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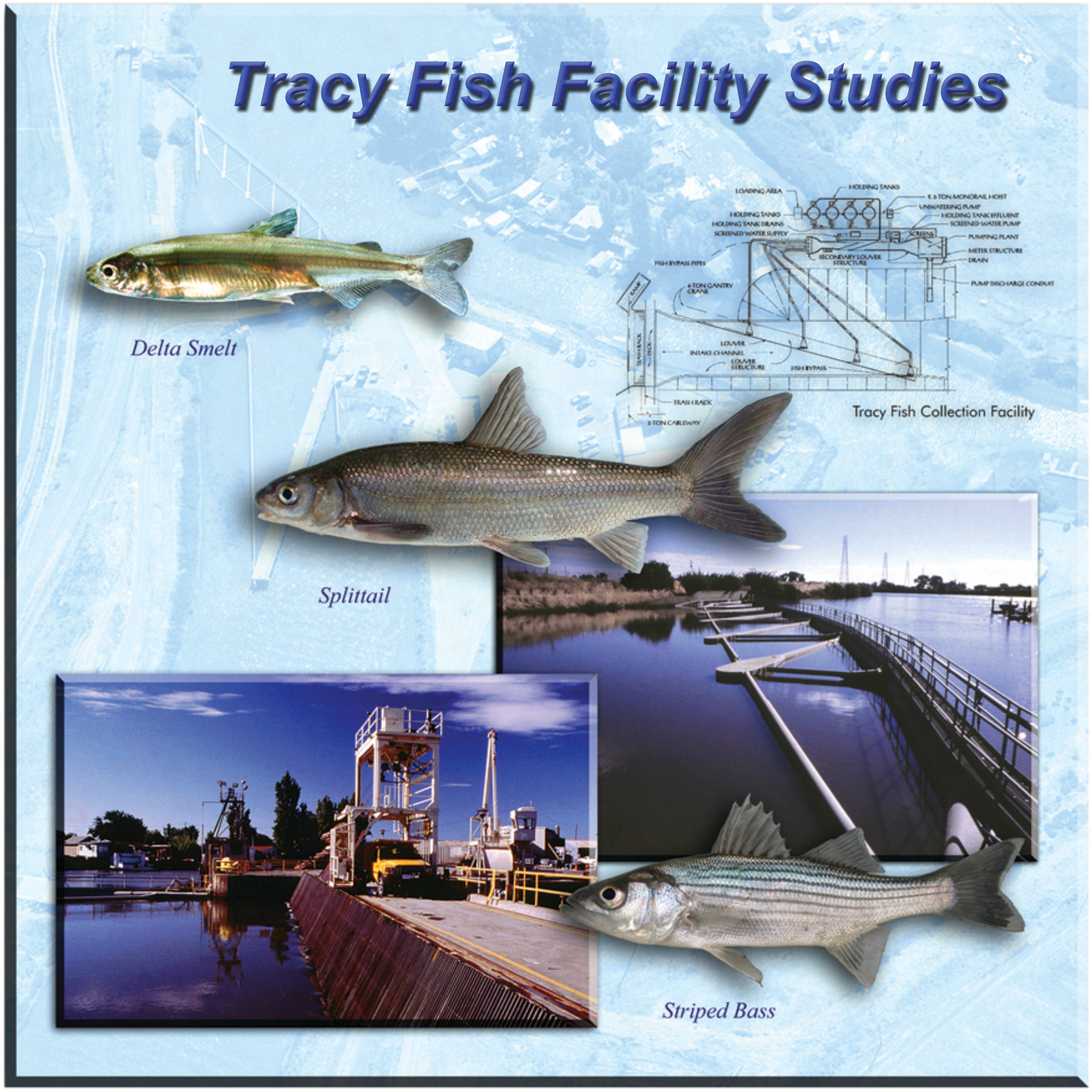

Modifications to Bypass System Operations to Improve Hydraulics at the Tracy Fish Collection Facility

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14. ABSTRACT
The Bureau of Reclamation's Tracy Fish Collection Facility, located at the head of the Delta-Mendota intake channel in the south Sacramento-San Joaquin Delta, was designed to salvage fish that would otherwise be entrained at the C.W. "Bill" Jones Pumping Plant. This hydraulic study examined whether closure of one or more of four primary bypasses can be used to increase facility compliance with stated bypass ratio and velocity criteria under a broader range of environmental conditions. Results show that closing bypasses will increase primary bypass ratios in remaining open bypasses. However, secondary velocities increase and secondary depths decrease, so secondary flow conditions must be monitored. Results also show that bypass closures can also be used in situations when primary bypass ratios are satisfactory, but secondary velocity is too high. After closing primary bypasses, pump settings in the secondary channel can be readjusted to reduce the secondary velocity. Because this operational technique has shown favorable hydraulic results, it is recommended that field experiments be conducted to determine the impact on fish and debris.

15. SUBJECT TERMS
Tracy Fish Collection Facility, hydraulics, criteria, bypass ratio, bypass pipe, velocity, velocity profile

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Tracy Fish Facility Studies
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Modifications to Bypass System Operations to Improve Hydraulics at the Tracy Fish Collection Facility

Volume 47

by

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April 2011

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Tracy Fish Facility Improvement Program

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Cover

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EXECUTIVE SUMMARY

The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF) is located at the head of the Delta-Mendota intake channel in the south Sacramento-San Joaquin Delta (Delta). The facility was designed to salvage fish that would otherwise be entrained at the C.W. "Bill" Jones Pumping Plant. At the TFCF, the primary and secondary channels must effectively guide fish along louvers and into bypass systems in order to collect fish in the holding tanks. Fish collection efficiencies are strongly influenced by channel velocities and bypass ratios at the bypass intakes. High pumping rates at Jones Pumping Plant and low water levels in the Delta produce high velocities in the TFCF primary channel which make it difficult or impossible to achieve stated facility criteria.

This hydraulic study determines whether closure of one or more of four primary bypasses can increase facility compliance with stated bypass ratio and velocity criteria under a broader range of environmental flow conditions. System-wide hydraulic data, including primary, secondary, and holding tank flow rates, primary and secondary velocities, bypass ratios, pump operation, and water levels were recorded or calculated from facility instrumentation for each test. Velocity profiles were collected in the primary and secondary channels before and during bypass closures to evaluate changes in velocity distribution or direction that could affect fish salvage.

When one or more primary bypasses were closed, more water flowed through the remaining open bypasses, thereby increasing bypass ratios in those bypasses. However, secondary velocities often increased and secondary depths decreased. Therefore, flow conditions must be monitored in the secondary channel to ensure that velocity criterion is achieved and water depths remain high enough for water to flow into the holding tanks. Results also showed that bypass closures can be used in situations where primary bypass ratios are satisfactory, but secondary velocity is too high. After closing primary bypasses, pump settings in the secondary channel can be adjusted to reduce the secondary velocity.

Because this operational technique has shown favorable hydraulic results, it is recommended that tagged fish be released in the primary channel upstream of the bypass intakes to verify that fish respond favorably to the closure of bypasses. Since the bypass valves are located at the end of the bypass pipes near the secondary channel, debris accumulation in closed bypasses should also be monitored during field trials. If bypass closures are recommended by researchers and approved by TFCF management and regulatory agencies, a facility operations table can be created to provide operational guidance at a given primary water depth and primary water velocity.

INTRODUCTION

The Tracy Fish Collection Facility (TFCF) is located at the head of the Delta-Mendota intake channel in the south Sacramento-San Joaquin Delta (Delta) near Tracy, California (Figure 1). The facility was constructed in the 1950s to salvage fish, primarily striped bass (*Morone saxatilis*) and Chinook salmon (*Oncorhynchus tshawytscha*), that would otherwise be entrained at the C.W. "Bill" Jones Pumping Plant. At the TFCF, the primary and secondary channels must effectively guide fish into bypass systems in order to salvage fish. Fish pass into the facility through a 34.1-m-long (112-ft) trashrack structure with 5.1-cm (2-in) spacing. The primary channel consists of a diagonal line of primary louvers designed to guide fish into one of four primary bypass intakes. The primary channel is 25.45 m (83.5 ft) wide at the start of the louvers and the louver length is 98.30 m (322.5 ft) on an angle of 15° with the flow direction. The louvers consist of a series of vertical slats placed at 2.5-cm (1-in) spacing with slats oriented normal to the flow direction. The louvers are designed to generate disturbances in the flow field that fish respond to and avoid. Fish maintain a distance off of the louver face, while sweeping flow is intended to guide fish along the louver line and into the bypasses.

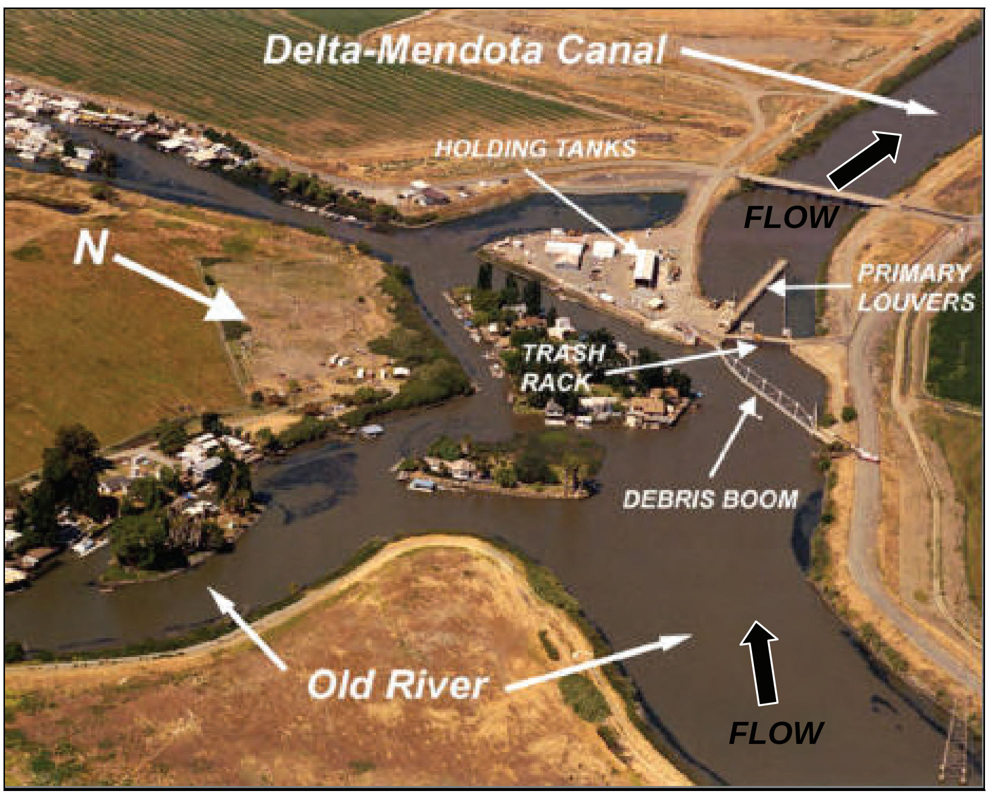

Figure 1.—Aerial photograph of the Tracy Fish Collection Facility.

Each bypass intake is 15.2 cm (6 in) wide by 6.7 m (22 ft) high with a vertically tapered choke section that transitions the rectangular box into pipes that carry fish and flow into a secondary channel. The four bypass pipes enter the secondary channel with bypass 1 on the left side of the channel and bypass 4 on the right side. Two sets of secondary louvers guide fish to another 15.2-cm-wide (6-in) fish bypass and into the holding tank area. Fish that are moved through the secondary bypass are concentrated in 6.1-m-diameter (20-ft) holding tanks until they are transported by tanker trucks to locations in the Delta out of the zone of influence of the pumping plant. Figure 2 shows a plan view schematic of the facility.

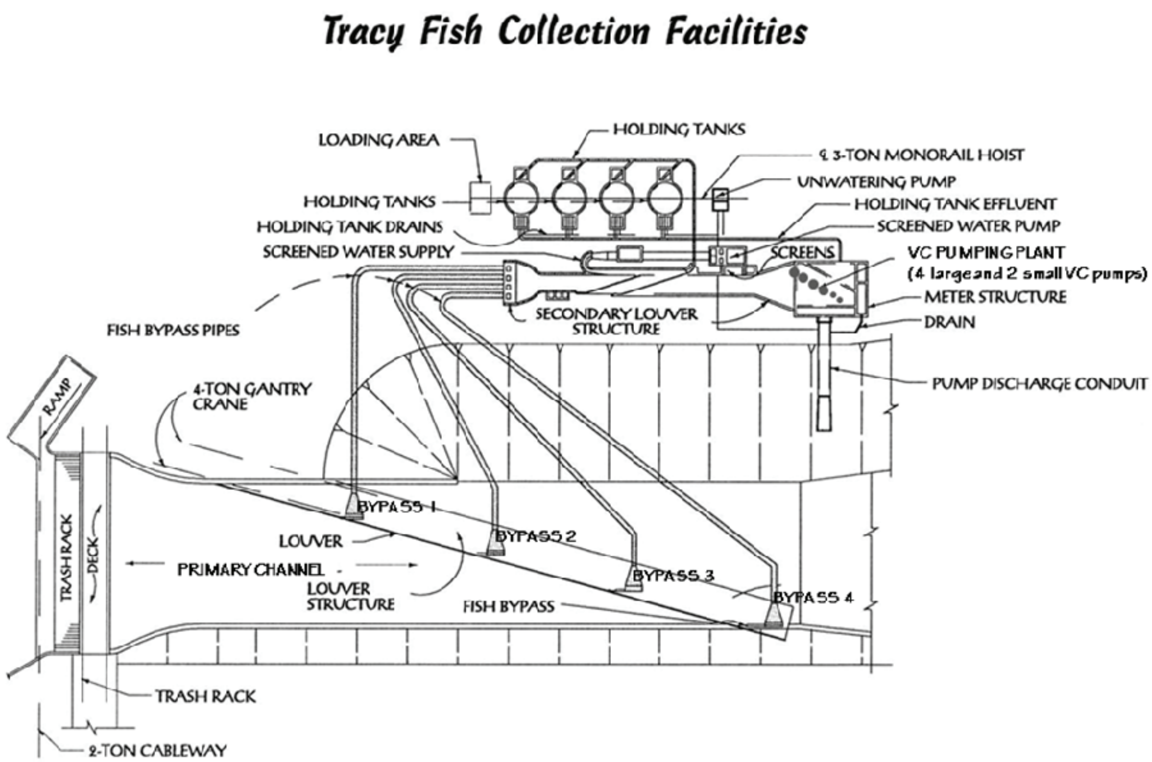

Figure 2.—Schematic of major features of the Tracy Fish Collection Facility.

The secondary channel flow rate is controlled by a bank of low head pumps positioned at the downstream end of the secondary channel. These pumps are referred to as “velocity control” or “VC” pumps. Four large (VC pumps 1, 2, 3, and 4) and two small (VC pumps 5 and 6) constant speed pumps can be turned on as needed to draw flow through the primary bypass intakes and into the secondary channel. VC pumps are turned on or off by facility operators to achieve criteria for primary bypass ratio and secondary velocity. If needed, butterfly valves can be opened in the sump to re-circulate water past the pumps. Opening the butterfly valves reduces flow drawn through the secondary channel for the same pump operation. Butterfly valves are typically maintained in the closed position.

Fish collection efficiencies are strongly influenced by channel flow velocity and bypass ratio of the bypass intakes. Channel velocity affects the amount of time that fish are in the system, their exposure time to predators, and their ability to successfully navigate the louver and bypass systems. Bypass ratio is defined as the ratio of bypass entrance velocity to channel velocity. Bates *et al*. (1960) and California Department of Water Resources (1967) have shown the importance of sustaining bypass ratios greater than 1.0 to maintain effective fish collection. Based on California State Water Resources Control Board Water Rights Decision 1485, the TFCF operates such that bypass ratios in the primary and secondary channels must be above 1.0 and the secondary channel velocity must be held at 0.91−1.07 m/s (3.0–3.5 ft/s) from November 1–May 14 while salmon are present and less than 0.76 m/s (2.5 ft/s) [preferably less than 0.46 m/s (1.5 ft/s)] from May 15–October 31 for striped bass, shad, catfish, and other fish (California State Water Resources Control Board 1978). According to the 2009 National Marine Fisheries Service (NMFS) Biological and Conference Opinion, "Reclamation shall operate the facility (Tracy Fish Collection Facility) to meet design criteria for louver bypasses and channel flows at least 75 percent of the time" (NMFS 2009).

Primary channel velocities are not within the control of facility operators. Operators make hydraulic adjustments to the facility to achieve operational criteria, if possible, under the given hydraulic conditions in the Delta-Mendota intake channel. High pumping rates at Jones Pumping Plant and low water levels in the Delta produce high velocities in the TFCF primary channel. VC pumps need to be turned on in the secondary channel to produce primary bypass entrance velocities that are greater than primary channel velocities. However, when many VC pumps are in operation, unacceptably high velocities in the secondary channel can result. Hydraulic field evaluations conducted in 2004 showed that bypass ratios less than 1.0 generate secondary flow patterns and eddies near bypass intakes as flow slows down toward intake entrances (DeMoyer 2007). Bypass ratios greater than 1.0 produced efficient acceleration of flow into intakes with little flow disruption.

The objective of this study was to determine if closing one or more primary bypasses can be used to increase facility compliance with stated criteria under a broader range of environmental flow conditions. By closing valves in one or two of four primary bypass pipes, more water will flow through bypasses that remain open when the VC pumping rate stays constant. This will produce higher primary bypass ratios in the open bypasses while limiting overall flow to the secondary channel. However, it is possible that secondary velocities may increase and secondary water levels may decrease under these operating conditions. Secondary velocities must be held within the range of acceptable operating criteria and the water level at the secondary bypass entrance must be above 1.16 m (3.8 ft) for the bypass pipe to flow full and fish to pass through into the holding tanks. In order to be an effective operational technique, bypass closures must meet all criteria at the bypass entrances and in the secondary channel.

Additional factors need to be considered when examining bypass closures as an operational strategy. Past studies have shown that the majority of fish are collected through the final bypass (Bates *et al*. 1960), so bypass 4 should always remain open.

The maximum recommended fish exposure duration on a screen face is 60 s (National Marine Fisheries Service 1995). If similar guidance is applied to the TFCF louver system, two adjacent bypasses may not be able to be closed at the same time depending on water velocity.

Closing bypasses at the TFCF was recommended by Mecum (1977) to improve striped bass salvage. This document contains an operations table that recommends bypass closures and VC pump operations for any combination of primary depth and primary velocity. When this procedure was employed at the TFCF, closed bypasses backed up with debris because the valves are located at the end of the bypass pipes. The resulting maintenance issues prevented this technique from being used during regular operations. Other complexities associated with closing bypasses, such as maintaining a minimum secondary water depth, were not considered at the time.

The merit of this type of operation is being reevaluated due to the need to achieve criteria under difficult hydraulic conditions. If a thorough hydraulic evaluation shows that closing bypasses is a reasonable operational technique from a hydraulic standpoint, questions about fish entrainment and debris accumulation in non-operating bypasses will need to be addressed in field demonstrations to ensure that fish salvage and facility maintenance are not negatively impacted by closing bypasses. Once all concerns are addressed, this operational change could be enacted after agency approval with no associated capital cost. A facility operations table (*e.g.*, Mecum 1977) can be created to recommend the best operation at a given primary water depth and primary water velocity.

METHODOLOGY

Field tests were conducted to document changes in hydraulic conditions in the primary and secondary channel when bypass closures occurred and to recommend future action on implementing bypass closures as an operational strategy. During field testing of replacement bypass intakes in 2004 and 2005, two initial data sets with closed bypasses were collected (DeMoyer 2004 and 2007). A more complete field evaluation was conducted at the TFCF in 2010.

System-wide hydraulic data were recorded from facility instrumentation for all tests. Water depths in the primary and secondary channels were measured with permanent ultrasonic water level sensors. Primary velocity and flow rate were measured with a ChannelMaster H-ADCP model acoustic Doppler current profiler (ADCP) installed in the primary channel (Teledyne RD Instruments, Inc., San Diego, California). Secondary flow rate was calculated as the sum of the bypass pipe flow rates measured on each pipe with Panametrics DigitalFlow DF868 ultrasonic meters (Olympus NDT, Inc., Waltham, Washington). Secondary velocity was calculated from the secondary discharge and secondary water depth. Average primary bypass intake velocity is calculated from the total secondary channel flow rate and the secondary bypass intake velocity is calculated from the total holding tank flow rate. Primary bypass ratio is the primary bypass intake velocity divided by the primary channel velocity. Secondary bypass ratio is the secondary bypass intake velocity divided by the secondary channel velocity. For each test, VC pump operation was recorded.

Large trashrack differentials, as seen during the 2004 and 2005 preliminary tests, have a significant effect on primary channel hydraulics by producing highly skewed flow distributions in the primary channel. Installation of an automated trashrack cleaner (Ovivo, Inc., Salt Lake City, Utah) in 2010 has decreased debris accumulation on the trashrack and maintained primary channel flow conditions that provide the best opportunity for fish collection in the bypass intakes. Debris levels were low during field testing in 2010 with water surface differentials across the trashrack of less than 0.15 m (0.5 ft) and differentials across the primary louvers of less than 0.15 m (0.5 ft).

During field tests in 2004, velocity profiles were collected with a portable OTT Qliner ADCP (OTT Hydromet GmbH, Kempten, Germany) at three lateral locations in the secondary channel upstream of the louver line and one location in the center of the channel directly upstream of the louvers (DeMoyer 2004). Data were collected during operation with all four primary bypasses open and then during operations with one or two primary bypass pipes closed. Velocity profiles were averaged over a 60-s interval at 2,000 kHz allowing effects of outliers and boat movement to be minimal. A handheld computer collected data via a Bluetooth transmitter. Raw data were processed in OTT Qliner Review software. A schematic of the measurement locations in the secondary channel is shown in Figure 3.

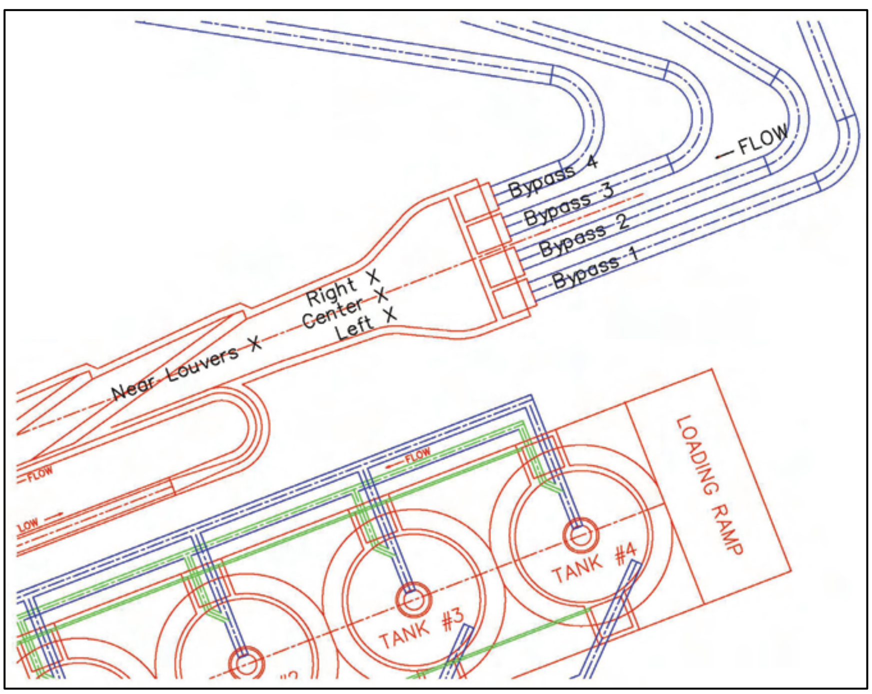

Figure 3.—Schematic of bypass pipe locations and velocity profile measurement locations in the secondary channel.

During field tests in 2005, primary bypass ratios needed to be raised above 1.0 to evaluate the performance of the replacement bypass intakes (DeMoyer 2007). Up to three bypasses were closed to increase bypass ratios above 1.0. In order to identity changes in velocity fields due to bypass closures, velocity data were collected inside the primary bypass intakes with a SonTek acoustic Doppler velocity meter (ADV) (SonTek/YSI, Inc., San Diego, California) and 4.6 m (15 ft) upstream of the primary bypass intakes with an OTT Qliner ADCP. The ADV was affixed to the louver panel in the mouth of the bypass intake. The ADCP was attached to a rope and floated upstream of a bypass intake as in Figure 4. Single plane, narrow beams provided accurate data close to the primary louver line.

Figure 4.—OTT Qliner current profiler floating upstream of a bypass intake.

In 2010, five hydraulic experiments were conducted to expand upon findings from previous field tests. Field tests were desired during maximum pumping with five pumps at Jones Pumping Plant because it is the most difficult time to achieve criteria at the TFCF. However, five pump operations were not available during most of the 2010 season. Field studies were instead conducted in June during four pump operations. Although facility criteria could be achieved during all field tests with typical facility operations, the manipulation of bypass operations shows how hydraulics at the facility can change due to bypass closures.

In Test 1, velocity profiles were collected 3.7 m (12 ft) and 4.6 m (15 ft) upstream of bypass 1 to observe changes in approach conditions when a bypass was closed. Velocity profiles were collected with a Qliner ADCP to identify the flow field that fish would experience while approaching a closed bypass. Eddying, reverse flows, or skewed velocity profiles would indicate potential problems with closing bypasses as an operational strategy. Tests 2 through 4 examined how VC pump operations can be modified during bypass closures to improve hydraulic conditions. In these tests, facility instrumentation was recorded and analyzed.

Test 5 was conducted to determine the extent to which the velocity profile in front of a bypass changes when an increasing flow is drawn through the bypass. For this test, all bypasses were closed except for bypass 1, and the number of VC pumps in operation increased in order to force more flow through the only open bypass. Four different VC configurations were tested:

- One small VC pump (pump 5) with one butterfly valve in the pumping plant set to 45 degrees
- One large VC pump (pump 1) with the butterfly valve closed
- Two large VC pumps (pumps 1 and 2) with the butterfly valve closed
- Three large VC pumps (pumps 1, 2, and 3) with the butterfly valve closed

Butterfly valves can be opened in the sump to re-circulate pumped water back into the pumping plant. Opening the butterfly valves reduces the flow drawn through the secondary channel. Butterfly valves are typically maintained in the closed position, but can be opened to obtain more precise secondary discharges. In this test, one of the butterfly valves was opened to 45° when one small VC pump was operated in order to obtain a low discharge through the secondary channel.

RESULTS

Secondary channel velocity data were collected with all four primary bypasses open and then during operations with one or two primary bypass pipes closed in Figures 5–8 (DeMoyer 2004). Results show that closing primary bypasses does not skew the flow approaching the secondary louvers; therefore closing bypasses should not affect the ability of fish to gain entrance to the secondary fish bypass.

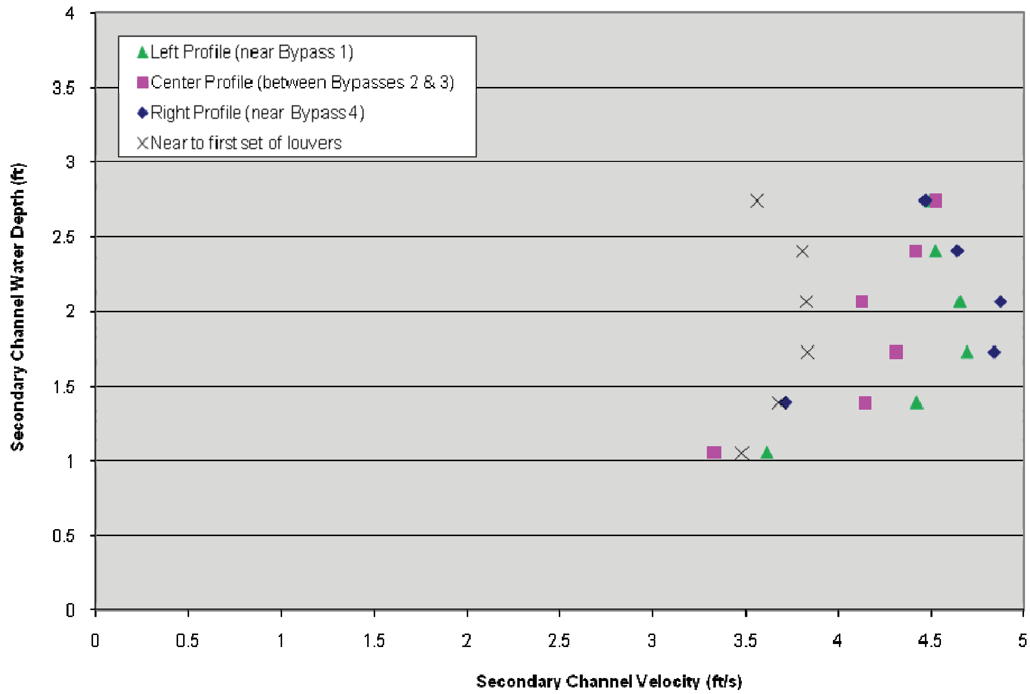

Figure 5.—Data collected at three lateral locations across the secondary channel and directly upstream of the secondary louver line while all bypasses are open (DeMoyer 2004). Metric equivalent: 1 m = 3.28 ft.

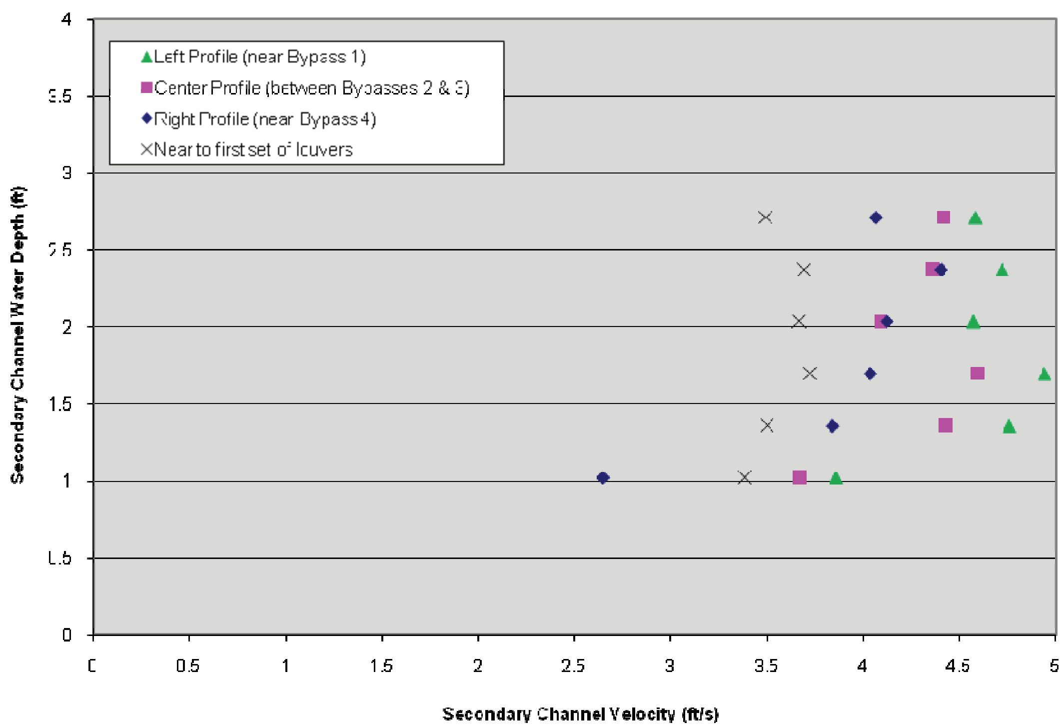

Figure 6.—Data collected at three lateral locations across the secondary channel and directly upstream of the secondary louver line while bypass 1 is closed (DeMoyer 2004). Metric equivalent: 1 m = 3.28 ft.

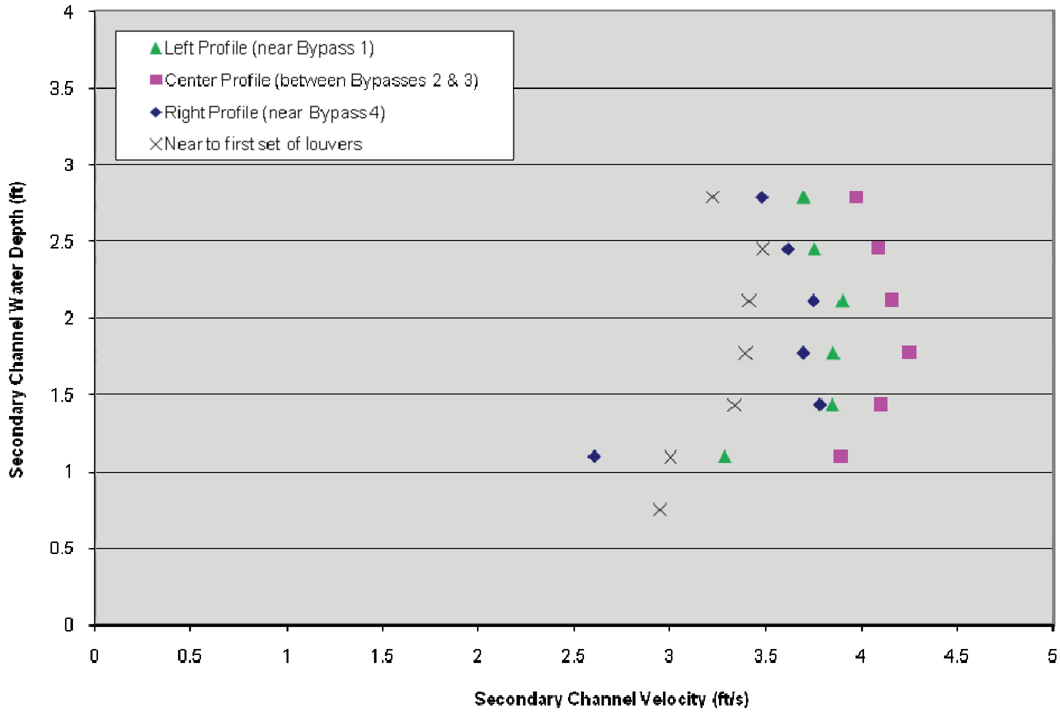

Figure 7.—Data collected at three lateral locations across the secondary channel and directly upstream of the secondary louver line while bypass 1 and 3 are closed (DeMoyer 2004). Metric equivalent: 1 m = 3.28 ft.

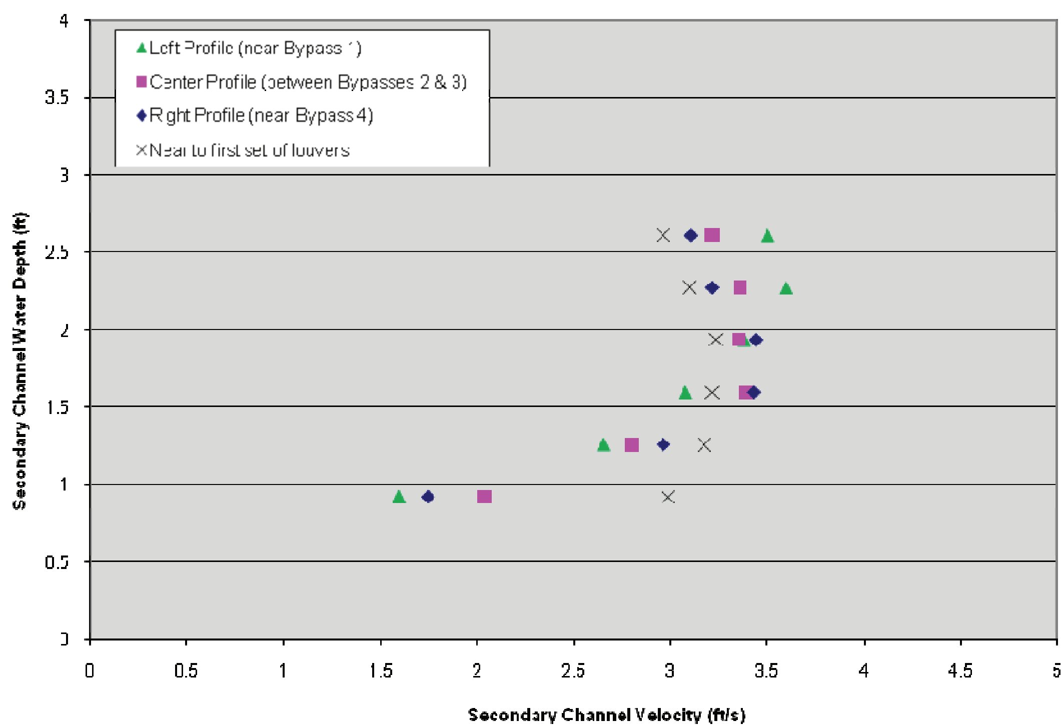

Figure 8.—Data collected at three lateral locations across the secondary channel and directly upstream of the secondary louver line while bypass 1 and 2 are closed (DeMoyer 2004). Metric equivalent: 1 m = 3.28 ft.

Velocity data collected inside primary bypass intake 1 and 4.6 m (15 ft) upstream of primary bypass intake 1 show how velocity magnitude and distribution changes with bypass closures. Closing bypasses 1 and 2 increased the bypass ratio of bypass 4 from 1.05 to 1.32 and produced an acceleration of flow into the bypass intake as seen in Figures 9 and 10. Results showed that the shape of the approach bypass profiles looked similar to the approach profiles collected during operation with four bypasses. Decreased secondary water depths and increased secondary velocities were reported along with the increase in bypass ratios.

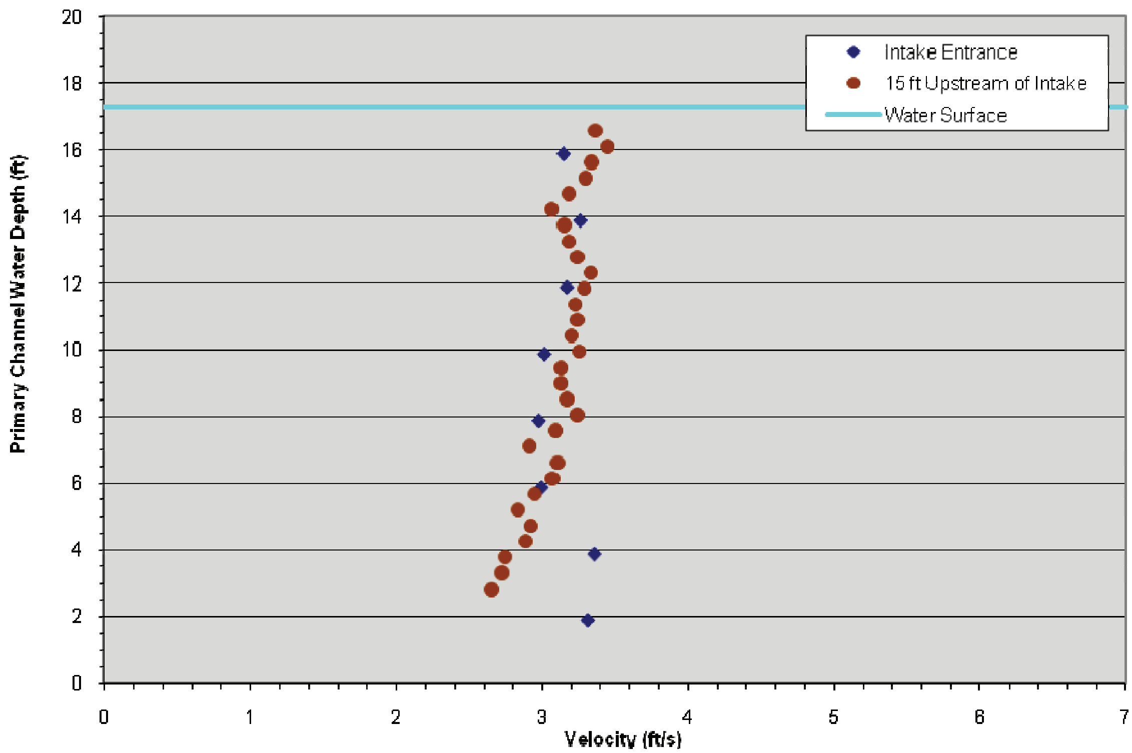

Figure 9.—Velocity profiles collected at bypass 4 with all four bypasses open and a bypass ratio of 1.05 (DeMoyer 2007). Metric equivalent: 1 m = 3.28 ft.

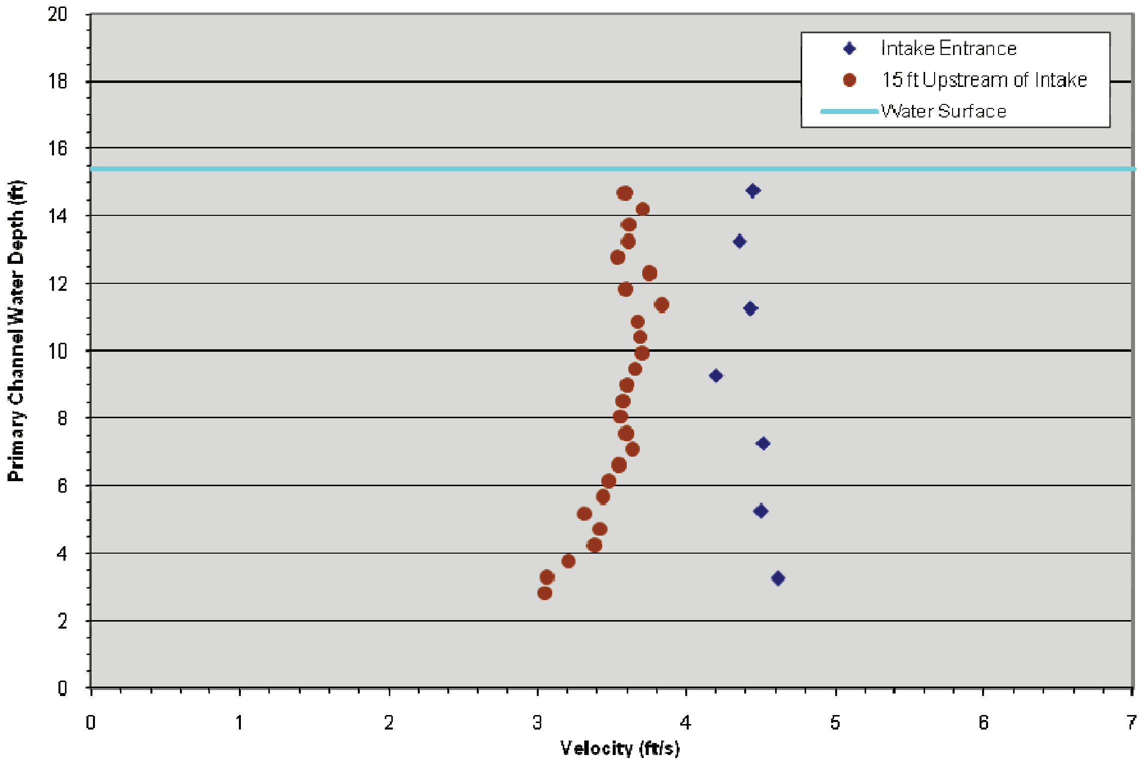

Figure 10.—Velocity profiles collected at bypass 4 with bypass 1 and 2 closed and a bypass ratio of 1.32 (DeMoyer 2007). Metric equivalent: 1 m = 3.28 ft.

In Test 1 in 2010, velocity profiles collected in front of bypass 1 show that velocity distributions 3.7 m (12 ft) and 4.6 m (15 ft) upstream of the bypass intake are not negatively impacted by the closure of bypass 1 (Figure 11). It is unclear why the velocity profile is more uniformly distributed vertically after the bypass is closed; however it is notable that velocity profiles collected after the bypass closure do not indicate the presence of eddying, reverse flows, or sudden velocity changes that could affect fish salvage.

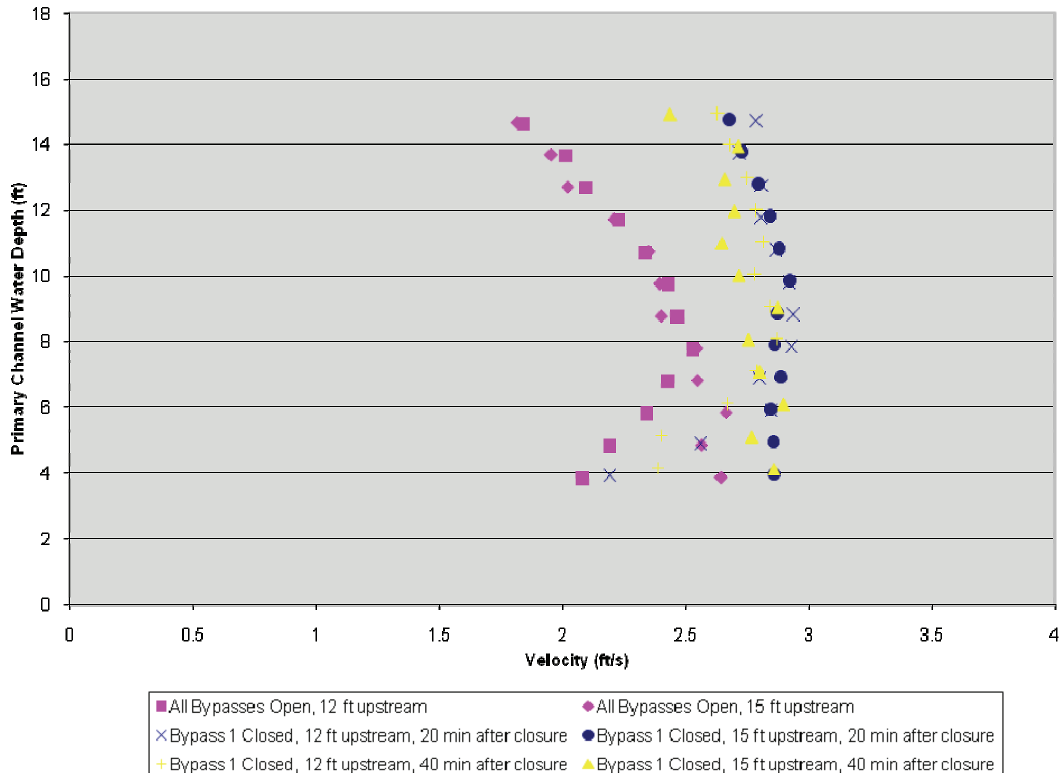

Figure 11.—Velocity profiles collected 3.7 m (12 ft) and 4.6 m (15 ft) upstream of bypass 1 when the bypass is open and closed. Metric equivalent: 1 m = 3.28 ft.

Initially, all bypasses were fully open with VC pumps 3, 4, and 5 producing a total discharge of 2.42 m^3/s (85.6 ft^3/s) through the bypass pipes. The average primary bypass ratio was approximately 1.11, the secondary flow depth was 1.52 m (5.00 ft), and the secondary velocity was 0.65 m/s (2.14 ft/s). Then, bypass 1 was closed and no adjustments were made to the VC pumps in the secondary channel. The average primary bypass ratio increased to approximately 1.39, the secondary depth decreased to 1.36 m (4.47 ft), and the secondary velocity increased to 0.73 m/s (2.41 ft/s). Although the primary bypass ratio increased by 0.28, the secondary velocity increased by 0.08 m/s (0.27 ft/s) and the flow depth declined by 0.16 m (0.53 ft). Table 1 details the hydraulic conditions during Test 1.

To provide further insight into the effect of closing bypass 1, the overall VC pumping rate was reduced by turning one large pump off and turning one small pump on. With VC pumps 3, 5, and 6 producing a total discharge of 2.27 m^3/s (80.3 ft^3/s) through the bypass pipes, the secondary velocity decreased to 0.63 m/s (2.08 ft/s) and the secondary flow depth increased to 1.47 m (4.82 ft). The average primary bypass ratio decreased to 1.17 which is similar to the initial primary bypass ratio of 1.11 (Table 1). From this test, it appears that closing primary bypasses may be used for a reason other than to increase the primary bypass ratio. This operational technique could also be used to reduce the secondary channel velocity while maintaining the same primary bypass ratio. Three more data sets were collected to detail this phenomenon.

Table 1.—Test 1 hydraulic data during the closure of bypass 1.

	TEST 1		
	All Bypasses Open	**Bypass 1 Closed: VC Pumps Not Adjusted**	**Bypass 1 Closed: VC Pumps Adjusted**
Bypasses Open	1, 2, 3, 4	2, 3, 4	2, 3, 4
Primary Velocity - m/s (ft/s)	0.70 (2.30)	0.76 (2.48)	0.83 (2.71)
Primary Depth - m (ft)	5.09 (16.69)	5.09 (16.70)	5.13 (16.83)
Primary Intake Velocity - m (ft/s)	0.78 (2.56)	1.05 (3.44)	0.97 (3.18)
Primary Bypass Ratio	1.11	1.39	1.17
VC Pumps On	Pumps 3,4,5	Pumps 3,4,5	Pumps 3,5,6
Bypass 1 Discharge - m^3/s (ft^3/s)	0.66 (23.4)	0 (0)	0 (0)
Bypass 2 Discharge - m^3/s (ft^3/s)	0.63 (22.2)	0.87 (30.6)	0.81 (28.6)
Bypass 3 Discharge - m^3/s (ft^3/s)	0.60 (21.1)	0.81 (28.7)	0.77 (27.3)
Bypass 4 Discharge - m^3/s (ft^3/s)	0.54 (18.9)	0.76 (26.8)	0.69 (24.4)
Total Bypass Discharge - m^3/s (ft^3/s)	2.42 (85.6)	2.44 (86.1)	2.27 (80.3)
Secondary Velocity - m/s (ft/s)	0.65 (2.14)	0.73 (2.41)	0.63 (2.08)
Secondary Depth - m (ft)	1.52 (5.00)	1.36 (4.47)	1.47 (4.82)
Secondary Intake Velocity - m (ft/s)	1.01 (3.31)	0.97 (3.17)	1.00 (3.27)
Secondary Bypass Ratio	1.55	1.32	1.57

Hydraulic data collected during Test 2 are displayed in Table 2. When all bypass pipes were open with three large VC pumps drawing a total discharge of 3.21 m^3/s (113.4 ft^3/s), the average primary bypass ratio was 1.18, the secondary velocity was 0.76 m/s (2.50 ft/s), and the secondary depth was 1.73 m (5.66 ft). When bypass 1 was closed with the same VC pump operation, the primary bypass ratio of 1.18 was raised to 1.38. The secondary depth dropped from 1.73 to 1.57 m (5.66 to 5.14 ft) and the secondary velocity stayed about the same at 0.76 m/s (2.50 ft/s).

When one large VC pump was turned off, the total discharge through the bypass pipes decreased from 3.21 to 2.39 m^3/s (113.4 to 84.4 ft^3/s). The primary bypass ratio decreased to 1.16, which is close to the initial bypass ratio of 1.18, and the secondary velocity decreased significantly to 0.56 m/s (1.83 ft/s). In a situation where the bypass ratio is above 1.0, but the secondary velocity is too high, this technique could be used to lower the secondary velocity while maintaining a similar primary bypass ratio.

Table 2.—Test 2 hydraulic data during the closure of bypass 1.

	TEST 2		
	All Bypasses Open	**Bypass 1 Closed: VC Pumps Not Adjusted**	**Bypass 1 Closed: VC Pumps Adjusted**
Bypasses Open	1, 2, 3, 4	2, 3, 4	2, 3, 4
Primary Velocity - m/s (ft/s)	0.83 (2.71)	0.83 (2.73)	0.83 (2.72)
Primary Depth - m (ft)	5.41 (17.74)	5.42 (17.77)	5.44 (17.84)
Primary Intake Velocity - m (ft/s)	0.97 (3.20)	1.15 (3.77)	0.96 (3.15)
Primary Bypass Ratio	1.18	1.38	1.16
VC Pumps On	Pumps 1,3,4	Pumps 1,3,4	Pumps 1,3
Bypass 1 Discharge - m^3/s (ft^3/s)	0.91 (32.0)	0 (0)	0 (0)
Bypass 2 Discharge - m^3/s (ft^3/s)	0.82 (29.1)	1.02 (36.1)	0.86 (30.2)
Bypass 3 Discharge - m^3/s (ft^3/s)	0.77 (27.3)	0.93 (32.8)	0.80 (28.2)
Bypass 4 Discharge - m^3/s (ft^3/s)	0.71 (25.0)	0.89 (31.5)	0.74 (26.0)
Total Bypass Discharge - m^3/s (ft^3/s)	3.21 (113.4)	2.84 (100.4)	2.39 (84.4)
Secondary Velocity - m/s (ft/s)	0.76 (2.50)	0.74 (2.44)	0.56 (1.83)
Secondary Depth - m (ft)	1.73 (5.66)	1.57 (5.14)	1.75 (5.75)
Secondary Intake Velocity - m (ft/s)	0.93 (3.04)	0.80 (2.62)	0.70 (2.28)
Secondary Bypass Ratio	1.21	1.07	1.24

Hydraulic data collected during Test 3 are displayed in Table 3. In Test 3, the primary bypass ratio of 1.53 was increased to 1.81 when bypass 1 was closed. The secondary depth declined from 1.58 to 1.41 m (5.18 to 4.62 ft) and the secondary velocity stayed about the same at 0.83 m/s (2.70 ft/s). When one large VC pump was turned off, the overall discharge to the secondary channel decreased. This produced a decrease in the primary bypass ratio to 1.52, similar to the initial primary bypass ratio of 1.53, with a much reduced secondary velocity of 0.63 m/s (2.08 ft/s).

Table 3.—Test 3 hydraulic data during the closure of bypass 1.

	TEST 3		
	All Bypasses Open	**Bypass 1 Closed: VC Pumps Not Adjusted**	**Bypass 1 Closed: VC Pumps Adjusted**
Bypasses Open	1, 2, 3, 4	2, 3, 4	2, 3, 4
Primary Velocity - m/s (ft/s)	0.64 (2.11)	0.65 (2.14)	0.65 (2.13)
Primary Depth - m (ft)	5.28 (17.33)	5.26 (17.27)	5.24 (17.20)
Primary Intake Velocity - m (ft/s)	0.98 (3.23)	1.18 (3.86)	0.99 (3.24)
Primary Bypass Ratio	1.53	1.81	1.52
VC Pumps On	Pumps 1,3,4	Pumps 1,3,4	Pumps 1,3
Bypass 1 Discharge - m^3/s (ft^3/s)	0.87 (30.6)	0	0
Bypass 2 Discharge - m^3/s (ft^3/s)	0.82 (28.9)	1.02 (35.9)	0.83 (29.4)
Bypass 3 Discharge - m^3/s (ft^3/s)	0.78 (27.4)	0.94 (33.3)	0.81 (28.5)
Bypass 4 Discharge - m^3/s (ft^3/s)	0.71 (25.0)	0.88 (30.9)	0.72 (25.6)
Total Bypass Discharge - m^3/s (ft^3/s)	3.17 (111.9)	2.83 (100.1)	2.36 (83.5)
Secondary Velocity - m/s (ft/s)	0.82 (2.70)	0.83 (2.71)	0.63 (2.08)
Secondary Depth - m (ft)	1.58 (5.18)	1.41 (4.62)	1.53 (5.03)
Secondary Intake Velocity - m (ft/s)	1.20 (3.93)	1.34 (4.41)	1.19 (3.91)
Secondary Bypass Ratio	1.45	1.63	1.88

In Test 4, the primary bypass ratio increased from 1.01 to 1.36 when bypass 1 was closed. The secondary depth declined from 1.63 to 1.46 m (5.34 to 4.79 ft) and the secondary velocity increased slightly from 0.69 to 0.72 m/s (2.27 to 2.35 ft/s). When one small VC pump was turned off, the overall discharge to the secondary decreased, causing a decrease in the primary bypass ratio to 1.03. The secondary depth increased to 1.64 m (5.38 ft) and the secondary velocity decreased significantly to 0.49 m/s (1.60 ft/s).

Table 4.—Test 4 hydraulic data during the closure of bypass 1.

	TEST 4		
	All Bypasses Open	**Bypass 1 Closed: VC Pumps Not Adjusted**	**Bypass 1 Closed: VC Pumps Adjusted**
Bypasses Open	1, 2, 3, 4	2, 3, 4	2, 3, 4
Primary Velocity - m/s (ft/s)	0.85 (2.80)	0.79 (2.58)	0.80 (2.62)
Primary Depth - m (ft)	5.21 (17.10)	5.20 (17.07)	5.22 (17.11)
Primary Intake Velocity - m (ft/s)	0.86 (2.84)	1.07 (3.51)	0.82 (2.69)
Primary Bypass Ratio	1.01	1.36	1.03
VC Pumps On	Pumps 3,4,5	Pumps 3,4,5	Pumps 3,4
Bypass 1 Discharge - m^3/s (ft^3/s)	0.77 (27.2)	0 (0)	0 (0)
Bypass 2 Discharge - m^3/s (ft^3/s)	0.73 (25.7)	0.92 (32.4)	0.72 (25.6)
Bypass 3 Discharge - m^3/s (ft^3/s)	0.67 (23.7)	0.86 (30.5)	0.65 (23.0)
Bypass 4 Discharge - m^3/s (ft^3/s)	0.58 (20.4)	0.76 (27.0)	0.58 (20.4)
Total Bypass Discharge - m^3/s (ft^3/s)	2.75 (97.0)	2.55 (89.9)	1.95 (69.0)
Secondary Velocity - m/s (ft/s)	0.69 (2.27)	0.72 (2.35)	0.49 (1.60)
Secondary Depth - m (ft)	1.63 (5.34)	1.46 (4.79)	1.64 (5.38)
Secondary Intake Velocity - m (ft/s)	0.89 (2.91)	1.02 (3.33)	0.98 (3.21)
Secondary Bypass Ratio	1.28	1.42	2.00

In Test 5, all bypasses were closed except for bypass 1. Primary bypass ratios increased from 1.15 to 2.18 at bypass 1 by increasing VC pump discharges. As more flow entered through the bypass, the velocity profile shifted to a larger velocity magnitude and the velocity distribution became more uniform. The overall discharge drawn into the secondary channel did not increase when pumping operations increased from two to three VC pumps; however secondary depth and velocity were affected. Results from Test 5 show that increases in the primary bypass ratio at a specific bypass will improve bypass hydraulics with no recorded negative hydraulic implications near the primary bypass intake (Table 5 and Figure 12).

Table 5.—Test 5 hydraulic data when bypass flows were increased from one small VC pump (with butterfly valve in the pump station open to 45°) to three large VC pumps (with butterfly valve closed).

	TEST 5			
	1 Small VC Pump (Valve open 45°)	**1 Large VC Pump**	**2 Large VC Pumps**	**3 Large VC Pumps**
Bypasses Open	1	1	1	1
Primary Velocity - m/s (ft/s)	0.82 (2.70)	0.81 (2.67)	0.84 (2.74)	0.82 (2.70)
Primary Depth - m (ft)	5.36 (17.58)	5.31 (17.43)	5.32 (17.47)	5.34 (17.51)
Primary Intake Velocity - m (ft/s)	0.95 (3.12)	1.47 (4.82)	1.80 (5.90)	1.79 (5.88)
Primary Bypass Ratio	1.15	1.80	2.15	2.18
VC Pumps On	Pump 5	Pump 1	Pump 1,2	Pumps 1,2,3
Bypass 1 Discharge - m^3/s (ft^3/s)	0.78 (27.4)	1.19 (42.0)	1.46 (51.5)	1.46 (51.5)
Bypass 2 Discharge - m^3/s (ft^3/s)	0 (0)	0 (0)	0 (0)	0 (0)
Bypass 3 Discharge - m^3/s (ft^3/s)	0 (0)	0 (0)	0 (0)	0 (0)
Bypass 4 Discharge - m^3/s (ft^3/s)	0 (0)	0 (0)	0 (0)	0 (0)
Total Bypass Discharge - m^3/s (ft^3/s)	0.78 (27.4)	1.19 (42.0)	1.46 (51.5)	1.46 (51.5)
Secondary Velocity - m/s (ft/s)	0.18 (0.58)	0.35 (1.16)	0.62 (2.03)	0.72 (2.37)
Secondary Depth - m (ft)	1.79 (5.88)	1.38 (4.54)	0.97 (3.17)	0.83 (2.72)

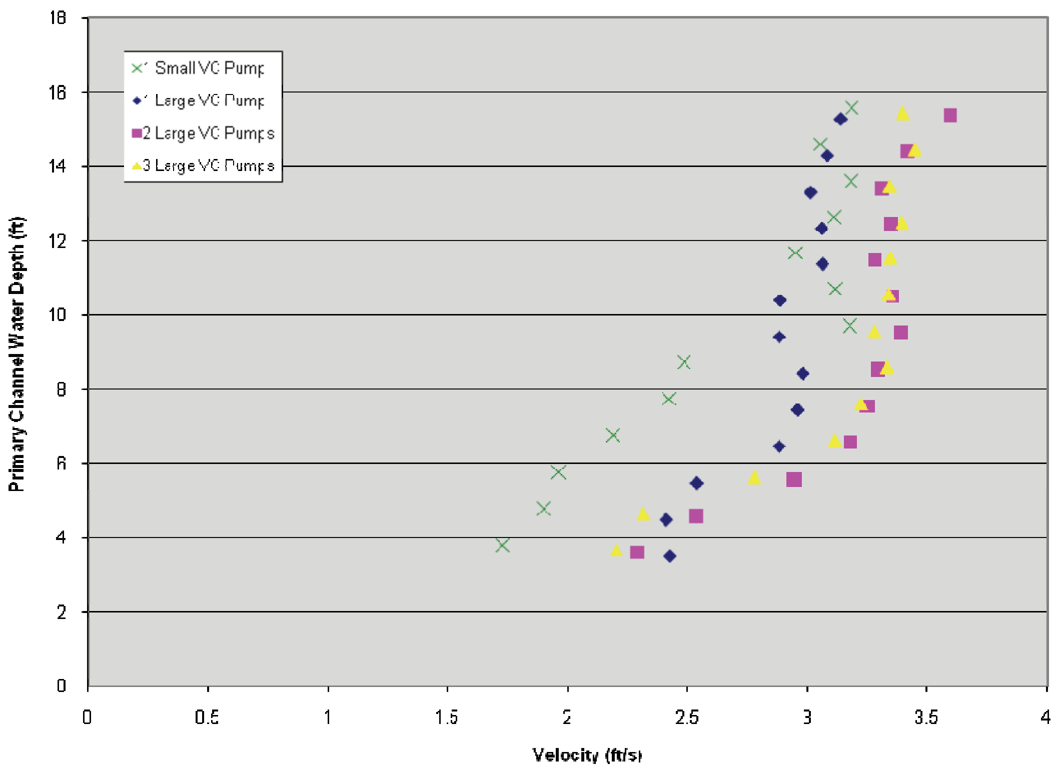

Figure 12.—Velocity profiles collected 3.6 m (12 ft) upstream of bypass 1 when VC pumping operation is increased from one small VC pump to three large VC pumps.

Metric equivalent: 1 m = 3.28 ft.

CONCLUSIONS AND RECOMMENDATIONS

Results from previous experiments have shown the importance of maintaining bypass ratios greater than 1.0 with gradual acceleration into the bypass intakes. Regulations mandate that bypass ratios be maintained above 1.0 in the primary and secondary channel and secondary channel velocities must be held within specified ranges during certain times of the year (California State Water Resources Control Board 1978). According to the 2009 NMFS Biological and Conference Opinion, “Reclamation shall operate the facility to meet design criteria for louver bypasses and channel flows at least 75 percent of the time” (NMFS 2009).

From the hydraulic evaluations conducted in 2004, 2005, and 2010, it appears that bypass closures can have hydraulic benefits when it is difficult or impossible to achieve facility criteria with all four bypasses open. Flow conditions in front of open and closed bypasses and in the secondary channel are not adversely impacted by bypass closures. Bypass closures can be used to either increase primary bypass ratios or decrease secondary velocities, depending on flow conditions.

When one or more of four primary bypass pipes is closed, flows increase through the bypasses that remain open. During testing, average primary bypass ratios increased by 0.2–0.35 when one bypass was closed and VC pumping rates were kept constant. No detrimental hydraulic conditions occurred at the closed bypasses, such as eddying, reverse flows, or skewness in the velocity profiles. Tests showed that hydraulic conditions in the secondary channel are also acceptable when bypasses are closed (DeMoyer 2004). If there is no risk of exceeding secondary velocity criteria and a secondary depth of at least 1.16 m (3.8 ft) can be maintained in order to fill the holding tanks, this technique can be used to successfully raise the primary bypass ratio. Bypass closures can also be used in situations where primary bypass ratios are well above 1.0, but secondary velocity exceeds criteria. Tests showed that secondary velocities could be lowered by up to 0.20 m/s (0.67 ft/s) by closing a bypass and then lowering the VC pumping rate.

It is recommended that mark and recapture tests be conducted to verify that fish respond favorably to the closure of bypasses. Tagged fish should be released in the primary channel upstream of the bypass intakes. There may be fish losses through the louver line as fish negotiate closed bypasses or fish may be entrained inside closed bypass pipes. It may be possible to estimate fish entrainment by using acoustic imagery at the bypass entrance. Debris accumulation in closed bypasses will need to be monitored during field experiments to ensure that debris does not collect inside the system or cause maintenance problems. Depending on field results, the primary intake guide walls may need to be removed to optimize fish guidance around non-operating bypasses or a method to close off the bypass entrance may need to be designed. If bypass closures are recommended by researchers and approved by TFCF management and regulatory agencies, a facility operations table (*e.g.*, Mecum 1977) can be created to provide operational guidance at a given primary water depth and primary water velocity.

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