Suisun Marsh Salinity Control Gates
Salmon Passage Evaluation Report
2001

Department of Water Resources
and
Department of Fish and Game

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List of Preparers

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2001 Velocity Study Report ……………………………………………..Callie Harrison DWR

Chinook Salmon Swimming Ability and Water Velocities through the SMSCG Open Boat Lock…………………………………………………………………..…Jim Long DWR

Report on Continuous Water Quality Data, September to October 2001 Suisun Marsh Salinity Control Gate Stations S-64 & S-71……………………………………….. Phil Giovannini DWR

Adult Salmon Migration Monitoring, Suisun Marsh Salinity Control Gates, September – November 2001

Introduction

From September 24 – November 1, 2001, as a continuation of telemetry studies started in 1993 (Tillman *et al* 1996; Edwards *et al* 1996), adult chinook salmon were monitored during their upstream migration for percent passage and passage time through the Salinity Control Gates located across Montezuma Slough in the Suisun Marsh.

Underwater biotelemetry is commonly used for studies of fish migration, orientation, mechanisms, and movement patterns at obstructions (Stasko and Pincock 1977). Salmon were tagged with internal sonic tags coded with a unique pulse interval and frequency to identify individual fish. The signals were picked up by stationary monitoring sites consisting of a hydrophone, receiver, and palmtop computer to detect the location of tagged fish. Monitoring sites were located upstream, downstream, and on the Salinity Control Gates (Figure 1). Mobile monitoring using a boat mounted hydrophone and portable receiver was conducted in both Montezuma Slough and the Sacramento and San Joaquin Rivers.

Adult fall-run salmon were captured using a large mesh gill net, tagged and released downstream of the Salinity Control Gates. The gates were studied during three different operational configurations (phases) including flashboards in or out, gates up or operating, and boat lock open or closed (Figure 2). Sixty-six tagged salmon were released at the beginning of each 2-week operational phase and monitored for their passage rate and passage time through the Salinity Control Gates. Mobile monitoring was used to track fish movement in Montezuma Slough and find fish that may have died during tagging.

Previous studies have focused on modifying the flashboard structure to allow passage of migrating salmon during full-bore operations (DWR 1977). The 2001 study focused on the possible use of the existing boat lock as a fish passage structure for upstream migrating adult chinook salmon.

Results

During the 6-week time period of the study, covering all three operational phases of the Salinity Control Gates, 198 adult salmon were tagged and released downstream of the gates. A total of 118 tagged salmon passed through the gates, with the largest percentage passing during the boat lock open phase, although it was not a statistically significant number (Figure 3). Fifty-eight tagged salmon moved back downstream, and 22 were removed from the sample population due to non-detection or having died after tagging (Several fish were subsequently found by mobile monitoring in the Sacramento and San Joaquin Rivers after non-detection at the gates). Tagged fish ranged in size from 600 – 1070 mm fork length and were evenly distributed between male and female (Table 1). One hundred and twelve fish were tagged during daylight and 86 tagged at night. The average time for fish passage ranged from 15.3 – 47.4 hours (Figure 4). Passage times were analyzed using an Analysis of Variance and a Tukey Post Hoc test for comparison of probabilities. There was not a statistical difference in passage times between the full open and full operation, boat lock open, configurations ($P>0.05$). There was a significant difference between the full open and full operation boat lock closed configurations ($P < 0.05$).

Phase I

During Phase I operation of the Control Gates, the flashboards were out, gates up, and boat lock closed. This configuration ran from September 24 – October 7. A total of 66 adult chinook salmon were tagged between September 24 – 26 and released near the Grizzly Bay boat ramp, approximately 1.5 miles downstream from the Salinity Control Gates. Thirty-eight tagged fish (58%) were recorded passing the gates, and of these, 10 went back downstream. Twenty-two tagged fish turned back downstream without approaching the gates and 6 were removed from the population: 5 were recorded at the upstream site only and 1 was found dead near the boat launch ramp. The fish ranged from 600 – 970 mm fork length, with 43 females, 22 males, and 1 unsexed. The average time for the fish to move past the gates was 15.3 hours.

Phase II

During Phase II operation of the Control Gates, the flashboards were in, gates tidally operated, and boat lock open (mitigation configuration). This configuration ran from October 8 – 21. Of the 66 adult chinook salmon tagged October 9 – 11, forty-four (67%) were recorded passing the gates with 7 going back downstream. Thirteen tagged fish turned back downstream without approaching the gates and 9 were removed from the population: 8 had no records at all and 1 was recorded at the upstream site only. The fish ranged from 600 – 1010 mm fork length, with 25 females, 35 males and 6 unsexed. The average time for the fish to move past the gates was 25.5 hours.

Phase III

During Phase III operation of the Control Gates, the flashboards were in, gates tidally operated, and boat lock closed. This configuration ran from October 22 – November 2. Of the 66 adult chinook salmon tagged October 22 – 23, thirty-six (55%) were recorded passing the gates with 5 going back downstream. Twenty-three tagged fish turned back downstream without approaching the gates and 7 were removed from the population: 3 had no records, 3 were recorded at the upstream site only, and 1 was found dead by the mobile monitoring crew. The fish ranged from 610 – 1070 mm fork length, with 24 females, 40 males, and 2 unsexed. The average time for the fish to move past the gates was 47.4 hours.

Salmon Usage of the Boat Lock

During the Phase II configuration (flashboards in, gates operating and boat lock open), of the 44 tagged salmon to pass the gates 14 (32%) were recorded moving through the boat lock (Figure 5). The average time spent in the boat lock was 13 minutes. Tagged fish passed through the boat lock equally during flood and ebb tides.

Mobile Monitoring

Mobile monitoring tracked 57 individual tagged salmon in Montezuma Slough October 1 – November 1. Of these, 27 passed through the Salinity Control Gates and returned downstream, 26 did not pass the gates and went downstream, 1 was found dead by the boat launch ramp, and 3 were never recorded after tagging.

Discussion

The Phase II configuration (flashboards in, gates tidally operated, boat lock open) had the highest percentage of fish passage, although it wasn't statistically significant. During this configuration, passage through the boat lock was available to migrating salmon 24 hours a day for the entire 2-week period of October 8 – 21, except when operated to pass boats. Passage through the radial gates was available only 12 hours a day due to tidal operation, which closes the gates for a 6-hour period twice daily. The boat lock represented 7% of the available area for passage compared to 93% for the radial gates. While not significant when compared to the other configurations, fish were using the boat lock for passage, even when a larger area was available through the radial gates. Of more importance is the difference in passage times between the 3 operational configurations of the gates (Figure 6). The passage rate for the full open and the full operation with boat lock open configurations were not statistically different ($P > 0.05$). This would imply that the fish could move through the boat lock configuration as easily as if there were no structure there.

Mobile monitoring showed a tendency for some migrating salmon to hold or exhibit milling behavior in Montezuma Slough. Similar behavior was observed in tagged fish leaving Montezuma Slough and entering the Sacramento and San Joaquin Delta. Crews conducting concurrent studies of tagged salmon using the same equipment tracked the tagged fish moving within the delta. Although this tracking shows some salmon do not migrate straight up to their spawning grounds, we cannot judge the effect that any delay may have on survival or spawning success. The study at the Salinity Control Gates is important in determining and hopefully alleviating any delays in upstream migration for adult salmon already facing several impediments to migration and spawning including barriers, water quality, predators, or loss of habitat. The results of the 2001 study, investigating the feasibility of the boat lock for fish passage, look promising, and the study will be repeated in 2002 and 2003 to see if similar results occur in all three years.

If leaving the boat lock open improves salmon passage at the Salinity Control Gates, this information could be useful at other structures such as the Delta Cross Channel where radial gates are also used to control flows.

References

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Edwards, G.W., K.A.F. Urquhart, and T.L. Tillman. 1996. *Adult salmon migration monitoring, Suisun Marsh Salinity Control Gates, September – November 1994.* Technical Report 50, Interagency Ecological Program for the San Francisco Bay/Delta Estuary. 27pp.

Stasko, A.B., and D.G. Pincock. 1977. Review of underwater biotelemetry, with emphasis on ultrasonic techniques. J. Fish. Res. Board Can. 34: 1261-1285.

Tillman, T.L., G.W. Edwards, and K.A.F. Urquhart. 1996. *Adult salmon migration during the various operational phases of the Suisun Marsh Salinity Control Gates in Montezuma Slough, August-October 1993.* Agreement to the Department of Water Resources, Ecological Services Office by Department of Fish and Game; Bay-Delta and Special Water Projects Division. 25 pp.

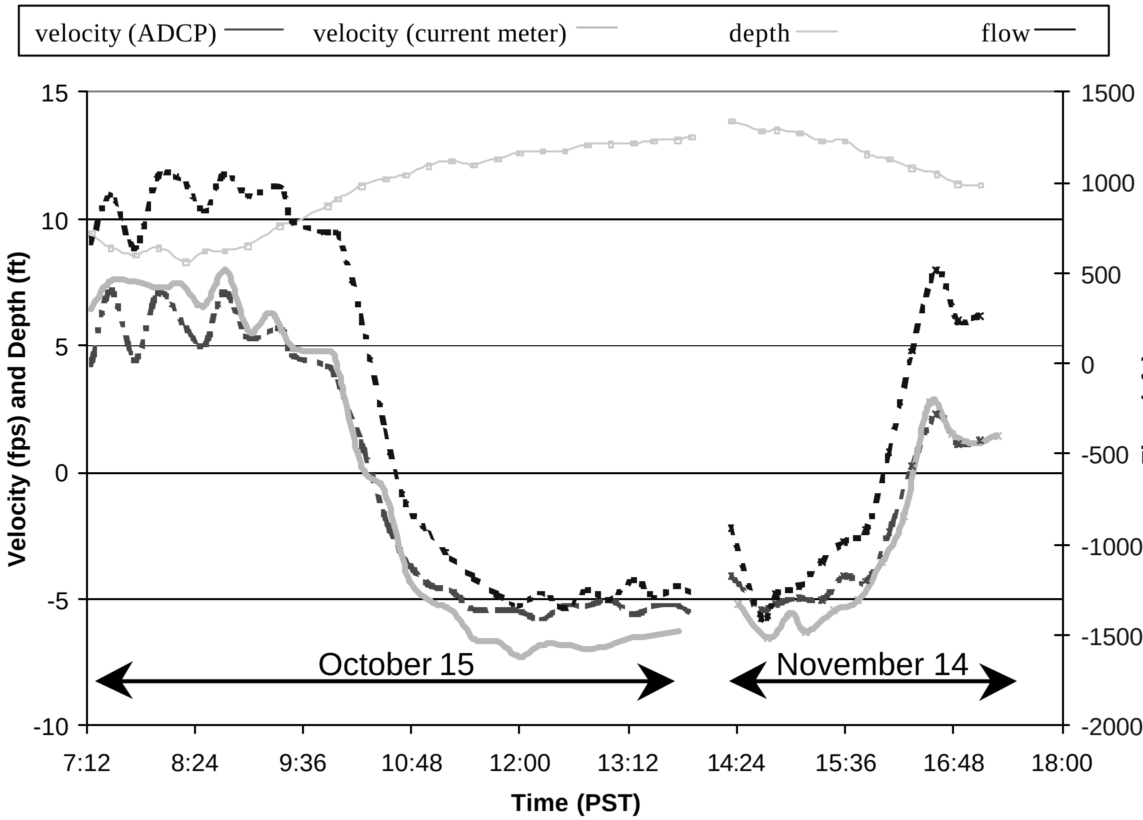

Figure 3. Average transect flow, velocity, and depth (note that flow is plotted on the right side y-axis).

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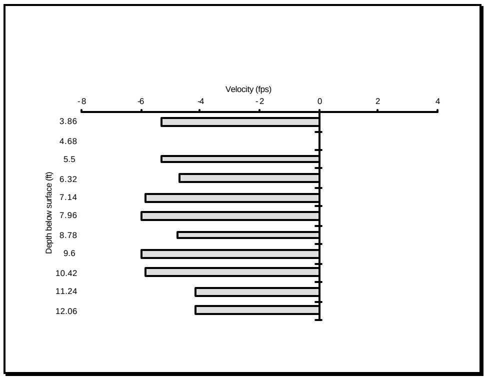

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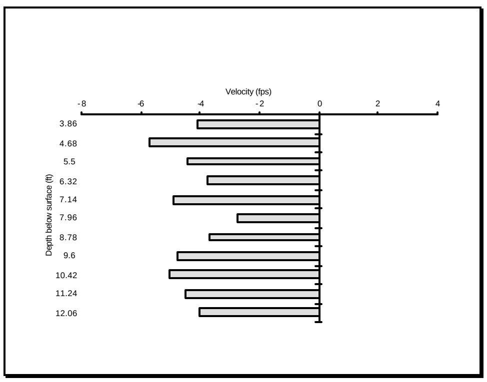

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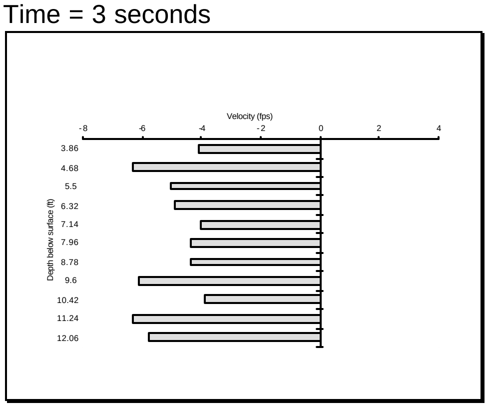

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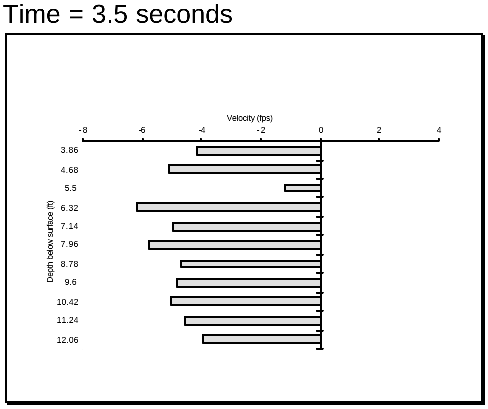

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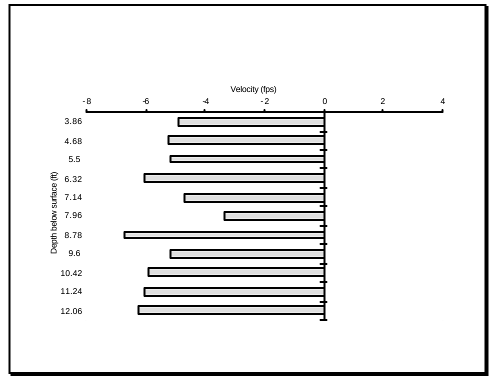

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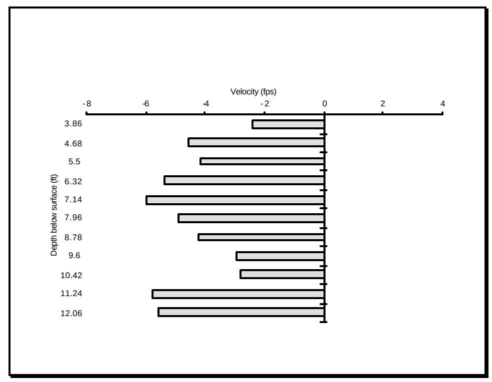

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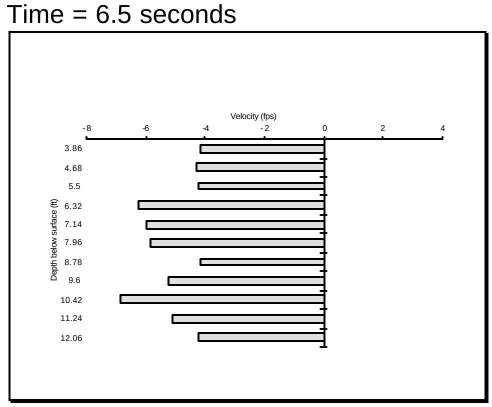

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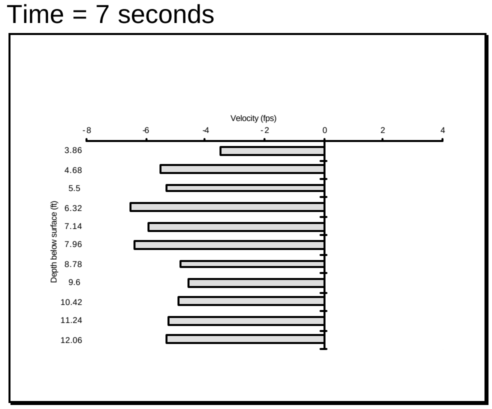

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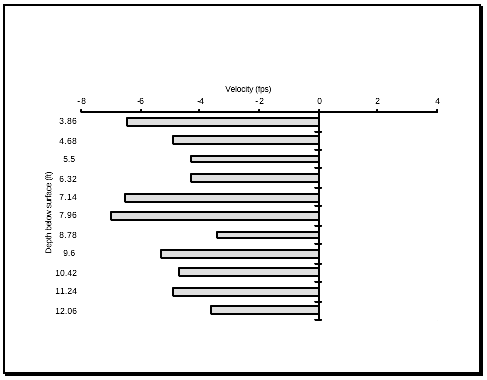

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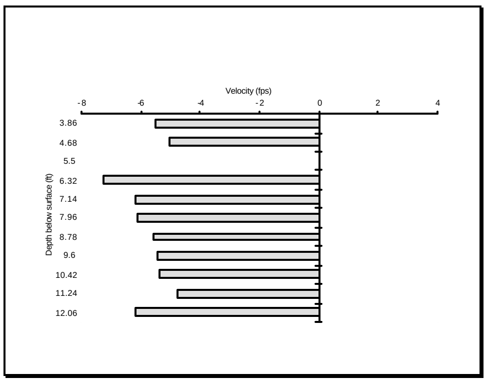

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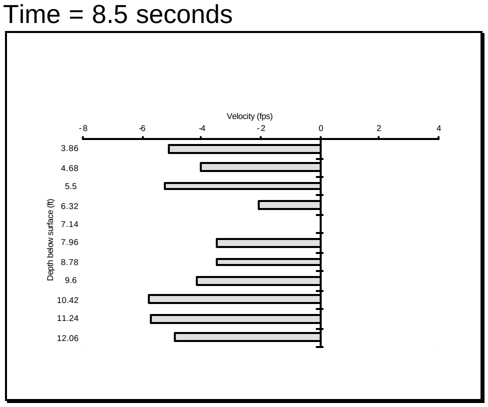

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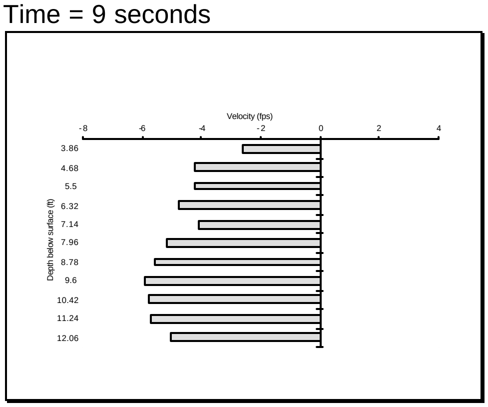

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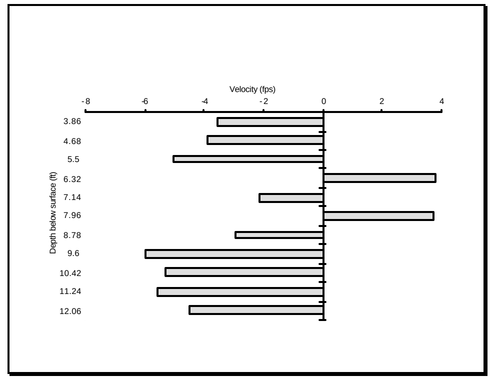

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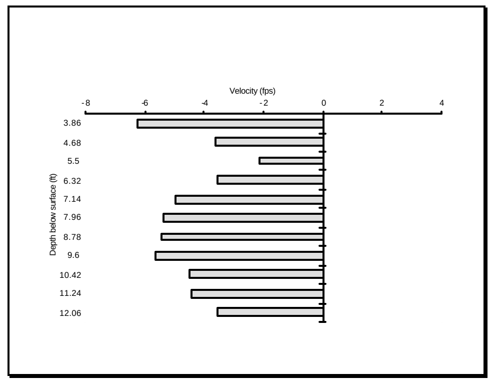

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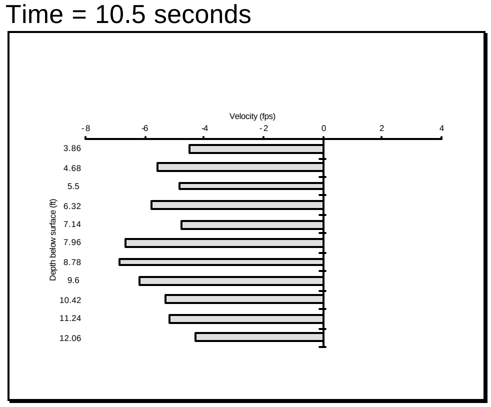

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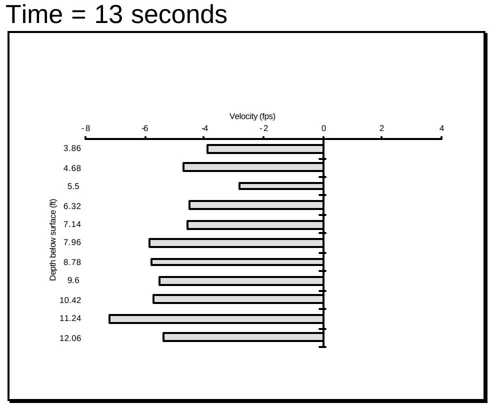

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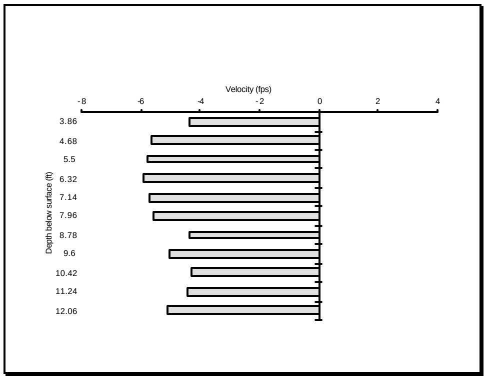

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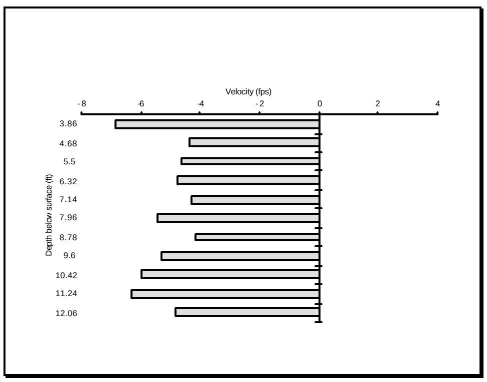

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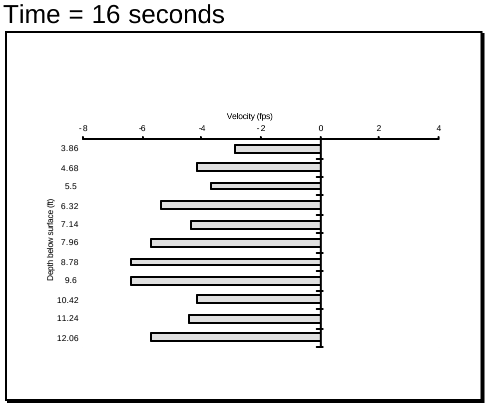

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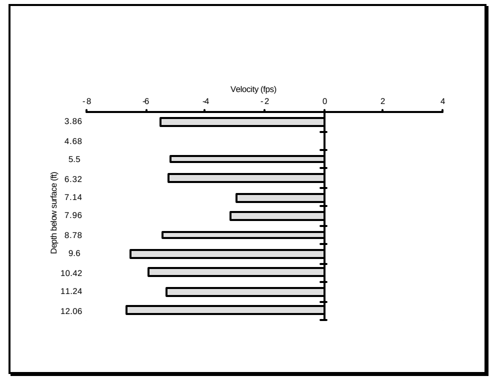

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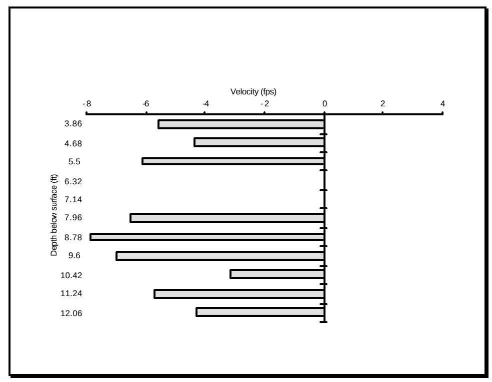


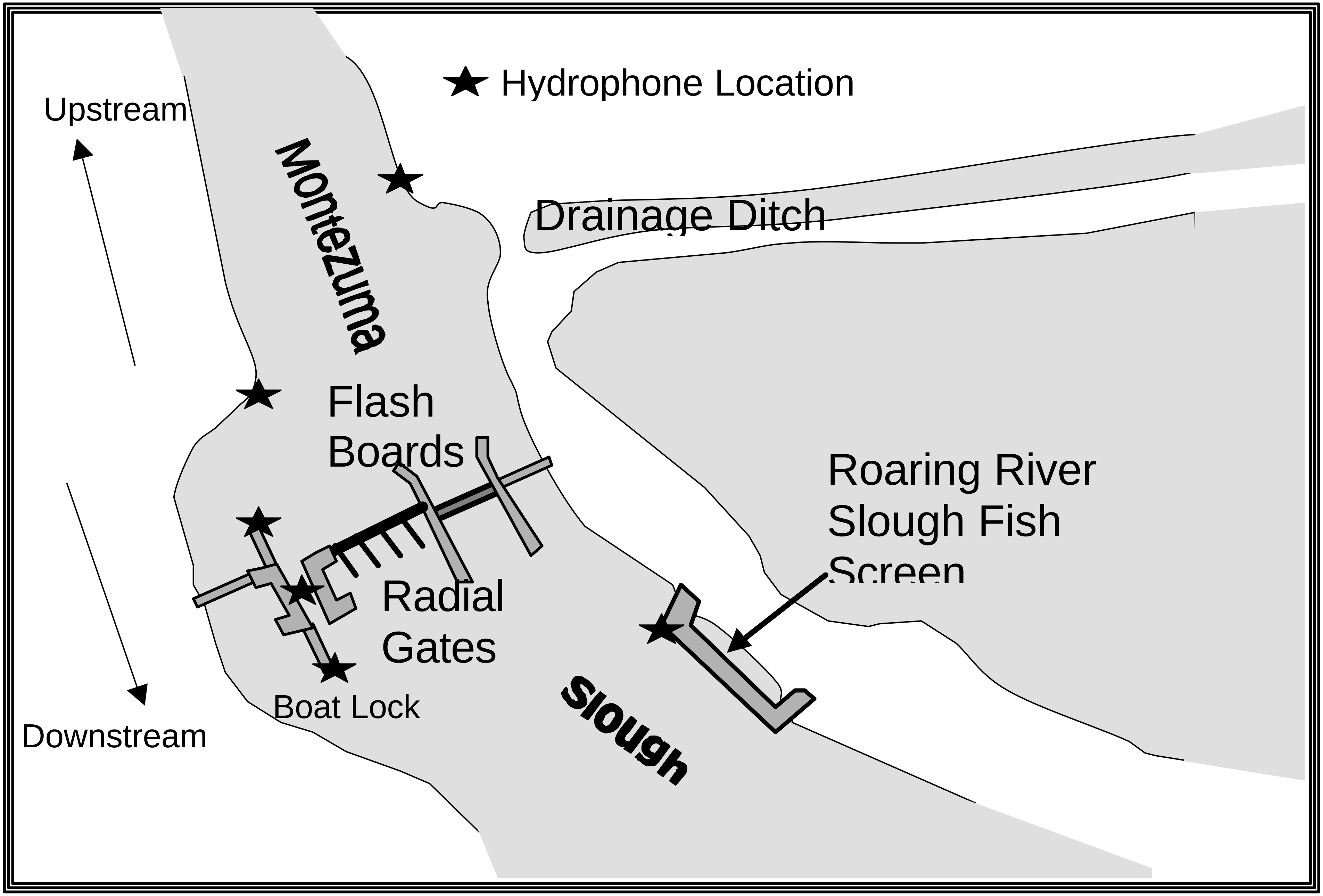


Figure 1. Hydro Phone Locations at the Salinity Control Gates, Sept – Nov, 2001

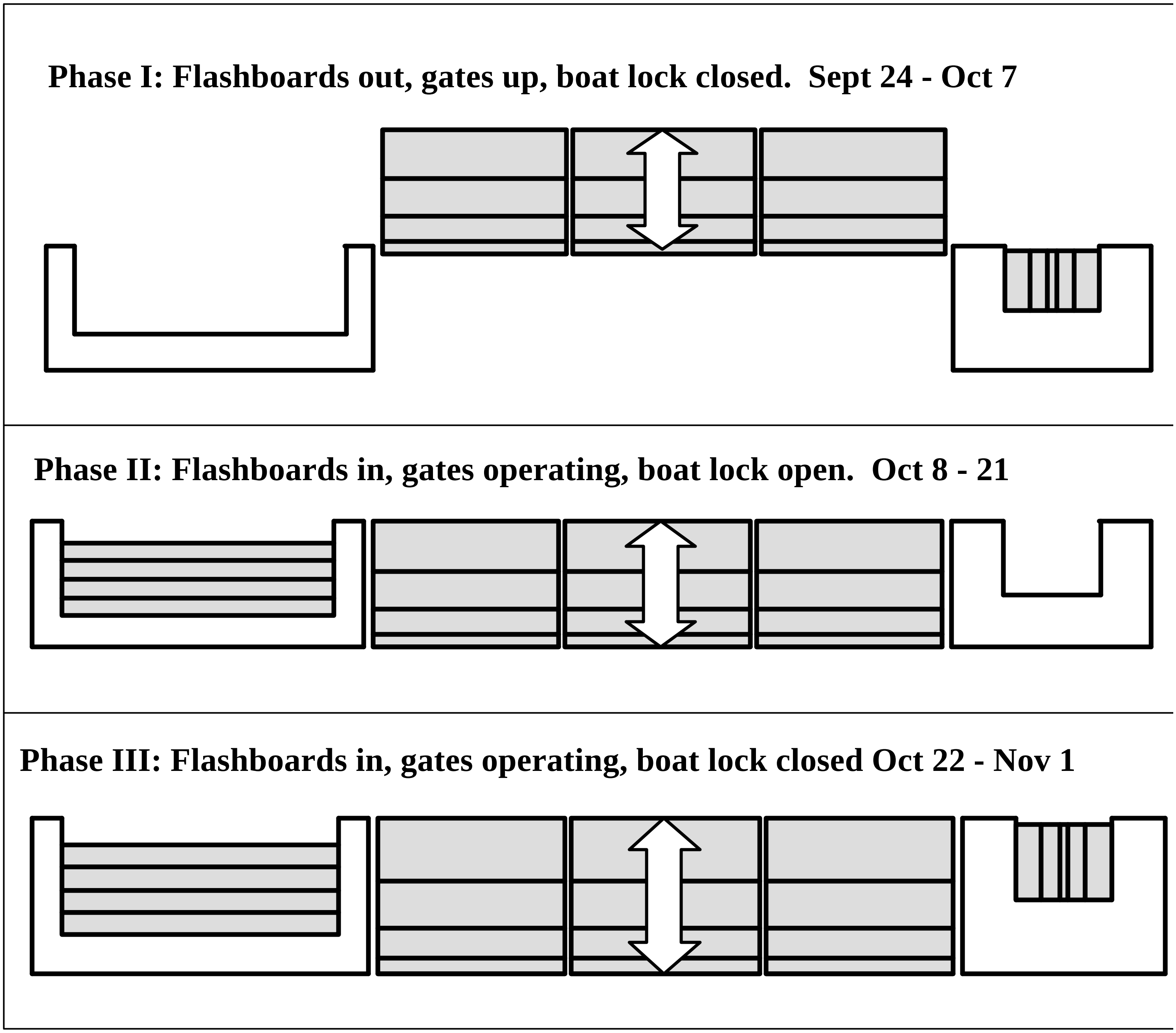


Figure 2. The 3 Operational Phases of the Salinity Control Gates for Sept – Nov 2001

Table 1
Adult Chinook Salmon Tagged During
September 24 – November 1

Date Tagged	Operational Phase	Number Tagged	Sex	
Sept 24 – 26	I	66	M	22
			F	43
			Unknown	1
Oct 9 – 11	II	66	M	35
			F	25
			Unknown	6
Oct 22 – 23	III	66	M	40
			F	24
			Unknown	2

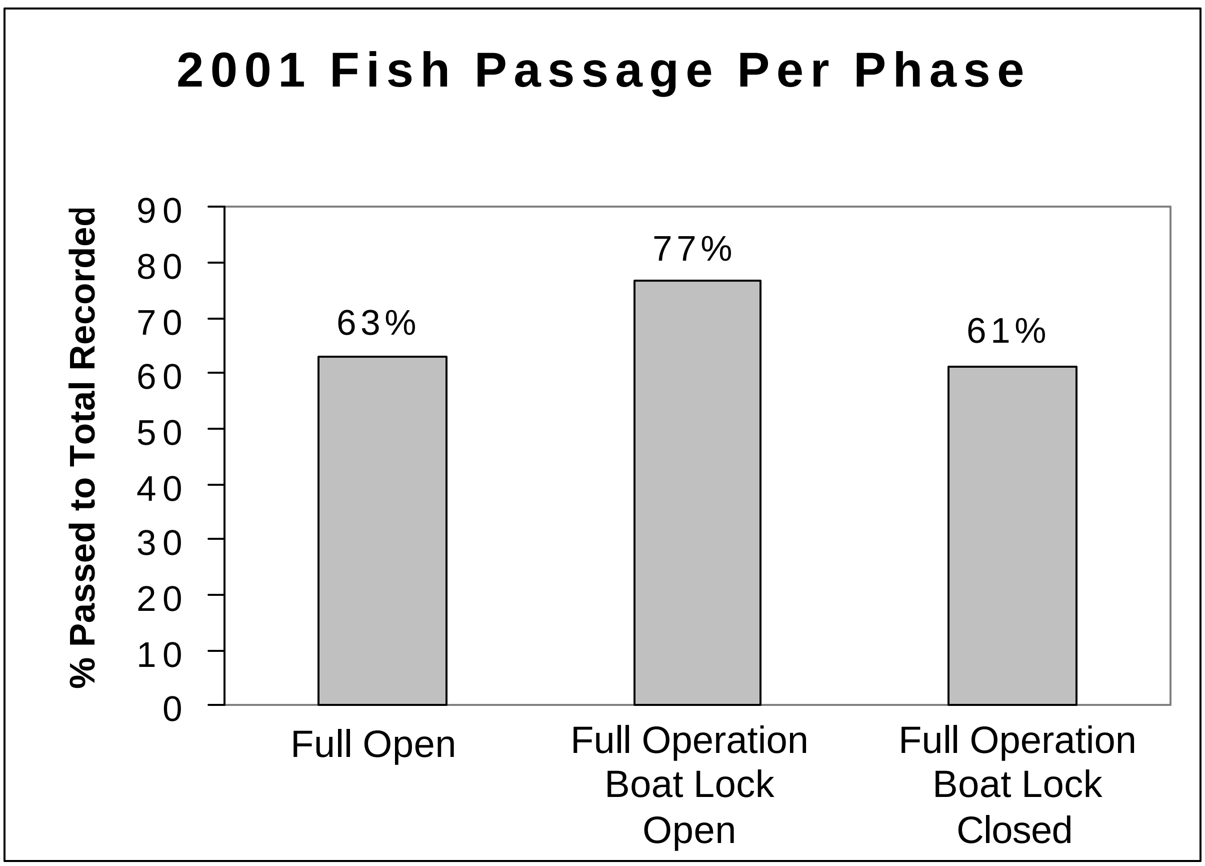


Figure 3. Fish Passage by Phase at the Salinity Control Gates, Sept – Oct 2001

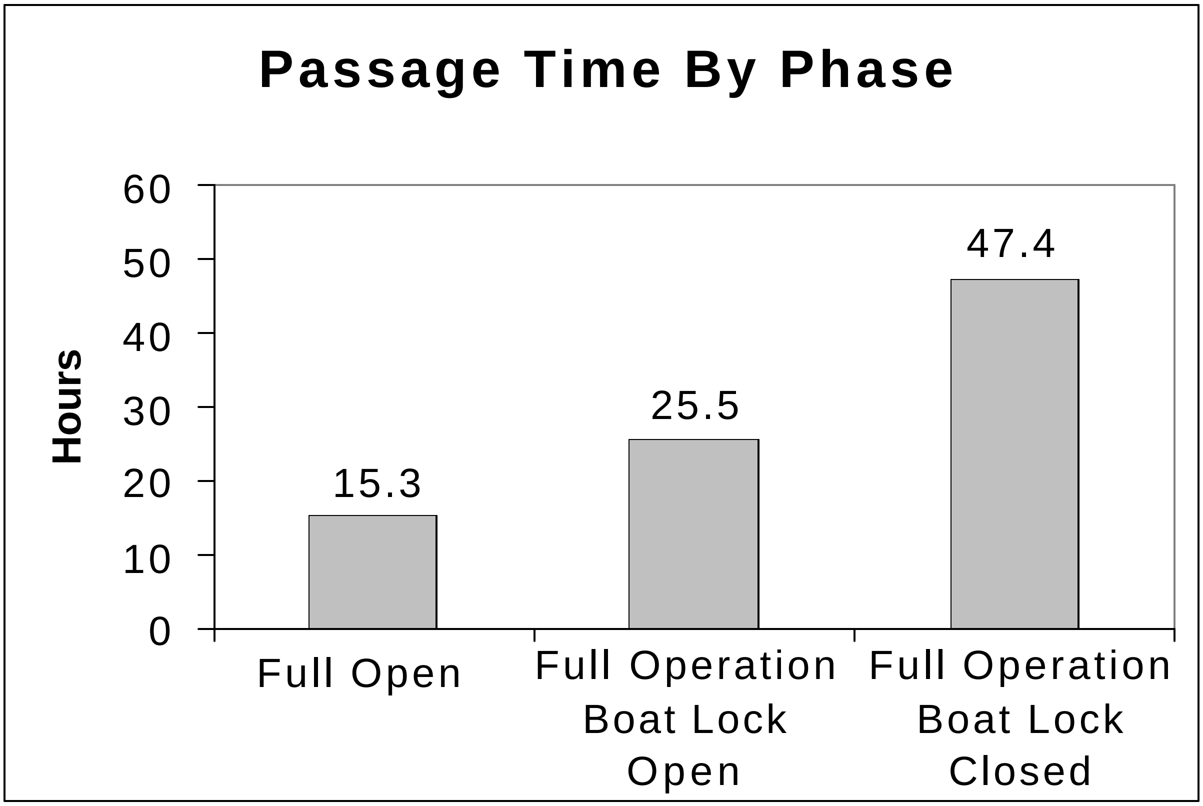


Figure 4. Passage Time by Phase at the Salinity Control Gates Sept – Nov 2001

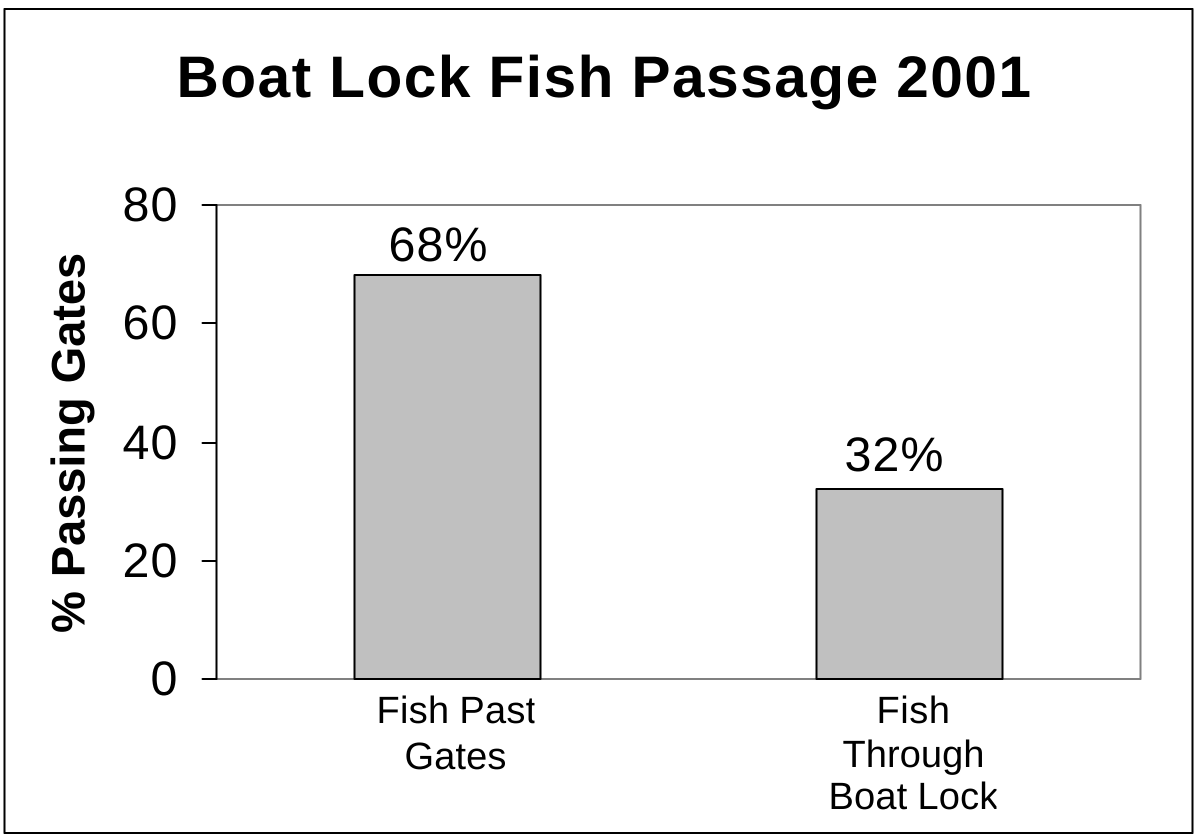


Figure 5. Fish Passage at the Salinity Control Gates Boat Lock Oct 8 – 21 2001

2001 Velocity Study within the Suisun Marsh Salinity Control Gates Boat Lock

Purpose

The structural modification under investigation in the 2001-2003 study years at the SMSCG is the open boat lock. This opening gives adult chinook salmon a vertical slot for passage throughout all phases of the tide. However, the hydrodynamics of such a modification was unknown at the outset. Primarily, DWR and DFG biologists were concerned with the maximum velocities occurring in the boat lock. It was thought that velocities greater than approximately 8 feet per second (fps) could hinder salmon passage. Additionally, the complexity of flow velocities and direction was also a question. The purpose of the velocity study was to characterize the hydrodynamics of the boat lock, at several time scales, that might affect the ability of an adult salmon to pass.

Tidal Conditions

The study was conducted under spring tide conditions on October 15 and November 14, 2001 in order to capture the maximum possible flows during the salmon passage study period. Figure 1 shows the tidal flow in Montezuma Slough on those days and the times during which velocity testing was conducted. As shown in Figure 1, the velocity test covered a complete tidal cycle from maximum ebb to maximum flood to slack flow over the two study days.

The SMSCG Boat Lock

The SMSCG boat lock is located on the eastern side of the structure and is approximately 20 feet wide by 70 feet long. Depths in the boat lock vary between approximately 9 – 14 feet. The boat lock allows boats to pass when the radial gates are operating and the flashboards are in. The boat lock is controlled by an onsite operator and is in operation only during daylight hours. Under normal operating procedures, the boat lock is maintained in a closed position and is opened only to allow boats to pass the structure.

For the purpose of the salmon passage study, the boat lock was maintained in an open position and only closed by operators to allow boat passage. Times were logged by the on duty operator when the lock was closed to allow boat passage. At mean tide level (about 1’ above NGVD29), when the radial gates are open, the boat lock cross-sectional area is only approximately 7% of the total cross-sectional area of the lock and radial gates.

Equipment and Methods

Velocity in the boat lock was measured at 15-minute intervals using two types of equipment: (1) a RD Instruments Workhorse Rio Grande Acoustic Doppler Current Profiler (ADCP) 1200 kHz, and (2) a Price current meter. Two types of instrumentation were used in order to compare the results. The ADCP was mounted to the bow of the boat and submerged approximately one foot. A 50-lb weight was attached to the Price current meter to ensure vertical alignment in the water column. It was lowered and raised by a winch system attached to the boat.

The ADCP measures velocity in unequally spaced vertical columns made up of equally spaced (0.25 m) horizontal rows. The ADCP transducers emit a signal at a ping rate of 2 Hz, thus column width is determined by the speed of movement of the ADCP across the lock. The Price current meter was read at approximately 6/10 depth of the water.

Two types of ADCP measurement were made: (1) transects across the width of the lock, and (2) stationary center measurements. The transects were made every 15 minutes on both study days. The stationary center measurements were made every 15 minutes on November 14th only. The boat was tethered by ropes at four corners to prevent excessive movement in the upstream or downstream direction and to generate the transects by manually pulling the boat across the lock. The boat motor was off during the study.

Transects were run from left bank to right bank in approximately the center (length and width-wise) of the boat lock. When the flow direction changed, the boat was turned so that it was always facing against the flow. For the stationary center measurements, the boat-mounted ADCP was held in center of boat lock and ½ second interval velocity measurements were made for no more than 30 seconds to assess the change in flow variation at one location over time. If boat drift laterally was greater than 0.25', the measurement was not used.

The Price current meter was counted for at least 50 clicks. Published rating charts were used to convert the reading to a velocity. Price meter readings were made in approximately the center (length and width-wise) of the boat lock immediately after each 15-minute ADCP transect was completed.

Gate Operations

Table 1 shows a timeline of operations at the SMSCG during all phases of the salmon passage study. Phase I operation was conducted as planned: radial gates remained open, boat lock was open, and flashboards were not installed. Phase II and Phase III radial gate operations were affected by failure of the ultrasonic velocity meter (UVM) on October 6, 2001. The UVM is used to trigger the automatic closing of the gates when flow velocity exceeds 0.1 fps in the upstream direction. Because automatic operation was impossible, a manual schedule for operation was developed. This manual schedule, however, timed the operation on stage rather than flow. The timing problem was discovered on 17 October (over half-way through Phase II) and it was decided to keep the operation based on stage in order to maintain the integrity of the salmon passage study. After completion of the study, automatic operation of the radial gates resumed. Thus, manual operation of the radial gates occurred from 8 October – 2 November 2001.

The effect of operating based on stage rather than flow resulted in gates being closed during part of ebb and open during part of flood. This lag of flow behind stage is due primarily to momentum effects and resulted in gates being opened and closed about 2 1/2 hours early. Additionally, when gates were closed during ebb, velocities in the boat lock were relatively high in the downstream direction. Similarly, low velocities in the boat lock were experienced during part of the flood tide. These conditions would not be seen under normal operation.

Results

Flow within the boat lock is fairly turbulent during high flows. Turbulence and flow eddies are caused primarily by bumpers and floating tie-offs mounted on the both sides of the lock which protrude approximately 8 inches.

Velocity distributions across the middle of the boat lock were plotted for each 15-minute interval and presented to the SMSCG Technical Team and Steering Group. Figure 2 displays the velocity distribution at 30-minute intervals. Negative velocities indicate flow in the upstream direction, positive in the downstream. Maximum instantaneous velocities ranged from 12.6 feet per second (fps) during ebb to 12.2 fps during flood flow. A wide distribution of flow rates was seen across the boat lock, especially under high velocity conditions. When instantaneous peak velocities occurred, relatively low velocities were seen in other portions of the cross-section. Often, eddies are evident where a predominantly positive (downstream flow) transect also shows a negative (upstream flow) area, or vice versa.

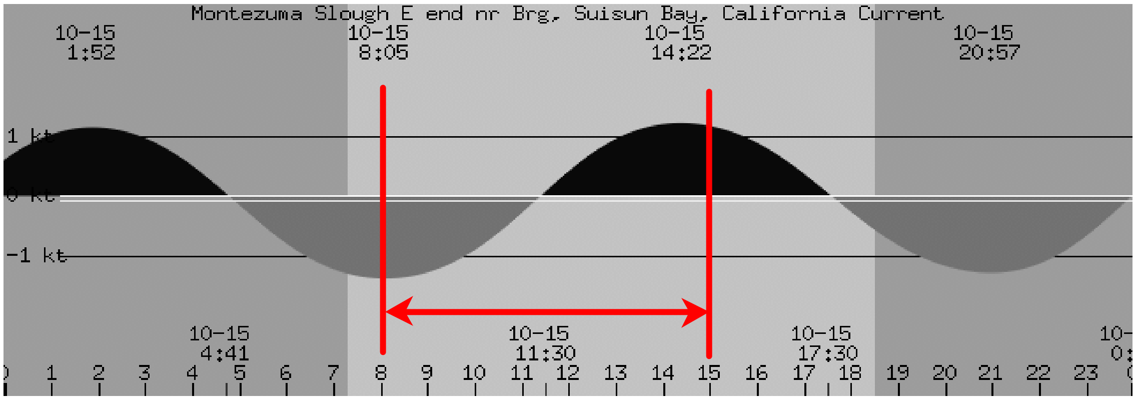
Figure 3 shows the average transect flow, velocity, and depth. Maximum average transect velocity was 7.2 fps ebb and 5.4 fps flood. As shown, velocities measured using the Price current meter compare well to those measured using the ADCP. The current meter measures consistently higher velocities due to the single measurement location of 6/10 depth. The relationship between stage and flow is also shown in this figure. When flow is at slack, stage is near maximum or minimum. Similarly, when stage peaks high or low, flow is nearing maximum or minimum.

Figure 4 shows plots of stationary center measurements during one measurement period of approximately 17 seconds. This figure shows the high variability of the instantaneous velocities. For this particular measurement period (November 14, 14:28, 0-17 seconds), the coefficient of variation for each depth ranged between 15% - 49%. Notice the reversal of flow direction at two depths at time = 9.5 seconds, and back again ½ second later. This could indicate either an eddy moving under and out from under the ADCP within the second, or a small (less than 0.25’) movement of the boat laterally, thus picking up an eddy at a slightly different location.

Summary

Flows in the SMSCG boat lock can be fairly complex and rapidly changing. Turbulence and eddies were seen especially under high velocity periods. Overall, because of the transitory nature in time and space of velocities greater than 8 fps within the boat lock, DWR and DFG biologists agreed that neither the instantaneous nor average velocities appear to hinder adult salmon passage.

15 October 2001



14 November 2001

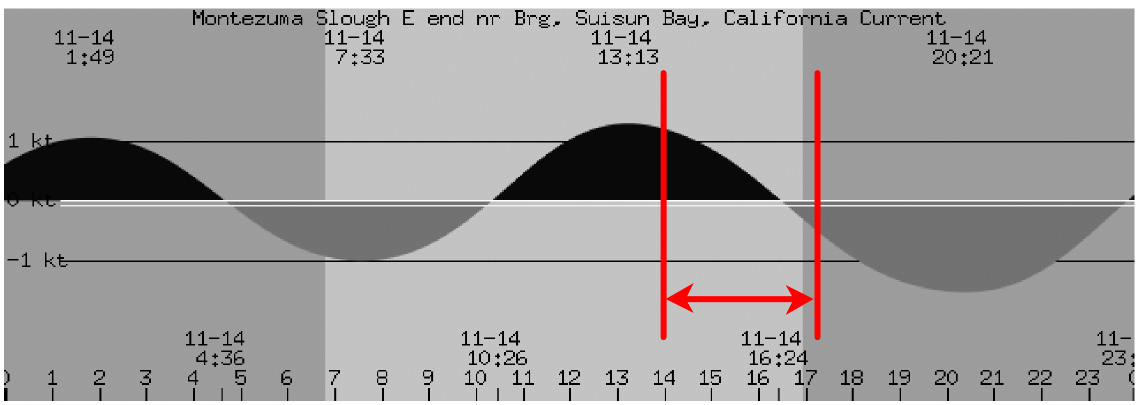
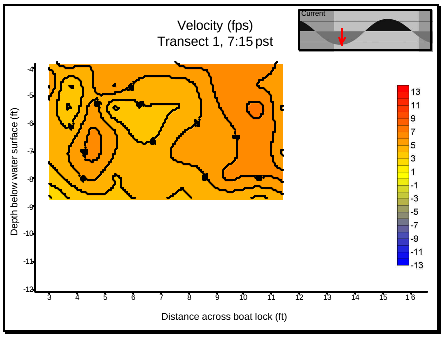


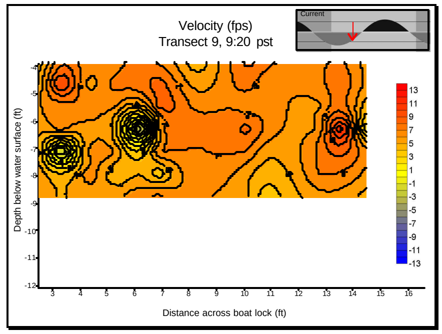
Figure 1. Tidal current at Montezuma Slough, E end near Bridge (from WXTide32 version 6). Red lines indicate time of velocity study.

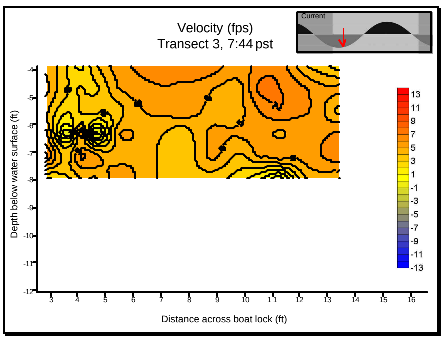
Date	Phase	Operation / Activity			Notes
		Radial Gates	Boat Lock	Flashboards	
24 Sep - 8 Oct	I	Open	Open	Not in	Pre-operational.
6 Oct	II	Operating (but stayed open)	Open	Out	Started operating gates, but stayed open since not being triggered by UVM.
7 Oct			Open	In	Flashboards installed.
8 Oct		Operating	Open	In	Manual operation of radial gates due to failure of ultrasonic velocity meter (UVM) used for automatic operation. Timing was based on stage rather than flow. This resulted in gates being closed during part of ebb and open during part of flood flow.
20 Oct	III	Operating	Closed	In	
26 Oct - 29 Oct		One of the radial gates (gate 3) was stuck closed. Other 2 gates operating.			
2 Nov	Study ends	Operating	Closed	In	UVM repaired on 2 Nov and automatic operation (based on flow) of gates resumed.

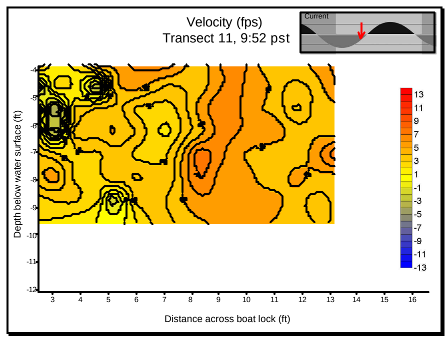
Table 1. Timeline of operations at the SMSCG during the 2001 Salmon Passage Study.

October 15:


Velocity (fps)
Transect 1, 7:15 pst
Current
Depth below water surface (ft)
Distance across boat lock (ft)


Velocity (fps)
Transect 9, 9:20 pst
Current
Depth below water surface (ft)
Distance across boat lock (ft)


Velocity (fps)
Transect 3, 7:44 pst
Current
Depth below water surface (ft)
Distance across boat lock (ft)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Current
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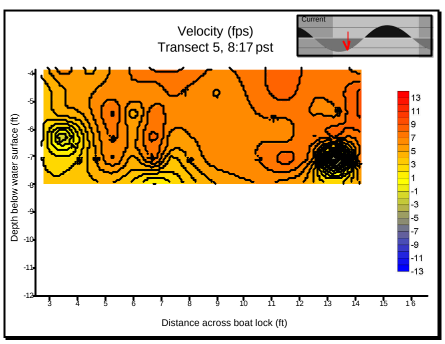
Distance across boat lock (ft)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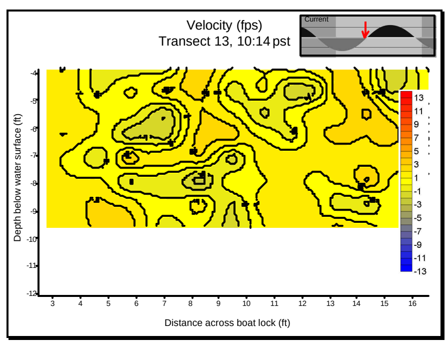
Distance across boat lock (ft)


Velocity (fps)
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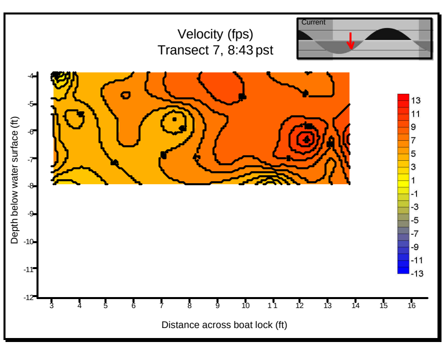
Current
Depth below water surface (ft)
Distance across boat lock (ft)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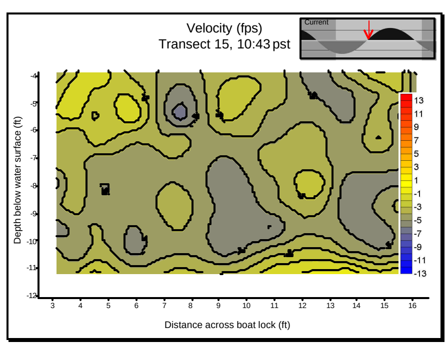
Depth below water surface (ft)
Distance across boat lock (ft)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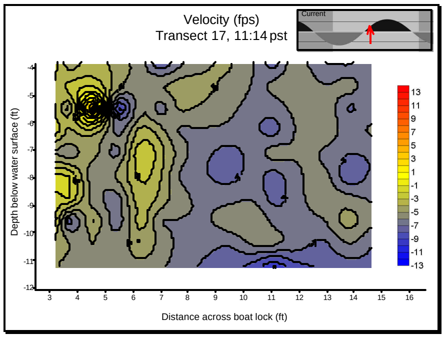
Depth below water surface (ft)
Distance across boat lock (ft)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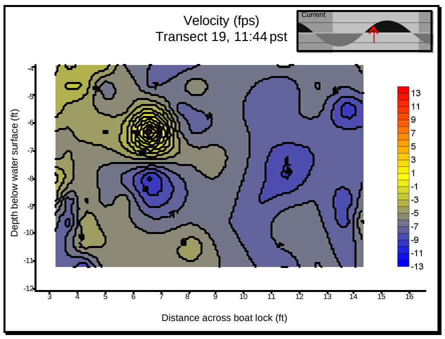
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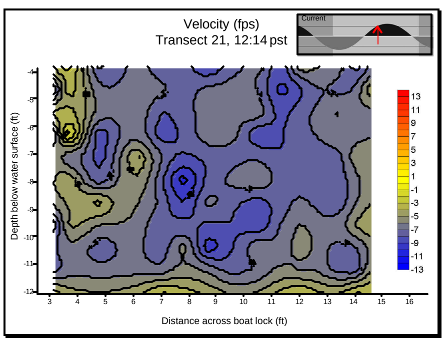
Distance across boat lock (ft)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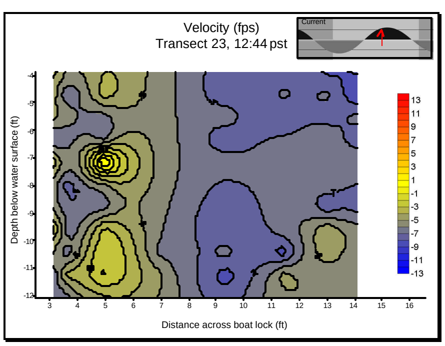
Distance across boat lock (ft)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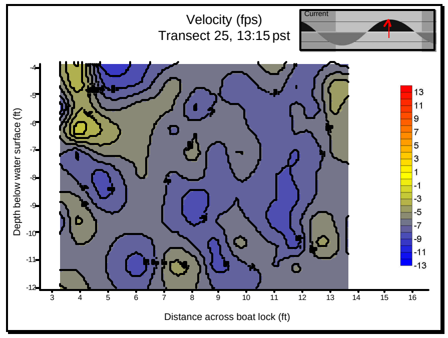
Current
Depth below water surface (ft)
Distance across boat lock (ft)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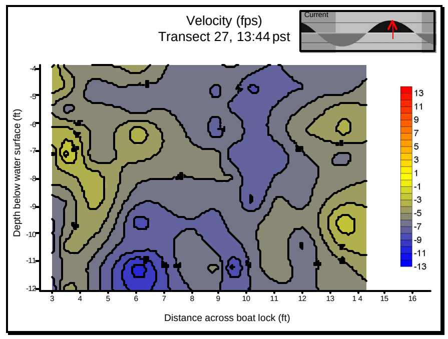
Current
Depth below water surface (ft)
Distance across boat lock (ft)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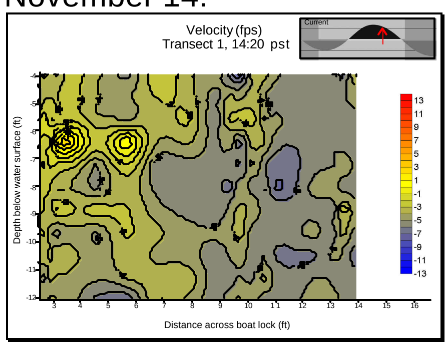
Current
Depth below water surface (ft)
Distance across boat lock (ft)

November 14: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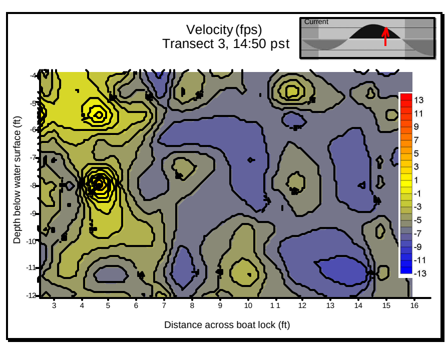
Current
Depth below water surface (ft)
Distance across boat lock (ft)


Velocity (fps)
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Current
Depth below water surface (ft)
Distance across boat lock (ft)

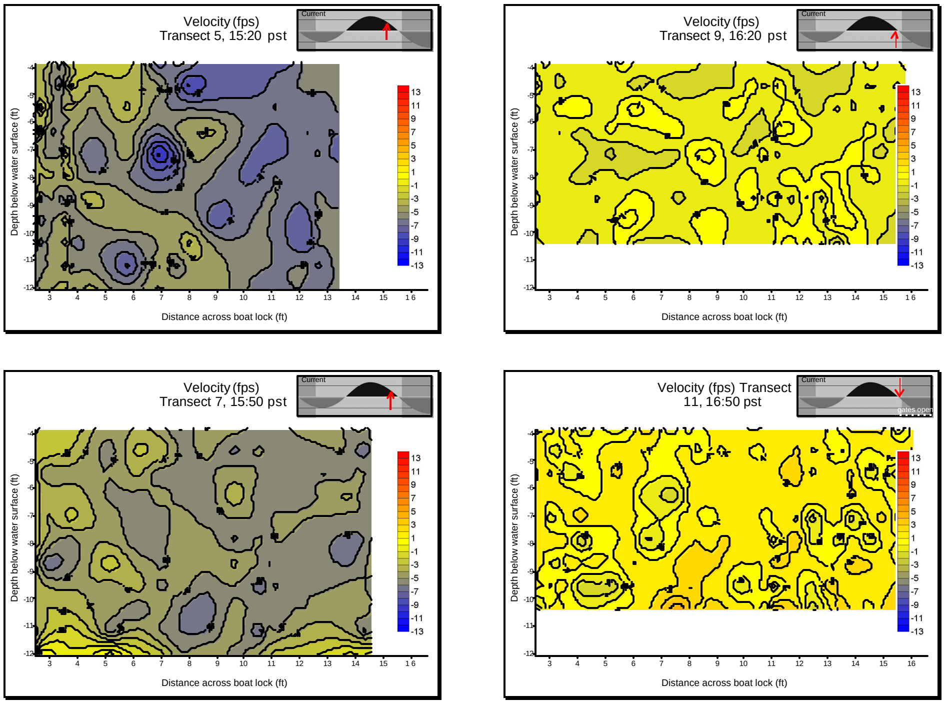


Figure 2. Instantaneous velocity transects at 30-minute intervals on October 15 and November 14, 2001.

Chinook Salmon Swimming Ability and Water Velocities Through the SMSCG Open Boat Lock

During the 2001 Adult Chinook Salmon Fish Passage Study, tagged salmon used the open boat lock channel to pass the SMSCG during the second operational phase (Phase II - full operation with boat lock open). An ultrasonic velocity meter (UVM), which is located just upstream of the SMSCG, normally controls the operation of the radial gates automatically according to flow and stage. After discovering that the UVM failed to operate properly near the start of Phase II, the Department of Water Resources (DWR) put a manual system of operation into effect in which gate operations were based on stage. This caused the gates to be opened and closed two to three hours earlier than normal. Because of this shift, the radial gates remained closed during part of ebb flow and open during part of flood flow.

In conjunction with the tidal cycle, the open boat lock and the stage-operated radial gates produced two characteristic flows past the SMSCG in each direction: (1) when closed, the radial gates blocked 93% of the available channel area, concentrating all flow through the open boat lock; and (2) when the radial gates were open, flow was distributed across a greater proportion of the channel (through the boat lock and radial gates). Thus flows of higher velocities and lower velocities were achieved through the boat lock daily, in either direction based on tide. Had the UVM not failed, higher velocity flow through the boat lock would have occurred only in the upstream direction, during flood flow, which was the only time the radial gates would have been closed. Conversely, downstream ebb flow would have been distributed across more of the channel when the radial gates were open which would have resulted in relatively slow velocities through the boat lock. Once the discrepancy with normal operations was discovered, DWR decided to continue with the shifted schedule of operation for the remainder of the study.

Bell (1990) suggests that adult chinook salmon frequently seek higher velocities at obstructions, a tendency that may be utilized to attract them to fishway entrances. Following the closure of the radial gates, flow channeled through the open boat lock may have attracted tagged chinook salmon and shortened their passage time. However, this attraction flow occurred in both directions. Chinook salmon that passed the gates and had not moved beyond the structure's influence on flow, may have passed back through the boat lock against this higher or attracting upstream flow. This might explain the behavior of some tagged salmon that moved back and forth past the SMSCG rather than immediately heading upstream.

Bell (1990) and Clay (1995) (citing Bell (1984)) describe swimming abilities of fishes based on three categories of velocity and sustainability: (1) <u>Cruising</u> characterizes a velocity that can be maintained for many hours at a time, and is used for migration; (2) <u>Sustained</u> speeds are used for passage through difficult areas, and can be maintained for minutes to hours at a time; and (3) <u>Darting</u> represents a single, unsustainable effort that can only be maintained for seconds, and is generally reserved for feeding and escape. Bjornn and Reiser (1979) (citing Bell (1984)) list swimming ability ranges for chinook salmon as 3.41 feet per second (fps) for cruising velocities, 3.41-10.79 fps for sustained velocities, and 10.79-22.41 fps for darting velocities. Bell (1990) states that in the design of upstream facilities velocities must be kept well below darting speeds for general passage, but may exceed cruising speeds. In the case of the boat lock, approximately 90% of the velocity samples measured on October 15, 2001 were less than 8fps and well below the darting speed of chinook salmon. Less than 0.5% of the instantaneous velocities measured were greater than the minimum darting speed of chinook salmon, but well within their maximum swimming ability. Peak instantaneous velocities measured never exceeded 13 fps and were both relatively small in area, and transient in time and space. Given these facts, and considering the turbulent flow, such high instantaneous downstream velocities should not inhibit upstream salmon passage through the boat lock.

According to Jones (1968), investigations have shown that fish are able to sense velocity changes as slight as 0.328 fps. As fish sense changes in velocity they may avoid moving from one gradient to another, particularly from a lower to a higher gradient. When guiding or directing fish, smooth transitions and accelerations are desirable in order to prevent them from stopping, hesitating or refusing to enter a particular area (Bell, 1990). Several tagged salmon were observed to have been holding a stationary position against the current immediately following their passage through the open boat lock. Others were observed doing the same within the boat lock. Turbulent flow through and adjacent to the boat lock may have had an influence on salmon behavior during their passage of the SMSCG. Despite such influence, the average time of passage for tagged salmon during Phase II was 25.5 minutes. In Phase III the average time of passage was 47.4 minutes.

The abnormal operation of the radial gates during Phase II created periodic high velocity flows downstream through the SMSCG open boat lock. These attraction flows may have induced adult chinook salmon to pass through the boat lock or through the radial gates when open. Peak instantaneous velocities measured in the boat lock never exceeded the maximum swimming speed of adult salmon. Although the turbulent nature of flow through the open boat lock in Phase II may have had a slowing effect on the behavior of passing tagged salmon, the average passage time was nearly half that of Phase III.

References

Bell, M.C., 1990. Fisheries Handbook of Engineering Requirements and Biological Criteria: Chapter 6 – Swimming Speeds of Adult and Juvenile Fish, U.S. Army Corps of Engineers, North Pacific Division, Portland, OR. pp. 6.1-6.9.

Bell, M.C., 1984. Fisheries Handbook of Engineering Requirements and Biological Criteria, U.S. Army Corps of Engineers, North Pacific Division, Portland, OR. 290 pp. (Cited by Clay (1995)).

Bjornn, T.C., and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. American Fisheries Society Special Publication 19: 83-138.

Clay, Charles H., 1995. *Design of Fishways and Other Fish Facilities, 2nd ed.*: Chapter 3.16 – Design Considerations for Anadromous Species Worldwide, CRC Press, Boca Raton, New Orleans. pp. 115-120.

Jones, F.R. Harden, *Fish Migration*. Fisheries Laboratory, Lowestoft. St. Martin's Press, New York. 1968. (as cited by Bell, 1990).

Report on Continuous Water Quality Monitoring
September to October 2001
Suisun Marsh Salinity Control Gate Stations S-64 & S-71

Continuous water quality data were recorded for stations S-64 (National Steel) and S-71 (Roaring River) in the Montezuma Slough during the period of September 21st through October 18th 2001 (Figure 1). These data were recorded with a YSI model 6600 that automatically recorded dissolved oxygen (DO), temperature, specific conductance, pH, turbidity, and chlorophyll. The water samples were drawn from a one-meter depth by pump and analyzed with the on-shore model 6600 multi-function sonde.

These data were examined to determine whether any environmental water quality conditions occurred during the salmon telemetry studies which could have affected adult salmon migration through the Suisun Marsh Salinity Control Gates.

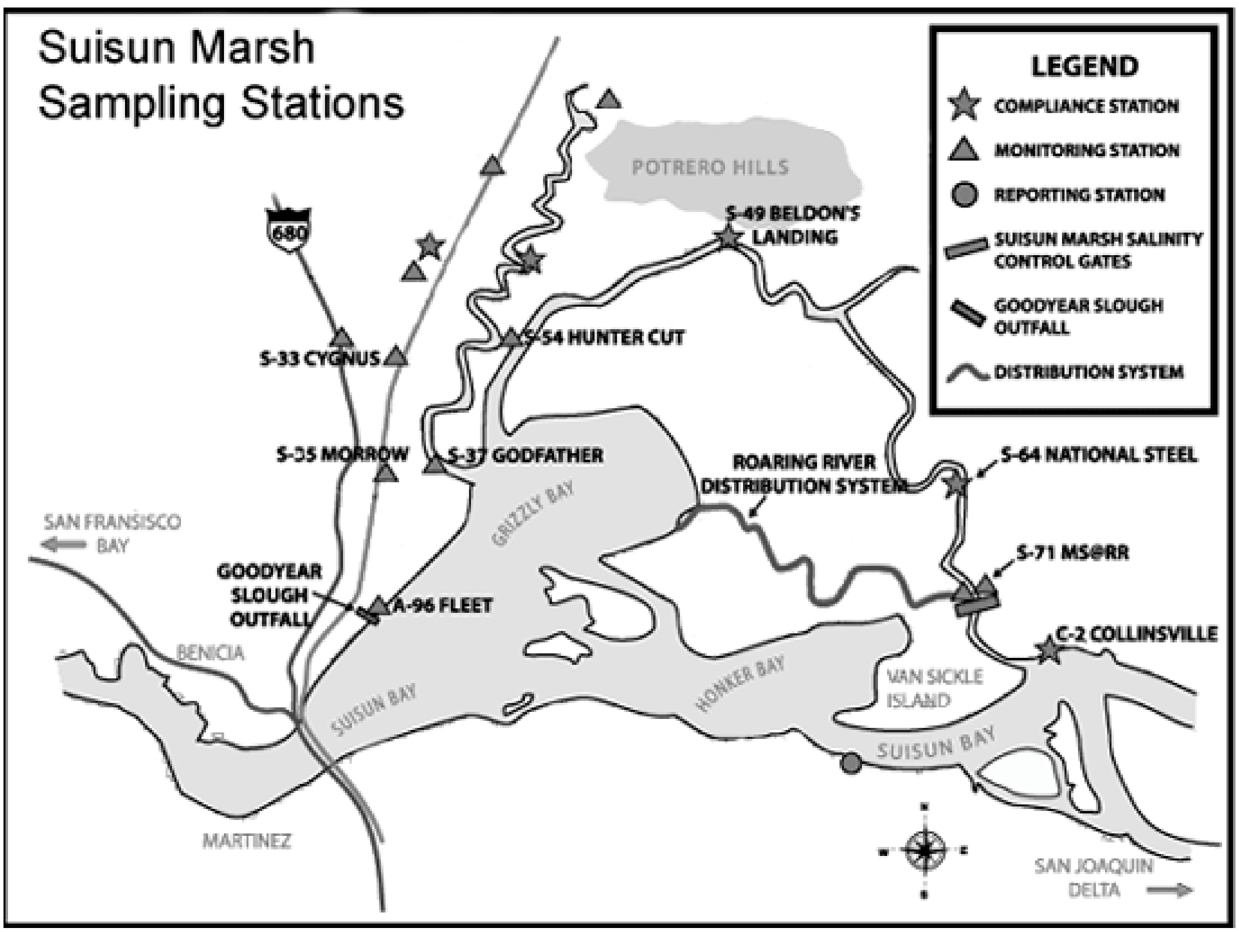


Figure 1: Location of Suisun Marsh Sampling Stations S-71 and S-64.

As noted by Jay Aldrich (DWR) in a November 11th 2001 memo (Appendix 1), several problems occurred during the water quality data collection effort. Due to pump failure, the collection of water quality data ended prematurely at stations S-64 and S-71 on October 19th and October 17th, respectively. Temporary pump failure was also noted as a cause of lost data within the recording period. These temporary gaps resulted in long periods missing data during Phase I. In addition, DO data are missing for a major portion of both Phase I and Phase II of the study period. Loss of these DO data is believed to be due to failure and instability of the DO probes. This problem is being addressed by shortening the probe maintenance time in half from the suggested two-week interval to one week. Finally, no data are recorded for Phase III due to the pump failure mentioned earlier.

The water quality data show marked diel fluctuations for some parameters. In order to determine the major factors affecting water quality in this area, tidal stage data for station S-71 were compared with water quality data during Phase I and Phase II. These data were downloaded from the DWR Suisun Marsh Monitoring web site (http://iep.water.ca.gov/suisun).

Station S-71 is located downstream of the Suisun Marsh Salinity Control Gates. During Phase I, the SMSCG were held open, and the flashboards were not installed. During Phase II, the gates were operated, although the boat lock was held open. In this configuration, flood tides are blocked (except for flow through the open boat lock) while ebb tides are unimpeded. During this operational phase the gates were operated manually based on tidal stage rather than automatically triggered by the flow measurement device (UVM). As a result, the radial gates were opened and closed about 2.5 hours early on each tide. This resulted in the gates being open during part of the flood and closed during part of the ebb flow.

Salmon Fish Passage Study

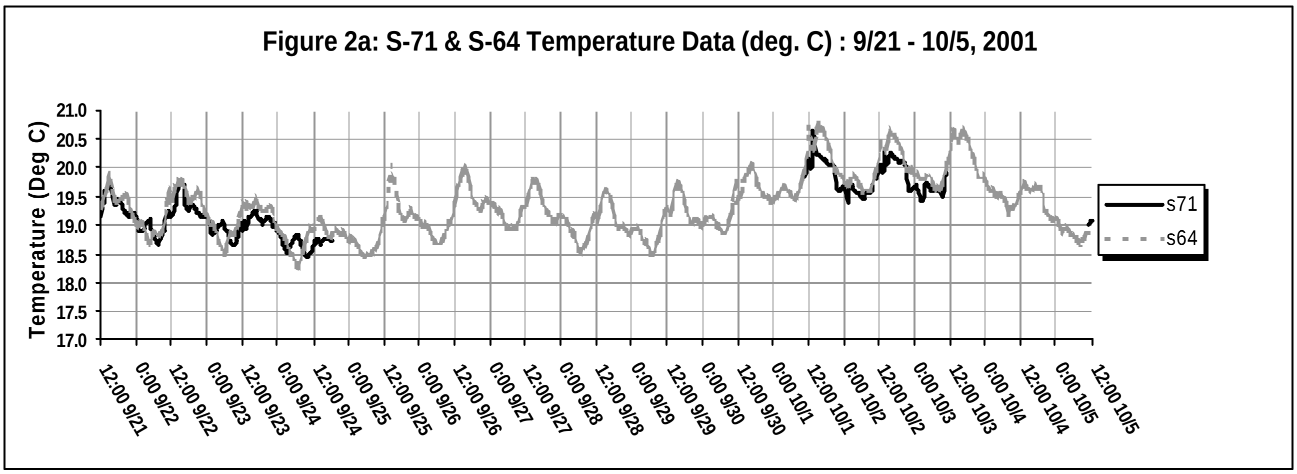
The salmon fish passage study was conducted in Montezuma Slough beginning on September 24th and ending November 1st 2001. Phase I (full open) occurred September 24th through October 10th, Phase II (modified operation) occurred from October 10th through the 22nd, and Phase III (normal operation) occurred from October 22nd through November 1st.

Because of the failure of the water quality recording equipment, water quality data are only available for comparison with Phase I and part of Phase II. There are no water quality data corresponding to Phase III, and there are missing data for both Phase I and II.

Water Quality Data

Temperature

Surface water temperatures were measured at stations S-71 and S-64 (Figures 2a and 2b). Temperatures above 20 °C are of concern because it was determined from previous studies that high water temperatures, together with capture and tagging, cause excessive stress on salmon. Because high temperatures can be detrimental to adult salmon, the study protocol states that salmon will not be tagged when water temperatures exceed 20 °C. Measured temperatures exceeded 20 °C during nine days, and approached 20 °C (exceeded 19.5 °C) on an additional 7 days at either station S-71 or S-64. However, 8.5 days of data are missing for S-71 during this study period, it is likely that there may be additional days in which the measured water temperature exceeded or approached 20 °C. However, tagging operations were conducted on only one day (October 10th) when measured temperature exceeded 20 °C.



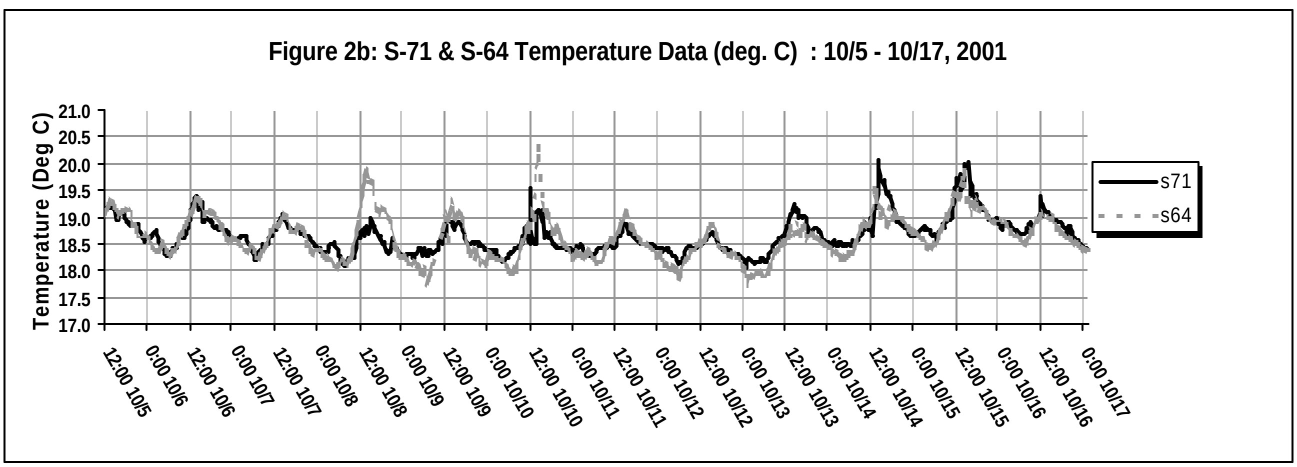


Figure 2a & 2b: Temperature data September 21st to October 17th , Stations S-71 & S-64.

In general, water temperature at stations S-71 and S-64 measured within 0.5° C. Daily temperatures for both S-71 and S-64 showed a diurnal minima at about 9 am, followed by a sharp linear increase during the day to a maxima at about 2-3 p.m. The daily temperature decline was equally sharp beginning in most cases immediately after the maxima.

For data available in Phase I, S-71 water temperature is plotted against tidal stage level and against air temperature from a nearby location in the Sacramento River (Station RSAC075 at Pittsburgh) (Figure 3). The results show there is no correlation of water temperature with tidal stage; however, there appear to be recurring periodic patterns that are unlikely to be caused by solar irradiance alone. For example, late afternoon minimum measured temperatures correspond exactly to the peak of the inferior (low-high) tide. It is notable that even though water temperatures were approaching 20 °C, that air temperatures were generally cooler than water temperatures. The tidal data did not seem to correspond with any significant changes in water temperature. The low air temperatures were likely due to the presence of a westerly delta breeze blowing cool air in from the San Francisco Bay; however, it appears that the water arriving on the flood tide was warmed to about the same temperature as the river water entering from upstream.

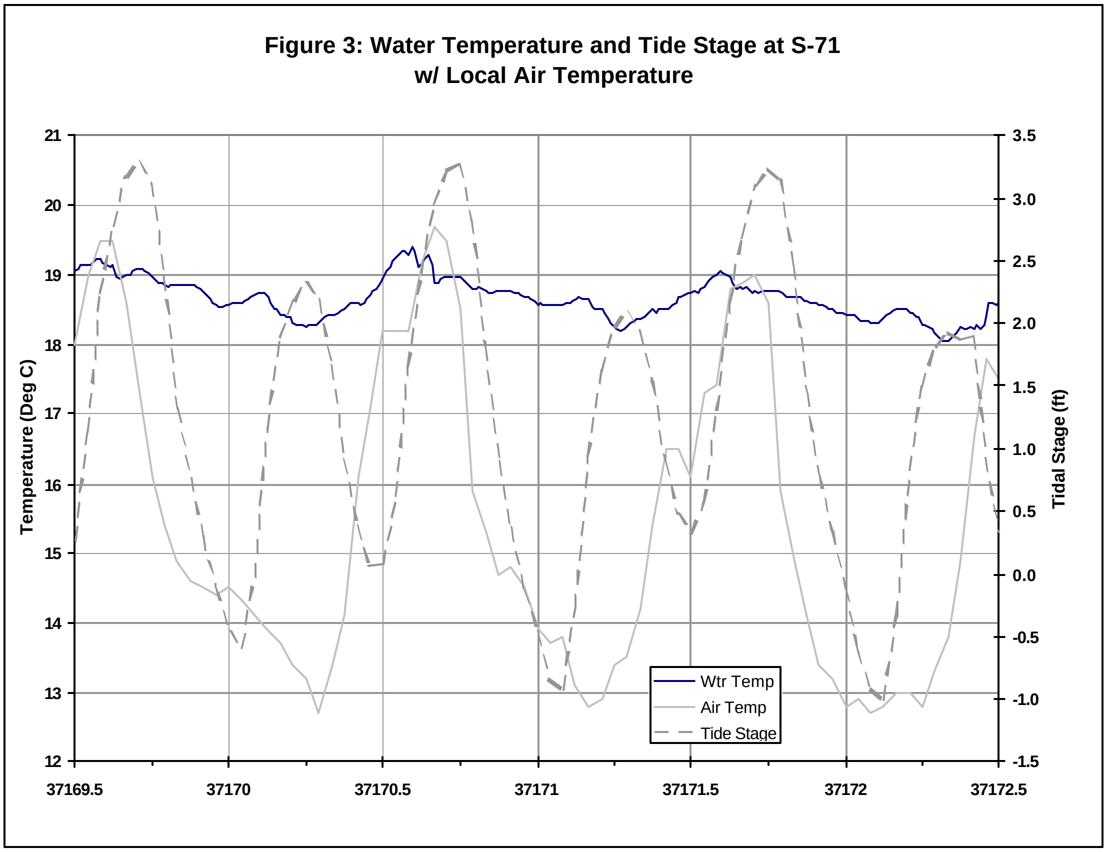


Figure 3: Water temperature, air temperature and tidal stage at S-71.

Because measured water temperature does not appear to be influenced by tidal movement, the diel pattern is probably determined chiefly by solar irradiance.

It would be desirable to collect actual depth profile measurements, since it does not appear to be known whether Montezuma Slough is normally fully mixed or stratified. In future studies temperature should be measured in at least two locations in the water column, at the bottom and at the surface.

Specific Conductance

Data gathered for specific conductance (SC) are shown in Figures 4a and 4b. These data show that during Phase I there was a strong salinity gradient between stations S-64 and S-71. Station S-64, which is downstream from S-71 shows measured SC levels consistently in the range of 2.0 – 5.0 mS/cm above the measured SC level at station S-71. As expected, SC followed a tidally influenced pattern.

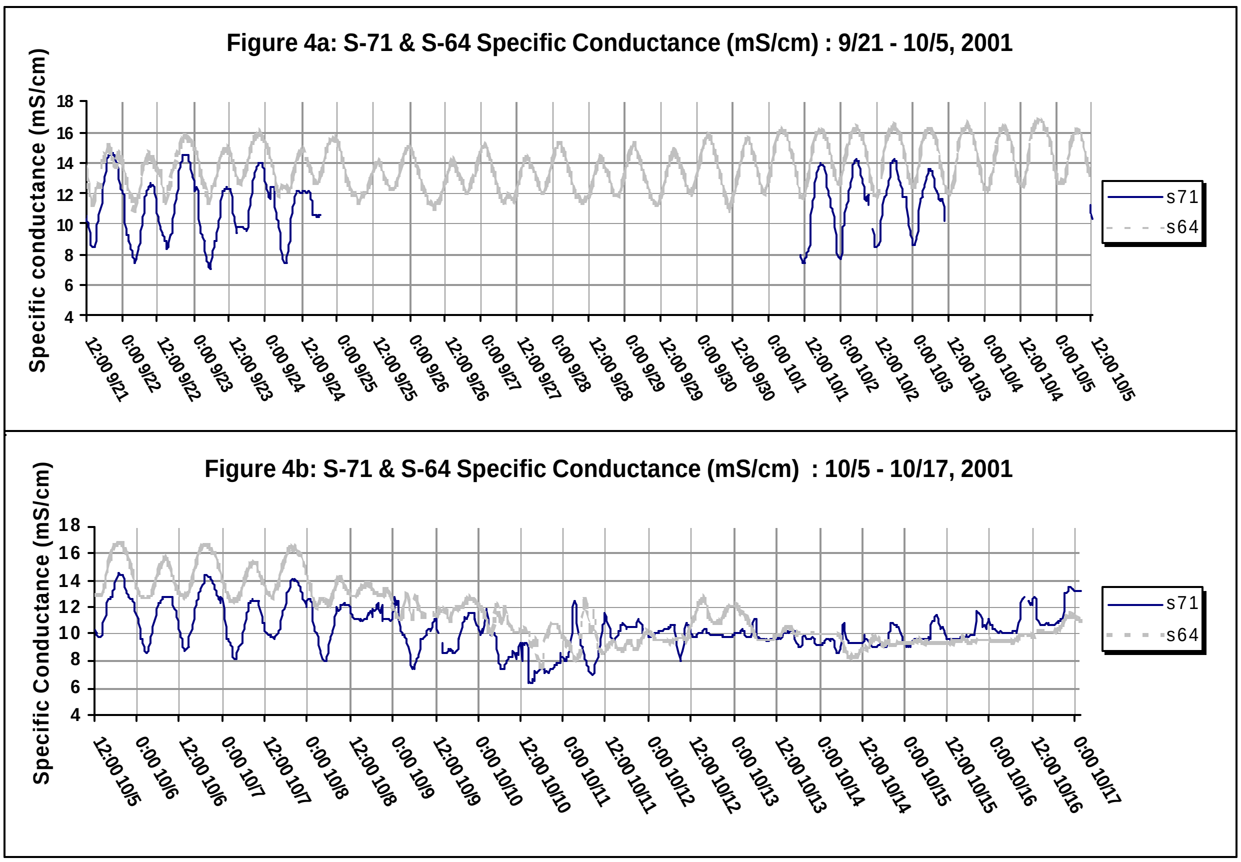


Figure 4a & 4b: Specific conductance September 21st to October 17th , Stations S-71 & S-64.

During Phase II, the measured SC at both sampling stations fluctuated considerably, and no clear salinity gradient existed between the two stations. An exception to this occurred starting on about October 14th when the upstream sampling site (S-71) salinity was greater than downstream salinity. This was seen in the data as periodic increases in measured SC at S-71 of about 2.0-3.0 mS/cm from an average level of about 10 mS/cm (Figure 4b). These pulses of high salinity appear to correspond to tidal stages (Figure 5) and occur during the ebb tide. Consequently, the data show that when the salinity control gates opened for the ebb tide flow, higher salinity water entered from upstream. This pattern was recorded in the water quality data up until the end of the data set when the water quality measurements were discontinued.

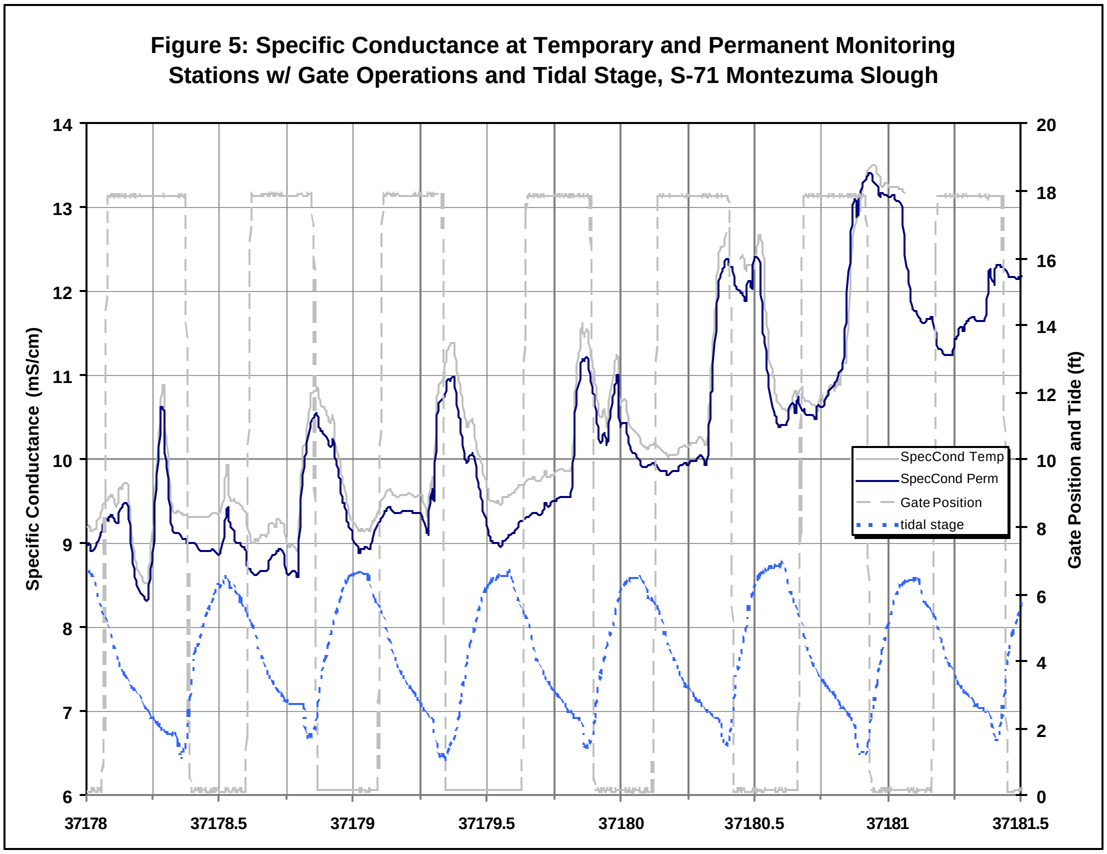


Figure 5: Specific conductance, tidal stage and gate position at station S-71.

An analysis of data from the nearest upstream sampling station (Collinsville) was conducted to confirm the possible presence of higher salinity water upstream of the control gates. Unfortunately, the Collinsville data were missing for several days during this period, however good data exist for October 15th through October 17th. These data show that upstream salinities were as high as 14.57 mS/cm during this period. This salinity level was significantly higher than that recorded downstream of the salinity control gates. These data support the evidence that during Phase II of this study that the SMSCG passed higher salinity water into the Montezuma Slough during ebb tides. It is not clear how long this occurred, but the water quality data show it occurred for at least 3 days, from October 14th to October 17th 2001 when the data set ended. This effect was not seen in earlier Phase I data. This is a typical phenomenon that occurs for a brief period of time when the gates are first operated at the beginning of each control season.

Dissolved Oxygen

Dissolved oxygen data are incomplete, however what are available show that DO levels were consistently higher at S-64 than S-71 by about 0.5 mg/l (Figures 6a and 6b). This indicates that DO declined slightly in a gradient from downstream to upstream towards the salinity control gates. Therefore, it should be expected that measured diurnal DO would show a tidally influenced pattern, that increased as higher DO water from downstream moved upstream on the flood tide, and decreased as lower DO water upstream moved down on the ebb tide. However, the data show that DO declined on the flood tide and rose on the ebb tide. Therefore, although downstream water showed a higher measured DO, during flood tide, DO levels dropped at both sites. This indicates that both stations are probably being influenced by the same factor, which in this case could be the presence of low DO water downstream of both stations. If this is the case, then it is possible that significantly lower DO concentrations existed downstream of S-64 and S-71. The data from stations S-64 and S-71, however, show DO levels well above this study's threshold critical level of 6 mg/l.

Figure 6a: S-71 & S-64 Dissolved Oxygen (mg/l) : 9/21 - 10/5, 2001

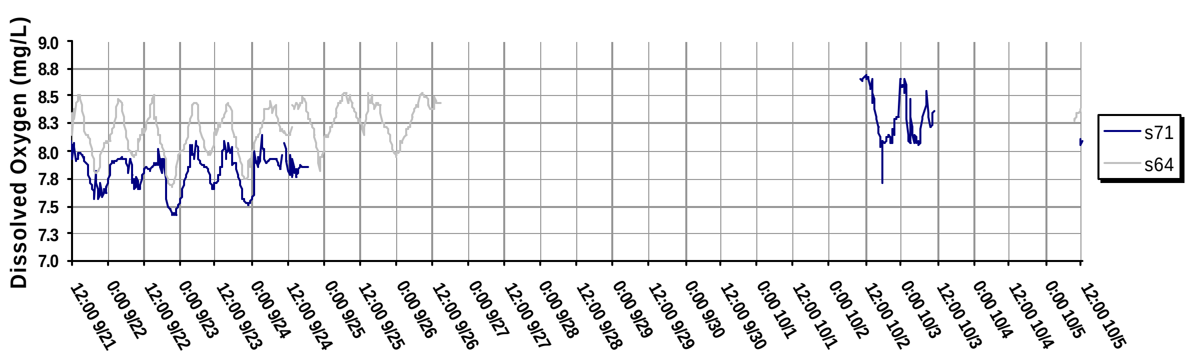
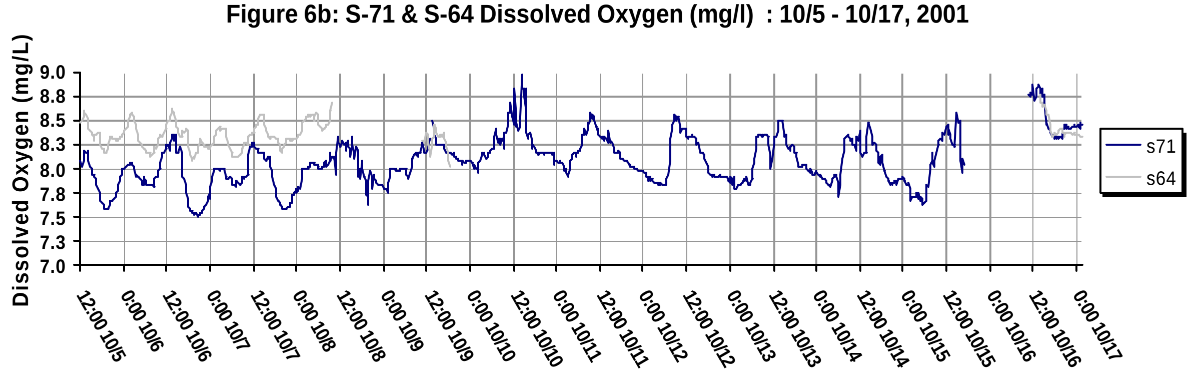


Figure 6b: S-71 & S-64 Dissolved Oxygen (mg/l) : 10/5 - 10/17, 2001



The YSI Model 6600 automated water quality recording device records pH, chlorophyll and turbidity data along with the parameters discussed above. These data were recorded because of the capability of the recording device and not because of any particular data needs for this study.

Chlorophyll data are not very useful without supporting data and calibration with specific algal species present at the study site. These data are simply measures of fluorescence and cannot be interpreted as a measure of algal biomass or primary production without extensive auxiliary data.

Measured pH shows a pattern of diurnal fluctuation at both stations, with the pH measured consistently higher at the upstream station S-71 than at the downstream station S-64 (Figures 7a and 7b). The pH measured at S-71 appears to be tidally influenced with pH falling on the flood tide and rising on the ebb during Phase I. The pH at S-71 also shows a strong inverse correlation with specific conductivity, with pH falling as specific conductivity increases. This is consistent with the previous observation, as specific conductivity increases with the flood tide. This pattern of diurnal pH fluctuation is likely to be the result of lower pH water moving upstream from Station S-64 during flood tide and receding with the ebb.

Figure 7a: S-71 & S-64 pH Data : 9/21 - 10/5, 2001

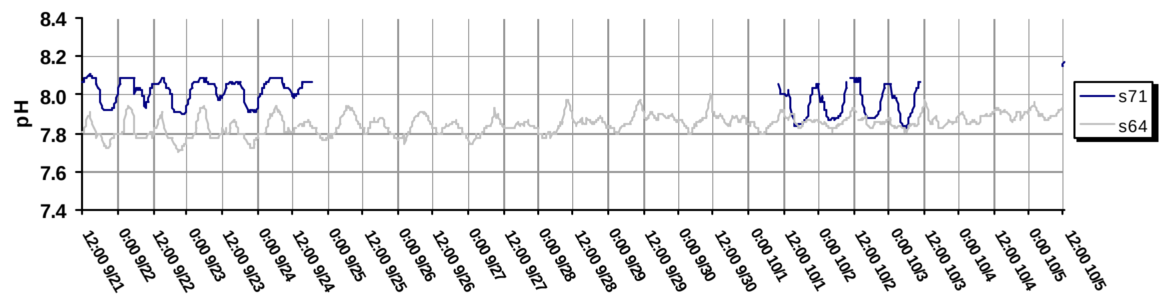


Figure 7b: S-71 & S-64 pH Data : 10/5 - 10/17, 2001

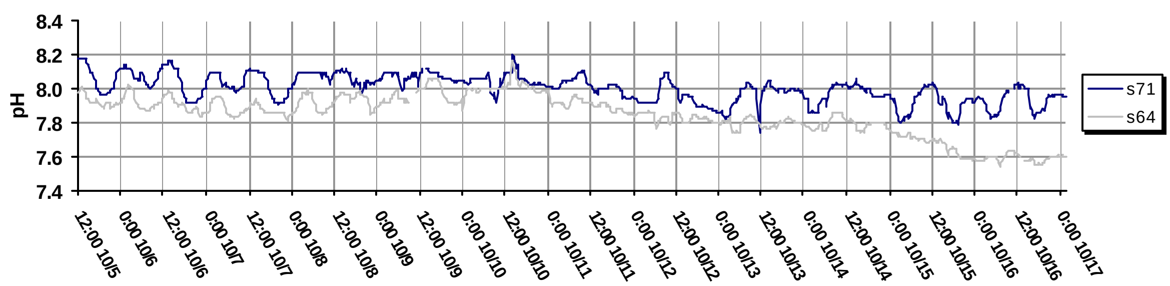


Figure 6a & 6b: pH data, September 21st to October 17th , Stations S-71 & S-64.

During Phase II, the data available show that the relationship between pH and specific conductivity reversed for at least some time. During the period in which higher salinity water entered the slough from upstream (as discussed above), pH rose as specific conductivity increased, and fell as it decreased.

Much of the turbidity data show no discernable pattern, although there are periodic spikes in the data that may be attributable to foreign matter present in the measuring flow chamber (Appendix I). Turbidity data from Phase I show no apparent influence from tide, however turbidity data do show a strong influence of tidal stage during the latter portion of Phase II. During Phase II, from October 12th through the end of the recorded data on October 17th, turbidity increased markedly by a factor of 4 – 6, during ebb tide when control gates were open, and subsequently decreased proportionally during flood time, when gates were closed. This effect is not seen in earlier Phase II data from that month.

Summary

Data analysis for this study is hampered by the lack of data for significant portions of the study period, which includes parts of Phase I and Phase II, as well as all of Phase III. Despite the lack of data, however, there are some important observations that can be made, and several questions that result, that should be addressed in subsequent water quality monitoring studies.

The data show that the water quality environment in the slough is rather complex. These data show that migrating fish would encounter an environment that may or may not have higher water temperatures, and/or critical DO levels. These environmental parameters are variable in a free flowing slough and are significantly influenced by the operation of the salinity control gates.

Since temperature and DO are critical environmental variables, they will continue to be documented to facilitate a comparison of the different gate operation scenarios.

Recommendations

- Continuous water quality data should continue to be gathered to document conditions in the slough during fish passage studies.

- Improve DO data reliability by increasing probe maintenance schedules and, if possible, to suspend sampler in the water column.

- Measure DO and temperature at two depths in water column in order to get a vertical profile.

Appendix I

21 Nov 2001

To: Heidi Rooks
From: Jay Aldrich

- Two YSI 6600s were installed at Montezuma Slough @ Roaring River (S – 71) and National Steel (S – 64). The parameters collected are date, time, temperature (°C), specific conductivity (mS/cm), D.O. saturation %, D.O. (mg/L), pH, turbidity (NTU), chlorophyll (μg/L), and batteries (volts D.C.).

- S – 71 was installed 29 Aug and ran to 2 Sep 2001 for a test run. S – 71 then ran from 17 Sep to 17 Oct 2001. I have the data from the 17 to 21 Sep 2001, for some reason the data did not get to your edited copy.

- S – 64 was installed 21 Sep and ran until 19 Oct 2001.

- The study ended prematurely due to unknown failures in the pumps.

- Whole data streams missing, with the exception of date and time, is due to the temporary failures in the pumps; for example the pump losing it's prime and not able to due have a good suction, or the pumps getting clogged with plants in my test run.

- Missing D.O. data was caused by instability and failure of the D.O. probe. The D.O. would sometimes slowly drift down over time due to the solution in the probe was being consumed.

- Any one point or small blocks of data missing on any of the other parameters (like turbidity and chlorophyll) was due to an out of character jump in values, most likely caused by foreign material floating in the flow chamber. An example would be chlorophyll on S – 64 starting on 3 Oct 2001 starting at 9:15 p.m.: 6.7, 61.6, 2.1, 141.3, 4.6 μg/l.