

Measured Flow and Tracer-Dye Data Showing Anthropogenic Effects on the Hydrodynamics of South Sacramento-San Joaquin Delta, California, Spring 1996 and 1997

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CONVERSION FACTORS AND ABBREVIATIONS,

	Multiply	By	To obtain
	foot (ft)	0.3048	meter
	mile (mi)	1.609	kilometer
	cubic foot (ft ³)	.02832	cubic meter
	gallon (gal)	3.785	liter
	foot per second (ft/s)	.3048	meter per second
	cubic foot per second (ft ³ /s)	.02832	cubic meter per second

Concentrations of chemical constituents in water are given in micrograms per liter ($\mu\text{g/L}$).

Measured Flow and Tracer-Dye Data Showing Anthropogenic Effects on the Hydrodynamics of South Sacramento-San Joaquin Delta, California, Spring 1996 and 1997

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ABSTRACT

Tidal flows were measured using acoustic Doppler current profilers and ultrasonic velocity meters during spring 1996 and 1997 in south Sacramento-San Joaquin Delta, California, when (1) a temporary barrier was installed at the head of Old River to prevent the entrance of migrating San Joaquin River salmon smolts, (2) the rate of water export from the south Delta was reduced for an extended period of time, and (3) a 30-day pulse flow was created on the San Joaquin River to move salmon smolts north away from the export facilities during spring 1997. Tracer-dye measurements also were made under these three conditions.

INTRODUCTION

Background

During the spring of years when the San Joaquin River flow is less than about 7,000 cubic feet per second (ft^3/s), a temporary barrier of rock is installed by the California Department of Water Resources (DWR) at the head of Old River (HOR) in the south Sacramento-San Joaquin Delta, California, to prevent migrating salmon smolts in the San Joaquin River from entering Old River and being drawn to the State Water Project (SWP) and Federal Central Valley Project (CVP) pumping plants (fig. 1). The export rate of the pumping plants also is reduced during this migration period to minimize the draw of fish to the export facilities through the channels connected to the San Joaquin River north of the HOR, such as Turner Cut, Columbia Cut, and Middle River. During spring 1997, a 30-day pulse flow was created on the San Joaquin River to further assist salmon smolts north through the Delta to Suisun Bay. To evaluate the effectiveness of these approaches, data are needed to show the movement of water and fish in the Delta under these conditions.

The channel flows of the Delta are constantly changing, primarily because of the effects of ocean tides that propagate through San Francisco Bay and into the Delta, and also because of the

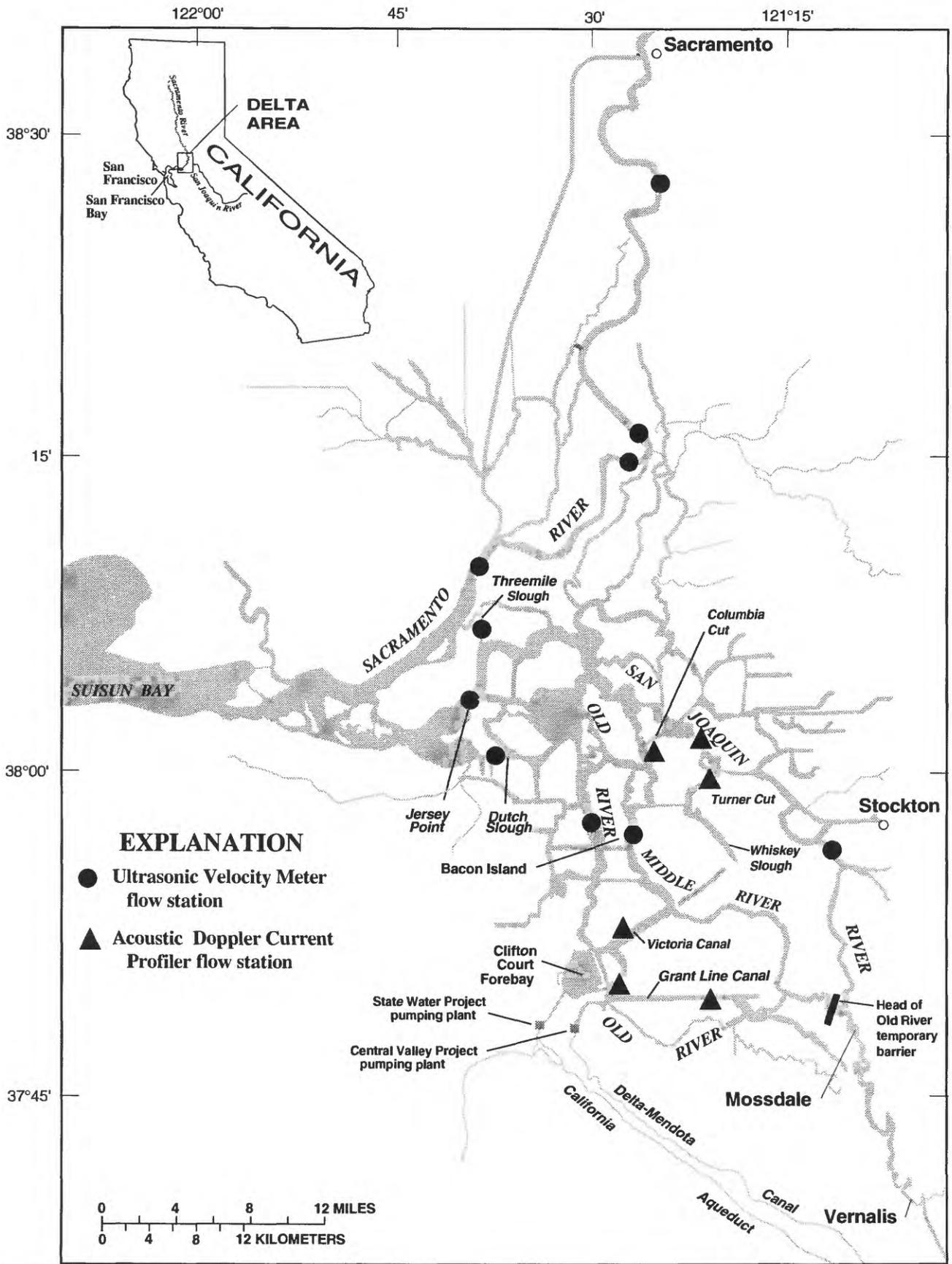


Figure 1. Locations of tidal-flow monitoring stations, Sacramento-San Joaquin Delta, California.

varying rates of inflow and exportation of Delta water. Until recently, measured tidal-flow data for the Delta was limited because of the difficulties associated with the measurement of the dynamic flows of the Delta. During the past several years, the U.S. Geological Survey (USGS), in cooperation with the DWR, U.S. Bureau of Reclamation (USBR), California State Water Resources Control Board, Contra Costa Water District, and the City of Stockton, has developed a network of ten continuous tidal-flow monitoring stations using ultrasonic velocity meters (UVM) (fig. 1). The UVMs have provided valuable time-series of tidal-flow data that have been used (1) to improve the understanding of the hydrodynamics of the Delta, and (2) for calibration of the several hydrodynamic models presently being applied to the Delta.

Data from several of the UVM stations will be used in this report to show the hydrodynamics of the south Delta during the spring of 1996 and 1997 when the HOR temporary barrier was installed and when the export rate of the pumping plants was reduced for an extended period of time. In addition to the flow data from the UVMs, data collected as part of the 1997 study described below also are presented in this report.

During the spring of 1997, the USGS collected flow and tracer-dye data to (1) assist State and Federal agencies with the evaluation of the effectiveness of the HOR temporary barrier and the San Joaquin River pulse flow for moving salmon smolts north through the Delta; (2) learn more about the hydrodynamics of the Delta, in particular, the effects of the HOR temporary barrier and the pulse flow on the hydrodynamics of the Delta; and (3) further calibrate flow and transport models of the Delta.

This report presents only hydrodynamic data. Presentation of salmon smolt movement in the Delta during the spring are not within the scope of this report.

Acknowledgments

Data collection in 1997 was a cooperatively funded effort by the DWR and the USGS. The collection of flow and tracer-dye data during spring 1997 would not have been possible without the funding provided by the Ecosystem Initiative Program, which was used to purchase several of the velocity measuring instruments, and the Drinking Water Initiative Program. The author also thanks Ralph Cheng, Jeffrey Gartner, and Timothy Rowe of the USGS for the loan of field equipment for the 1997 data collection and the USBR for the laboratory space used during the tracer-dye study. The author gratefully acknowledges the assistance of the following USGS personnel: James DeRose, Jon Burau, Richard Adorador, Jay Cuetara, Michael Simpson, Melissa Carlozzi, and Sylvia Stork; without their efforts this report would not have been possible.

METHODS OF MEASURING TIDAL FLOWS IN THE DELTA

Ten UVMs are deployed throughout the Delta, but only three are in the south Delta (fig. 1). Because the installation and maintenance of a UVM station is expensive, the USGS used six upward-looking acoustic Doppler current profilers (ADCP) in the south Delta during the spring of 1997 to provide a time-series of measured velocity that could be used to produce a tidal flow time-series similar to that provided by a UVM.

A UVM transmits acoustic pulses back and forth across a river channel along an acoustic path that is positioned 45° to the direction of primary flow. The difference in the measured acoustic travel times of the pulses as they travel back and forth across the channel provides the average water velocity across the channel at the depth of the transducers. This is referred to as an index velocity. To produce a time-series of 15-minute interval tidal-flow data, the index velocity is converted to mean cross-sectional velocity using a rating that is defined from numerous flow measurements made with a vessel-mounted downward-looking ADCP flow-measuring system (Simpson and Oltmann, 1993). Mean cross-sectional water velocities are then multiplied by the corresponding channel cross-sectional area to calculate discharge. Channel cross-sectional area is calculated from a water-surface elevation and channel cross-sectional area relation that is developed from channel field surveys.

An upward-looking ADCP is deployed on the bottom of the channel. ADCPs measure the water velocity above the instrument by transmitting acoustic pulses from multiple transducers into the water column and measuring the frequency shift of echoes reflected back to the instrument from inorganic and organic material in the water. The frequency shift of the echoes is used to determine Doppler shift, which is used to determine water velocity. This ADCP-measured velocity is then used as an index velocity and converted to flow in the same manner as is UVM-measured velocity.

From April 1-2, to June 23, 1997, upward-looking ADCPs were deployed at the six stations shown in figure 1. Numerous flow measurements were made throughout the tidal range at each ADCP site during the deployment period with a downward-looking ADCP flow-measuring system. The flow measurements were used to develop velocity ratings for each ADCP site as described earlier in this report. Tidal-flow hydrographs computed for each ADCP site are shown in figure 2. The hydrographs show that flows were successfully computed for the entire deployment period of each site, except for the Grant Line Canal site, where the ADCP was knocked over 17 days after deployment. The dynamic nature of the tidal flows at each ADCP site also is shown in figure 2.

Residual, or net-flow, hydrographs (heavy line) are overlaid on the tidal-flow hydrographs (fig. 2). The net-flow hydrographs are generated by processing the tidal-flow data with a low-pass digital filter (Godin, 1972) to remove the tidal frequencies. The resulting net-flow hydrographs are used in this report to show the hydrodynamics of the south Delta in 1997.

FLOW DATA FOR SPRING 1996

Daily flow and net flow for February 19 (day 50 of the annual calendar) to July 18, 1996, (day 200) are shown in figure 3 to show the hydrodynamics of the south Delta for the spring of 1996. The 5-month period includes an extended period of reduced exports from April 15 (day 106 - vertical line 1) to May 15 (day 136), and a brief period when the HOR temporary barrier was installed from May 11 (day 132 - vertical line 2) to May 16 (day 137 - vertical line 3). Figure 3A shows daily flows for the San Joaquin River at Vernalis, which is not a UVM station but is part of the USGS hydrologic data network (Rockwell and others, 1997), and the combined export of the SWP and the CVP (California Department of Water Resources, 1986). Figure 3B, 3C, and 3D, respectively, are for the UVM stations at San Joaquin River at Stockton, Old River at Bacon Island, and Dutch Slough. The three numbered vertical lines connecting the hydrographs show the periods when the combined export rate was reduced, and when the HOR temporary barrier was installed and breached.

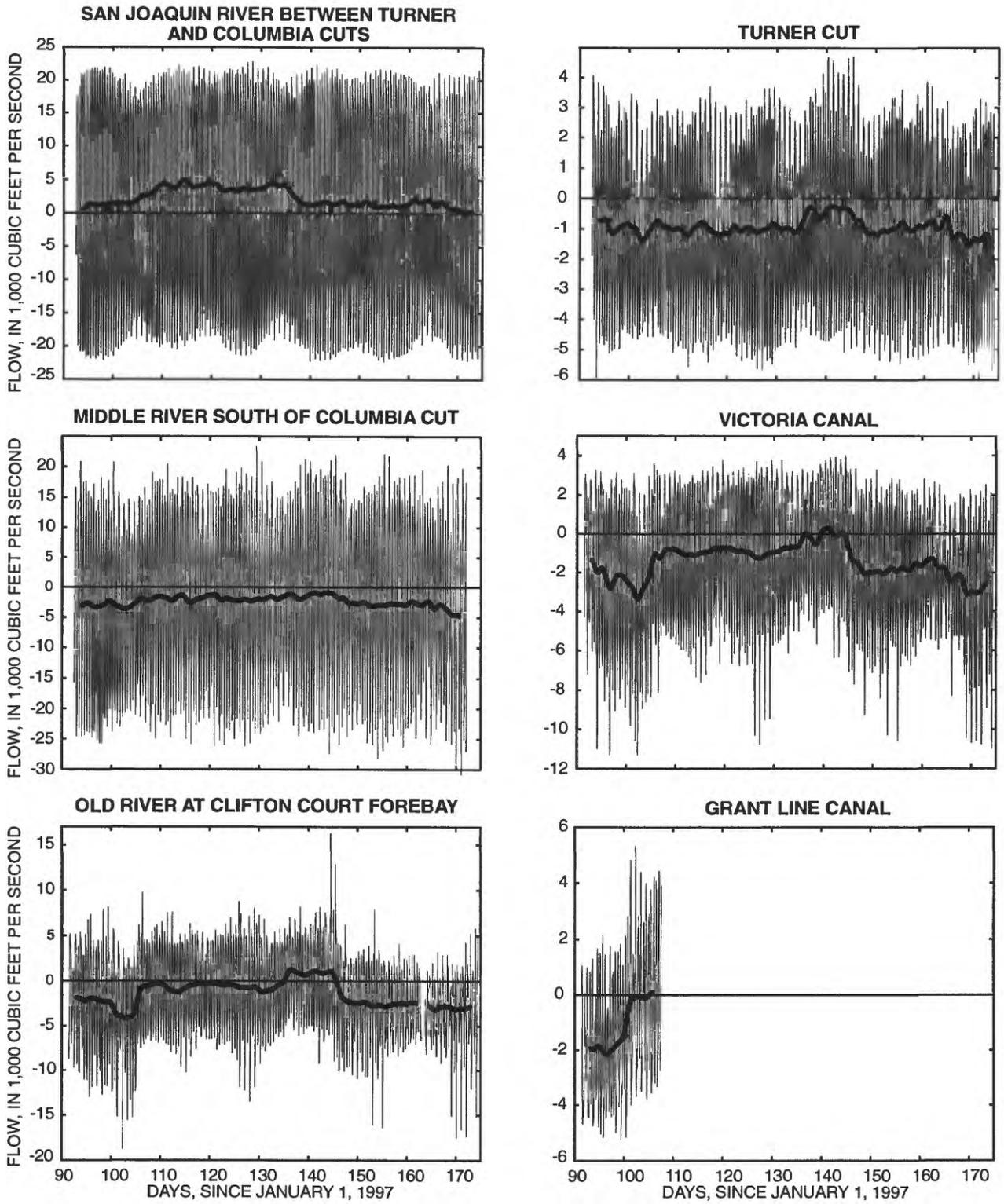


Figure 2. Tidal and net (heavy line) flow at acoustic Doppler current profiler sites, April 1 to June 23, 1997, south Sacramento-San Joaquin Delta, California.

At the start of the 5-month period, the flows entering the south Delta from the San Joaquin River (fig. 3A) were high with a peak daily flow of 17,600 ft³/s on March 10 (day 70). The high flow rate of the San Joaquin River and the low export rate caused a northward (positive) net-flow direction at the Old River UVM site (fig. 3C), and a westward (positive) net-flow direction at the Dutch Slough UVM site (fig. 3D). As the San Joaquin River flows decreased and the export rate increased after the March 10 peak, the positive net flows decreased at the three UVM sites. The direction of the net flow reversed at the Old River site and was close to reversing at the Dutch Slough site. However, when the export rate was reduced by about 8,000 ft³/s at the start of the reduced export period (day 106 - vertical line 1), the direction of the net flow again was northward at Old River, and the magnitude of the Dutch Slough westerly net flow increased. DWR began installing the HOR temporary barrier on May 6 (day 127 - vertical line 2); the installation was completed on May 11. From May 6 to May 16 (day 137 - vertical line 3), when the barrier was breached, the net flow increased at the Stockton UVM site (fig. 3B), decreased and changed direction at the Old River UVM site (fig. 3C), and decreased at Dutch Slough (fig. 3D). The breach of the temporary barrier and the increased flow of the San Joaquin River (after vertical line 3) resulted in a decrease, followed by an increase, in net flow at the Stockton UVM site (fig. 3B), another flow reversal at the Old River UVM site (fig. 3C), and an increase of the westerly net flows at Dutch Slough (fig. 3D). On May 15 (day 136) the combined export rate began to increase and was above 10,000 ft³/s on May 25 (day 146); the

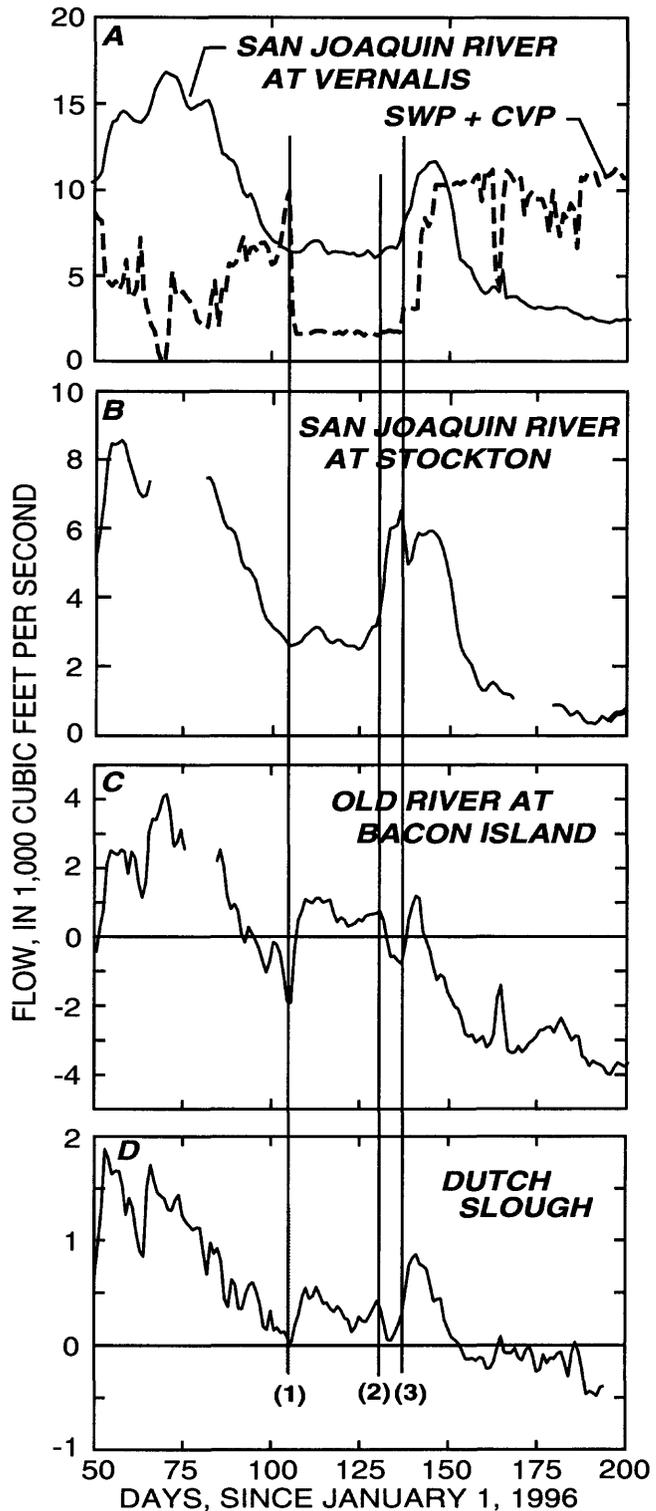


Figure 3. Daily flow at San Joaquin River at Vernalis, daily combined exports of State Water Project (SWP) and Central Valley Project (CVP), and net flow of San Joaquin River at Stockton, Old River at Bacon Island, and Dutch Slough, February 19 to July 18, 1996, south Sacramento-San Joaquin Delta, California. (1) Export rate reduced, (2) Head of Old River (HOR) temporary barrier installation started, (3) HOR temporary barrier breached.

San Joaquin River at Vernalis peaked at 11,700 ft³/s on May 24 (1 day earlier). The San Joaquin River flows declined steadily from the peak on May 24 to the end of the period. However, the export rate remained high, which resulted in the net flows for Old River and Dutch Slough to reverse and flow toward the export facilities.

FLOW DATA FOR SPRING 1997

The tidal-flow hydrograph (fig. 4) for the UVM station on the San Joaquin River at Stockton for April 1 (day 91) to May 30 (day 150), 1997, shows the occurrence of the pulse flow used to move salmon smolt through the Delta to Suisun Bay and the installation and removal of the HOR temporary barrier. The tidal flows at the Stockton station were bidirectional prior to the start of installation of the HOR temporary barrier on April 9 (day 99), but the flow became unidirectional, although tidally affected, when the barrier began reducing San Joaquin River flow from entering Old River (vertical line 1); installation of the temporary barrier was completed April 16 (day 106 - vertical line 2). The completed barrier contained two culverts that

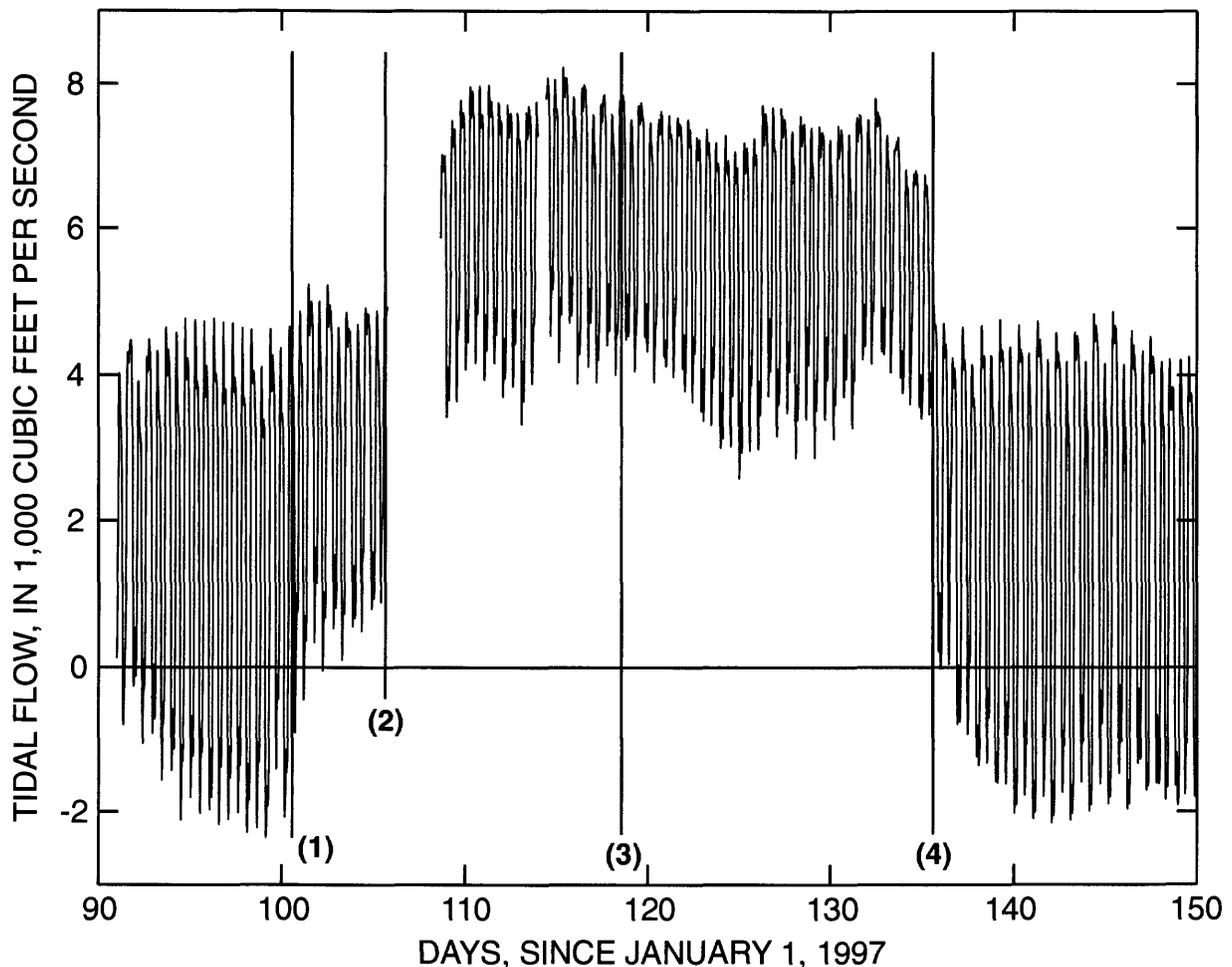


Figure 4. Tidal flow at the ultrasonic velocity meter site, San Joaquin River at Stockton, April 1 to May 30, 1997, south Sacramento-San Joaquin Delta, California. (1) Head of Old River (HOR) temporary barrier being installed, (2) Pulse flow started, (3) Dye released, (4) HOR breached and pulse flow ended.

could pass about 300 ft³/s. The pulse flow began April 15 (day 105 - vertical line 2) and continued until May 15 (day 135 - vertical line 4). The increased flow raised the magnitude of the hydrograph relative to that prior to the pulse flow, but it still was tidally affected. Bidirectional tidal flows did not occur again until after May 15 (day 135 - vertical line 4) when the HOR temporary barrier was breached and the pulse flow was terminated.

The ADCP site net-flow hydrographs on figure 2 and the daily export hydrographs for the SWP and the CVP are presented in figures 5-7 to show the affects of the HOR temporary barrier, the San Joaquin River pulse flow, and the export rate on the hydrodynamics of the Delta at the ADCP flow sites.

Net-flow hydrographs for the Grant Line Canal and Victoria Canal ADCP sites are shown in figure 5, in addition to the combined daily export rate of the SWP and CVP. The installation of the HOR temporary barrier began April 9 (day 99 - vertical line 1). Prior to the installation of the barrier and while the export rate was medium to high, the Grant Line Canal net flow was about 2,000 ft³/s westward (negative) toward the export facilities. After April 9, the export rate remained high and the net flow for Grant Line Canal approached zero because the barrier prevented the draw of San Joaquin River water from the east. The net flow for Victoria Canal also

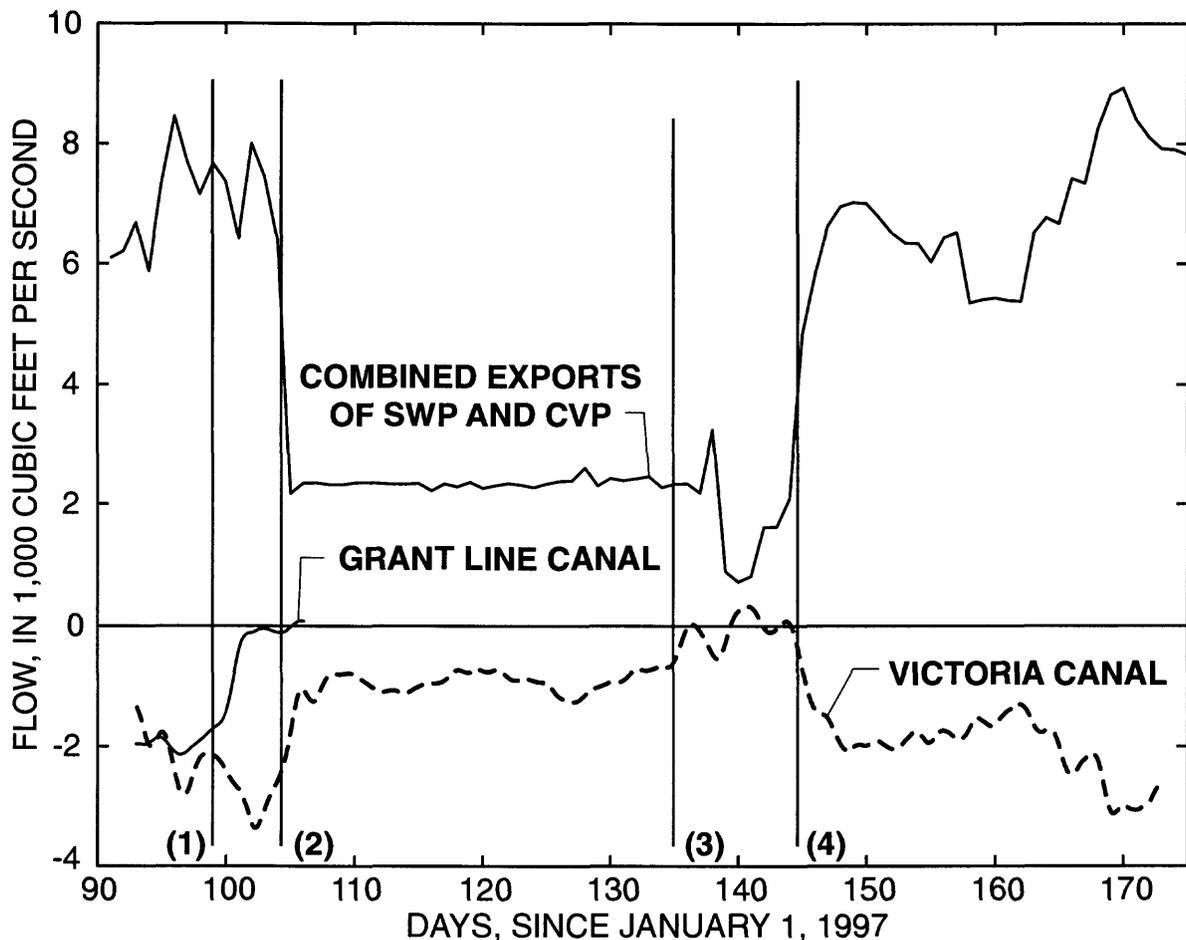


Figure 5. Net flow at acoustic Doppler current profiler sites Grant Line Canal and Victoria Canal and daily combined exports of the State Water Project (SWP) and Central Valley Project (CVP), April 1 to June 23, 1997, south Sacramento-San Joaquin Delta, California. (1) Head of Old River (HOR) temporary barrier installation began, (2) Export rate reduced, (3) HOR temporary barrier breached, (4) Export rate increased.

was about 2,000 ft³/s toward the export facilities (southwest flow is negative) prior to the installation of the HOR temporary barrier, and then increased to about 3,500 ft³/s toward the export facilities during construction of the barrier. The increased net flow through Victoria Canal resulted from the reduced flow from the San Joaquin River through Grant Line Canal to the export facilities. When the export rate was reduced on April 15 (day 105 - vertical line 2), the draw of the export facilities was reduced through Victoria Canal but still was toward the southwest. After the HOR temporary barrier was breached on May 15 (day 135 - vertical line 3), and the export rate further reduced to about 800 ft³/s (day 140), the net flow of Victoria Canal reversed direction toward the northeast until the export rate was increased near May 24 (day 144 - vertical line 4) again resulting in southwest net flows.

Figure 6 shows the net-flow for the ADCP site on Old River located just south of the intake channel to the SWP Clifton Court Forebay, and north of Grant Line Canal (fig. 1). Also shown are the SWP and CVP daily export rates. At the beginning of the period, the CVP export rate was about 4,500 ft³/s, which resulted in a net flow of about 2,000 ft³/s from the north (negative) toward the

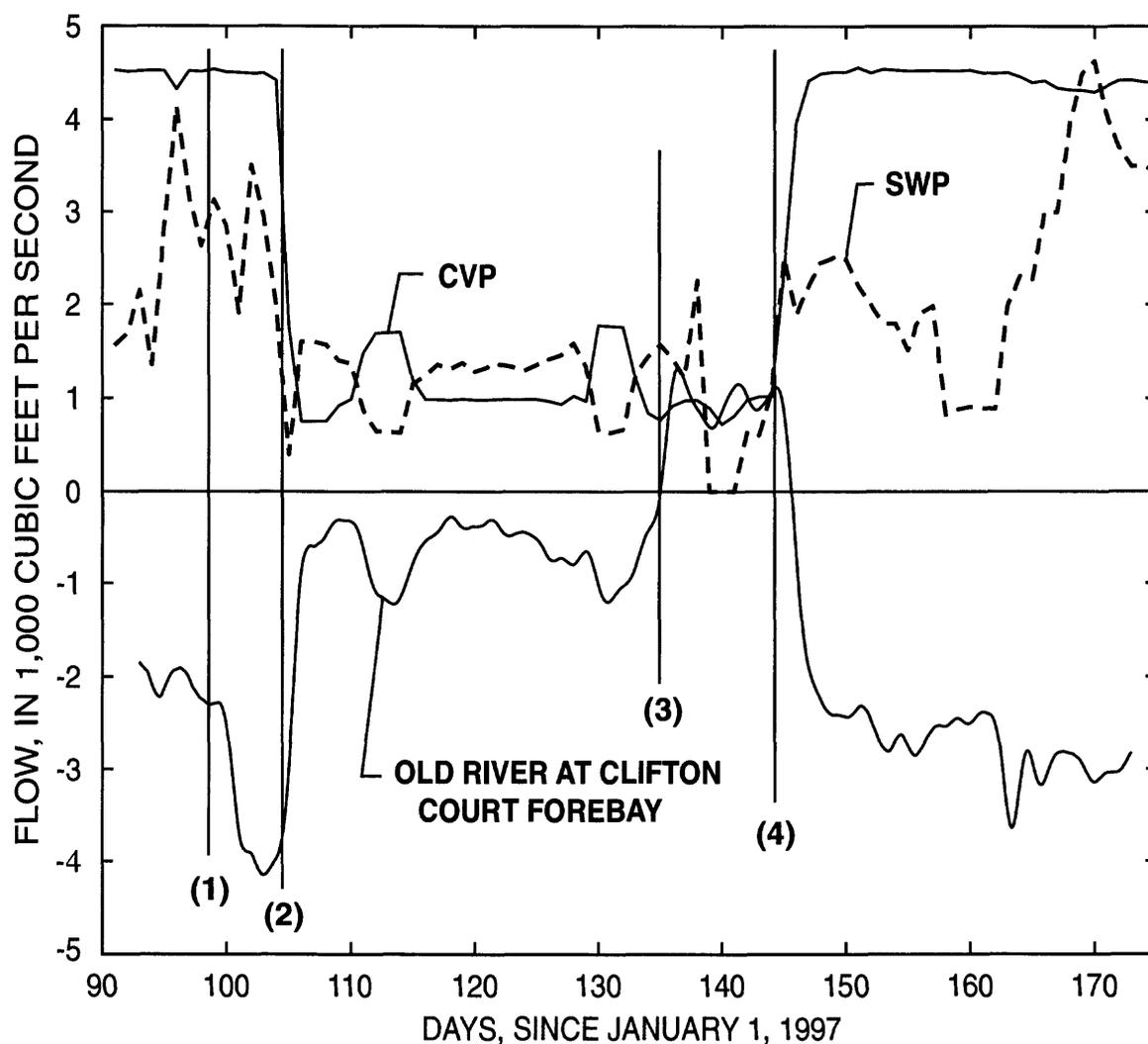


Figure 6. Net flow at acoustic Doppler current profiler sites Old River at Clifton Court Forebay and daily combined exports of the State Water Project (SWP) and Central Valley Project (CVP), April 1 to June 23, 1997, south Sacramento-San Joaquin Delta, California. (1) Head of Old River (HOR) temporary barrier installation began, (2) Export rate reduced, (3) HOR temporary barrier breached, (4) Export rate increased.

CVP export facility. Once the installation of the HOR temporary barrier began on April 9 (day 99 - vertical line 1) and the export rate remained the same, the draw of San Joaquin River water from the east through Grant Line Canal was reduced and the northward draw through Old River was increased by about 2,000 ft³/s. This 2,000 ft³/s increase corresponds with the approximate 2,000 ft³/s decrease for the Grant Line Canal shown in figure 5. After the export rate was reduced at both export facilities on April 15 (day 105 - vertical line 2), the Old River net-flow decreased but was still from the north. Note that the ADCP-generated flow hydrograph responds directly to the two small increases in the CVP export rate near days 112 and 131. After the HOR temporary barrier was breached (day 135 - vertical line 3), and until the CVP export rate was increased to 4,500 ft³/s (day 144 - vertical line 4), the net flow at the ADCP site was northward; the increase in export rate to 4,500 ft³/s resulted in net flows from the north.

The net flow for the San Joaquin River ADCP site between Turner and Columbia Cuts is shown in figure 7. The hydrograph shows an approximately 3,000 ft³/s increase in the net flow of the San Joaquin River during the April 15 (day 105) to May 15 (day 135 - vertical line 2) pulse-flow period

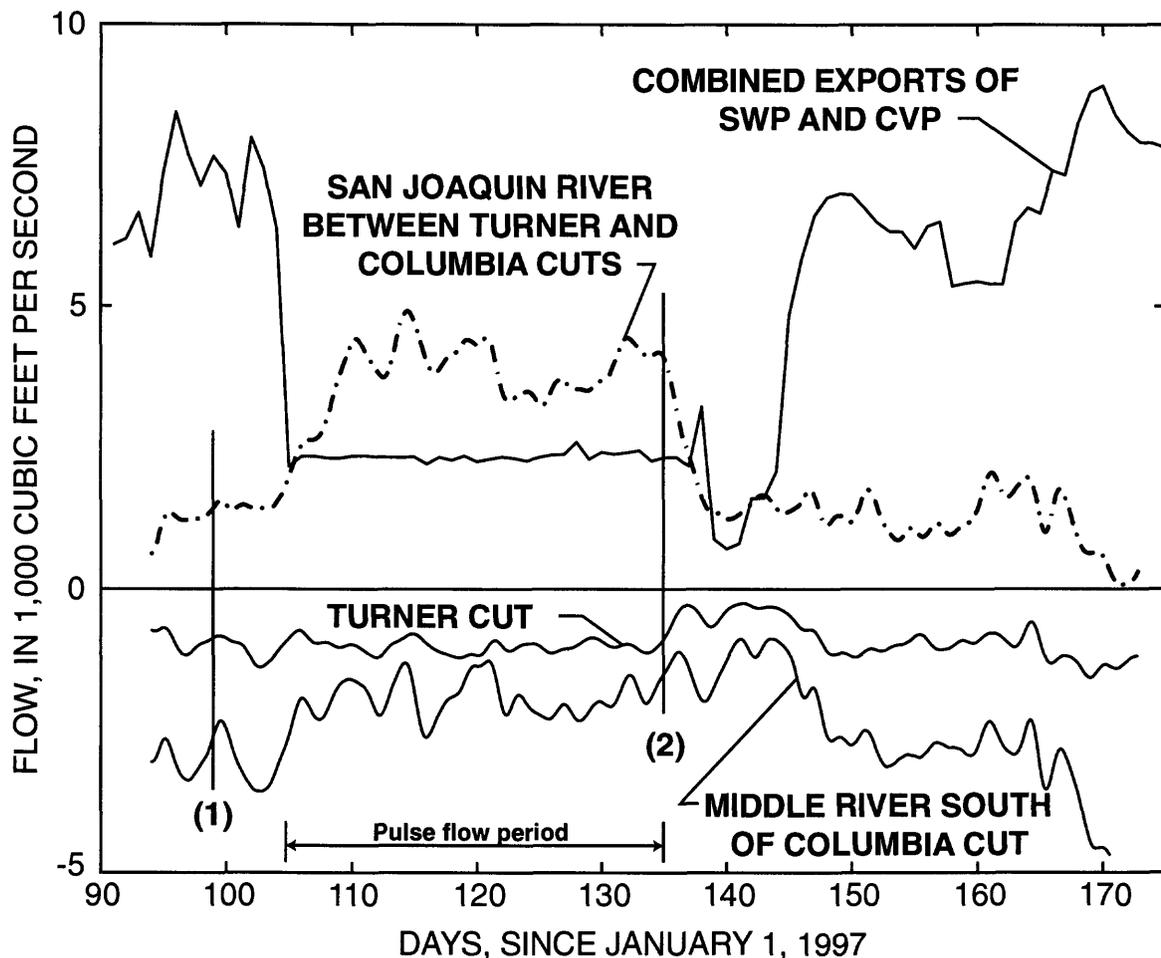


Figure 7. Net flow at acoustic Doppler current profiler sites San Joaquin River between Turner and Columbia Cuts, Turner Cut, Middle River south of Columbia Cut and daily combined exports of the State Water Project (SWP) and Central Valley Project (CVP), April 1 to June 23, 1997, south Sacramento-San Joaquin Delta, California. (1) Head of Old River (HOR) temporary barrier installation began, (2) HOR temporary barrier breached.

(northward is positive). It is unknown how the 3,000 ft³/s increase in net flow affects the movement of salmon smolts northward, relative to the 20,000- to 23,000-ft³/s tidal flows (fig. 2). Figure 7 also shows net flow for the Turner Cut and Middle River south of Columbia Cut ADCP sites. The hydrographs show that the net-flow direction for the two sites was to the southwest (negative) for Turner Cut and south (negative) for Middle River, both flowing toward the export facilities for the entire ADCP data-collection period. The two ADCP-flow hydrographs also show an increase in flow toward the export facilities after the installation of the HOR temporary barrier began (day 99 - vertical line 1) as shown for Victoria Canal (fig. 5) and Old River at Clifton Court Forebay (fig. 6). When the export rate was reduced during the pulse-flow period (days 105 - 135), the Middle River net flow toward the export facilities was reduced, however, the Turner Cut net flows do not seem to have been affected. The San Joaquin River pulse flow does not seem to have affected the net flows of Middle River or Turner Cut. However, when the HOR temporary barrier was breached on May 15 (day 135 - vertical line 2) and the export rate was reduced to about 800 ft³/s (day 140), the Middle River and Turner Cut net flows still were toward the export facilities, but at a reduced rate. When the export rate increased near day 145, the net-flow increase toward the export facilities was greater for Middle River than for Turner Cut. It is not understood what is causing the apparent dampening of the net flow in Turner Cut, but it may result from the tidal filling and draining of Whiskey Slough, which is a 4-mile dead-end slough that is connected to Turner Cut about 2 miles southwest of the ADCP site.

TRACER-DYE CONCENTRATION DATA FOR 1997

On April 28, 1997, 12.7 gallons of a nontoxic tracer dye (rhodamine WT) were poured into the San Joaquin River at Mossdale (fig. 1) 1 hour prior to the release of 50,000 coded-wire tagged salmon smolts by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Game (CFG). The purpose of the dye release was to track the movement through the Delta of the water mass into which the salmon smolts were released. The dye movement was tracked using automatic samplers that were programmed to collect water samples hourly at the nine dye stations shown in figure 8. The samples were retrieved daily and transported to the laboratory to be processed with a fluorometer to determine the dye concentration.

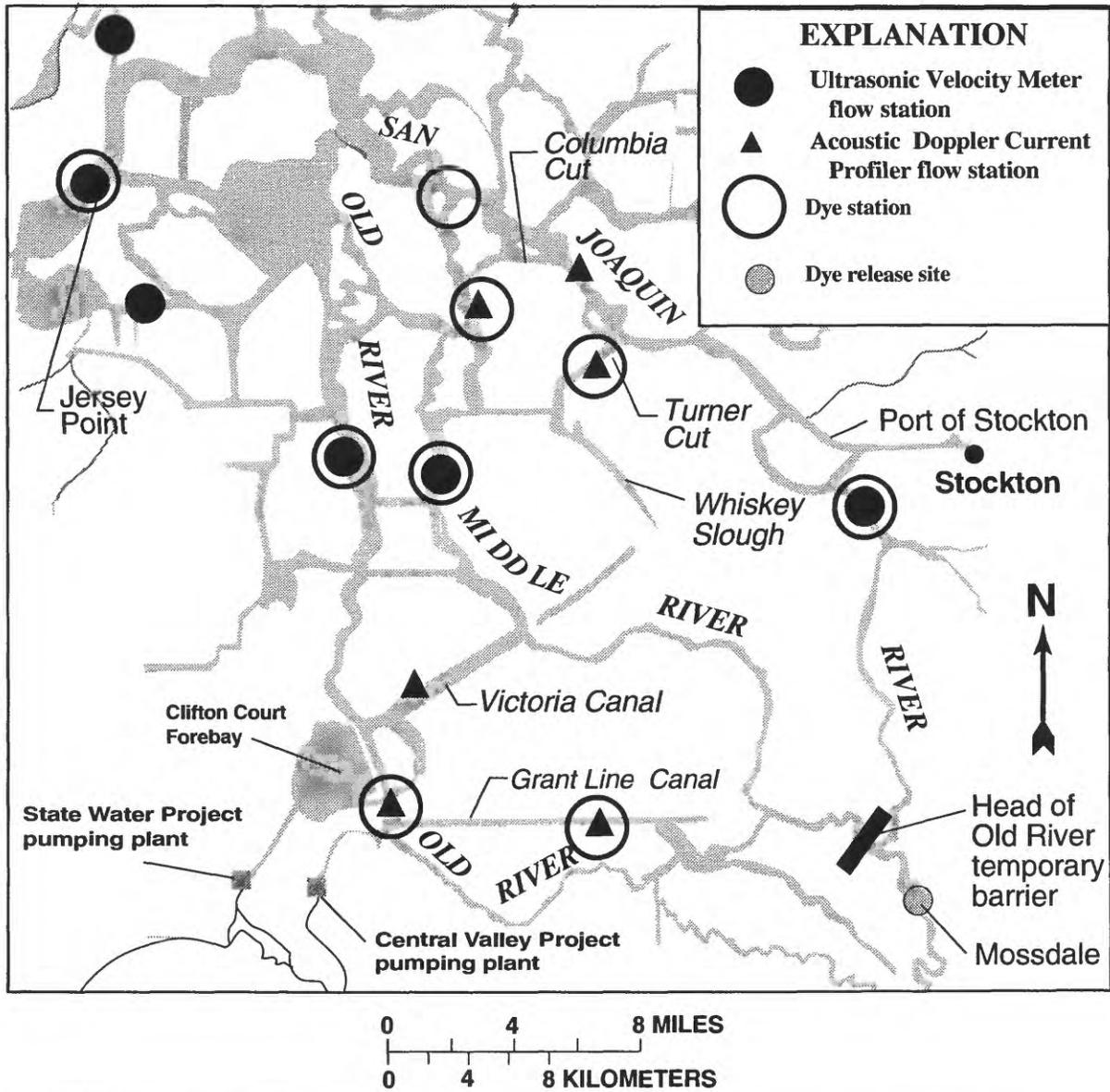


Figure 8. Flow and tracer-dye monitoring sites, 1997, south Sacramento-San Joaquin Delta, California.

The dye was released during the pulse-flow period at noon on April 28 (fig. 4, vertical line 3). The dye traveled the 13 miles from Mossdale to the San Joaquin River at Stockton UVM sampling site in about 10 hours, which equates to a mean velocity of 1.9 feet per second (ft/sec). The dye-concentration and tidal-flow hydrographs for the Stockton site are shown in figure 9. The dye-concentration hydrograph shows a peak of 10.5 $\mu\text{g/L}$ and that it took about 4 hours for the dye to pass the sampling site. The flow hydrograph shows that the flow was tidally affected, but unidirectional.

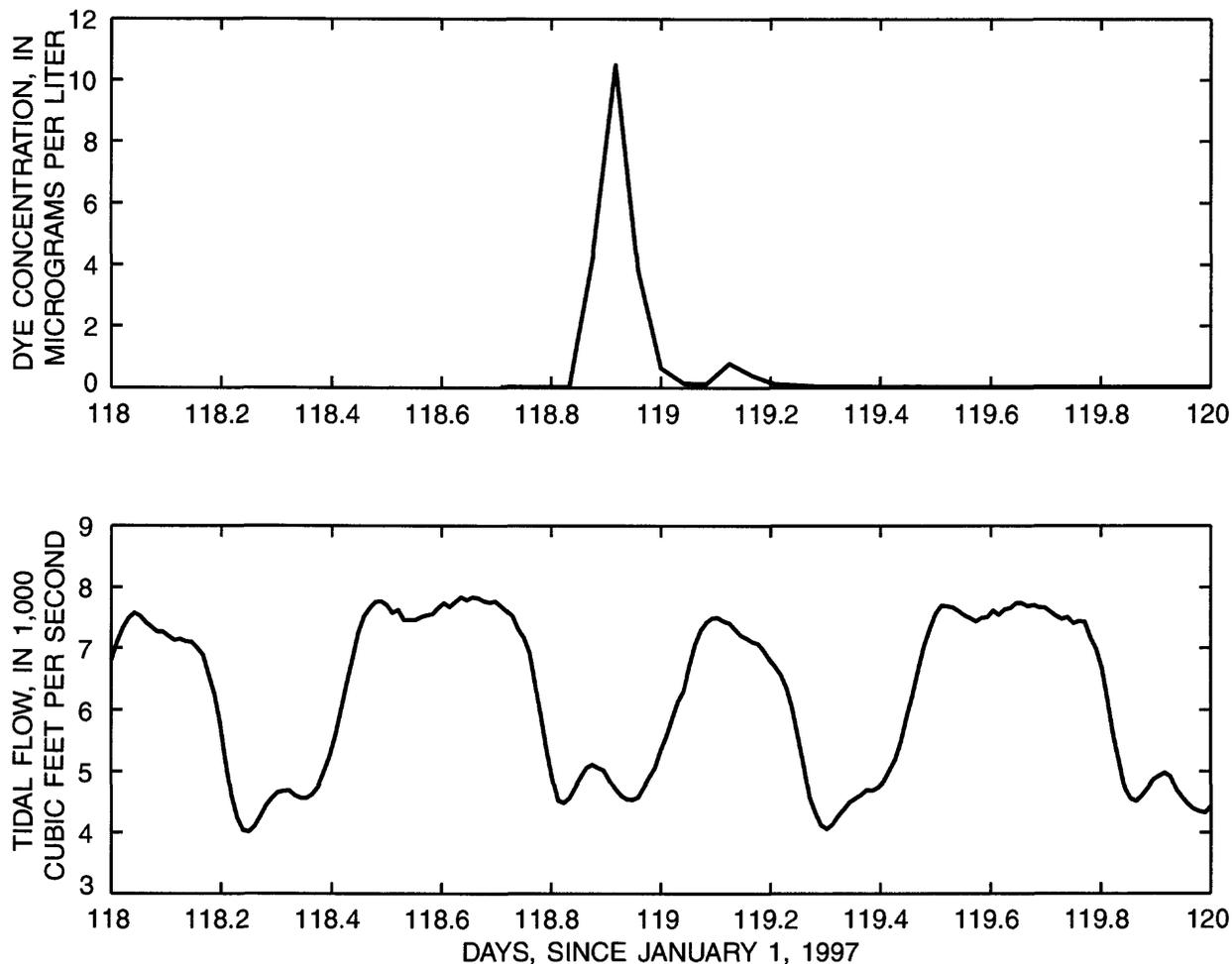


Figure 9. Tracer-dye concentration and tidal flow at San Joaquin River at Stockton, April 28, 29, 1997, south Sacramento-San Joaquin Delta, California.

The next dye sampling site was Turner Cut (fig. 8), which is about 10 miles downstream from the Stockton UVM site; the travel time for the dye to Turner Cut was about 25 hours, equating to a mean velocity of 0.6 ft/sec. The decrease in mean velocity was due to the dye being subjected to bidirectional tidal flows about 2 miles downstream of the Stockton UVM site when it reached the Port of Stockton; the San Joaquin River is much wider and deeper at the Port compared with the relatively narrow and shallow channel at, and upstream of, the UVM station. The peak dye concentration recorded at the Turner Cut site was 0.8 $\mu\text{g/L}$, which was considerably lower than the 10.5 $\mu\text{g/L}$ peak recorded at Stockton. Figure 10 shows that the dye first entered Turner Cut during the southwest (negative) flows of April 29 (day 119 - vertical line 1), and that most of the dye arrived on the subsequent southwest flow on the next day (day 120 - vertical line 2). The plot shows that the dye was transported back and forth with the tidal flows for several days before completely passing the site.

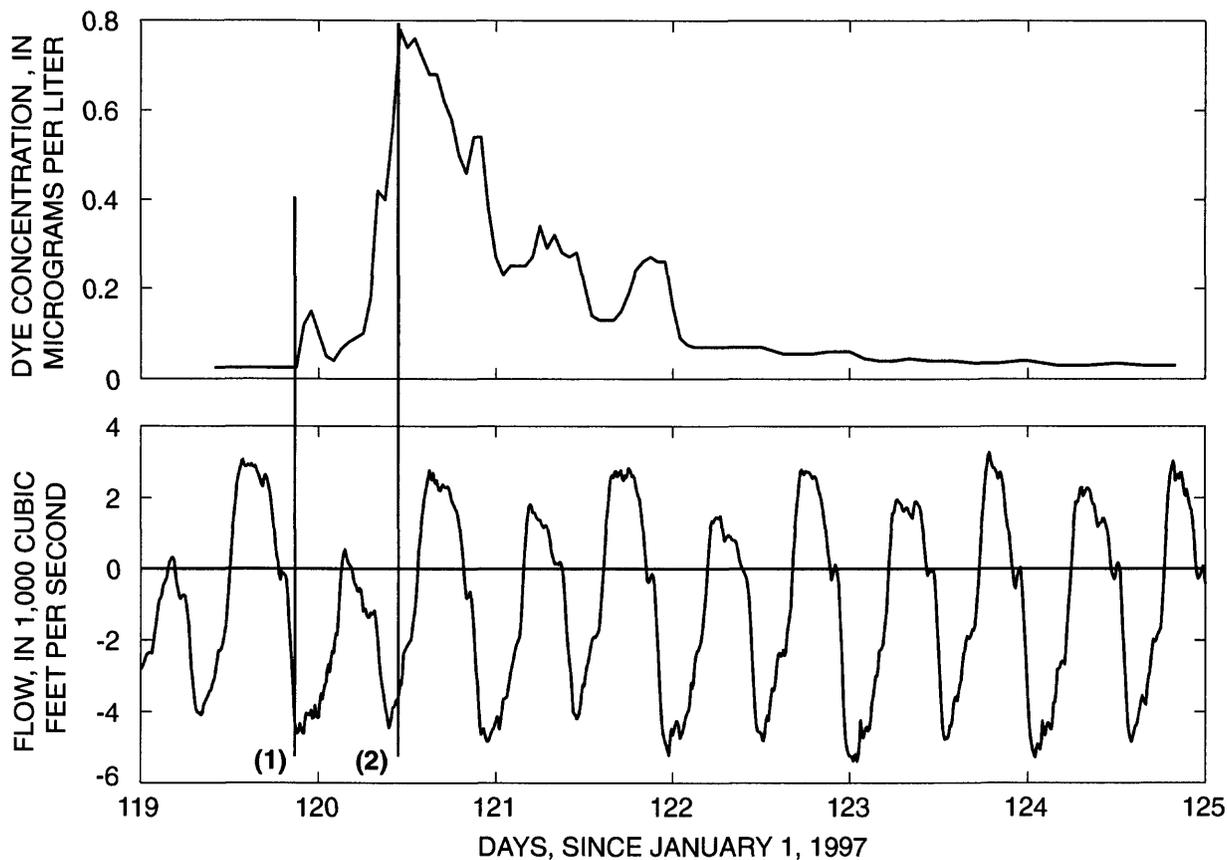


Figure 10. Tracer-dye concentration and tidal flow at Turner Cut, April 29 to May 4, 1997, south Sacramento-San Joaquin Delta, California. (1) Dye first arrives, (2) Peak concentration.

Dye-concentration hydrographs for sampling sites farther downstream are shown in figure 11 and include the San Joaquin River at Middle River, and the Middle River ADCP site south of Columbia Cut (fig. 8). The Turner Cut dye-concentration hydrograph shown on figure 10 also is shown for comparison. The hydrographs in figure 11 show that dispersion attenuated the peak dye-concentration and broadened the base of the dye-concentration graph as the dye moved through the Delta. Dye was detected at the Old and Middle River UVM sites, but at concentrations slightly above background concentrations of about 0.04 $\mu\text{g/L}$ (data not shown); it was uncertain whether dye was detected at the San Joaquin River at Jersey Point UVM site. Low concentrations of dye were detected at the Grant Line Canal sampling site, which indicates that some of the dye passed through the culverts in the HOR temporary barrier and(or) the rock barrier.

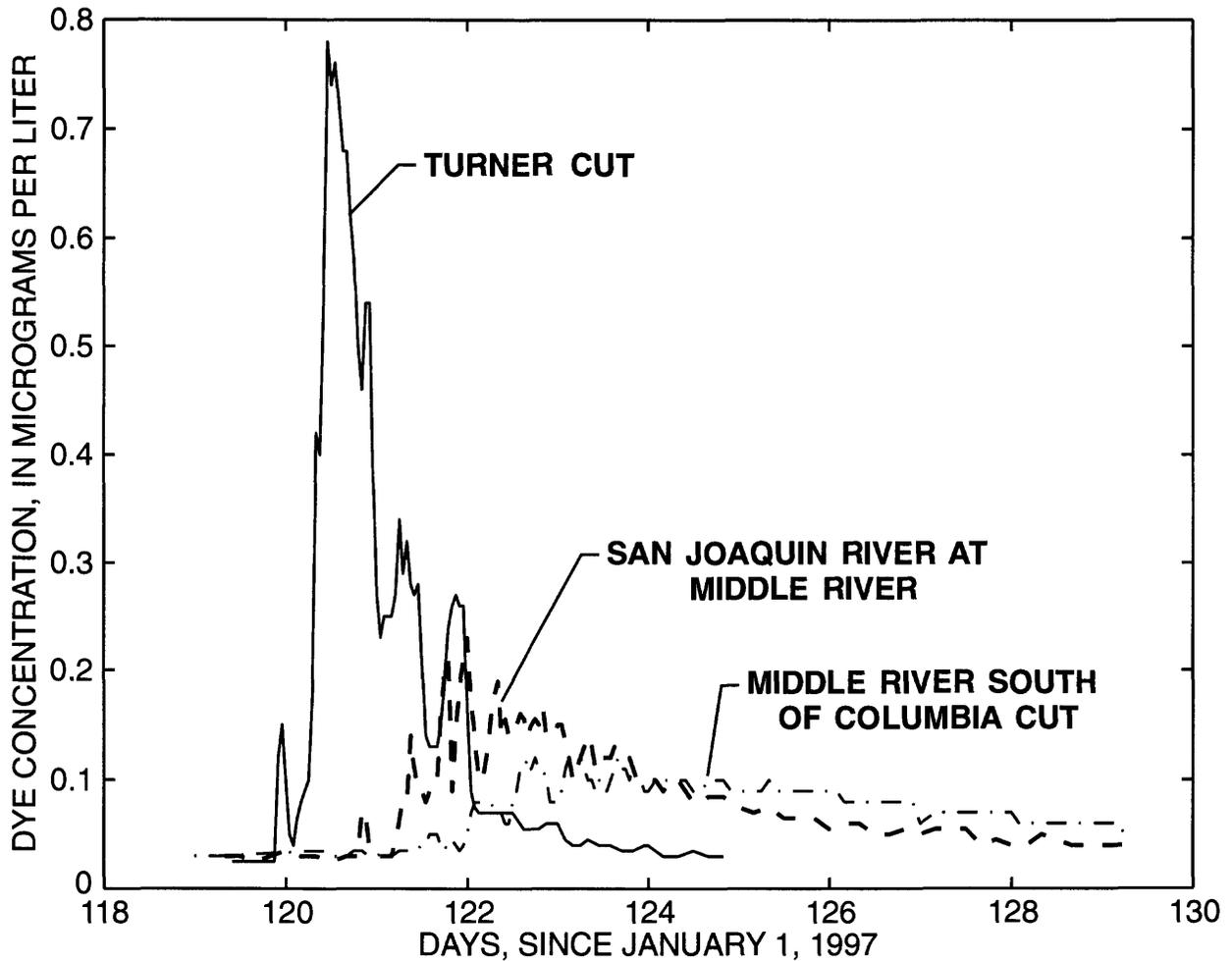


Figure 11. Tracer-dye concentration at Turner Cut, San Joaquin River at Middle River, and Middle River south of Columbia Cut, April 29 to May 9, 1997, south Sacramento-San Joaquin Delta, California.

COLLECTION OF FLOW AND DYE-CONCENTRATION DATA FOR SPRING 1998

The flow of the San Joaquin River during the spring of 1998 was too high (16,000 to 25,000 ft³/s) for the installation of the HOR temporary barrier. However, salmon smolt release and recapture studies were done by USFWS and CFG and the USGS conducted another tracer-dye study on April 16, 1998, in conjunction with the release of salmon smolts at Mossdale. In addition to the UVM network flows, ADCPs again were deployed in the south Delta to provide additional flow time-series data. The ADCPs were deployed on April 1, 1998, at the same locations as for 1997; the ADCPs are scheduled to be retrieved at the end of June 1998. The data were not available for presentation at the time of the preparation of this report.

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