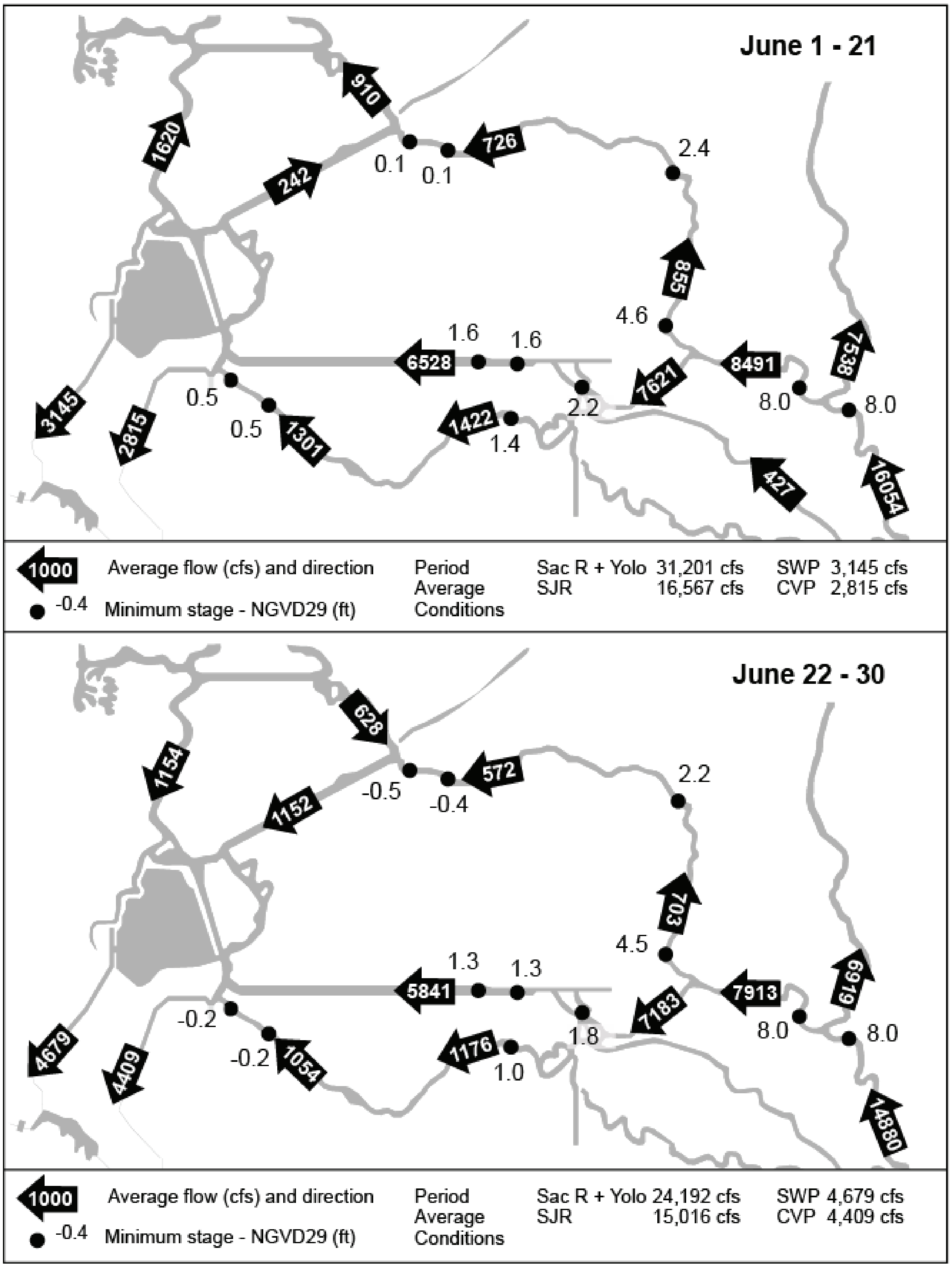


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.

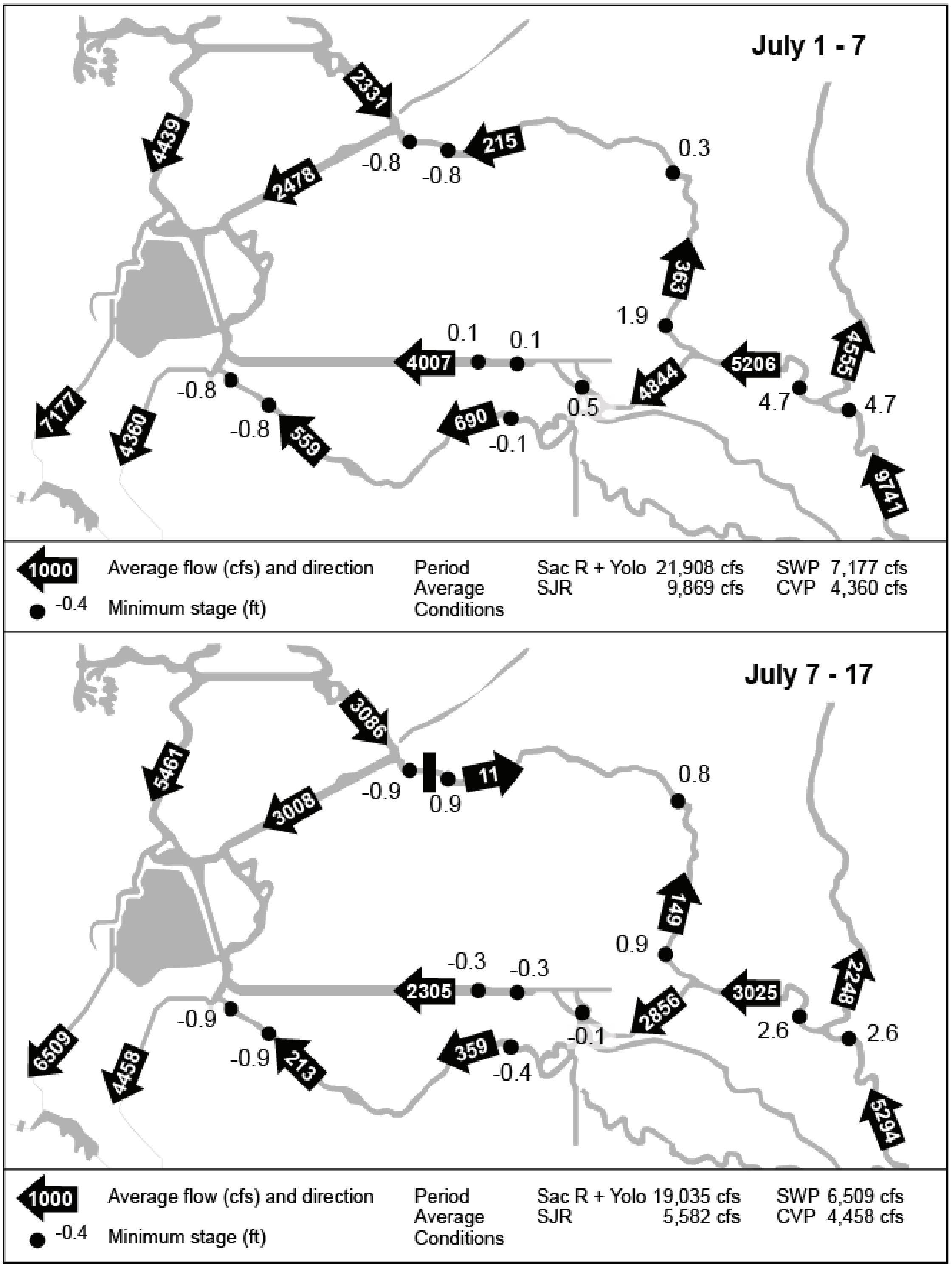


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.

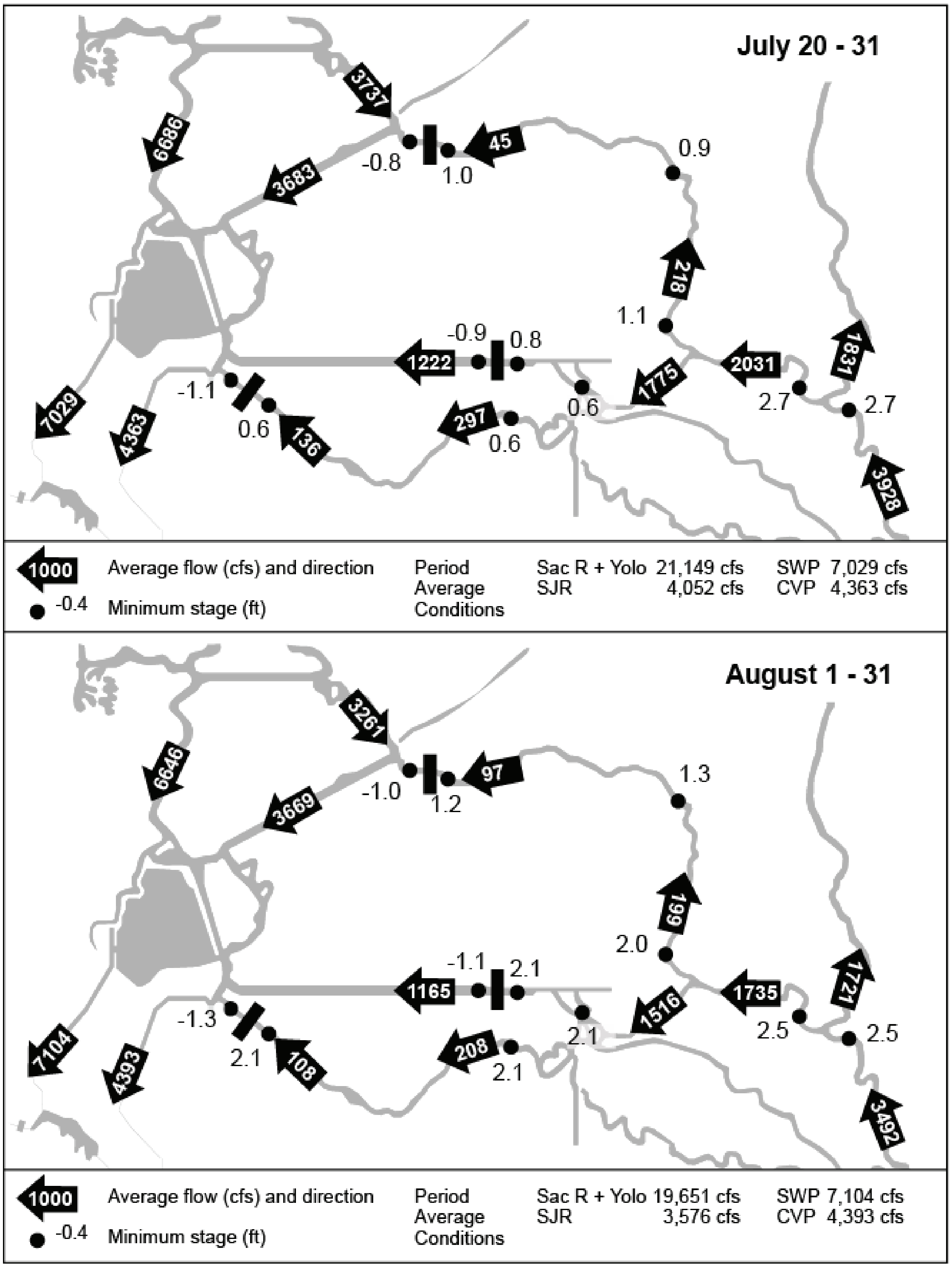


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.

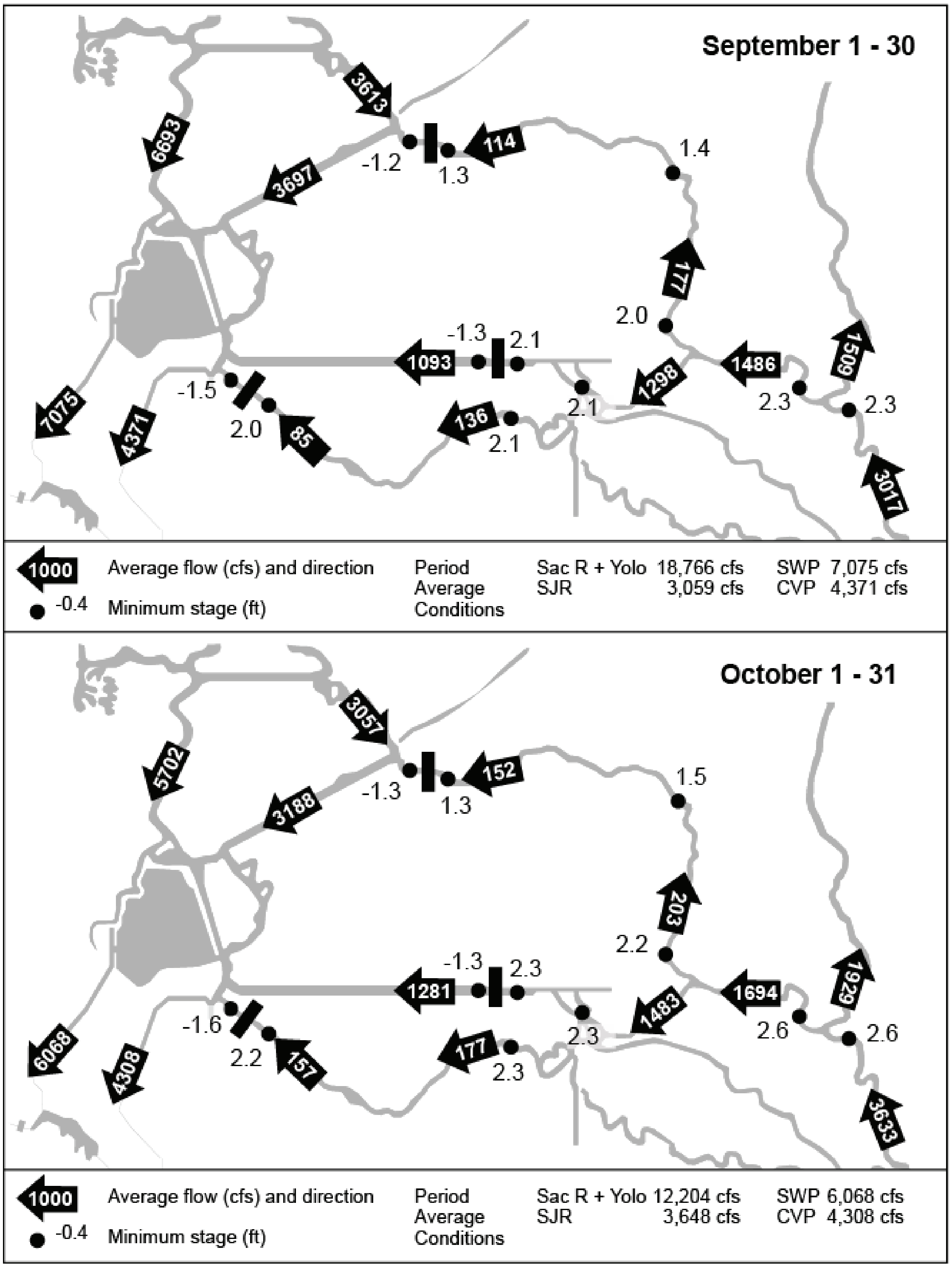
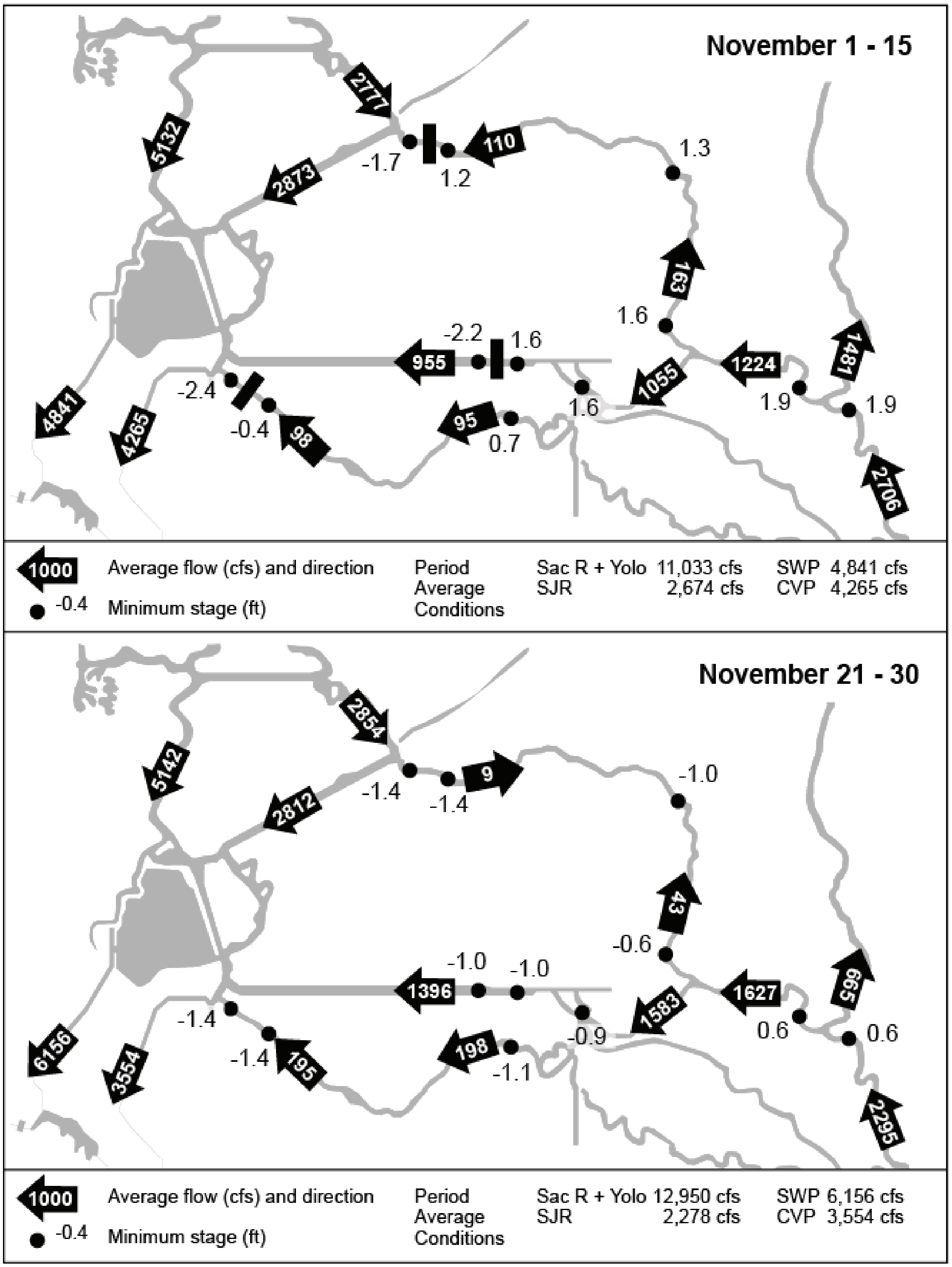


Figure 9-8 (cont.). DSM2-simulated average flow patterns and minimum stages for 2006.



Appendix A. Chinook Salmon Survival Investigations

Figure A-1. Water Temperature Monitoring Locations

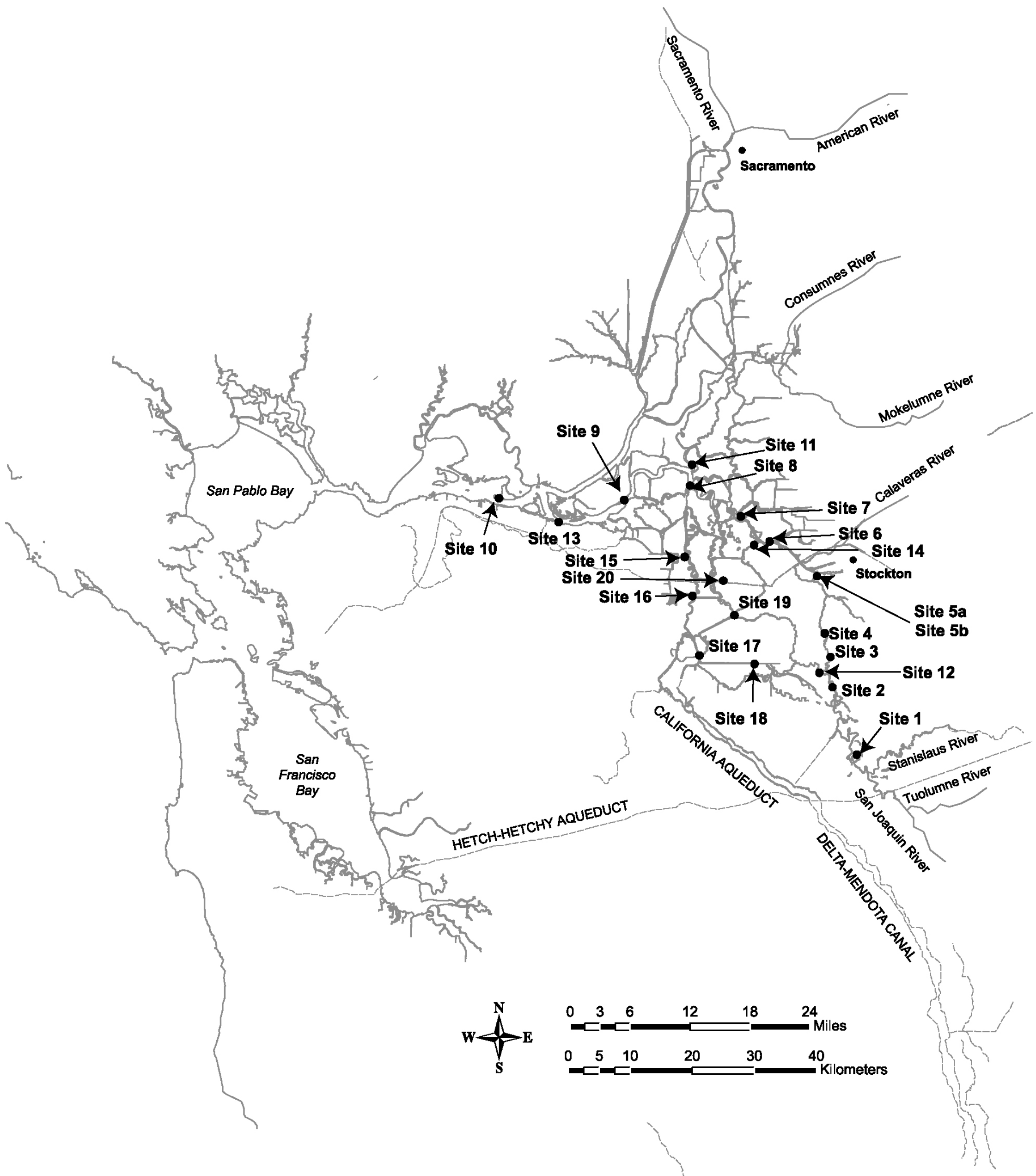


Table A-1. VAMP 2005 Water Temperature Monitoring

Site #	Logger Number	Temperature Monitoring Location	Latitude	Longitude	Distance from Durham Ferry	Date Deployed	Date Retrieved	Notes
	551654	Merced River Hatcher - 1			n/a	3/27/06	5/23/06	
	562570	Merced River Hatcher - 2			n/a	3/27/06	5/23/06	
1	877664	Durham Ferry	N 37 41.381	W 121 15.657	n/a	4/4/06	6/8/06	
2	900627	Mossdale	N 37 47.180	W 121 18.425	11	4/4/06	6/8/06	Logger Lost
3	900626	Dos Reis	N 37 49.808	W 121 18.665	16	4/4/06	6/8/06	
4	900625	DWR Monitoring Station	N 37 51.869	W 121 19.376	19	4/4/06	6/8/06	
5a	900624	Confluence – Top	N 37 56.818	W 121 20.285	27	4/4/06	6/8/06	
5b	900615	Confluence- Bottom	N 37 56.818	W 121 20.285	27	4/4/06	6/8/06	
6	900616	Downstream of Channel Marker 30	N 37 59.776	W 121 25.569	33	4/4/06	6/8/06	
7	900617	"Q" Piling 1/2 mile upstream of channel marker 13	N 38 01.940	W 121 28.769	37	4/4/06	6/8/06	
8	877663	All Pro abandoned boat	N 38 04.522	W 121 34.413	45	4/4/06	6/8/06	Logger malfunction - no data
9	877667	Jersey Point USGS Gauging Station	N 38 03.172	W121 41.637	56	4/4/06	6/8/06	Logger Lost
10	877668	Chipps Island	N 38 03.084	W 121 55.463	72	4/4/06	6/8/06	
11	877666	Mokelumne River- Lighthouse Marina	N 38 06.334	W 121 34.213	40	na	6/8/06	Not deployed this year due to no Mokelumne releases
12	877669	Old River at HORB	N 37 48.457	W 121 19.872	13	4/4/06	6/8/06	
13	900619	Antioch Marina	N 38 01.147	W121 48.829	53	4/4/06	6/8/06	
14	900620	Turner Cut	N 37 59.468	W121 27.267	40	4/4/06	6/5/06	Logger Semi-Dewatered: Lying in very shallow water (2-3 inches)
15	877666	Holland Riverside Marina	N 37 58.323	W 121 34.887	42	4/18/06	6/5/06	
16	900618	Old River / Indian Slough Confluence	N 37 54.954	W 121 33.949	34	4/18/06	6/5/06	
17	900622	CCF Radial Gates	N 37 49.773	W 121 33.096	26	4/18/06	6/6/06	Fisher man said has been periodically dewatered by curious people.
18	822253	Grant Line Canal at Travy Blvd Bridge	N 37 49.143	W 121 27.026	21	4/18/06	6/6/06	Casing smashed, but logger present. Dewatered at some point
19	900621	Middle River at Victoria Canal Confluence	N37 53.323	W121 29.334	32	4/18/06	6/6/06	
20	877665	Werner Cut: Channel above Woodward Isle	N 37 56.319	W 121 30.584	40	4/18/06	6/6/06	

Figure A-2a. Water Temperature Monitoring: Merced River Fish Hatchery to Mossdale

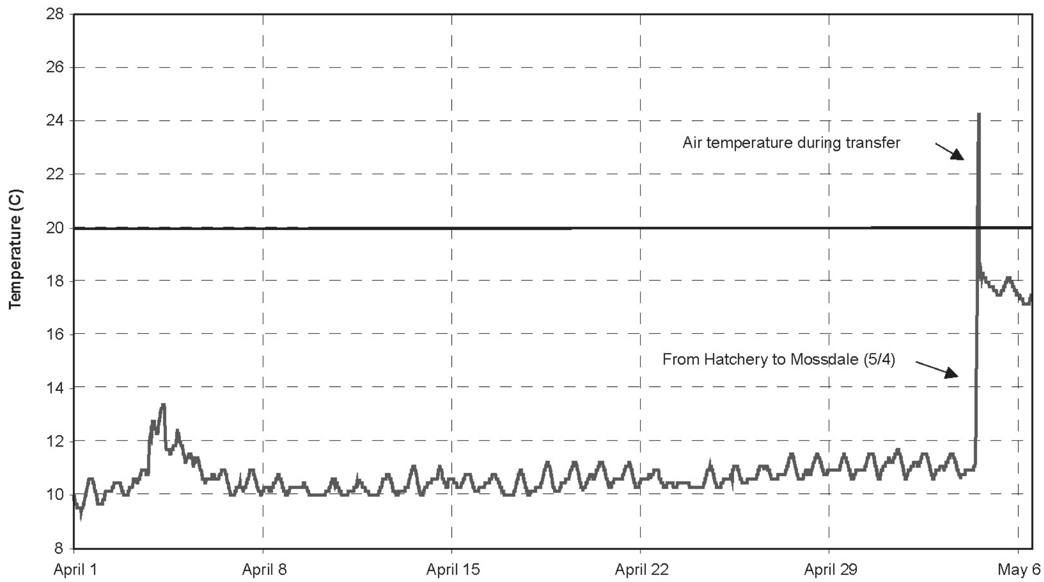


Figure A-2b. Water Temperature Monitoring: Merced River Fish Hatchery to Mossdale

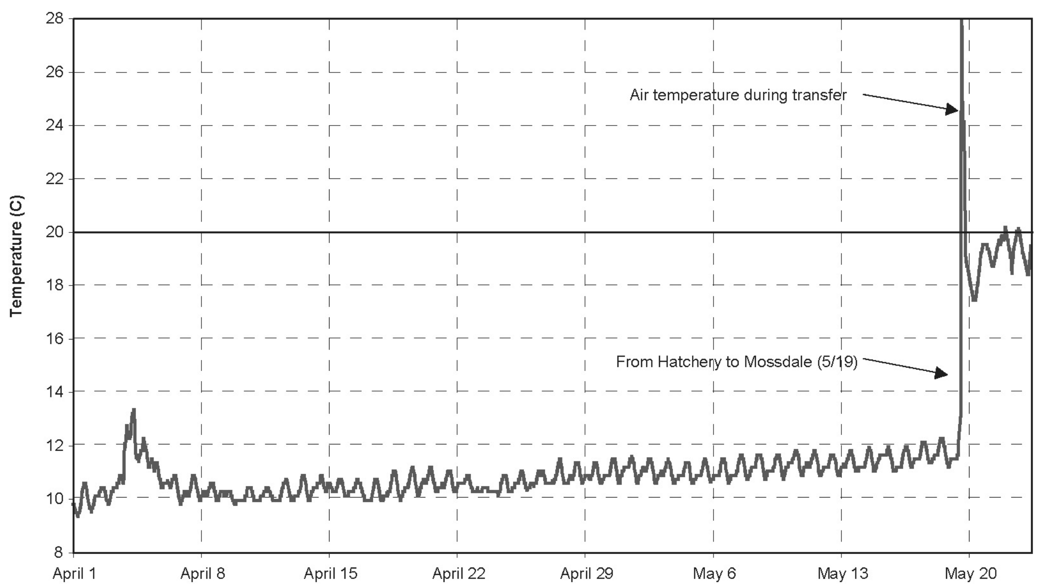


Figure A-3. Water Temperature Monitoring: Site 1 - Durham Ferry

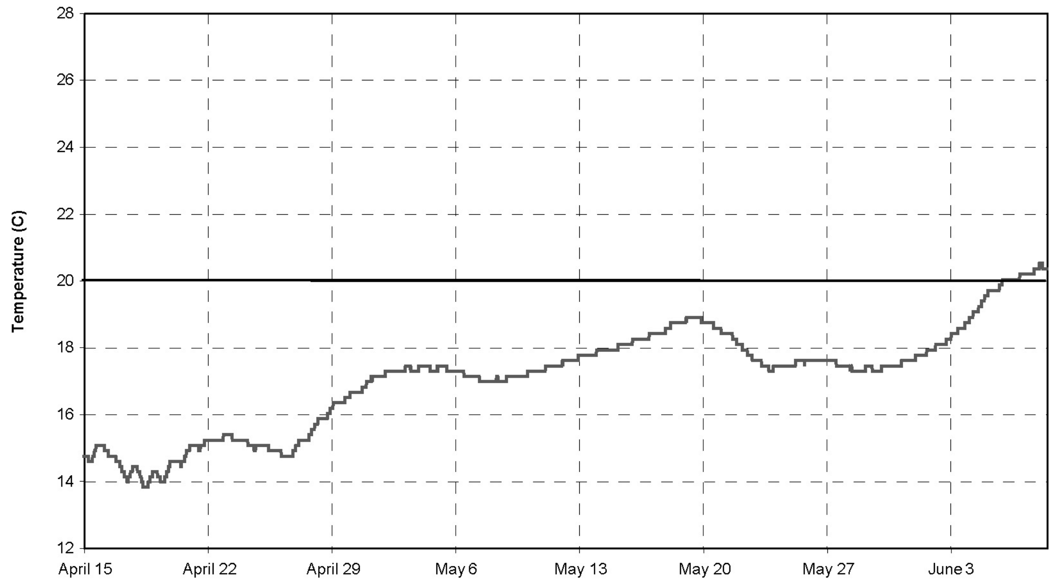


Figure A-4. Water Temperature Monitoring: Site 3 - Dos Reis

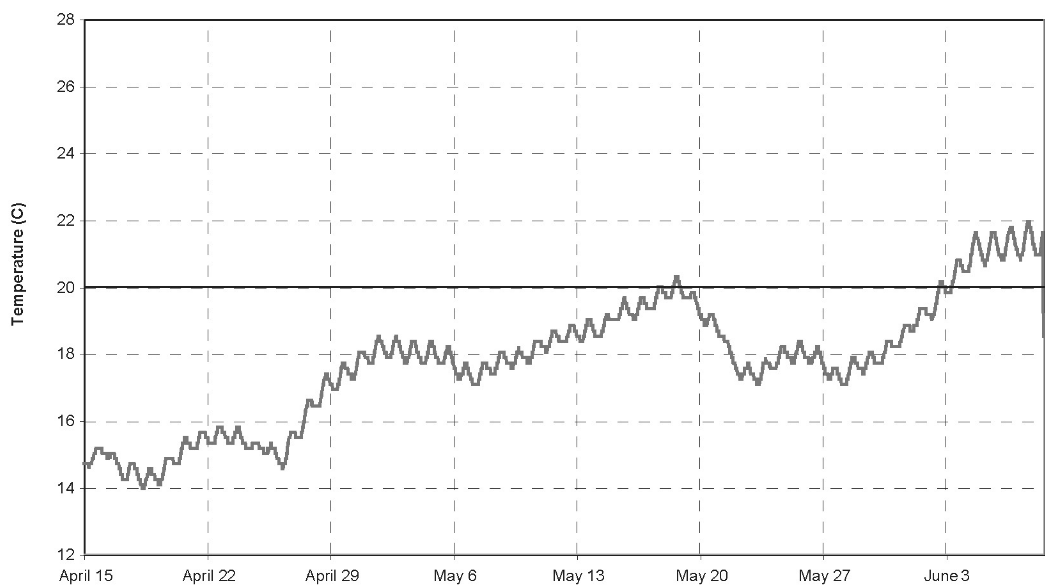


Figure A-5. Water Temperature Monitoring: Site 4 - DWR Monitoring Station

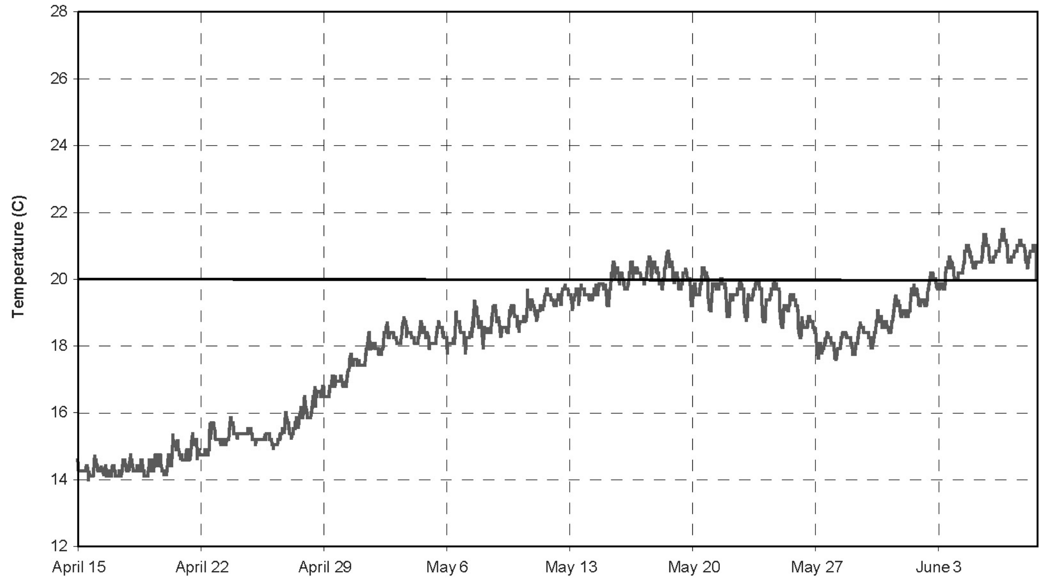


Figure A-6. Water Temperature Monitoring: Site 5a - Confluence -Top

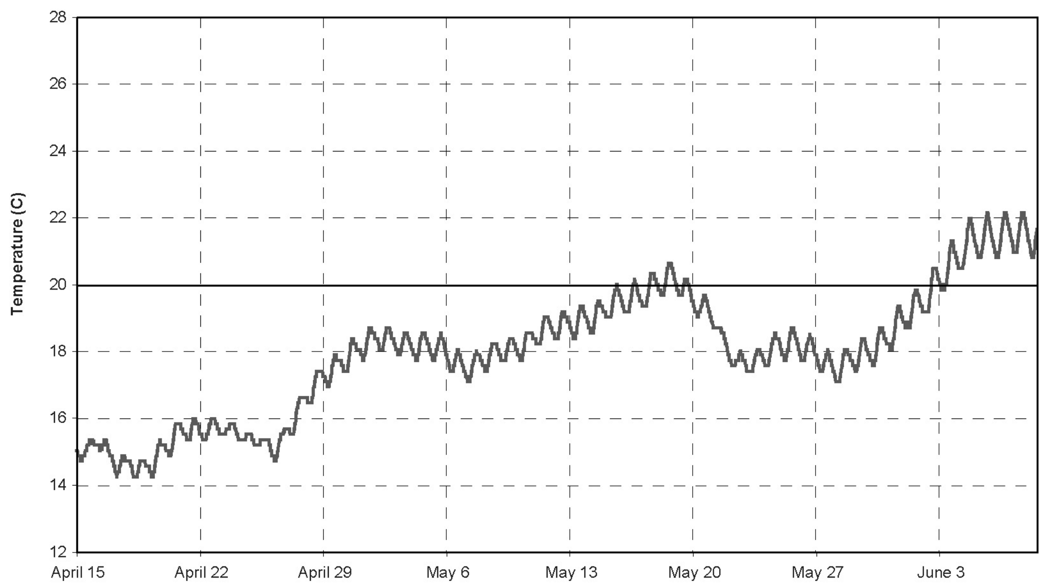


Figure A-7. Water Temperature Monitoring: Site 5b - Confluence - Bottom

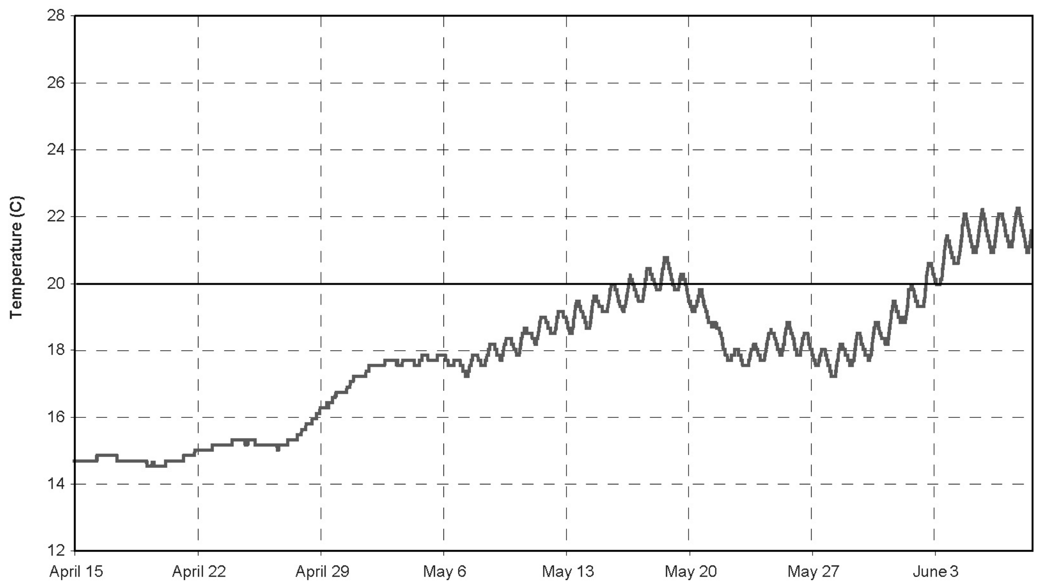


Figure A-8. Water Temperature Monitoring: Site 6 - Downstream of Channel Marker 30

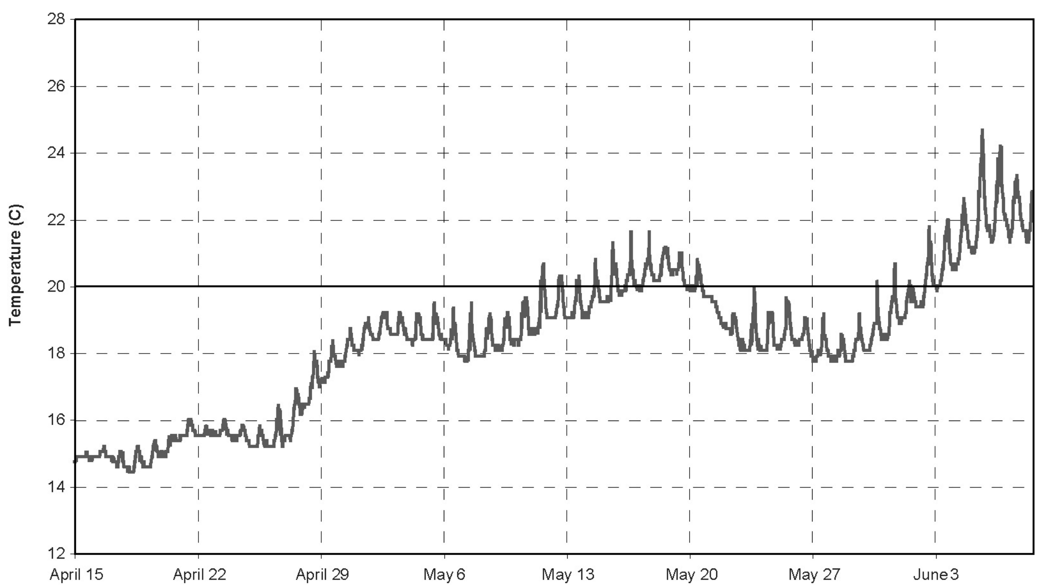


Figure A-9. Water Temperature Monitoring: Site 7 - Upstream of Channel Marker 13

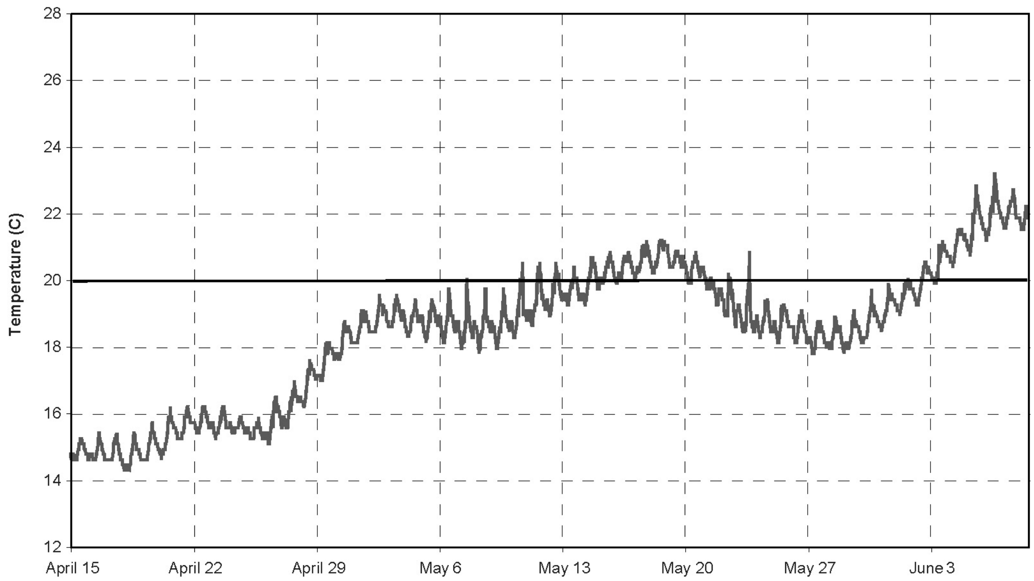


Figure A-10. Water Temperature Monitoring: Site 10 - Chipps Island

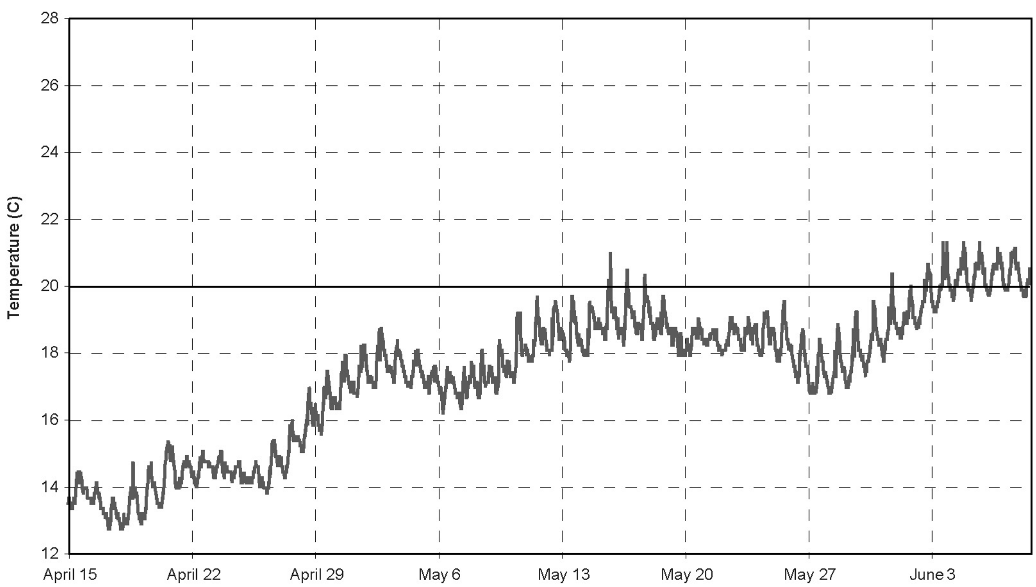


Figure A-11. Water Temperature Monitoring: Site 12 - Old River at Head of Old River Barrier

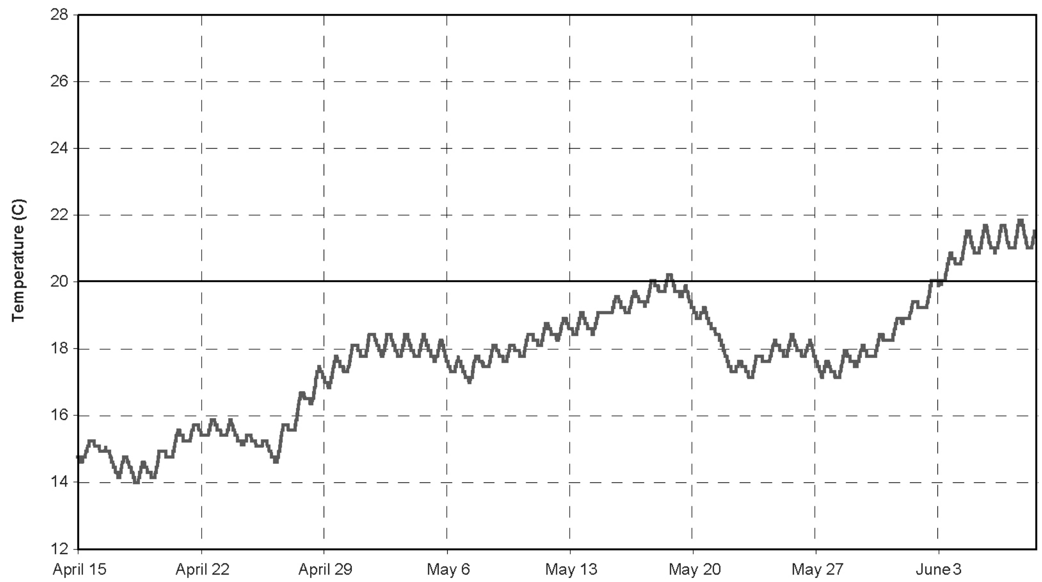


Figure A-12. Water Temperature Monitoring: Site 13 - Antioch Marina

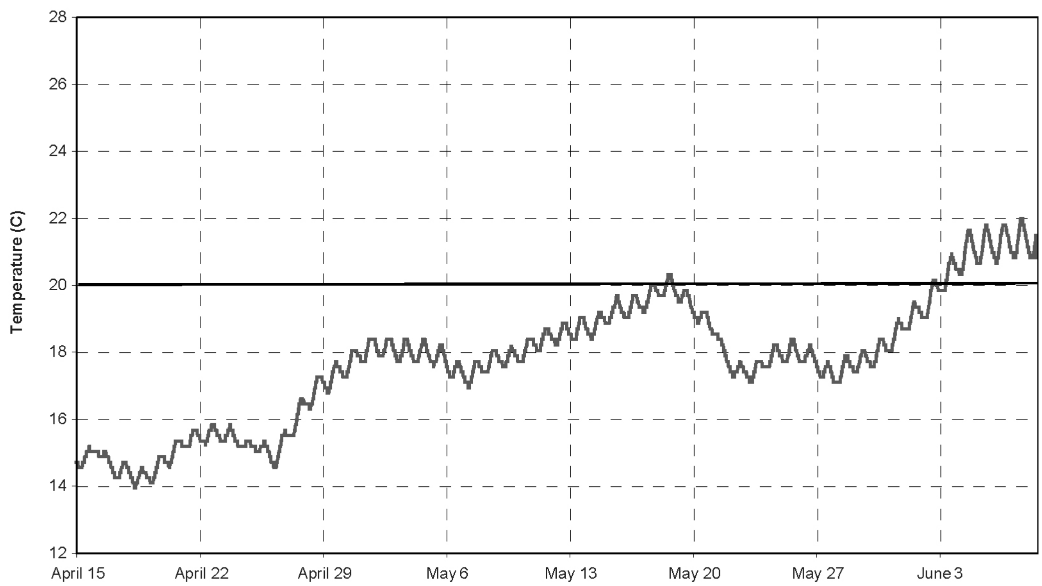


Figure A-13. Water Temperature Monitoring: Site 14 - Turner Cut

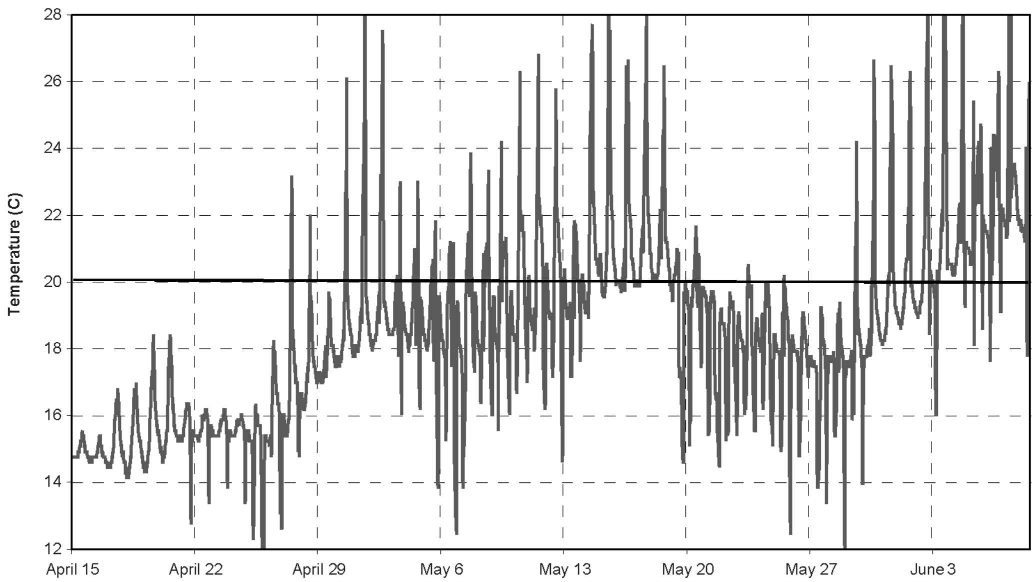


Figure A-14. Water Temperature Monitoring: Site 15 - Holland Riverside Marina

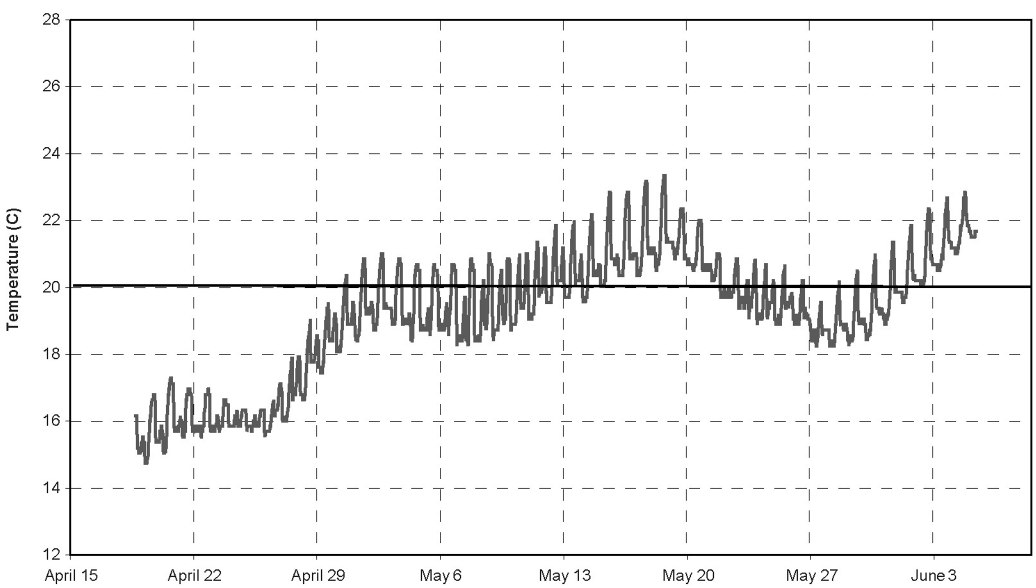


Figure A-15. Water Temperature Monitoring: Site 16 - Old River at Confluence with Indian Slough

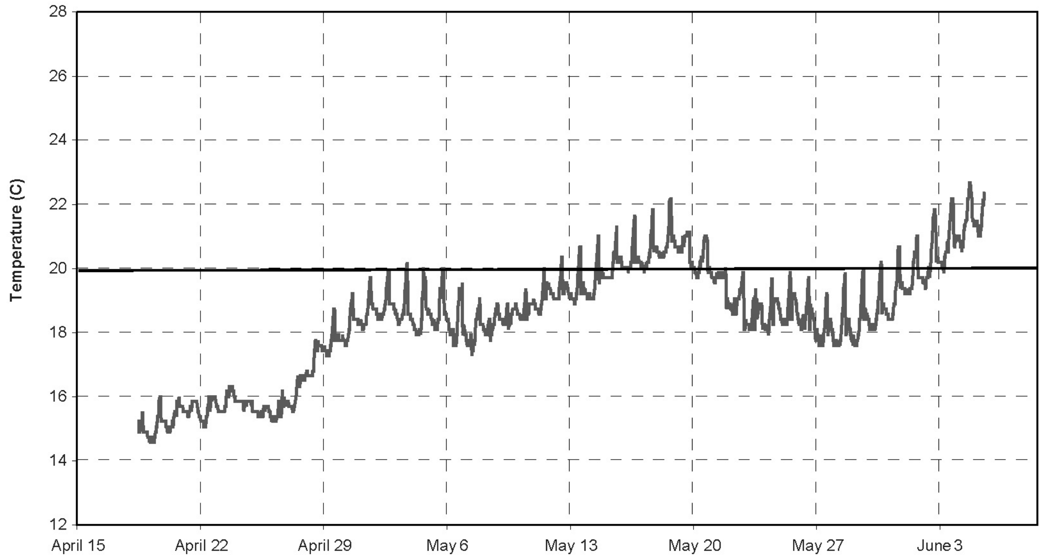


Figure A-16. Water Temperature Monitoring: Site 17 - CCF Radial Gates

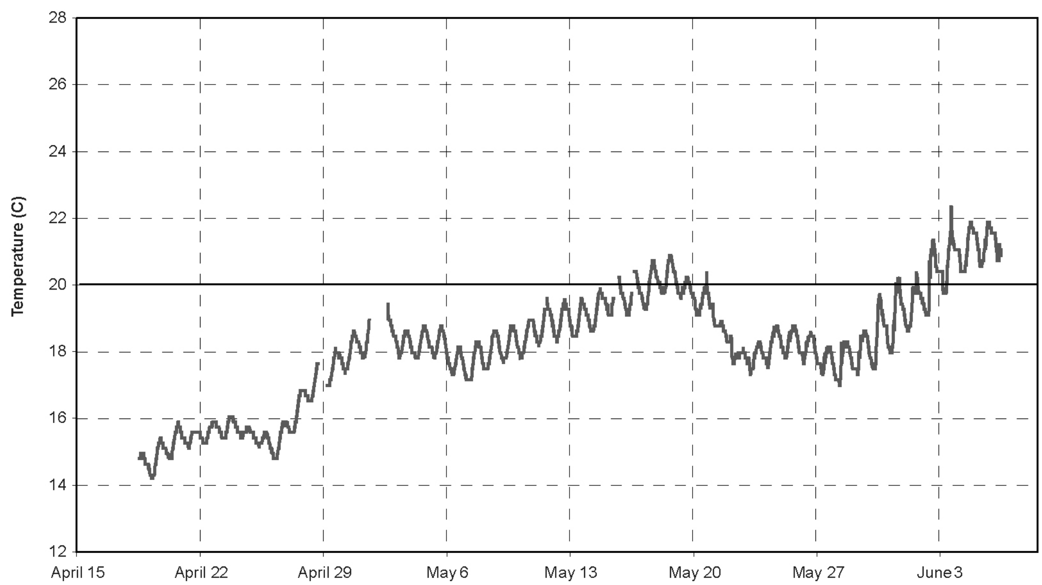


Figure A-17. Water Temperature Monitoring: Site 18 - Grant Line Canal at Tracy Blvd. Bridge

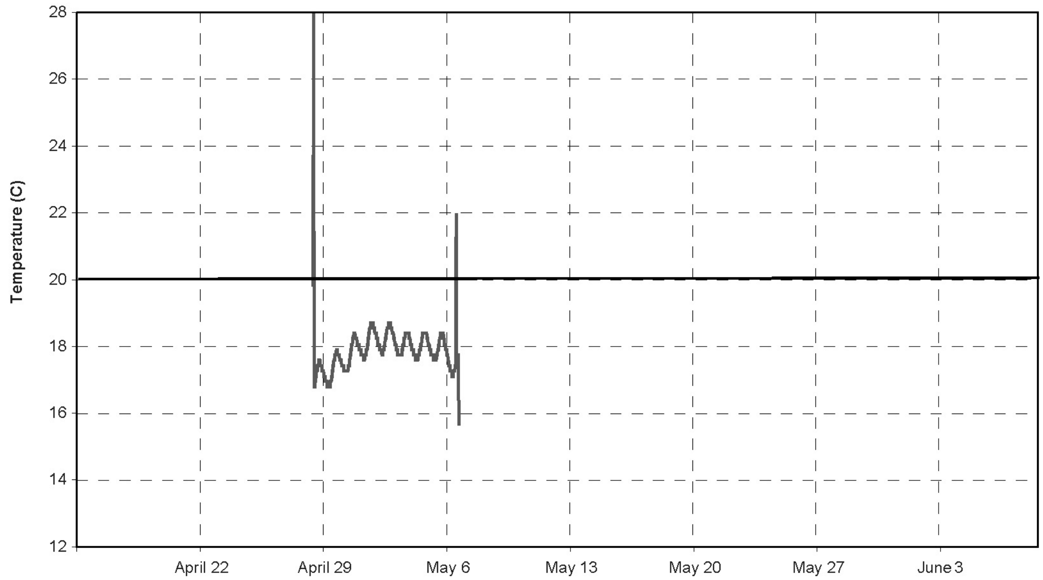


Figure A-18. Water Temperature Monitoring: Site 19 - Middle River at the Confluence with Victoria Canal

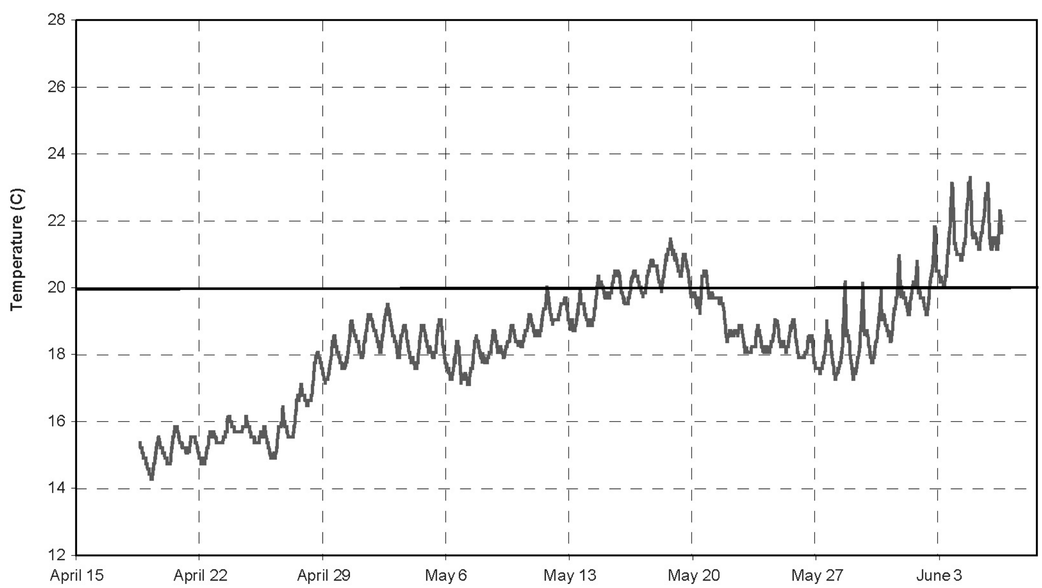


Figure A-19. Water Temperature Monitoring: Site 20 - Werner Cut; Channel above Woodward Isle

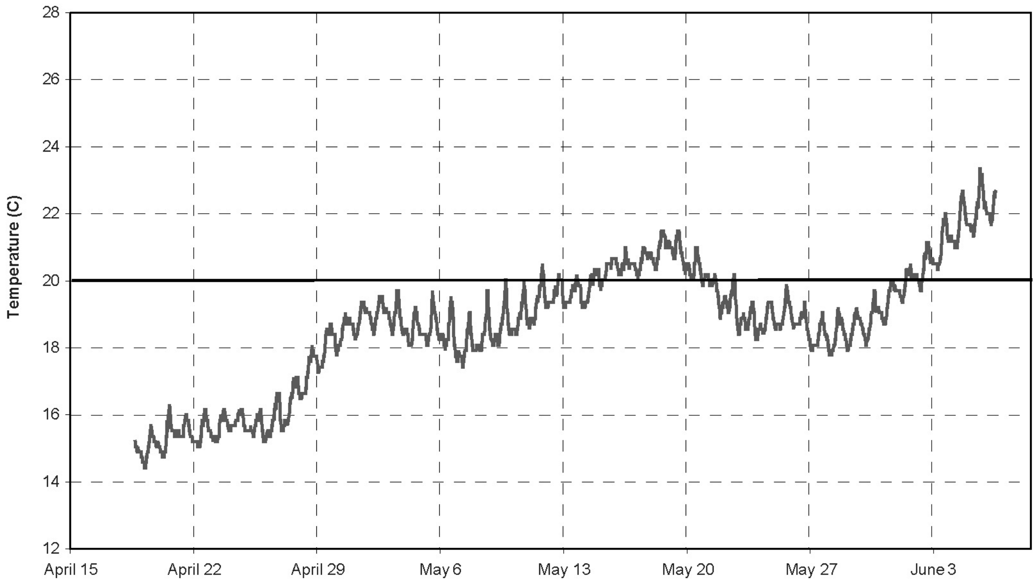


Table A-2. Chinook salmon smolt condition post-transport, immediately after VAMP 2006 releases.

Release Site	Examination Date	Mean Fork Length (mm)	Mean Weight (g)	Vigor (%)	Mean Scale Loss (%)	Normal Body Color (%)	Fin Hemorrhaging (%)	Normal Eye Quality (%)	Normal Gill Color %	Complete Adclip (%)
Mossdale	5/4/06	85	7	100	6	100	2	100	100	88
Dos Reis	5/5/06	81	6	100	6	100	0	100	100	84
Jersey Point	5/8/06	86	7	100	5	100	0	100	100	92
Mossdale	5/19/06	92	9	100	5	100	12	100	100	87
Jersey Point	5/22/06	89	8	100	5	100	8	100	100	100
* % correct tag code of those that retained tags.										

Table A-3. Chinook salmon smolt condition 48-hours post-release.

Release Site	Examination Date	Mean Fork Length (mm)	Mean Weight (g)	Vigor (%)	Net Pen Mortalities	Mean Scale Loss (%)	Normal Body Color (%)	Fin Hemorrhaging (%)	Normal Eye Quality (%)	Normal Gill Color %	Complete Adclip (%)
Mossdale	5/6/06	86	7	100	0	8	100	0	100	100	86
Dos Reis	5/7/06	81	6	100	0	8	100	0	100	100	80
Jersey Point	5/10/06	86	7	100	0	6	100	12		100	92
Mossdale	5/21/06	93	9	100	0	7	100	16	100	97	95
Jersey Point	5/24/06	92	8	16**	0	7	16**	0	100	84	100
** Transport truck delayed for 2 1/2 hours due to flat tire; fish very pale (color, gills), vigor diminished.											

Figure A-20. Chipps Island/Mossdale 1

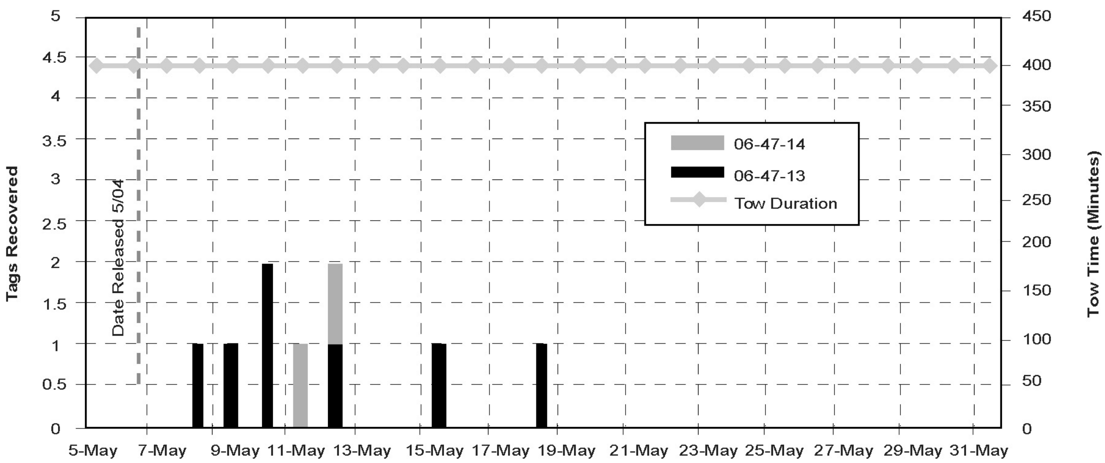


Figure A-21. Chipps Island/Jersey Point 1

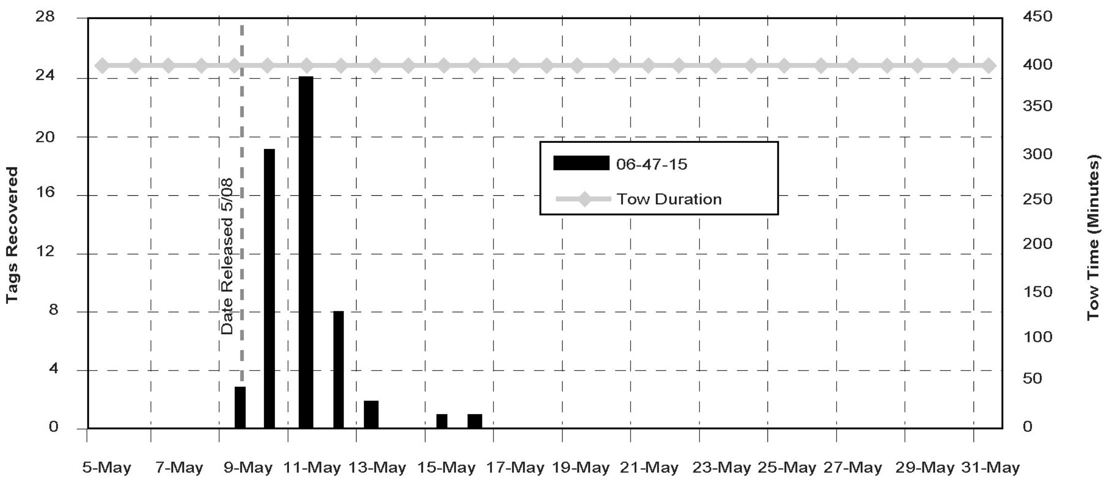


Figure A-22. Chipps Island/Dos Reis 1

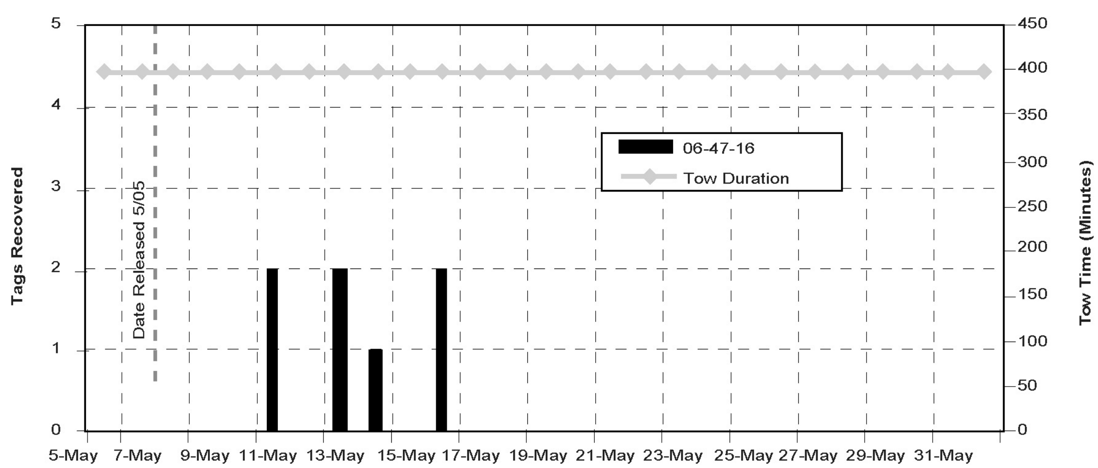


Figure A-23. Chipps Island/Mossdale 2

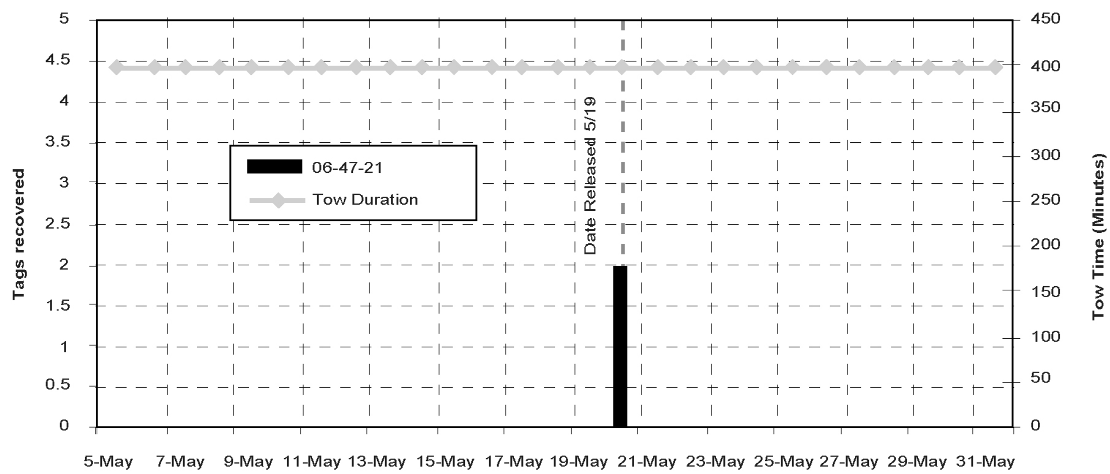


Figure A-24. Chipps Island/Jersey Point 2

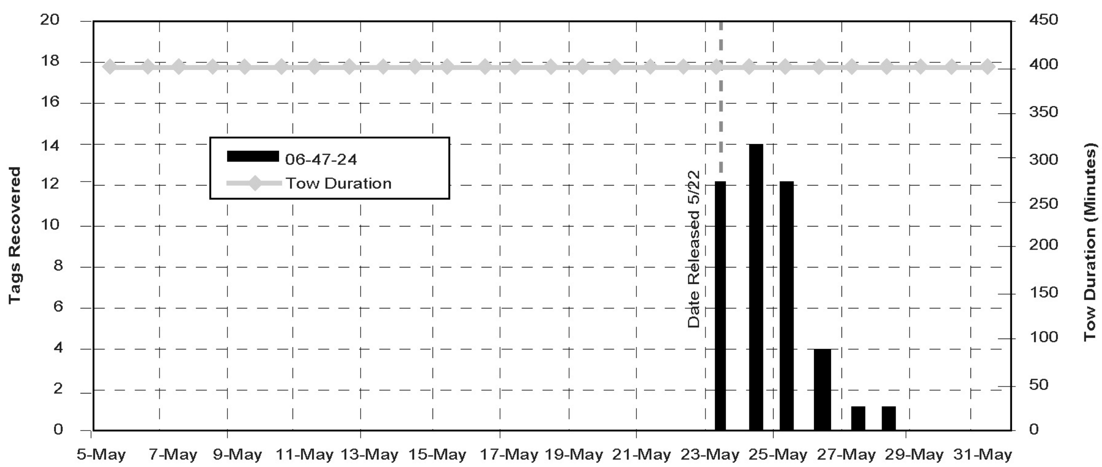


Figure A-25. Antioch/Mossdale 1

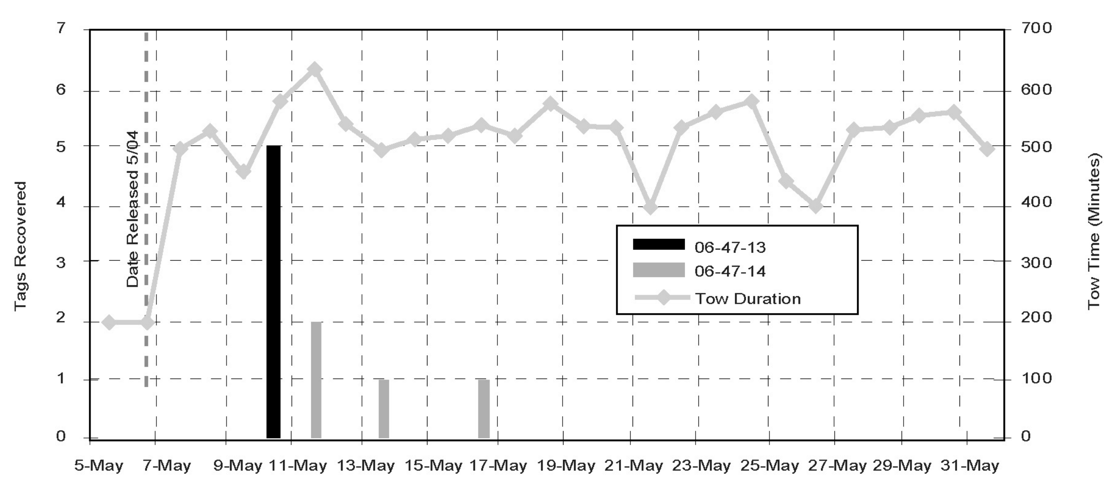


Figure A-26. Antioch/Jersey Point 1

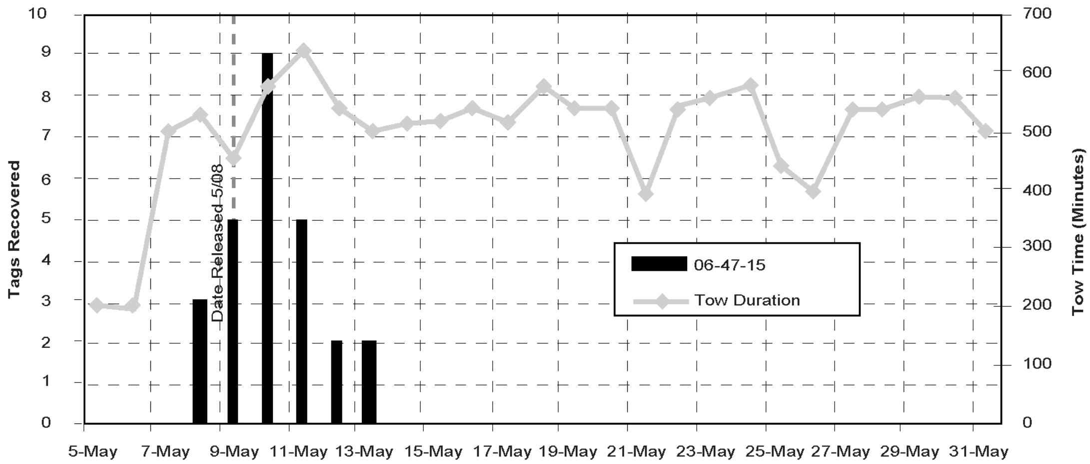


Figure A-27. Antioch/Dos Reis 1

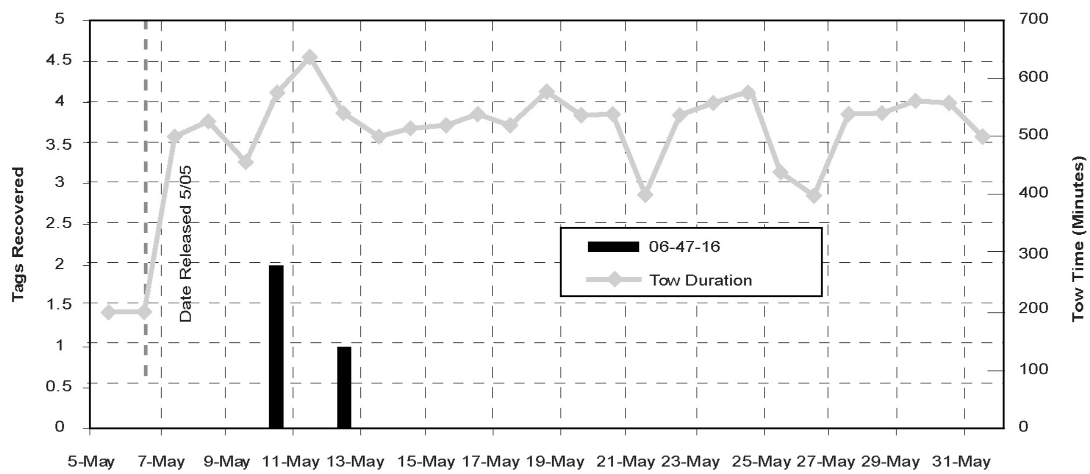


Figure A-28. Antioch/Mossdale 2

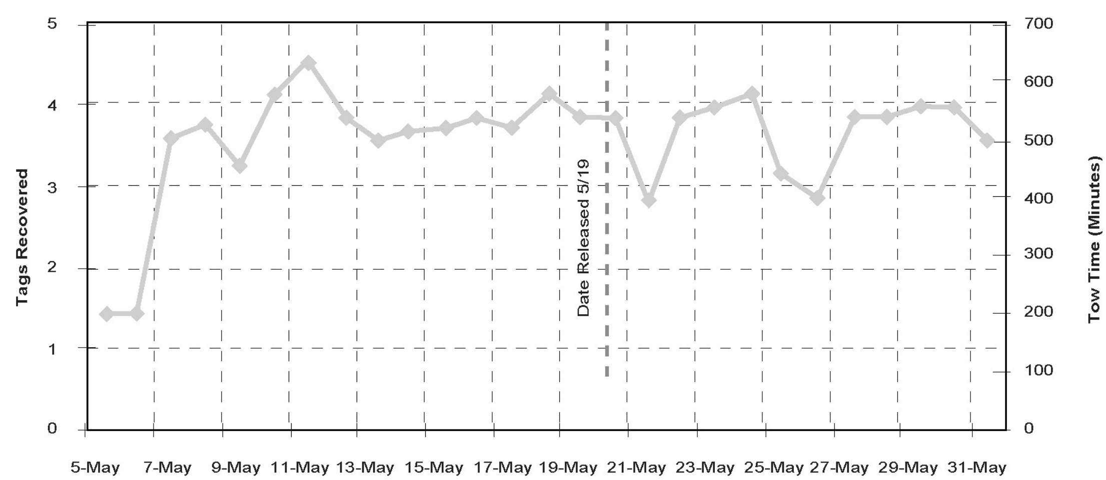
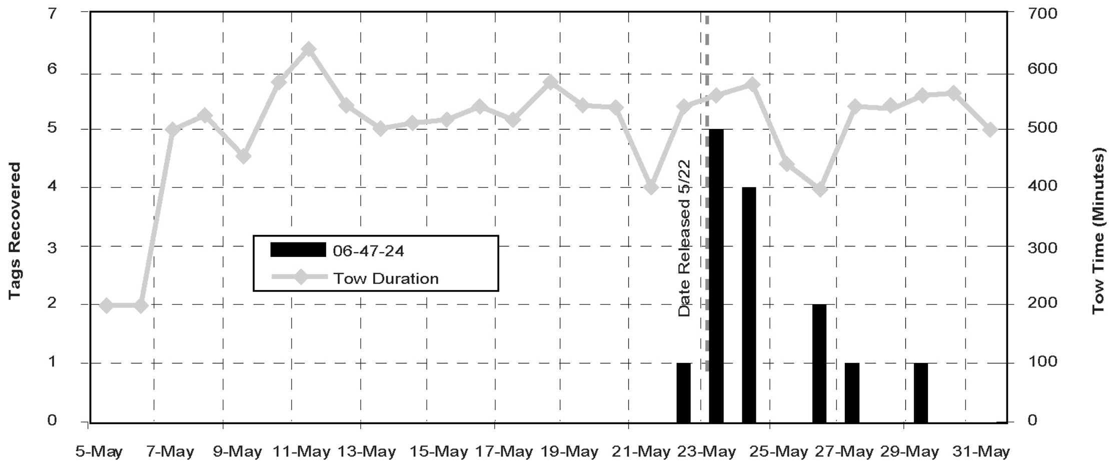


Figure A-29. Antioch/Jersey Point 2



Appendix B. Stage and Flow Data

This appendix consists of the stage and flow data that is earlier presented graphically in via box plots. The values are derived from 15-minute simulated stage and flow over each of the 20 time periods in 2005 presented in Table 3.

Figure B-1. Locations stage and flow data presented for the simulation of 2006 hydrodynamics.

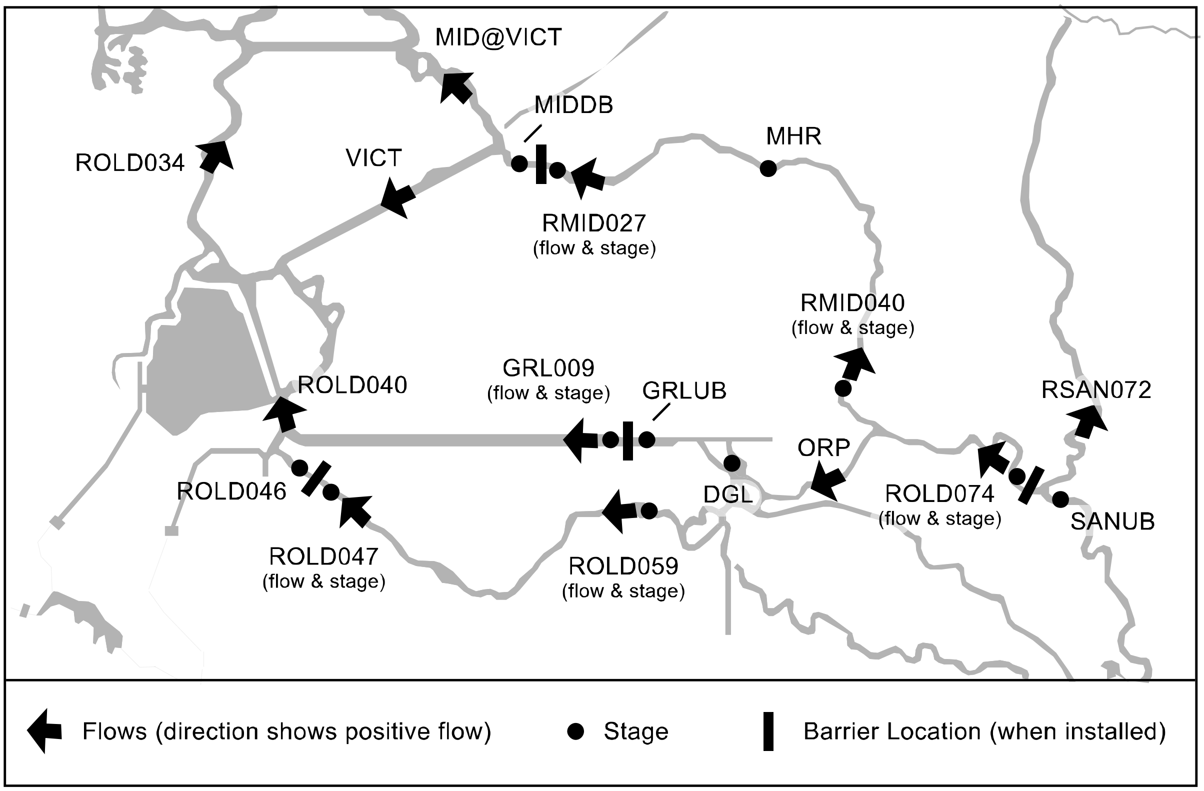


Table B-1. Distribution of stages (feet-NGVD29) by study period in 2006.

		GRL009					GRLUB					DGL				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	3.23	4.23	4.91	5.42	8.06	3.23	4.23	4.91	5.42	8.06	3.51	4.54	5.16	5.64	8.17
	7 - 21	1.68	3.33	4.00	4.58	6.89	1.68	3.33	4.00	4.58	6.89	2.06	3.67	4.39	4.97	7.08
	22 - 31	1.34	2.13	3.05	3.81	5.91	1.34	2.13	3.05	3.81	5.91	1.64	2.33	3.24	3.99	6.02
Feb	1 - 14	1.03	1.87	2.63	3.27	5.16	1.03	1.87	2.63	3.27	5.16	1.29	2.04	2.78	3.41	5.25
	15 - 28	0.38	1.47	2.21	2.80	5.68	0.38	1.47	2.21	2.80	5.68	0.61	1.61	2.35	2.93	5.80
Mar	1 - 20	1.61	2.78	3.50	4.13	5.92	1.61	2.78	3.50	4.13	5.92	1.81	3.05	3.74	4.32	6.05
	21 - 31	1.77	3.16	3.87	4.59	6.54	1.77	3.16	3.87	4.59	6.54	2.17	3.46	4.13	4.82	6.71
Apr	1 - 9	3.03	4.27	4.93	5.60	6.68	3.03	4.27	4.93	5.60	6.68	3.50	4.72	5.39	6.08	7.29
	10 - 20	5.36	6.35	6.76	7.14	8.11	5.36	6.35	6.76	7.14	8.11	6.29	7.31	7.71	8.05	8.86
	21 - 31	5.57	5.98	6.37	6.67	7.94	5.57	5.98	6.37	6.67	7.94	6.67	7.00	7.31	7.55	8.58
May	1 - 17	4.60	5.47	5.89	6.27	7.53	4.60	5.47	5.89	6.27	7.53	5.53	6.37	6.73	7.09	8.22
	18 - 31	3.46	4.75	5.20	5.58	7.10	3.46	4.75	5.20	5.58	7.10	4.29	5.57	5.94	6.27	7.58
Jun	1 - 21	1.63	2.96	3.56	4.08	5.72	1.63	2.96	3.56	4.08	5.72	2.15	3.42	3.98	4.46	6.00
	22 - 30	1.26	2.16	2.73	3.16	4.89	1.26	2.16	2.73	3.16	4.89	1.84	2.62	3.14	3.52	5.06
Jul	1 - 7	0.14	0.81	1.44	1.93	3.74	0.14	0.81	1.44	1.93	3.74	0.48	1.05	1.74	2.27	3.82
	7 - 17	-0.27	0.58	1.30	1.74	4.31	-0.27	0.58	1.30	1.74	4.31	-0.07	0.72	1.44	1.86	4.42
	17 - 19	-0.02	0.43	1.16	1.75	3.65	-0.02	0.43	1.16	1.75	3.65	0.19	0.60	1.32	1.93	3.70
	20 - 31	-0.86	0.46	1.18	1.66	4.26	0.75	2.45	2.67	2.81	3.96	0.58	2.47	2.70	2.84	4.04
Aug	1 - 31	-1.08	0.19	0.95	1.35	4.49	2.11	2.31	2.60	2.74	4.38	2.12	2.33	2.62	2.76	4.45
Sep	1 - 30	-1.32	0.13	0.85	1.25	4.32	2.06	2.26	2.50	2.65	4.17	2.07	2.27	2.52	2.67	4.23
Oct	1 - 31	-1.32	0.10	0.85	1.31	4.14	2.25	2.42	2.62	2.72	4.02	2.27	2.44	2.64	2.75	4.08
Nov	1 - 5	-2.16	-0.04	0.82	1.55	4.09	1.56	2.13	2.42	2.61	3.87	1.56	2.14	2.44	2.63	3.94
	16 - 17	-1.11	-0.28	0.34	0.67	2.82	1.31	1.48	1.69	1.87	2.51	1.31	1.48	1.69	1.87	2.53
	18 - 20	-1.36	-0.10	0.52	0.86	3.23	0.39	1.43	1.68	1.88	2.85	0.61	1.43	1.70	1.89	2.92
	21 - 30	-1.04	-0.24	0.53	0.89	3.32	-1.04	-0.24	0.53	0.89	3.32	-0.93	-0.13	0.61	0.96	3.42
Dec	1 - 31	-0.98	-0.18	0.54	1.08	3.73	-0.98	-0.18	0.54	1.08	3.73	-0.87	-0.10	0.62	1.16	3.80

Table B-1 (cont.). Distribution of stages (feet-NGVD29) by study period in 2006.

		ROLD046					ROLD047					ROLD059				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	2.30	3.68	4.49	5.12	7.80	2.30	3.68	4.49	5.12	7.80	3.10	4.19	4.88	5.41	8.12
	7 - 21	0.88	2.50	3.32	3.97	6.68	0.88	2.50	3.32	3.97	6.68	1.52	3.25	3.94	4.54	6.94
	22 - 31	0.62	1.73	2.67	3.45	5.71	0.62	1.73	2.67	3.45	5.71	1.24	2.06	3.01	3.79	5.98
Feb	1 - 14	0.39	1.50	2.29	2.95	4.98	0.39	1.50	2.29	2.95	4.98	0.93	1.82	2.58	3.23	5.20
	15 - 28	-0.24	1.13	1.89	2.49	5.44	-0.24	1.13	1.89	2.49	5.44	0.26	1.41	2.16	2.75	5.76
Mar	1 - 20	1.05	2.23	3.03	3.78	5.68	1.05	2.23	3.03	3.78	5.68	1.53	2.72	3.46	4.11	5.99
	21 - 31	0.88	2.60	3.41	4.21	6.28	0.88	2.60	3.41	4.21	6.28	1.63	3.10	3.85	4.58	6.65
Apr	1 - 9	2.01	3.44	4.18	4.94	6.47	2.01	3.44	4.18	4.94	6.47	2.90	4.21	4.88	5.55	6.75
	10 - 20	3.69	4.77	5.32	5.88	7.22	3.69	4.77	5.32	5.88	7.22	5.25	6.28	6.71	7.10	8.08
	21 - 31	3.57	4.24	4.89	5.42	7.21	3.57	4.24	4.89	5.42	7.21	5.47	5.90	6.31	6.63	7.91
May	1 - 17	2.77	3.91	4.53	5.07	6.76	2.77	3.91	4.53	5.07	6.76	4.43	5.36	5.78	6.18	7.48
	18 - 31	1.65	3.26	3.94	4.54	6.59	1.65	3.26	3.94	4.54	6.59	3.24	4.60	5.08	5.48	7.10
Jun	1 - 21	0.46	2.04	2.78	3.47	5.43	0.46	2.04	2.78	3.47	5.43	1.38	2.79	3.44	3.99	5.80
	22 - 30	-0.20	1.22	1.89	2.46	4.59	-0.20	1.22	1.89	2.46	4.59	0.95	1.91	2.54	3.04	4.92
Jul	1 - 7	-0.76	0.14	0.78	1.31	3.49	-0.76	0.14	0.78	1.31	3.49	-0.09	0.57	1.22	1.73	3.69
	7 - 17	-0.86	0.20	0.93	1.46	4.02	-0.86	0.25	0.96	1.46	4.02	-0.44	0.48	1.18	1.61	4.28
	17 - 19	-0.82	-0.05	0.70	1.07	3.53	0.21	0.64	1.22	1.83	2.84	0.23	0.61	1.20	1.79	2.88
	20 - 31	-1.08	0.30	1.01	1.54	4.14	0.55	2.41	2.59	2.76	3.53	0.63	2.43	2.61	2.76	3.81
Aug	1 - 31	-1.25	0.02	0.78	1.21	4.38	2.10	2.30	2.55	2.69	4.14	2.11	2.30	2.57	2.70	4.36
Sep	1 - 30	-1.48	-0.05	0.69	1.11	4.22	2.04	2.26	2.48	2.62	3.92	2.06	2.26	2.49	2.62	4.14
Oct	1 - 31	-1.57	-0.11	0.67	1.15	4.03	2.23	2.42	2.60	2.70	3.80	2.25	2.42	2.61	2.71	4.00
Nov	1 - 5	-2.43	-0.19	0.67	1.42	3.99	-0.44	2.14	2.38	2.60	3.71	0.70	2.14	2.40	2.60	3.88
	16 - 17	-0.77	-0.19	0.39	0.65	2.58	-0.77	-0.19	0.39	0.65	2.58	0.34	0.69	1.03	1.29	2.55
	18 - 20	-0.88	-0.08	0.51	0.87	3.00	-0.88	-0.08	0.51	0.87	3.00	0.46	0.64	1.09	1.43	2.96
	21 - 30	-1.39	-0.50	0.30	0.70	3.15	-1.39	-0.50	0.30	0.70	3.15	-1.11	-0.29	0.48	0.86	3.36
Dec	1 - 31	-1.35	-0.43	0.29	0.84	3.58	-1.35	-0.43	0.29	0.84	3.58	-1.04	-0.27	0.45	1.00	3.78

Table B-1 (cont.). Distribution of stages (feet-NGVD29) by study period in 2006.

		MIDDB					RMID027					MHR				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	2.07	3.60	4.45	5.13	7.63	2.13	3.68	4.49	5.15	7.67	3.64	4.71	5.30	5.72	7.99
	7 - 21	0.75	2.36	3.17	3.86	6.44	0.79	2.43	3.24	3.93	6.49	2.32	3.93	4.55	5.05	6.91
	22 - 31	0.46	1.76	2.70	3.53	5.61	0.51	1.80	2.73	3.58	5.65	1.87	2.55	3.34	4.05	5.88
Feb	1 - 14	0.30	1.64	2.43	3.14	4.92	0.33	1.67	2.46	3.16	4.95	1.44	2.27	2.94	3.51	5.15
	15 - 28	-0.29	1.31	2.10	2.81	5.47	-0.26	1.33	2.13	2.83	5.51	0.76	1.86	2.54	3.14	5.69
Mar	1 - 20	0.86	2.13	3.00	3.79	5.51	0.92	2.19	3.04	3.83	5.57	1.98	3.27	3.85	4.35	5.87
	21 - 31	0.57	2.40	3.25	4.13	5.94	0.62	2.47	3.30	4.15	6.01	2.44	3.60	4.21	4.84	6.45
Apr	1 - 9	1.52	3.04	3.82	4.66	6.13	1.61	3.12	3.89	4.71	6.18	3.77	4.83	5.45	6.05	7.17
	10 - 20	2.35	3.78	4.47	5.19	6.72	2.59	3.96	4.62	5.31	6.81	6.35	7.35	7.71	8.04	8.62
	21 - 31	2.23	3.31	4.12	4.87	6.84	2.51	3.51	4.28	4.97	6.97	6.82	7.13	7.36	7.54	8.33
May	1 - 17	1.70	3.02	3.81	4.55	6.34	1.90	3.18	3.94	4.64	6.43	5.60	6.36	6.70	7.04	7.98
	18 - 31	0.88	2.63	3.45	4.23	6.27	1.07	2.78	3.56	4.32	6.38	4.55	5.65	5.97	6.24	7.33
Jun	1 - 21	0.05	1.76	2.58	3.37	5.25	0.12	1.84	2.65	3.44	5.31	2.35	3.56	4.05	4.54	5.84
	22 - 30	-0.51	1.15	1.85	2.54	4.49	-0.42	1.22	1.92	2.58	4.55	2.16	2.87	3.31	3.63	4.94
Jul	1 - 7	-0.84	0.24	0.98	1.55	3.53	-0.83	0.28	1.01	1.59	3.56	0.29	1.06	1.77	2.41	3.75
	7 - 17	-0.87	0.47	1.29	1.95	4.28	0.91	1.25	1.74	1.96	4.19	0.84	1.21	1.76	2.02	4.32
	17 - 19	-0.60	0.20	1.12	1.68	3.73	0.87	1.08	1.60	1.94	3.59	0.82	1.02	1.56	1.92	3.68
	20 - 31	-0.82	0.68	1.46	2.15	4.21	0.96	1.39	1.90	2.21	4.11	0.93	1.52	2.03	2.33	4.15
Aug	1 - 31	-0.99	0.41	1.24	1.87	4.46	1.21	1.36	1.82	2.01	4.44	1.30	1.52	1.98	2.21	4.48
Sep	1 - 30	-1.20	0.35	1.17	1.82	4.30	1.26	1.38	1.80	1.98	4.27	1.37	1.55	1.97	2.18	4.28
Oct	1 - 31	-1.31	0.26	1.08	1.77	4.09	1.30	1.40	1.78	1.91	4.05	1.48	1.62	2.00	2.16	4.13
Nov	1 - 5	-1.67	0.24	1.05	1.78	4.07	1.22	1.35	1.75	1.94	4.02	1.27	1.49	1.90	2.14	4.00
	16 - 17	-0.89	-0.12	0.64	1.20	2.81	-0.87	1.16	1.24	1.33	2.65	0.40	1.20	1.40	1.45	2.66
	18 - 20	-1.12	0.13	0.79	1.26	3.21	-1.09	0.13	0.81	1.27	3.23	0.05	0.59	1.15	1.52	3.11
	21 - 30	-1.38	-0.18	0.65	1.28	3.41	-1.37	-0.16	0.66	1.28	3.42	-0.97	0.08	0.78	1.24	3.38
Dec	1 - 31	-1.35	-0.04	0.72	1.36	3.71	-1.34	-0.03	0.73	1.36	3.73	-0.88	0.12	0.81	1.34	3.75

Table B-1 (cont.). Distribution of stages (feet-NGVD29) by study period in 2006.

		RMID040					ROLD074					SANUB				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	4.96	6.16	6.55	6.89	8.44	7.63	8.50	9.09	9.61	10.22	7.63	8.50	9.09	9.61	10.22
	7 - 21	3.78	5.54	6.30	7.03	8.12	6.53	8.58	9.29	10.24	10.74	6.53	8.58	9.29	10.24	10.74
	22 - 31	2.94	3.49	4.13	4.69	6.20	5.27	5.64	6.01	6.37	6.99	5.27	5.64	6.01	6.37	6.99
Feb	1 - 14	2.41	2.99	3.55	4.07	5.43	4.62	4.90	5.23	5.56	6.17	4.62	4.90	5.23	5.56	6.17
	15 - 28	1.51	2.45	3.05	3.54	5.88	3.35	4.14	4.59	4.94	6.28	3.35	4.14	4.59	4.94	6.28
Mar	1 - 20	2.70	4.59	4.99	5.42	6.58	4.59	7.35	7.39	7.86	8.48	4.59	7.35	7.39	7.86	8.48
	21 - 31	4.12	4.92	5.47	5.97	7.47	7.12	7.55	8.03	8.40	9.57	7.12	7.55	8.03	8.40	9.57
Apr	1 - 9	5.69	6.64	7.40	7.97	9.59	9.00	9.65	10.35	10.97	12.25	9.00	9.65	10.35	10.97	12.25
	10 - 20	9.15	10.17	10.56	10.95	11.36	12.06	13.03	13.40	13.84	14.06	12.06	13.03	13.40	13.84	14.06
	21 - 31	9.84	10.02	10.16	10.25	10.76	12.80	12.92	12.99	13.05	13.32	12.80	12.92	12.99	13.05	13.32
May	1 - 17	8.50	9.10	9.42	9.72	10.50	11.61	11.98	12.28	12.58	13.13	11.61	11.98	12.28	12.58	13.13
	18 - 31	7.30	8.39	8.54	8.74	9.40	10.70	11.50	11.53	11.66	11.94	10.70	11.50	11.53	11.66	11.94
Jun	1 - 21	4.56	5.66	6.10	6.49	8.02	8.00	9.03	9.38	9.67	10.97	8.00	9.03	9.38	9.67	10.97
	22 - 30	4.46	5.03	5.33	5.56	6.40	8.02	8.44	8.70	8.97	9.36	8.02	8.44	8.70	8.97	9.36
Jul	1 - 7	1.91	2.45	3.27	3.99	4.81	4.69	5.09	6.03	6.94	8.17	4.69	5.09	6.03	6.94	8.17
	7 - 17	0.92	1.53	2.14	2.51	4.62	2.61	3.15	3.79	4.41	5.57	2.61	3.15	3.79	4.41	5.57
	17 - 19	1.00	1.22	1.84	2.36	3.88	2.46	2.75	3.24	3.74	4.44	2.46	2.75	3.24	3.74	4.44
	20 - 31	1.14	2.41	2.70	2.87	4.22	2.67	3.25	3.56	3.77	4.78	2.67	3.25	3.56	3.77	4.78
Aug	1 - 31	2.00	2.25	2.59	2.78	4.57	2.52	2.94	3.29	3.54	4.92	2.52	2.94	3.29	3.54	4.92
Sep	1 - 30	1.95	2.19	2.49	2.64	4.33	2.30	2.74	3.06	3.30	4.57	2.30	2.74	3.06	3.30	4.57
Oct	1 - 31	2.16	2.38	2.62	2.73	4.20	2.63	3.04	3.29	3.47	4.51	2.63	3.04	3.29	3.47	4.51
Nov	1 - 5	1.57	2.04	2.38	2.60	4.04	1.94	2.46	2.83	3.15	4.21	1.94	2.46	2.83	3.15	4.21
	16 - 17	1.35	1.50	1.72	1.84	2.72	1.67	1.96	2.24	2.46	3.14	1.67	1.96	2.24	2.46	3.14
	18 - 20	1.16	1.35	1.71	1.96	3.12	1.70	1.93	2.31	2.65	3.45	1.70	1.93	2.31	2.65	3.45
	21 - 30	-0.60	0.29	0.96	1.34	3.50	0.59	1.41	1.88	2.23	3.60	0.59	1.41	1.88	2.23	3.60
Dec	1 - 31	-0.56	0.31	0.98	1.49	3.85	0.58	1.41	1.94	2.37	3.85	0.58	1.41	1.94	2.37	3.85

Table B-2. Distribution of flows (cfs) by study period in 2006.

		ROLD040					ROLD047					ROLD059				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	-16493	-1666	3084	7602	15822	-3712	-109	1351	2629	5199	-772	874	1342	1824	2447
	7 - 21	-9879	-152	4231	8289	18552	-2542	291	1532	2753	5047	-361	1068	1506	2004	2804
	22 - 31	-13225	-4662	167	5980	10429	-2514	-771	718	2234	3366	-439	152	707	1166	1483
Feb	1 - 14	-14041	-5008	-741	4835	10740	-2780	-705	588	2022	3356	-533	85	590	1031	1502
	15 - 28	-15951	-5100	-1191	3730	9875	-3086	-716	490	1746	3406	-636	41	498	883	1450
Mar	1 - 20	-13875	-4191	1163	6571	13892	-2817	-711	969	2451	4082	-493	377	949	1446	1829
	21 - 31	-10822	-612	4708	10170	19750	-3324	-642	1072	2588	4750	-631	434	1048	1554	2320
Apr	1 - 9	-10597	5229	8841	13036	18477	-3270	935	1972	3198	4333	-612	1676	1954	2459	3561
	10 - 20	5671	15244	17636	20226	23698	620	3472	4098	4827	5660	2903	3860	4084	4396	4691
	21 - 31	932	13434	16131	18909	24611	-771	3125	3838	4624	6081	2178	3655	3819	4015	4462
May	1 - 17	2289	11810	14498	17310	24023	-546	2610	3308	4084	5688	1875	3190	3367	3581	4298
	18 - 31	-5107	6708	10507	13962	21152	-2192	1687	2736	3694	5429	722	2551	2789	3080	3565
Jun	1 - 21	-11220	554	4962	9065	16905	-2810	-7	1301	2512	4292	-517	1063	1422	1842	2626
	22 - 30	-11106	-1032	2425	6813	12965	-2556	-22	1054	2288	3863	-407	891	1176	1534	1932
Jul	1 - 7	-11614	-2399	147	3692	10647	-2223	-228	559	1541	3150	-656	412	690	1038	1437
	7 - 17	-15802	-5247	-1994	2682	12556	-2987	-762	213	1440	3650	-699	-49	359	736	1360
	17 - 19	-12491	-4145	-2553	1341	9077	-1477	-110	-175	0	371	-648	-364	-24	228	1108
	20 - 31	-14756	-5147	-3116	-249	10988	-1433	111	136	259	911	-214	197	297	359	1040
Aug	1 - 31	-14723	-5161	-3187	-824	12202	-1519	62	108	225	1317	-36	119	208	239	1036
Sep	1 - 30	-14613	-5165	-3241	-962	11725	-1169	53	85	179	1165	-56	37	136	183	920
Oct	1 - 31	-13513	-4872	-2890	-756	11765	-1230	109	157	233	1112	-18	93	177	222	915
Nov	1 - 5	-13257	-5459	-3212	-967	11643	-1243	11	98	191	2463	-152	-38	95	165	1188
	16 - 17	-12114	-5137	-3023	-500	5351	-2135	475	814	1614	2142	-657	785	811	1137	1234
	18 - 20	-13256	-5220	-3085	-381	6160	-2434	344	742	1582	2267	-767	693	758	1112	1274
	21 - 30	-14138	-5201	-1981	1840	10122	-2520	-664	195	1142	2767	-653	-120	198	485	1045
Dec	1 - 31	-14915	-5411	-2575	1464	10824	-2714	-600	196	1195	2950	-704	-111	209	507	1085

Table B-2 (cont.). Distribution of flows (cfs) by study period in 2006.

		MID at VICT					RMID027					RMID040				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	-13267	-5078	-79	4676	7680	-1625	-34	764	1430	2946	398	658	770	883	1067
	7 - 21	-9379	-4268	867	5172	8489	-1228	146	867	1481	2943	402	685	855	1047	1220
	22 - 31	-9653	-6019	-701	4732	7484	-1521	-516	340	1168	1930	208	298	341	377	500
Feb	1 - 14	-11066	-6779	-1674	3866	6272	-1665	-589	235	1030	2109	68	217	255	292	414
	15 - 28	-12158	-6966	-2440	2360	7026	-1919	-598	164	887	2137	-35	155	189	233	400
Mar	1 - 20	-10999	-5362	-217	4988	7181	-1675	-366	522	1272	2184	115	504	521	591	720
	21 - 31	-10720	-4873	804	6190	9008	-1559	-270	619	1412	2692	463	541	617	674	934
Apr	1 - 9	-10160	-1274	3145	7478	9484	-1354	434	1110	1756	2544	750	896	1117	1292	1784
	10 - 20	-4677	3366	6955	10535	12053	294	1629	2198	2677	3543	1717	2067	2208	2372	2471
	21 - 31	-6331	1272	5494	9800	11613	-288	1418	2049	2555	3648	1978	2021	2049	2069	2171
May	1 - 17	-4608	2415	5905	9103	11043	-62	1251	1738	2228	3233	1541	1689	1798	1913	2112
	18 - 31	-8548	-1875	3382	7895	10044	-902	761	1449	1999	3223	1193	1491	1505	1551	1658
Jun	1 - 21	-9751	-3918	910	5387	8132	-1282	-12	726	1336	2538	586	763	855	915	1310
	22 - 30	-9628	-5100	-628	4210	6147	-1273	-83	572	1156	2181	573	660	703	746	859
Jul	1 - 7	-9369	-5727	-2331	1114	4268	-1390	-314	215	745	1876	218	266	363	443	615
	7 - 17	-11535	-7276	-3086	1122	4988	-1505	-421	-11	263	1443	17	104	149	192	333
	17 - 19	-10030	-6885	-3390	-70	3287	-1478	-261	-42	235	1265	48	81	120	134	281
	20 - 31	-11354	-7649	-3737	80	4096	-1541	-390	45	377	1461	27	207	218	240	271
Aug	1 - 31	-11293	-7079	-3621	-244	4468	-1548	-152	97	346	1550	-44	189	199	221	275
Sep	1 - 30	-10800	-7158	-3613	-232	4466	-1407	-139	114	347	1489	-77	173	177	197	235
Oct	1 - 31	-10907	-6733	-3057	551	4965	-1456	5	152	371	1405	-34	194	203	223	258
Nov	1 - 5	-10627	-6015	-2777	923	4951	-1464	-24	110	335	1261	-94	152	163	188	230
	16 - 17	-9061	-5998	-2764	462	2852	-1042	46	104	184	1920	-30	98	107	119	157
	18 - 20	-9877	-6853	-3049	619	4127	-1333	-464	52	619	1528	-84	102	116	152	164
	21 - 30	-10110	-6972	-2854	1373	5073	-1406	-564	-9	517	1565	-56	26	43	55	146
Dec	1 - 31	-10810	-6998	-3217	271	5341	-1553	-564	-16	526	1651	-109	25	41	57	154

Table B-2 (cont.). Distribution of flows (cfs) by study period in 2006.

		GRL009					ORP					ROLD074				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	-3663	4285	5555	7237	9575	4201	5929	6727	7590	8071	5198	6530	7509	8467	9061
	7 - 21	147	5074	6584	8188	10726	4854	6707	7353	8191	8507	5409	7465	8190	9197	9659
	22 - 31	-2432	1893	3416	5616	7023	2777	3843	4102	4458	5150	3218	4163	4438	4714	5423
Feb	1 - 14	-3043	1554	2991	5028	6903	2552	3463	3567	3810	4216	2997	3663	3821	4014	4661
	15 - 28	-3852	1279	2644	4470	6575	1876	2886	3149	3465	3835	1926	3063	3341	3640	4507
Mar	1 - 20	-2843	2909	4519	6468	7942	2630	5239	5452	6017	6465	3012	5943	5975	6526	7026
	21 - 31	-1628	3293	4964	6648	9396	4533	5637	6002	6247	7401	5516	6208	6624	6886	8250
Apr	1 - 9	-1377	6922	7869	9479	12798	6175	7559	8017	8521	9057	7442	8507	9154	9801	10849
	10 - 20	10548	13281	13960	14777	15778	9050	9724	10015	10348	10652	10690	11756	12225	12740	13083
	21 - 31	9452	12729	13391	14150	15168	9308	9631	9691	9776	9887	11534	11652	11737	11811	12029
May	1 - 17	8292	11492	12102	12808	14699	8483	8918	9139	9382	9782	10230	10600	10943	11325	11860
	18 - 31	6153	9714	10610	11613	12738	8282	8755	8832	8941	9052	9663	10271	10342	10481	10680
Jun	1 - 21	-474	5361	6528	7835	10160	6157	7259	7621	7934	8715	7085	8048	8491	8832	9970
	22 - 30	258	4992	5841	7070	8327	6112	6910	7183	7521	7768	7089	7617	7913	8246	8568
Jul	1 - 7	-1744	3182	4007	5185	6652	3202	4063	4844	5689	6766	3769	4297	5206	6127	7483
	7 - 17	-3586	1154	2305	3876	6484	1813	2534	2856	3166	3977	2064	2508	3025	3446	4533
	17 - 19	-3382	1382	2156	4350	5622	1779	2274	2387	2542	2871	1883	2313	2537	2660	3554
	20 - 31	-2139	1143	1222	1643	2879	1289	1569	1775	1955	2678	1451	1726	2031	2252	3485
Aug	1 - 31	-2279	1089	1165	1548	3279	914	1292	1516	1716	2705	1032	1426	1735	1914	3483
Sep	1 - 30	-1825	1063	1093	1413	3080	663	1051	1298	1515	2382	759	1162	1486	1711	2997
Oct	1 - 31	-1883	1207	1281	1572	3033	895	1311	1483	1655	2286	1000	1430	1694	1916	3119
Nov	1 - 5	-2012	821	955	1350	2398	381	787	1055	1289	2327	465	871	1224	1485	2741
	16 - 17	-1257	208	313	499	1453	830	964	1167	1325	1703	844	970	1286	1480	2354
	18 - 20	-1598	212	512	541	4923	808	942	1226	1427	1983	814	981	1343	1545	2561
	21 - 30	-3600	157	1396	2866	4961	616	1483	1583	1771	2003	438	1332	1627	2044	2593
Dec	1 - 31	-4012	310	1386	2966	5090	281	1491	1628	1811	2406	77	1369	1682	2026	2855

Table B-2 (cont.). Distribution of flows (cfs) by study period in 2006.

		VICT					ROLD034					RSAN072				
		Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max	Min	0.25	Avg	0.75	Max
Jan	1 - 6	-4312	-2386	857	3278	10183	-18772	-6590	-297	6301	10268	3094	5726	6492	7453	8252
	7 - 21	-4421	-2767	40	2576	7270	-13287	-5154	1301	7242	11499	4188	6528	7317	8284	8978
	22 - 31	-4008	-2294	1068	4145	7202	-13671	-8510	-1257	6306	10057	989	3346	3895	4620	5102
Feb	1 - 14	-3363	-1690	1912	5051	8759	-16523	-9964	-2890	4837	8423	1081	2587	3224	3969	4533
	15 - 28	-3796	-534	2600	5469	8840	-17334	-10584	-4265	1912	9430	-1535	2090	2626	3467	4080
Mar	1 - 20	-3910	-2378	758	3292	7928	-15347	-6840	-397	6792	9615	1025	4861	5243	5959	6523
	21 - 31	-5342	-3533	-156	2617	8947	-15921	-5778	1278	8842	12138	4273	5326	5874	6281	7580
Apr	1 - 9	-5995	-4564	-2014	525	7595	-14533	-543	5039	10948	13997	5863	7574	8373	9153	10885
	10 - 20	-7744	-6790	-4759	-3378	3905	-5770	6338	10673	15481	17541	10321	11785	12221	12726	13294
	21 - 31	-6904	-6123	-3416	-1886	4903	-8562	3934	8473	14221	16395	10998	11453	11707	11931	12211
May	1 - 17	-6740	-5862	-4199	-2707	3606	-5860	5173	9470	13513	15654	9607	10467	10840	11240	12000
	18 - 31	-5646	-4686	-1954	203	6696	-12180	30	5514	11471	13747	8766	9688	9917	10214	10471
Jun	1 - 21	-5016	-2946	-242	1858	8648	-14277	-4161	1620	7603	12133	5833	7043	7538	7967	9461
	22 - 30	-3145	-2061	1152	3966	7420	-14105	-7592	-1154	5361	8290	5624	6646	6919	7252	7748
Jul	1 - 7	-2045	576	2478	4242	7758	-14723	-8763	-4439	-578	5552	2459	3798	4555	5395	6561
	7 - 17	-2248	337	3008	5804	8797	-17118	-11292	-5461	-425	5846	-1015	1539	2248	2978	4088
	17 - 19	-1663	1404	3196	5093	7314	-14567	-10766	-6041	-2178	3729	-1270	1119	1696	2783	2935
	20 - 31	-1913	1737	3683	6196	8663	-16814	-11681	-6686	-2608	4826	-1303	1128	1831	2689	3154
Aug	1 - 31	-2306	1760	3669	5866	8984	-16948	-11012	-6646	-2770	5332	-1527	1094	1721	2574	3141
Sep	1 - 30	-1672	1742	3697	6010	8902	-16440	-11239	-6693	-2814	5021	-1599	765	1509	2417	2872
Oct	1 - 31	-2176	882	3188	5601	8449	-16066	-10511	-5702	-1303	5864	-1352	1348	1929	2660	3050
Nov	1 - 5	-1921	391	2873	4972	8308	-15742	-9376	-5132	-416	5799	-1902	887	1481	2333	2785
	16 - 17	-1104	715	2917	4920	6950	-13538	-9772	-5376	-1484	3130	-1318	556	1200	2023	2301
	18 - 20	-2080	1273	3065	5281	7389	-14751	-10729	-5713	-1836	5059	-1739	258	1054	2031	2369
	21 - 30	-2603	175	2812	5501	7692	-15221	-11005	-5142	530	6825	-2084	-633	665	1790	2398
Dec	1 - 31	-2749	1164	3173	5506	8556	-16439	-11187	-5964	-1976	7139	-2448	-635	633	1871	2439

Table 1-1. Schedule of Installation and Removal Dates for South Delta Temporary Barriers from 1987 through 2006

	Middle River							Old River near Tracy (DMC)							Grant Line Canal						
	Installation			Notched	Removal			Installation			Notched	Removal			Installation			Flashboards	Removal		
Year	Started	Closed	Completed		Started	Breached	Completed	Started	Closed	Completed		Started	Breached	Completed	Started	Closed	Completed	Adjusted	Started	Breached	Completed
1987			15-May		End of Sep		End of Sep														
1988	26-May		28-May		23-Sep		23-Sep														
1989			12-Apr		26-Sep		26-Sep														
1990			16-Apr		29-Sep		29-Sep														
1991	4-Apr		5-Apr		27-Sep		27-Sep	14-Aug		30-Aug		28-Sep		13-Oct. (i)							
1992	8-Apr		10-Apr		28-Sep		29-Sep	15-April boat port on		01-May 09-May boat port on		30-Sep		Oct-09(ii)							
1993	14-Jun		17-Jun		23-Sep		24-Sep	12-May		1-Jun		27-Sep		6-Oct							
1994	23-Apr		25-Apr		29-Sep		5-Oct	22-April boat port on. All culverts tied open (5/18 to 6/1)		24-April 01-May		26-Sep		10-Oct							
1995	8-Aug		11-Aug		10-Oct		10-Oct	3-Aug		8-Aug		27-Sep		6-Oct							
1996	18-May		20-May		29-Sep		29-Sep	12-May		10-Jun (iii)		29-Sep		16-Oct	17-Jun		10-Jul		2-Oct		15-Oct
1997	3-Apr		7-Apr		27-Sep		28-Sep	8-Apr		17-Apr		30-Sep		7-Oct	21-May		4-Jun		26-Sep		15-Oct
1998	(vii)							(vii)							(vii)						
1999	15-May		18-May		29-Sep		2-Oct	15-May		28-May		28-Sep		8-Oct	15-May		3-Jun		23-Sep		5-Oct
2000	4-Apr		6-Apr		1-Oct		7-Oct	4-Apr		16-Apr		1-Oct		7-Oct	19-May		1-Jun		1-Oct		7-Oct
2001	20-Apr		23-Apr		12-Nov	13-Nov	17-Nov	23-Apr		26-Apr		13-Nov	14-Nov	26-Nov	2-May		9-May		11-Nov	12-Nov	18-Nov
2002	10-Apr		15-Apr		20-Nov	20-Nov	23-Nov	1-Apr		18-Apr		16-Nov	16-Nov	29-Nov	1-Apr		12-Jun		14-Nov	16-Nov	25-Nov
2003	12-Apr	15-Apr	23-Apr	17-Sept.	7-Nov	8-Nov	10-Nov	1-Apr	14-Apr	22-Apr	17-Sept.	13-Nov	15-Nov	25-Nov	1-Apr. (Partial) 9-June (Complete)	11-Jun	23-Apr. (Partial) 17-June (Complete)	16-Sept.	10-Nov	12-Nov	25-Nov
2004	9-Apr	12-Apr	13-Apr	23-Sept.	9-Nov.	10-Nov.	12-Nov	1-Apr	15-Apr	20-Apr	10-Sept.	8-Nov.	8-Nov.	1-Dec.	1-Apr. (Partial) 2-June (Complete)	9-Apr (partial) 5-June (complete)	28_Apr (partial) 9-June (complete)	9-Sept.	11-Nov	12-Nov	6-Dec
2005	10-May	12-May	17-May	15-Sept.	7-Nov	8-Nov	9-Nov.	9-May	31-May	6-Jun	15-Sept.	8-Nov.	10-Nov	30-Nov	2-May	14-Jul	18-Jul	14-July & 14-Sept.	7-Nov	15-Nov	30-Nov
2006	5-Jul	7-Jul	8-Jul	1-Oct	17-Nov	18-Nov	20-Nov	7-Jul	17-Jul	31-Jul	1-Oct	13-Nov	16-Nov	8-Dec	7-Jul	20-Jul	26-Jul	20-Jul & 1-Oct	14_nov	21-Nov	6-Dec

	Spring Head of Old River						Fall Head of Old River (v)						
	Installation			Removal			Installation			Notched	Removal		
Year	Started	Closed	Completed	Started	Breached	Completed	Started	Closed	Completed		Started	Breached	Completed
1987							9-Sep		11-Sep				28-Nov
1988							22-Sep		28-Sep				2-Dec
1989							27-Sep		28-Sep		27-Nov		30-Nov
1990							10-Sep		11-Sep				27-Nov
1991							9-Sep		13-Sep		22-Nov		27-Nov
1992	15-April boat port on		23-April @ 4ft 26-April@6ft 01-May	2-Jun		8-Jun	8-Sep		11-Sep		30-Nov		4-Dec
1993							8-Nov (vii)		11-Nov		3-Dec		7-Dec
1994	21-April boat port on		23-April @10ft 01-May	18-May		20-May	6-Sep		8-Sep		28-Nov		30-Nov
1995	(vii)						(vii)						
1996	6-May		11-May	16-May		3-Sept (iv)	30-Sep		3-Oct		18-Nov		22-Nov
1997	9-Apr		16-Apr	15-May		19-May (viii)							
1998	(vii)						(vii)						
1999	(vii)						(viii)						
2000	5-Apr		16-Apr	19-May		2-Jun	27-Sep		7-Oct		27-Nov		8-Dec
2001	17-Apr		26-Apr	23-May		30-May	24-Sep		6-Oct		22-Nov	22-Nov	2-Dec
2002	2-Apr		18-Apr	22-May	24-May	7-Jun	24-Sep		4-Oct		11-Nov	12-Nov	21-Nov
2003	1-Apr	15-Apr	21-Apr	16-May	18-May	3-Jun	2-Sept.	15-Sept.	18-Sep	16-Sept.	3-Nov	4-Nov	13-Nov
2004	1-Apr	15-Apr	21-Apr	19-May	24-May	10-Jun	7-Sep	27-Sept.	29-Sept.	28-Sept.	1-Nov.	2-Nov.	12-Nov
2005	(vii)	(vii)	(vii)	(vii)	(vii)	(vii)	19-Sept.	28-Sept.	30-Sept.	29-Sep	7-Nov	8-Nov	15-Nov
2006	(vii)	(vii)	(vii)	(vii)	(vii)	(vii)	(ix)	(ix)	(ix)	(ix)	(ix)	(ix)	(ix)

(i) Barrier notched on Sept. 28, 1991. Construction resumed on Oct. 10 and finished on Oct. 13.

(ii) Barrier notched on Sept. 30, 1992. Construction resumed on Oct. 2 and finished on Oct. 9.

(iii) Construction was delayed on 5/17 and resumed on 6/5 due to high flows.

(iv) Barrier was breached on 5/ 16 on an emergency basis, but complete removal wasn't done until 9/3, after Corps demanded permit compliance of complete removal.

(v) Barrier was installed in previous years.

(vi) Installation delayed due to high flows.

(vii) Not installed due to high San Joaquin River flows.

(viii) Not installed upon DFG's request.

(ix) Not installed because existing flows and dissolved oxygen levels in the San Joaquin River were sufficient for Chinook Salmon.

Figure 4-28. Observed Chinook salvage at the SWP and CVP Delta Fish Facilities, August 2005 through July 2006.

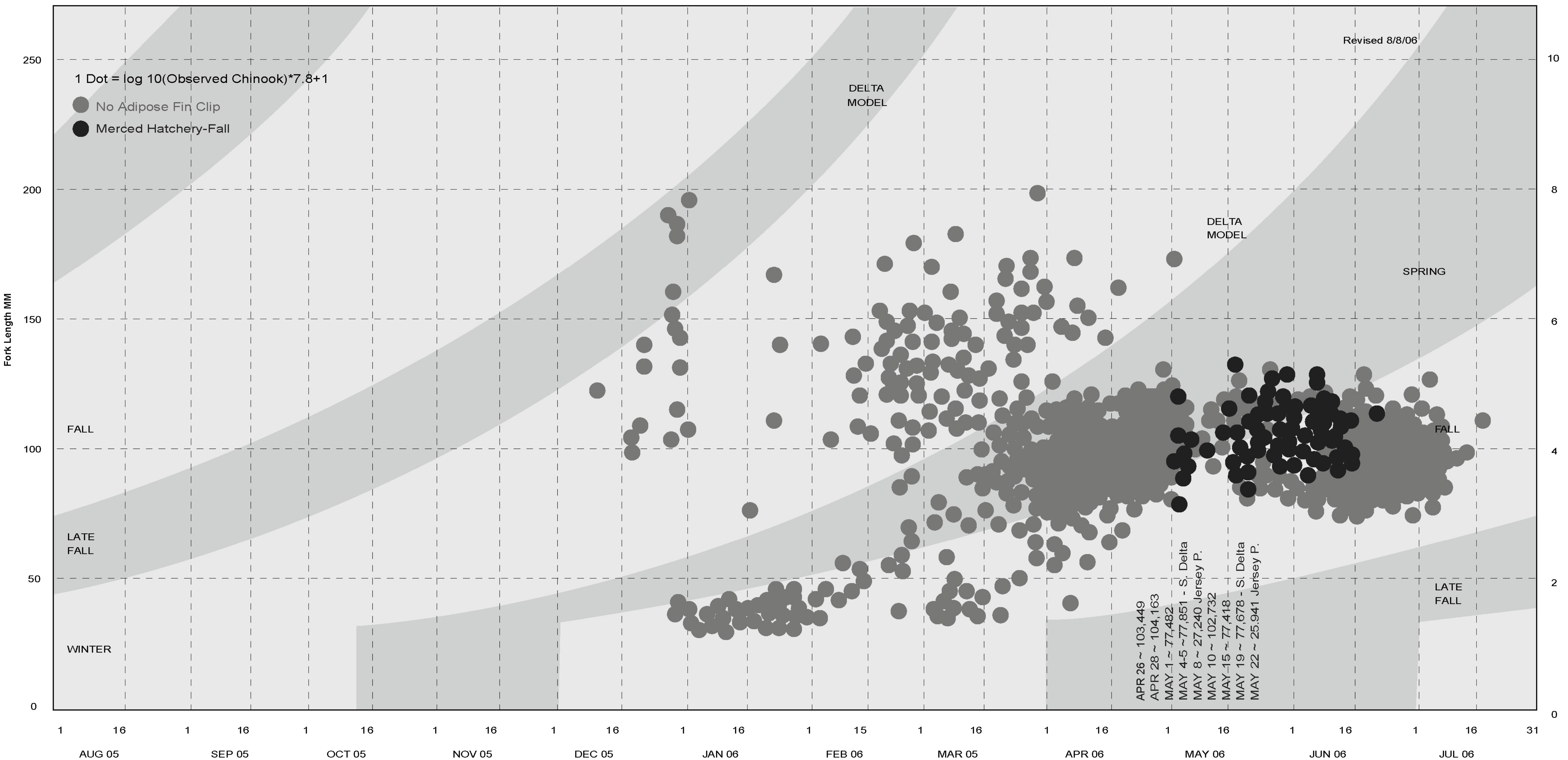


Table 4-5. Chinook salmon smolt recovery information at Antioch, Chipps Island, and the fish facilities for VAMP 2006 releases.

Tag Code	Release Site	Release Date	Antioch Recoveries								Chipps Island Recoveries							Fish Facilities Recoveries Raw Salvage (Expanded Salvage)		
			Corrected or Effective Release number	First Day Recovered	Last Day Recovered	Number Recovered	Recovery Effort (minutes sampled)	Percent of Time Sampled	Survival Index	Group index	First Day Recovered	Last Day Recovered	Number Recovered	Recovery Effort (minutes sampled)	Percent of Time Sampled	Survival Index	Group index	CVP	SWP	Recovery Days
06-47-13	Mossdale		24,703	5/10/06	5/10/06	5	580	0.403	0.036		5/8/06	5/18/06	7	4400	0.278	0.133		0	2 (12)	5/4/06
06-47-14	Mossdale		24,315	5/11/06	5/16/06	4	3255	0.377	0.031		5/11/06	5/12/06	2	800	0.278	0.038		0	1 (6)	5/4/06
	Total	**5/4/06**	**49,018**	**5/10/06**	**5/16/06**	**9**	**3835**	**0.380**		**0.035**	**5/8/06**	**5/18/06**	**9**	**4400**	**0.278**		**0.086**			**5/4/06 - 5/4/06**
06-47-16	Dos Reis	5/5/06	25,602	5/10/06	5/12/06	3	1760	0.407	0.021		5/10/06	5/15/06	7	2400	0.278	0.128		0	0	---
06-47-15	Jersey Point	5/8/06	26,192	5/8/06	5/13/06	26	3245	0.376	0.190		5/9/06	5/16/06	58	3200	0.278	1.036		0	0	---
06-47-21	Mossdale		25,105	--	--	0	0	0.000	--		5/20/06	5/20/06	2	400	0.278	0.037		1 (12)	0	5/19/06
06-47-22	Mossdale		24,008	--	--	0	0	0.000	--		--	--	0	0	0.000	--		1 (12)	0	5/19/06
~~06-47-23~~	~~Mossdale~~		~~25,066~~	~~5/24/06~~	~~5/24/06~~	~~1~~	~~580~~	~~0.403~~	~~0.007~~		~~5/20/06~~	~~5/20/06~~	~~2~~	~~400~~	~~0.278~~	~~0.037~~		~~2 (24)~~	~~0~~	~~5/19/06~~
	Total	**5/19/06**	**49,113**			**0**	**~~580~~**	**~~0.403~~**		**0.000**			**2**	**400**	**0.278**		**0.019**			**5/19/06 - 5/19/06**
06-47-24	Jersey Point	5/22/06	23,980	5/22/06	5/29/06	14	4160	0.363	0.116		5/23/06	5/28/06	44	2400	0.278	0.859		0	0	---
Mossdale group (6-47-23 tag code) not used in the analyses.																				

Table 8-6. Statistical summary of 2006 Old River continuous water quality data: specific conductance, turbidity and chlorophyll *a*

Month	Specific Conductance (µS/cm)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	489.3	632.0	541.0	483.9
Feb.	609.4	731.1	624.3	695.2
Mar	510.0	501.1	580.4	641.5
Apr	257.8	760.4	586.0	462.8
May	144.9	175.5	174.0	174.9
Jun	222.7	394.2	341.7	347.3
Jul	621.9	772.9	671.4	674.8
Aug	542.3	629.2	654.5	665.7
Sep	485.4	705.5	682.9	693.3
Oct	416.8	572.1	542.6	548.2
Nov	796.3	1489.6	1023.0	1113.6
Dec	818.9	1515.6	1261.4	1264.5
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	255.9	286.5	297.5	365.4
Feb.	372.9	444.8	437.9	430.8
Mar	276.9	265.7	290.6	291.8
Apr	158.6	189.4	203.3	176.2
May	116.0	130.6	140.5	139.4
Jun	128.0	186.8	188.7	191.9
Jul	386.0	459.4	410.3	399.1
Aug	409.5	500.0	567.9	563.5
Sep	399.4	505.5	566.4	565.2
Oct	329.2	396.5	447.5	446.9
Nov	656.2	767.9	691.0	690.8
Dec	672.8	804.7	748.6	730.4
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	166.4	177.3	173.9	233.6
Feb.	297.6	316.4	268.0	265.8
Mar	173.9	185.7	189.0	186.8
Apr	123.1	128.2	139.2	131.9
May	102.1	111.8	123.2	123.1
Jun	98.7	120.4	123.0	117.9
Jul	126.1	143.2	153.3	142.7
Aug	356.1	417.7	245.0	222.7
Sep	345.6	415.6	339.5	278.7
Oct	278.6	312.3	359.5	290.1
Nov	374.8	388.7	361.8	320.5
Dec	565.7	597.1	407.9	391.9
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	62.2	81.4	66.6	54.3
Feb.	48.9	91.5	77.0	74.3
Mar	85.6	52.9	60.2	60.3
Apr	21.4	67.1	54.4	54.5
May	7.2	8.6	9.4	7.7
Jun	16.1	46.5	30.9	85.4
Jul	94.2	118.7	167.7	170.8
Aug	21.5	38.6	42.9	54.7
Sep	29.8	55.1	42.1	49.1
Oct	26.4	49.7	44.9	47.8
Nov	99.6	185.4	166.7	184.1
Dec	71.3	154.5	217.1	225.8
2006 - Max.	818.9	1515.6	1261.4	1264.5
2006 - Avg.	346.7	411.2	416.2	431.2
2006 - Min.	98.7	111.8	123.0	117.9
2006 - S.D.	183.1	227.8	219.5	219.3

Month	Turbidity (NTU)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	120.9	53.0	108.0	26.0
Feb.	122.7	26.0	193.5	27.0
Mar	96.9	44.3	151.3	40.3
Apr	87.0	93.3	194.8	37.0
May	25.8	40.9	198.8	42.8
Jun	57.9	46.5	126.5	120.2
Jul	183.9	80.0	176.5	100.2
Aug	190.7	29.2	85.8	62.0
Sep	110.4	83.1	43.7	99.6
Oct	33.2	82.7	103.1	51.6
Nov	141.9	134.7	75.1	179.0
Dec	183.8	60.1	182.0	56.7
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	27.3	19.6	17.4	11.9
Feb.	15.3	11.0	10.5	11.8
Mar	19.2	14.5	13.5	13.0
Apr	11.6	31.1	26.8	17.7
May	6.8	17.0	19.1	18.4
Jun	25.0	27.2	30.3	28.6
Jul	29.6	26.1	31.3	26.7
Aug	19.5	17.3	14.5	17.4
Sep	18.2	19.6	12.4	15.0
Oct	16.5	15.5	12.7	14.8
Nov	15.2	16.1	13.1	11.6
Dec	12.4	13.3	12.5	10.3
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	8.7	7.2	5.2	6.4
Feb.	7.2	4.8	2.3	3.1
Mar	11.4	6.7	5.9	5.3
Apr	0.9	11.4	10.2	8.9
May	1.3	13.1	10.9	10.4
Jun	8.7	14.8	9.8	11.2
Jul	5.3	4.4	8.9	9.0
Aug	8.9	4.2	5.5	7.6
Sep	11.5	13.1	4.4	7.6
Oct	8.1	11.3	6.4	2.8
Nov	6.7	8.7	4.0	-0.9
Dec	6.1	5.3	3.6	2.8
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	16.9	9.2	8.3	3.5
Feb.	6.6	2.4	12.8	4.3
Mar	6.7	4.3	8.7	3.5
Apr	12.2	17.6	12.1	4.5
May	2.5	1.5	7.4	4.0
Jun	7.1	5.5	10.4	8.2
Jul	13.8	12.2	14.5	10.8
Aug	6.4	5.4	4.7	5.9
Sep	4.4	4.9	3.2	3.7
Oct	3.1	2.2	3.2	2.7
Nov	5.1	5.7	6.8	10.2
Dec	6.5	4.0	12.9	5.4
2006 - Max.	190.7	134.7	198.8	179.0
2006 - Avg.	18.1	19.0	17.9	16.6
2006 - Min.	0.9	4.2	2.3	-0.9
2006 - S.D.	10.9	9.6	11.7	8.6

Month	Chlorophyll *a* (µg/L)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	14.9	16.4	8.3	9.8
Feb.	12.4	53.4	26.2	21.9
Mar	29.3	32.4	17.0	12.0
Apr	24.6	49.7	52.6	37.5
May	29.9	28.7	73.6	32.6
Jun	33.1	116.4	29.0	62.6
Jul	204.5	207.3	60.3	50.4
Aug	118.6	74.4	35.9	27.8
Sep	60.3	70.7	29.2	28.3
Oct	14.0	21.7	24.1	9.2
Nov	15.8	95.8	29.7	13.4
Dec	34.0	179.8	111.5	43.1
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	4.2	-0.6	2.0	4.8
Feb.	1.2	10.3	6.0	7.7
Mar	6.2	6.1	6.4	4.9
Apr	7.6	11.6	10.1	8.7
May	6.6	4.8	6.8	6.6
Jun	14.3	26.9	11.1	12.0
Jul	59.4	63.1	13.2	7.8
Aug	35.7	20.9	11.9	7.3
Sep	23.2	12.1	7.7	8.1
Oct	3.7	0.9	3.2	4.8
Nov	4.8	5.4	4.9	4.1
Dec	10.9	22.6	21.8	11.3
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	-3.9	-8.3	-2.7	1.8
Feb.	-3.3	-7.9	1.2	2.2
Mar	-0.5	-3.0	1.4	0.6
Apr	-3.0	-0.1	4.2	3.5
May	-3.3	-3.8	0.1	1.7
Jun	9.9	5.3	2.9	1.7
Jul	10.2	9.4	1.8	0.9
Aug	6.7	2.0	1.0	-1.7
Sep	1.1	-4.2	-1.0	2.6
Oct	-4.9	-7.9	-1.2	1.1
Nov	-0.8	-7.9	-1.0	-1.5
Dec	2.0	-2.1	1.2	-0.7
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	2.2	4.1	2.0	1.4
Feb.	2.3	11.8	2.7	3.0
Mar	2.2	4.3	1.9	1.5
Apr	4.5	5.6	3.0	3.5
May	6.2	6.2	4.3	3.0
Jun	4.3	14.5	3.7	5.5
Jul	37.7	37.3	8.3	5.3
Aug	20.7	11.2	5.0	3.4
Sep	11.6	6.7	4.4	2.8
Oct	2.4	4.6	1.6	1.1
Nov	1.5	10.8	2.6	2.2
Dec	5.3	14.6	16.7	9.6
2006 - Max.	204.5	207.3	111.5	62.6
2006 - Avg.	15.7	15.7	8.9	7.4
2006 - Min.	-4.9	-8.3	-2.7	-1.7
2006 - S.D.	21.5	22.2	8.2	5.0

Table 8-7. Statistical summary of 2006 Grant Line Canal continuous water quality data: water temperature, dissolved oxygen and pH

Month	Water Temperature (°C)		
MAXIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	13.67	13.64
Apr	-	18.30	18.31
May	-	20.52	20.50
Jun	22.98	22.99	22.95
Jul	28.36	29.29	28.18
Aug	24.58	25.90	24.04
Sep	24.08	25.29	23.40
Oct	18.42	18.69	18.55
Nov	16.54	16.70	16.30
Dec	12.81	12.38	12.41
AVERAGES	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	12.63	11.73
Apr	-	14.69	14.68
May	-	18.34	18.33
Jun	21.24	20.80	20.78
Jul	24.22	24.51	24.33
Aug	22.77	23.16	22.87
Sep	20.67	20.95	20.72
Oct	16.28	16.38	16.34
Nov	13.86	13.76	13.72
Dec	9.69	9.60	9.62
MINIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	11.77	10.36
Apr	-	11.87	11.88
May	-	16.98	16.97
Jun	19.70	18.61	18.63
Jul	21.17	21.27	21.27
Aug	21.68	21.87	21.95
Sep	18.39	18.43	18.48
Oct	13.42	13.51	13.53
Nov	9.36	9.47	9.55
Dec	7.51	7.79	7.86
STD. DEVS.	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	0.47	0.72
Apr	-	1.32	1.33
May	-	0.77	0.77
Jun	0.72	0.94	0.93
Jul	1.86	2.07	1.89
Aug	0.53	0.80	0.49
Sep	1.58	1.67	1.57
Oct	1.22	1.24	1.20
Nov	1.53	1.62	1.60
Dec	1.21	1.16	1.17
2006 - Max.	28.36	29.29	28.18
2006 - Avg.	18.42	17.87	17.41
2006 - Min.	7.51	7.79	7.86
2006 - S.D.	5.08	4.79	4.81

Month	Dissolved Oxygen (mg/L)		
MAXIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	11.24	11.57
Apr	-	10.71	10.60
May	-	9.43	9.32
Jun	8.78	9.16	9.66
Jul	13.99	15.46	14.55
Aug	13.33	12.85	11.81
Sep	10.11	10.54	9.22
Oct	10.20	10.07	9.39
Nov	10.63	10.37	10.91
Dec	12.27	12.60	11.87
AVERAGES	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	10.54	11.01
Apr	-	8.57	8.74
May	-	8.27	8.19
Jun	8.45	8.26	8.35
Jul	8.21	9.39	9.56
Aug	8.71	8.75	8.95
Sep	8.00	7.83	7.77
Oct	8.82	8.46	8.44
Nov	9.02	8.74	9.12
Dec	10.95	10.83	10.63
MINIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	10.15	10.11
Apr	-	6.99	6.95
May	-	7.65	7.58
Jun	7.87	7.47	7.58
Jul	1.33	6.83	7.05
Aug	4.29	6.62	7.28
Sep	5.98	6.16	6.15
Oct	7.55	7.32	7.57
Nov	7.80	7.49	7.90
Dec	9.63	9.32	9.28
STD. DEVS.	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	0.14	0.36
Apr	-	0.95	0.94
May	-	0.47	0.50
Jun	0.72	0.28	0.27
Jul	1.64	1.93	1.73
Aug	1.34	1.14	0.87
Sep	0.55	0.57	0.48
Oct	0.48	0.56	0.40
Nov	0.59	0.60	0.70
Dec	0.57	0.64	0.64
2006 - Max.	13.99	15.46	14.55
2006 - Avg.	8.87	8.84	9.05
2006 - Min.	1.33	6.16	6.15
2006 - S.D.	1.29	1.25	1.26

Month	pH		
MAXIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	7.90	7.58
Apr	-	7.74	7.54
May	-	7.46	7.40
Jun	7.55	7.50	7.44
Jul	8.27	9.15	8.97
Aug	8.76	8.91	8.65
Sep	8.05	8.15	7.82
Oct	8.11	7.68	7.56
Nov	8.26	7.76	7.89
Dec	8.00	7.88	8.04
AVERAGES	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	7.79	7.42
Apr	-	7.41	7.27
May	-	7.31	7.21
Jun	7.40	7.33	7.33
Jul	7.49	7.66	7.61
Aug	7.77	7.81	7.70
Sep	7.56	7.56	7.48
Oct	7.68	7.54	7.44
Nov	7.80	7.62	7.64
Dec	7.79	7.69	7.86
MINIMUMS	**Doughty Cut**	**GLC at Barrier**	**GLC at Tracy Rd**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	7.63	7.10
Apr	-	7.21	7.13
May	-	7.21	7.14
Jun	7.29	7.23	7.23
Jul	7.15	7.15	7.02
Aug	7.37	7.43	7.35
Sep	7.33	7.33	7.24
Oct	7.30	7.40	7.26
Nov	7.50	7.50	7.49
Dec	7.58	7.44	7.70
STD. DEVS.	**Doughty Cut**	**Doughty Cut**	**GLC at Barrier**
Jan.	-	-	-
Feb.	-	-	-
Mar	-	0.06	0.07
Apr	-	0.13	0.11
May	-	0.06	0.07
Jun	0.05	0.04	0.04
Jul	0.29	0.54	0.49
Aug	0.25	0.32	0.33
Sep	0.12	0.12	0.12
Oct	0.26	0.05	0.06
Nov	0.23	0.06	0.10
Dec	0.10	0.07	0.06
2006 - Max.	8.76	9.15	8.97
2006 - Avg.	7.67	7.52	7.45
2006 - Min.	7.15	7.15	7.02
2006 - S.D.	0.24	0.30	0.31

Table 8-8. Statistical summary of 2006 Grant Line Canal continuous water quality data: specific conductance, turbidity and chlorophyll *a*

Month	Specific Conductance (μS/cm)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	489.3	632.0	541.0	483.9
Feb.	609.4	731.1	624.3	695.2
Mar	510.0	501.1	580.4	641.5
Apr	257.8	760.4	586.0	462.8
May	144.9	175.5	174.0	174.9
Jun	222.7	394.2	341.7	347.3
Jul	621.9	772.9	671.4	674.8
Aug	542.3	629.2	654.5	665.7
Sep	485.4	705.5	682.9	693.3
Oct	416.8	572.1	542.6	548.2
Nov	796.3	1489.6	1023.0	1113.6
Dec	818.9	1515.6	1261.4	1264.5
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	255.9	286.5	297.5	365.4
Feb.	372.9	444.8	437.9	430.8
Mar	276.9	265.7	290.6	291.8
Apr	158.6	189.4	203.3	176.2
May	116.0	130.6	140.5	139.4
Jun	128.0	186.8	188.7	191.9
Jul	386.0	459.4	410.3	399.1
Aug	409.5	500.0	567.9	563.5
Sep	399.4	505.5	566.4	565.2
Oct	329.2	396.5	447.5	446.9
Nov	656.2	767.9	691.0	690.8
Dec	672.8	804.7	748.6	730.4
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	166.4	177.3	173.9	233.6
Feb.	297.6	316.4	268.0	265.8
Mar	173.9	185.7	189.0	186.8
Apr	123.1	128.2	139.2	131.9
May	102.1	111.8	123.2	123.1
Jun	98.7	120.4	123.0	117.9
Jul	126.1	143.2	153.3	142.7
Aug	356.1	417.7	245.0	222.7
Sep	345.6	415.6	339.5	278.7
Oct	278.6	312.3	359.5	290.1
Nov	374.8	388.7	361.8	320.5
Dec	565.7	597.1	407.9	391.9
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	62.2	81.4	66.6	54.3
Feb.	48.9	91.5	77.0	74.3
Mar	85.6	52.9	60.2	60.3
Apr	21.4	67.1	54.4	54.5
May	7.2	8.6	9.4	7.7
Jun	16.1	46.5	30.9	85.4
Jul	94.2	118.7	167.7	170.8
Aug	21.5	38.6	42.9	54.7
Sep	29.8	55.1	42.1	49.1
Oct	26.4	49.7	44.9	47.8
Nov	99.6	185.4	166.7	184.1
Dec	71.3	154.5	217.1	225.8
2006 - Max.	818.9	1515.6	1261.4	1264.5
2006 - Avg.	346.7	411.2	416.2	431.2
2006 - Min.	98.7	111.8	123.0	117.9
2006 - S.D.	183.1	227.8	219.5	219.3

Month	Turbidity (NTU)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	120.9	53.0	108.0	26.0
Feb.	122.7	26.0	193.5	27.0
Mar	96.9	44.3	151.3	40.3
Apr	87.0	93.3	194.8	37.0
May	25.8	40.9	198.8	42.8
Jun	57.9	46.5	126.5	120.2
Jul	183.9	80.0	176.5	100.2
Aug	190.7	29.2	85.8	62.0
Sep	110.4	83.1	43.7	99.6
Oct	33.2	82.7	103.1	51.6
Nov	141.9	134.7	75.1	179.0
Dec	183.8	60.1	182.0	56.7
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	27.3	19.6	17.4	11.9
Feb.	15.3	11.0	10.5	11.8
Mar	19.2	14.5	13.5	13.0
Apr	11.6	31.1	26.8	17.7
May	6.8	17.0	19.1	18.4
Jun	25.0	27.2	30.3	28.6
Jul	29.6	26.1	31.3	26.7
Aug	19.5	17.3	14.5	17.4
Sep	18.2	19.6	12.4	15.0
Oct	16.5	15.5	12.7	14.8
Nov	15.2	16.1	13.1	11.6
Dec	12.4	13.3	12.5	10.3
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	8.7	7.2	5.2	6.4
Feb.	7.2	4.8	2.3	3.1
Mar	11.4	6.7	5.9	5.3
Apr	0.9	11.4	10.2	8.9
May	1.3	13.1	10.9	10.4
Jun	8.7	14.8	9.8	11.2
Jul	5.3	4.4	8.9	9.0
Aug	8.9	4.2	5.5	7.6
Sep	11.5	13.1	4.4	7.6
Oct	8.1	11.3	6.4	2.8
Nov	6.7	8.7	4.0	-0.9
Dec	6.1	5.3	3.6	2.8
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	16.9	9.2	8.3	3.5
Feb.	6.6	2.4	12.8	4.3
Mar	6.7	4.3	8.7	3.5
Apr	12.2	17.6	12.1	4.5
May	2.5	1.5	7.4	4.0
Jun	7.1	5.5	10.4	8.2
Jul	13.8	12.2	14.5	10.8
Aug	6.4	5.4	4.7	5.9
Sep	4.4	4.9	3.2	3.7
Oct	3.1	2.2	3.2	2.7
Nov	5.1	5.7	6.8	10.2
Dec	6.5	4.0	12.9	5.4
2006 - Max.	190.7	134.7	198.8	179.0
2006 - Avg.	18.1	19.0	17.9	16.6
2006 - Min.	0.9	4.2	2.3	-0.9
2006 - S.D.	10.9	9.6	11.7	8.6

Month	Chlorophyll a (μg/L)			
MAXIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	14.9	16.4	8.3	9.8
Feb.	12.4	53.4	26.2	21.9
Mar	29.3	32.4	17.0	12.0
Apr	24.6	49.7	52.6	37.5
May	29.9	28.7	73.6	32.6
Jun	33.1	116.4	29.0	62.6
Jul	204.5	207.3	60.3	50.4
Aug	118.6	74.4	35.9	27.8
Sep	60.3	70.7	29.2	28.3
Oct	14.0	21.7	24.1	9.2
Nov	15.8	95.8	29.7	13.4
Dec	34.0	179.8	111.5	43.1
AVERAGES	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	4.2	-0.6	2.0	4.8
Feb.	1.2	10.3	6.0	7.7
Mar	6.2	6.1	6.4	4.9
Apr	7.6	11.6	10.1	8.7
May	6.6	4.8	6.8	6.6
Jun	14.3	26.9	11.1	12.0
Jul	59.4	63.1	13.2	7.8
Aug	35.7	20.9	11.9	7.3
Sep	23.2	12.1	7.7	8.1
Oct	3.7	0.9	3.2	4.8
Nov	4.8	5.4	4.9	4.1
Dec	10.9	22.6	21.8	11.3
MINIMUMS	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	-3.9	-8.3	-2.7	1.8
Feb.	-3.3	-7.9	1.2	2.2
Mar	-0.5	-3.0	1.4	0.6
Apr	-3.0	-0.1	4.2	3.5
May	-3.3	-3.8	0.1	1.7
Jun	9.9	5.3	2.9	1.7
Jul	10.2	9.4	1.8	0.9
Aug	6.7	2.0	1.0	-1.7
Sep	1.1	-4.2	-1.0	2.6
Oct	-4.9	-7.9	-1.2	1.1
Nov	-0.8	-7.9	-1.0	-1.5
Dec	2.0	-2.1	1.2	-0.7
STD. DEVS.	**HEAD**	**TWA**	**ABOVE DMC**	**BELOW DMC**
Jan.	2.2	4.1	2.0	1.4
Feb.	2.3	11.8	2.7	3.0
Mar	2.2	4.3	1.9	1.5
Apr	4.5	5.6	3.0	3.5
May	6.2	6.2	4.3	3.0
Jun	4.3	14.5	3.7	5.5
Jul	37.7	37.3	8.3	5.3
Aug	20.7	11.2	5.0	3.4
Sep	11.6	6.7	4.4	2.8
Oct	2.4	4.6	1.6	1.1
Nov	1.5	10.8	2.6	2.2
Dec	5.3	14.6	16.7	9.6
2006 - Max.	204.5	207.3	111.5	62.6
2006 - Avg.	15.7	15.7	8.9	7.4
2006 - Min.	-4.9	-8.3	-2.7	-1.7
2006 - S.D.	21.5	22.2	8.2	5.0