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Roza Fish Screens Facility: Velocity Measurements at a High Canal Flow Rate

U.S. Department of the Interior
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14. ABSTRACT
A hydraulic evaluation was conducted in August 2004 at the Roza Fish Screens Facility at a high canal diversion rate of 1911 cfs. The primary objective of this evaluation was to determine whether primary bypass flow rates can be reduced from the recommended operating criteria of 65 cfs to 50 cfs during high canal diversion operations while maintaining drum screen velocity criteria. For both operational bypass conditions, approach and sweep velocities were measured near drum screens in two bays at five vertical locations and seven lateral locations per screen. Velocity data were analyzed for compliance with facility design criteria and federal fish protection criteria. Field weir ratings were developed for the full range of primary bypass weir operations. In the final bypass channel, bypass flow rates were measured for two operational water surface elevations in the secondary screening facility.

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fish screens, drum screens, screen criteria, velocity measurements, water diversion, fish bypass, sediment sluicing, weir rating

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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STUDY SUMMARY

A hydraulic evaluation was conducted in August 2004 at the Roza Fish Screens Facility at a high canal diversion rate of 1911 ft^3/s. The primary objective of the evaluation was to determine whether primary bypass flow rates can be reduced to 50 ft^3/s during high canal diversion operations while minimizing stress on downstream-migrating salmon and maintaining drum screen velocity criteria. In order to accurately set bypass flow rates in the screening bays, weir ratings were developed for the full range of weir operations. In the final bypass channel, appropriate weir heights were set for two operational water surface elevations in the secondary screening facility. The corresponding bypass flow rates were measured in the final bypass channel.

Approach and sweep velocities were measured in Bays 2 and 5 near six rotating drum screens under two operational conditions:

- *Recommended operating primary bypass flow rate* – bypass weirs set to 4.4 ft of head on the weir crest to pass approximately 65 ft^3/s.
- *Reduced primary bypass flow rate* – bypass weirs set at 3.35 ft of head on the weir crest to pass approximately 50 ft^3/s.

Velocities were measured near each drum screen at five vertical locations (0.05, 0.2, 0.5, 0.8, and 0.9 times the water depth) and seven lateral locations across the screen at a distance of approximately 3 inches in front of the drum screen face. For both bypass flow rate conditions, velocity data were analyzed for compliance with facility design criteria and National Oceanic and Atmospheric Administration (NOAA) fish protection criteria.

Conclusions from this evaluation include:

Primary Fish Bypass Weirs

- Primary bypass weirs are generally operated as submerged weirs.
- The onset of submergence occurs at approximately 2.8 ft of head on the weir (39.6 ft^3/s) with a water surface elevation of 1213.0 ft in the secondary screening facility.
- The bypass weirs cannot be considered suppressed rectangular weirs since the weir crest is partially contracted by 0.15 ft and the vertical sidewalls of the downwell are wider than the sidewalls of the approach channel, allowing for lateral contraction or expansion of the overflow jet. The standard weir rating for a partially contracted weir cannot be applied for several reasons: the adjustable weir blades are not sharp-crested, an aerated nappe is not maintained during operation in a partially submerged condition, and the weirs are typically operated in a submerged condition.
- An average leakage rate of 1.5 cfs exists at the adjustable weir gates.
- Field weir ratings for Bays 1, 3, and 5 are consistent when free flow and partially submerged conditions exist. Under submerged conditions, upstream bays (Bay 1) with longer fish bypass pipes become less efficient due to pipe headlosses.

- Although weir ratings vary slightly between bays, the general primary bypass weir rating equation can be used to calculate primary bypass flow rates or set bypass weirs with a water surface elevation of 1213.0 ft in the secondary screening facility:
  $Q = 1.5537 – 1.3761\ H + 8.4316\ H^2 – 1.1012\ H^3$
  where H is the head on the weir in feet and Q is the bypass flow rate in ft^3/s.
- From the weir ratings, the primary bypass flow rate for the recommended weir setting of 4.4 ft of head is 64.9 ft^3/s. To achieve a reduced bypass flow rate of 50 ft^3/s, the primary bypass weirs should be set to 3.35 ft of head.

Final Fish Bypass Weirs

- At a secondary screening elevation of 1213.0 ft with no juvenile fish ramp installed, 3.0 ft of head on the final bypass weir is needed to maintain an optimal tailwater pool for safe fish passage. This corresponds to a final bypass flow rate of 40.4 ft^3/s.
- At a secondary screening elevation of 1213.8 ft with the juvenile fish ramp installed, 3.6 ft of head on the final bypass weir is needed to maintain an optimal tailwater pool for safe fish passage. This corresponds to a final bypass flow rate of 39.9 ft^3/s.
- Measured final bypass flow rates are 25 percent higher than measurements in previous evaluations, possibly due to differences in the downwell condition set by the weir operator or bypass pipe blockage in previous evaluations.

Drums Screens

- A more detailed velocity distribution across the drum screen faces provides a better understanding of flow conditions near the screens.
  - Approach velocities measured at 0.05 and 0.5 times the water depth are represented by measurements at 0.2 times the depth.
  - Approach velocities measured at 0.8 times the water depth are typically higher than velocities measured at shallower depths.
  - Approach velocities measured at 0.9 times the water depth are significantly higher than velocities measured at shallower depths. The sluice gate placement and/or recessed floor may contribute to high velocities near the drum screens at the bottom of the water column.
- At the operating criteria of 4.4 ft of head on the primary bypass weirs, approach velocities measured at depths below the curvature of the screen exceed criteria more frequently than shallower measurements.
  - Approach velocities exceed the 0.4 ft/s NOAA screen criteria at 75 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth.
  - Approach velocities exceed the 0.5 ft/s facility design criteria at 58 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth.
- At the operating criteria of 4.4 ft of head on the primary bypass weirs:
  - For all data collected in Bays 2 and 5, 49 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1.
  - For data collected in Bay 5, 73 percent of 84 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1.

  - For data collected in Bay 2, 30 percent of 105 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1.
- When the primary bypass flow rate was reduced from 65 ft^3/s to 50 ft^3/s, sweep velocities decrease and, at some screens, approach velocities increase. Sweep-to-approach velocity ratios are less than 2:1 at 82 percent of 168 total measurement locations in Bays 2 and 5 and approach velocities exceed 0.4 ft/s at 92 percent of 168 measurement locations.
- At both bypass flow rates, sweep velocities do not produce a clear acceleration along the screens into the fish bypass channel.
- At both bypass flow rates, velocity distributions across the screens are nonuniform with the highest velocities occurring at the most upstream screen in each bay.
- Drum screen submergence was 76 percent of the water depth at the screen seat for all tests.

INTRODUCTION

Roza Diversion Dam is part of the Roza Division of the Bureau of Reclamation's Yakima Project. The dam is located 12 miles north of the city of Yakima on the Yakima River at River Mile 127.9. The dam diverts up to 2,200 ft^3/s of water from the Yakima River into the Roza Canal to provide water for irrigation and power generation. The canal headworks consist of a concrete structure in the right abutment with a trashrack at the inlet to protect a series of rotating fish screens (Figure 1). The Roza Fish Screens Facility protects fish from being entrained in the Roza Canal.

The facility consists of 27 drum screens (17 ft diameter, 12 ft width) in 5 bays with 7 screens in the upstream bay and 5 screens in each of the following bays. Bays are numbered from upstream to downstream and screens are numbered from right to left looking downstream with Screen 1 on the right side of the most downstream Bay 5 (Figure 2). Each bay contains a primary fish bypass (referred to as an intermediate fish bypass in some previous reports). An adjustable rectangular weir gate in each primary bypass controls flow through the fish bypass system. The closed conduit primary bypasses converge into a secondary screening facility where excess water is recovered through four vertical traveling screens. The final fish bypass returns fish to the Yakima River at an outfall downstream of Roza Diversion Dam.

Figure 1. – Roza Diversion Dam allows water to be diverted through the Roza Fish Screens Facility at the headworks of the Roza Canal.

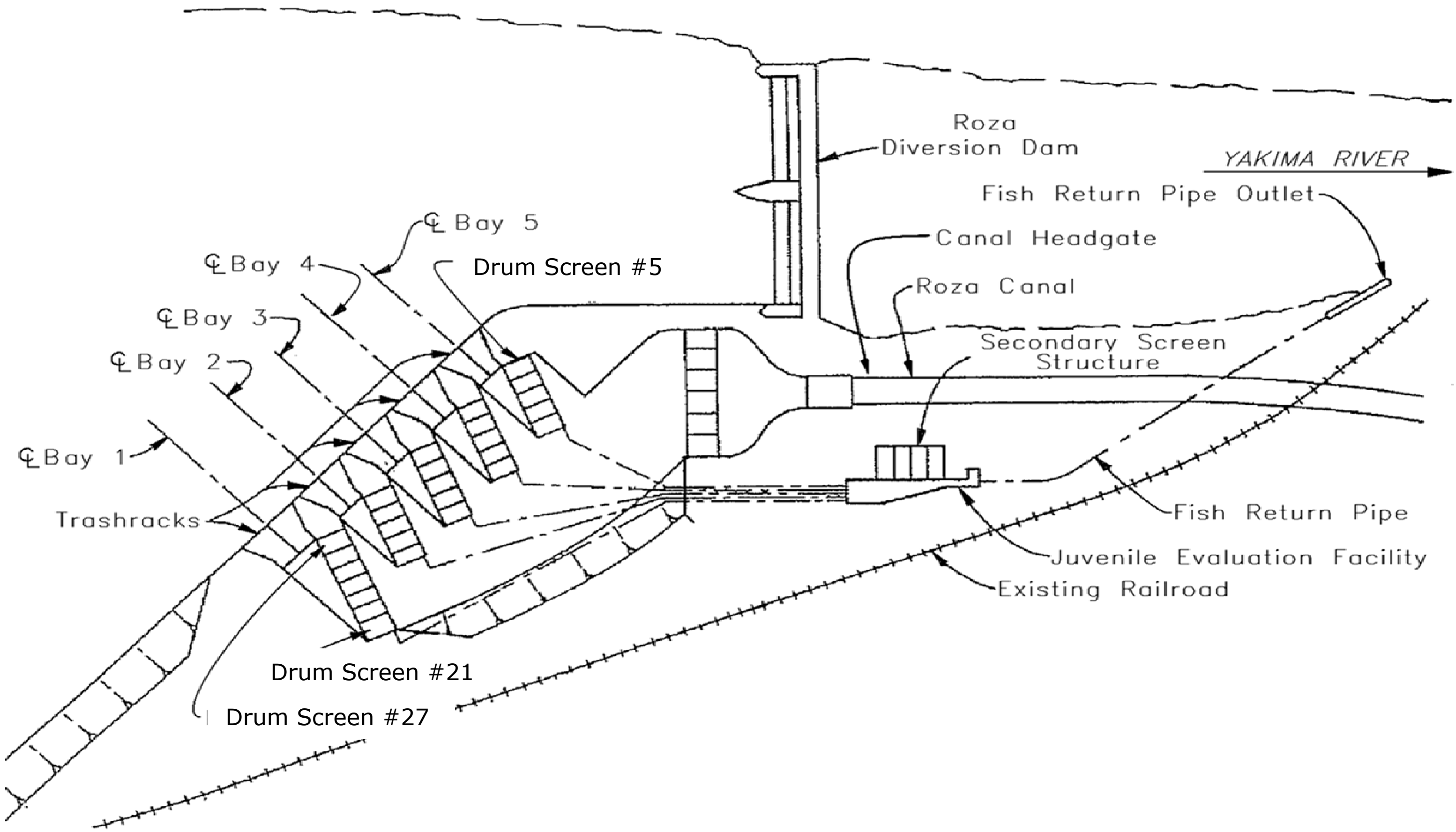

Figure 2. – Schematic of Roza Diversion Dam and Roza Fish Screens Facility.

A forebay elevation of 1220.5 ft is maintained through automatic control of the roller gates at the Roza Diversion Dam. At the fish screening facility, the forebay water surface elevation is measured at the staff gage in Bay 1. Since the staff gage datum is 0.1 ft lower at the screening facility, the forebay elevation reads 1220.4 ft at the standard operating water level. Operating Criteria for the Roza fish bypass system was recommended in 1989 by the National Marine Fisheries Service (Pearce, 1989). The National Marine Fisheries Service (NMFS), the previous name designation for the fisheries division of the National Oceanic and Atmospheric Administration (NOAA), is currently referred to as NOAA. This document specifies that the five primary bypass weir gates should be set to an elevation 4.4 ft below the upstream water surface to promote fish passage. The surplus weir gates in the secondary screening facility should be equally set such that the water surface elevation in front of the traveling screens is 1213.0 ft. When the juvenile trap is installed in the final fish bypass during juvenile migration season, the secondary water surface elevation should be set to 1213.8 ft to provide adequate flow into the trap.

The fisheries division of NOAA has developed fish screen criteria and guidelines to promote safe passage of fish through screening facilities (NOAA draft, 2004). Criteria relevant to this particular study include:

- Approach velocity normal to the screen face must be less than 0.4 ft/s.
- Sweeping velocity parallel to the screen face must be greater than approach velocity. Optimally, sweeping velocity should be 0.8 ft/s to 3.0 ft/s (minimum sweep-to-approach velocity ratio of 2:1).
- A uniform velocity distribution should be maintained over the screen surface to minimize approach velocities. Approach and sweep velocities should be measured approximately 3 inches from the screen face for every 5 percent of the screen area. Uniform approach conditions are achieved when no individual approach velocity measurement exceeds 110 percent of the 0.4 ft/s criteria, or 0.44 ft/s.
- At no point shall flow decelerate along the screen face or in the bypass channel. The minimum bypass entrance flow velocity should be greater than 110 percent of the maximum velocity upstream of the bypass entrance.
- For rotating drum screens, the design submergence must be between 65 and 85 percent of the drum diameter.

The NOAA fish passage criteria also states in Section 12.3 that if a fish screen was constructed to NOAA criteria established August 21, 1989 (prior to the establishment of these criteria), approval of these screens will be considered, providing that all of the following conditions are met:

1) The entire screen facility is still functioning as designed.
2) The entire screen facility has been maintained and is in good condition.
3) When the screen media wears out, it shall be replaced with screen media meeting the current criteria stated in this document.
4) No mortality, injury, entrainment, impingement, migrational delay or harm to anadromous fish has been noted that is being caused by the facility.
5) No emergent fry are likely to be located in the vicinity of the screen, as agreed to by a NOAA resource biologist familiar with the site.

Original fish passage facility design information from the Bureau of Reclamation Pacific Northwest Region Fish Screen Design Criteria Manual specifies that the maximum design approach velocity is 0.5 ft/s and that sweep velocities should be between 1.6 ft/s and 1.9 ft/s. Field velocity measurements near the drum screens and in the fish bypasses should be obtained periodically or when operational or structural changes occur at the screening facility to assure that original design criteria and/or NOAA fish passage criteria are satisfied.

Pacific Northwest National Laboratory (PNNL) has conducted many fish screen evaluations in the Yakima River Basin since 1985. Methods to evaluate screening facilities were developed and applied during the PNNL studies (Abernathy et al., 1989, 1990; Blanton et al., 1998, 1999; Carter et al., 2002; Chamness et al., 2001). In July 2003, Battelle-Pacific Northwest Division measured water velocities in front of drum screens in two of the five screening bays, in their associated primary fish bypasses, and in the secondary screening facility and final bypass at a canal flow rate of approximately 1,850 ft^3/s. This evaluation was conducted under two operational conditions (McMichael et al., 2003):

1.) Fish bypasses set to the recommended operating criteria of 4.4 ft of head on the weir (corresponding to approximately 65 ft^3/s per bypass) at a forebay elevation of 1220.4 ft and a secondary screening water surface elevation of 1213.0 ft.
2.) Fish bypasses set to half of the recommended operating criteria (corresponding to approximately 32 ft^3/s per bypass) at a forebay elevation of 1220.4 ft and a secondary screening water surface elevation of 1213.8 ft.

Results show that NOAA screen criteria were not met at several screens when the fish bypass flows were operated both in and out of operating criteria. Before the evaluation, sluice gates (porosity boards) were installed behind the drum screens in nonuniform configurations. The sluice gates were suspected to be a potential cause for the adverse and inconsistent hydraulic conditions at the screen faces.

In March 2004, velocities were measured near to the drum screens at 0.2 and 0.8 times the water depth and three lateral locations per screen. Velocities were collected in front of all drum screens in all bays to determine the effect of the sluice gates on the hydraulic performance of the drum screens at a canal flow rate of 820 ft^3/s (DeMoyer & Vermeyen, 2004). Sluice gates were installed in a uniform configuration prior to the evaluation. Tests were conducted with sluice gates installed and removed at the operating bypass criteria of 4.4 ft of head on the primary bypass weirs and a secondary screening water surface elevation of 1213.8 ft. Results indicated that sluice gates did not have a negative impact on hydraulic conditions at the drum screens. However, the estimated flow rate through the drum screens was lower than the reported canal discharge, which suggested that high velocity regions on the drum screens may have been missed. Results also showed that downstream primary bypass channels pass more water than upstream bypasses at the same weir setting.

The primary objective of the August 2004 hydraulic evaluation was to determine whether primary bypass flow rates can be reduced during high canal diversion operations to minimize stress on downstream-migrating salmon while maintaining drum screen criteria. The following data was collected in support of this effort:

1.) ***Field ratings of primary and final bypass weirs.***
Before this evaluation, bypass flow rates were estimated using a standard weir rating for a suppressed rectangular weir (Bureau of Reclamation, 2001). More accurate bypass ratings were developed for Bays 1, 3, and 5 to better quantify bypass flow rates.

2.) ***Detailed velocity measurements in front of screens in Bays 2 and 5***.
During the July 2003 and March 2004 evaluations, velocity data were collected at standard measurement locations of 0.2 and 0.8 times the water depth at three lateral locations per screen. Results indicated that six measurements per screen may not be sufficient to thoroughly define the flow field near to the drum screens. For this evaluation, velocities were measured at 5 depths and 7 lateral locations in an effort to more accurately define velocity distributions. This detailed collection scheme was used to determine if primary bypass flow rates can be reduced without negatively impacting the hydraulic performance of the drum screens. Data were collected with:

- Primary fish bypasses set to the operating criteria of 4.4 ft of head on the weir (approximately 65 ft^3/s).
- Primary fish bypasses set to a reduced bypass flow rate of 50 ft^3/s.

Using the field ratings, the primary bypass weirs were accurately set and the effect of reducing the primary bypass flow rate on compliance with NOAA fish screen criteria was documented.

INSTRUMENTATION AND METHODS

A hydraulic evaluation was conducted from July 27 – August 4, 2004 at the Roza Fish Screens Facility during a canal diversion of 1911 $\pm$ 4 ft^3/s. The forebay elevation was 1220.38 $\pm$ 0.02 ft with corresponding forebay water depths of 11.99 $\pm$ 0.02 ft. Drum screen submergence was 76 percent of the water depth at the screen seat. Sediment sluice gates (porosity boards) were installed downstream of each rotating drum screen in the stoplog slots. The sluice gates were placed 1 ft above the channel bottom to increase velocities near the bed as a means of reducing fine sediment deposits in front of the screens. The top of the sluice gates was about 1 ft below the water surface, allowing overtopping flow. The sluice gates were installed throughout this study.

Figure 3. – Bay of rotating drum screens at Roza screening facility with sluice gates installed.

The water surface in the secondary screening facility was maintained at the design elevation of 1213.0 ft which corresponds to a 12.0 ft water depth. At the onset of testing, primary bypass weirs were set to the operating criteria of 4.4 ft of head on the weir.

A downlooking 10-MHz SonTek Acoustic Doppler Velocimeter (ADV) was used to collect three-dimensional velocity data at a location 10 cm below the receiver at a sampling rate of 25 Hz for 60 seconds. The data were then time-averaged to obtain mean velocities at each measurement location with an accuracy of approximately 1 percent of the measured velocity range of 3 ft/s.

Velocity data were measured with the ADV in the following locations:

1.) Velocity data were measured at the bypass centerline at 0.2 and 0.8 times the water depth in primary bypass channels 1, 3, and 5 and in the final bypass. Data collected in May 2004 showed that centerline velocities adequately represented velocities across the width of the bypass channel (DeMoyer and Vermeyen, 2004).

2.) Approach and sweep velocities were measured approximately 3 inches (or as close as possible) in front of Screens 17, 18, 20 in Bay 2 and Screens 2, 3, 5 in Bay 5. Data were collected at 0.05, 0.2, 0.5, 0.8, and 0.9 times the water depth and laterally at 0.5, 2, 4, 6, 8, 10, and 11.5 ft from the upstream edge of each screen.

Primary Fish Bypass Weirs

To develop weir rating tables and equations, ADV velocities were measured over a range of head values in the primary bypasses of Bays 1, 3, and 5. Water sweeping past the drum screens rounds 90-degree bend from the screening bay into a 2-ft wide fish bypass channel. A ramped floor increases the fish attraction flow over an adjustable partially contracted rectangular weir (Figure 4). The weir frame obstructs 0.075 ft of flow on both sides of the channel so that the effective length of the weir blade is 1.85 ft. Leakage occurs along the bottom and sides of the adjustable weir frame. The steel weir blade is a 2-in-wide, curved blade. Water passing over the weir enters a downwell with a 30-inch steel bypass pipe to convey bypassed water and fish to the secondary screening facility (Figure 5).

Figure 4. – Adjustable rectangular weir in primary fish bypass channel.

Figure 5. – Water flowing freely at a low head over the 2-in-wide, 1.85-ft-long rectangular bypass weir into the downwell.

Reclamation's Water Measurement Manual (Bureau of Reclamation, 2001) defines the measurement of head on a weir as the difference between the weir crest elevation and the water surface elevation upstream of the weir at a distance of at least four times the maximum head on the weir crest. Since the approach channel upstream of the weir is shorter than the required distance for the upstream water surface elevation measurement and water depths do not vary significantly between bays, the forebay elevation was measured at the staff gage in Bay 1.

Free flow occurs when the weir blade is at a higher elevation than the tailwater elevation and the overflow nappe is fully aerated. The upstream water surface elevation controls the amount of flow that passes over the bypass weirs at a given weir setting. For rectangular weirs operating in a free flow condition, the standard power law equation is of the form:

$$Q = C\,L\,H^{3/2}$$

where Q = discharge over weir (ft^3/s), L = length of weir crest (ft), H = head above the weir crest (ft), C = coefficient of discharge ($ft^{1/2}/s$).

The weir is partially submerged when the weir blade elevation is higher than the tailwater elevation and the nappe is not fully aerated, causing the nappe to attach to the downstream weir blade. Under partially submerged conditions, the downstream water surface elevation may affect weir performance and the standard weir equation may not produce accurate values. A fully submerged condition exists when the tailwater elevation is higher than the weir blade elevation. When weirs are submerged, both the upstream and downstream water surface elevations control weir performance and the standard weir equation cannot be applied.

The steel mount supporting the ADV was inserted into stoplog slots just upstream of the onset of the ramped floor. For each bypass, velocity data were measured at the bypass channel centerline at 0.2 and 0.8 of the water depth to obtain a mean bypass channel velocity over the cross sectional flow area. Velocity data were collected from 0.0 ft head (including only gate leakage) to 5.0 ft head (maximum achievable head between the weir crest and the Bay 1 staff gage water surface elevation) at incremental head increases of 0.5 ft. The upstream water surface elevation and weir blade elevation were used to calculate the head on the weir. Due to heavy turbulence in the downwell, the tailwater surface elevation could not be precisely measured. The approximate tailwater elevation for each weir setting was used to determine whether the weir was operating in a free flow, partially submerged, or submerged condition.

Final Fish Bypass Weirs

The 2-ft-wide final bypass channel is located downstream of the secondary screening facility (Figure 6). A metal ramp transitions flow from the 1201.0 ft floor elevation of the secondary screening facility to the final bypass floor elevation of 1207.5 ft. An adjustable rectangular weir with a 2-inch-wide curved weir blade (similar to the primary bypass weirs) controls the flow rate into the final fish bypass conduit that returns fish to the river (Figure 7).

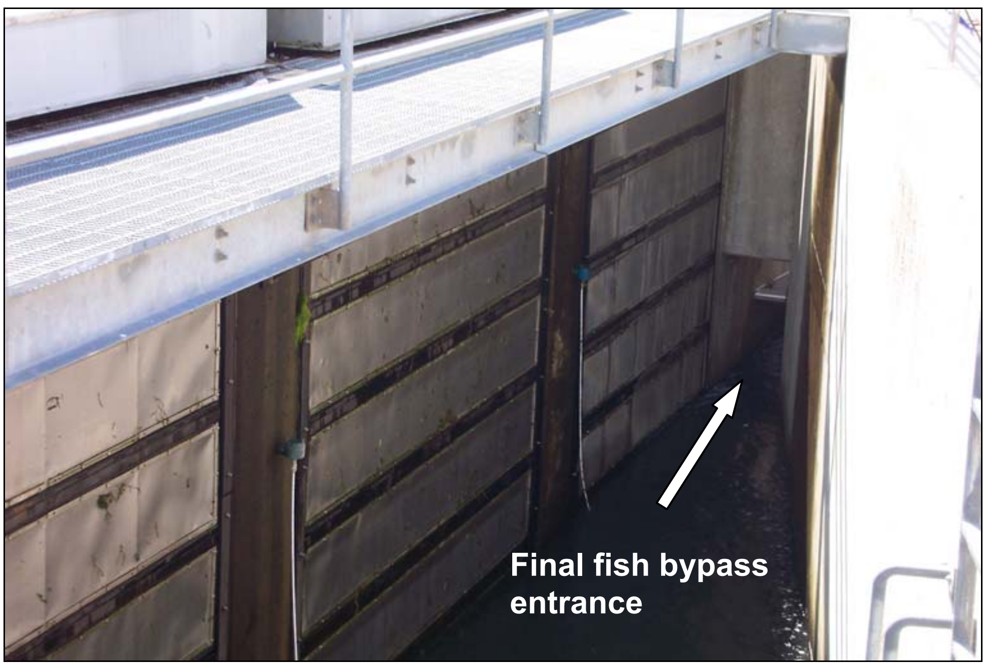

Figure 6. – Final fish bypass located downstream of the traveling screens in the secondary screening facility.

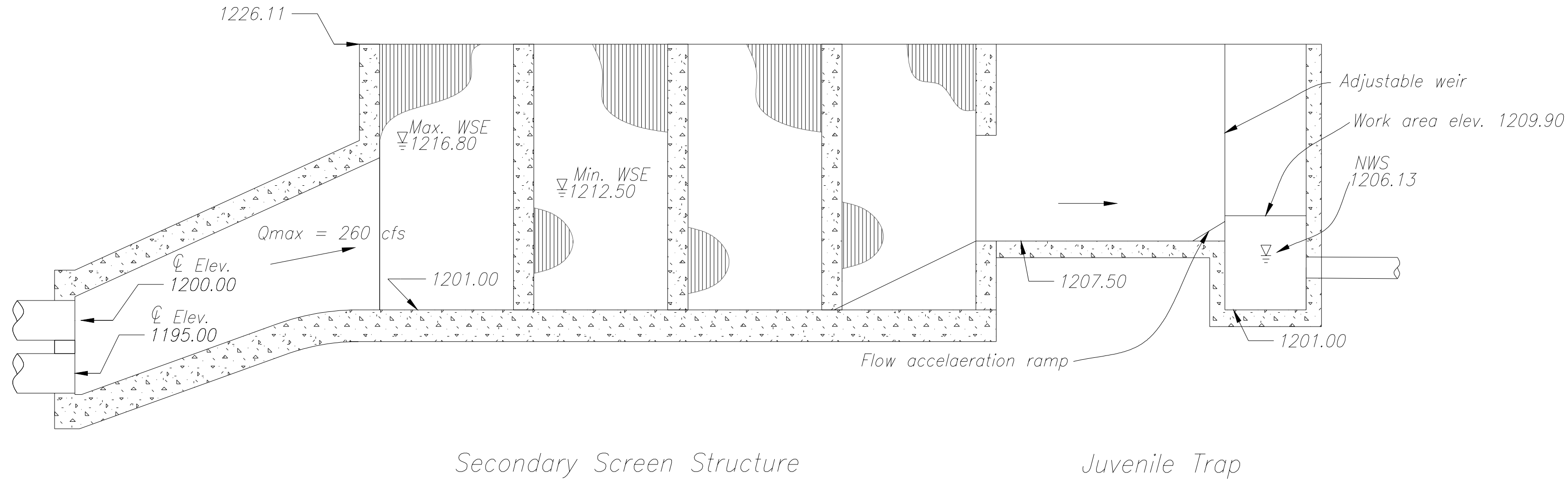

Figure 7. – Profile view of secondary screening facility with four vertical traveling screens and a juvenile trapping facility with an adjustable final bypass weir and downwell.

The water surface elevation in the secondary screening facility and the operational weir setting controls the head on the final bypass weir. Under standard operations, the design-specified water surface elevation in front of the traveling screens is 1213.0 ft. During the juvenile migration season, a temporary grated metal ramp is installed in the final bypass to guide fish into a juvenile trap. When the juvenile trap is installed, the water surface elevation must be set to 1213.8 ft to provide adequate flow into the trap.

The final bypass weir is only operated such that fish have an adequate tailwater pool for safe passage into the final bypass pipe. An unacceptable downwell condition means that an insufficient tailwater pool is available for juvenile fish and water passes directly into the final bypass pipe or too much water floods the juvenile trapping facility, making it inaccessible and ineffective. With these operational restraints, a full rating of the final bypass weir could not be performed. For each operational water surface elevation (1213.0 ft or 1213.8 ft), the weir could be set to only one head value to maintain an optimal tailwater pool for fish passage.

Velocity measurements were taken near the entrance of the final bypass channel immediately upstream from the temporary juvenile trap ramp. Like the primary bypasses, velocity measurements were collected at the bypass centerline at 0.2 and 0.8 times the water depth. The water depth was measured with a staff gage at the measurement location. Data were collected at 1213.0 ft with the juvenile ramp removed and at 1213.8 ft with the juvenile ramp installed.

Drum Screens

Approach and sweep velocities are the typical velocity components analyzed during fish screen evaluations. According to NOAA, the approach velocity in a fish screen evaluation is defined as the water velocity component perpendicular to and approximately three inches in front of the screen face. The sweeping velocity is defined as the water velocity component parallel and adjacent to the screen face.

Three-dimensional velocity data were measured with the ADV in front of Screens 17, 18, 20 in Bay 2 and Screens 2, 3, 5 in Bay 5. Data was collected at 0.2, 0.5, 0.8, and 0.9 times the water depth and laterally at 0.5, 2, 4, 6, 8, 10, and 11.5 ft from the upstream edge of each 12-ft-wide screen. Data were also collected at 0.05 times the water depth during the first test in Bay 2 at the operating fish bypass criteria. Since the velocity data collected at 0.05 depth were similar to velocity data at 0.2 depth, data was not collected at 0.05 for any other conditions. During the same first test, data was collected laterally at 0 ft and 12 ft from the edges of the screens. Since rubber seals along the outside edges of the screens blocked flow through the screen, data was collected laterally at 0.5 ft and 11.5 ft for the remaining tests.

To determine the mean velocity in a channel greater than 2 ft deep with a fully developed velocity profile, velocity data is typically measured at 0.2 and 0.8 times the water depth. In a previous PNNL study at the Roza facility by Abernathy et al. (1989), velocities measurements were made near to the drum screens at depths of 0.05, 0.2, 0.5, 0.8a, and 0.9. Since velocity data is difficult to collect underneath the curvature of the drum screen, additional measurements were made by PNNL at 0.8 times the depth on a vertical plane in front of the drum screen (point 0.8). Results from the 1989 study indicated that velocities measured at 0.05 and 0.5 were accurately represented by the standard measurements at 0.2 and 0.8 of the water depth. Limited velocity data collected near to the screen face at 0.8a and 0.9 indicated that sweep and approach velocities may be higher at these locations.

Since measurements at 0.2 and 0.8 often accurately represent the vertical velocities experienced over the height of the drum screen, this method has become the standard for evaluating velocities near fish screens in the Yakima River Basin. In this evaluation, a more detailed velocity distribution, like the 1989 study, was performed in order to fully evaluate the impact of reducing the primary bypass flow rate, particularly in areas affected by the sluice gates and central dividing piers between screens.

Upstream of the drum screen seat, the forebay floor drops by 1 ft (Figure 8). Fractional water depths are based on the forebay floor elevation as measured from the water surface. With 76 percent screen submergence, the 0.05, 0.2, and 0.5 depth measurements are at or above the centerline of the drum and the ADV can be easily positioned close to the screen face (Figure 9). Since the 0.8 and 0.9 depths are well below the curvature of the drum screens, access to the screen face is difficult for large diameter drum screens such as the Roza screens (Figure 8).

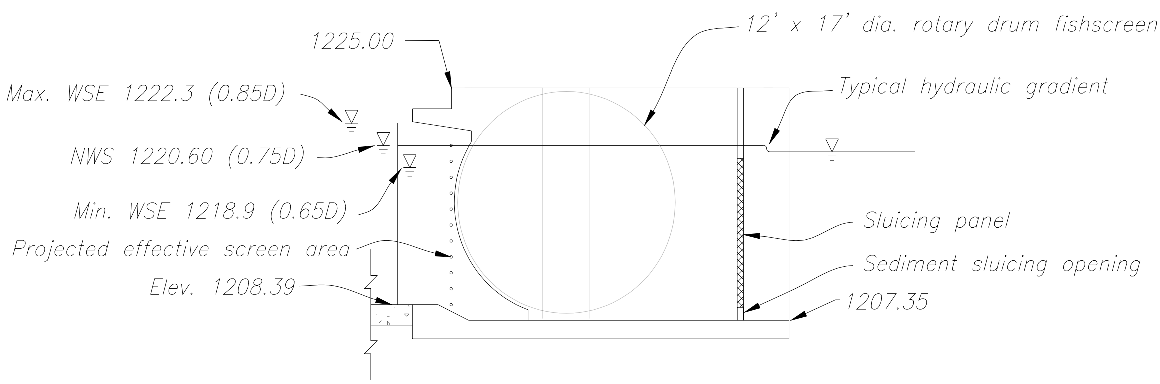

Figure 8. – Rotating drum screen with recessed floor in front of the screen and sluice gate installed downstream of the screen.

Figure 9. – Positioning of ADV at 0.05 times the water depth with the 10-cm sampling location at 3 inches from the drum screen.

Maintaining an upright probe orientation, it was not possible to obtain near-screen measurements of 3 inches from the rotating fish drum at the 0.8 and 0.9 depths in this study. Due to limitations in the ADV mount and the body shape of the ADV instrument, velocity measurements could only be taken approximately 19 inches at 0.8 depth and 28 inches away at 0.9 depth from the screen face. Inverting the probe was considered but not performed due to the high probability of equipment damage from unprotected probe transducers contacting the screen face, the probe cable hanging up on bottom debris, and silt deposition restricting lateral movement.

The ADV deployment mount was reused from the July 2003 evaluation (McMichael et al., 2003). The 23-ft-long L-shaped steel frame allowed adjustments for the depth of the ADV in the water column and the distance from the screen face (Figure 10). Once the ADV was positioned at the proper depth, the assembly was fixed to a gantry crane and positioned laterally along the screens (Figure 11). In each bay, all lateral locations were measured at one depth before the mount was detached from the gantry crane and removed from the water. The probe was repositioned on the mount and the instrument was redeployed to measure all lateral locations at another depth.

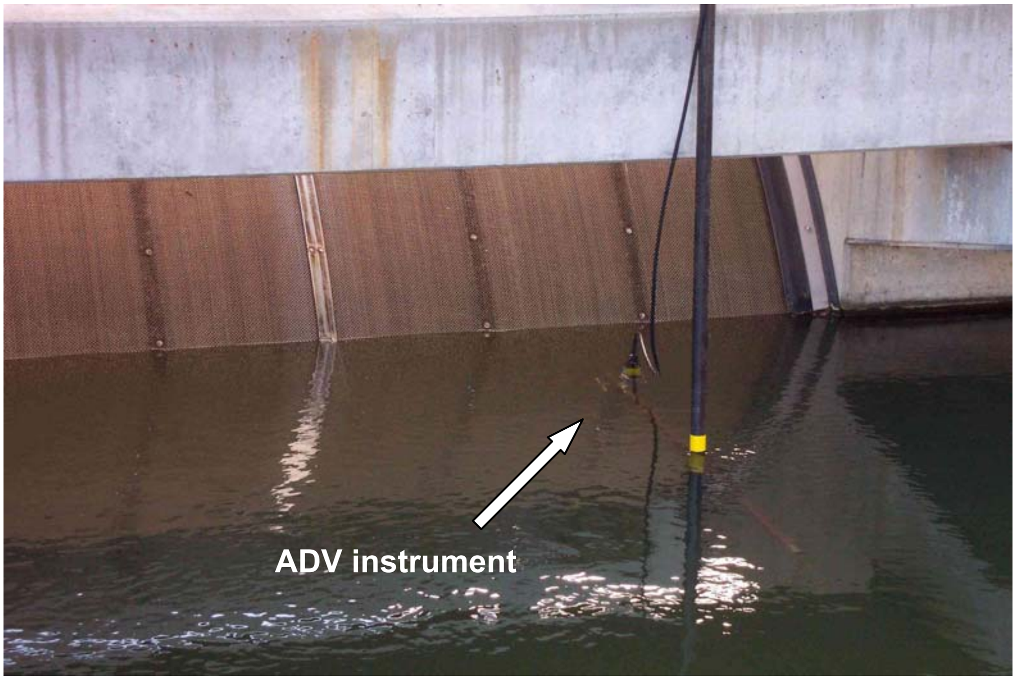

Figure 10. – ADV instrument positioned approximately 3 inches from the screen face with the deployment mount.

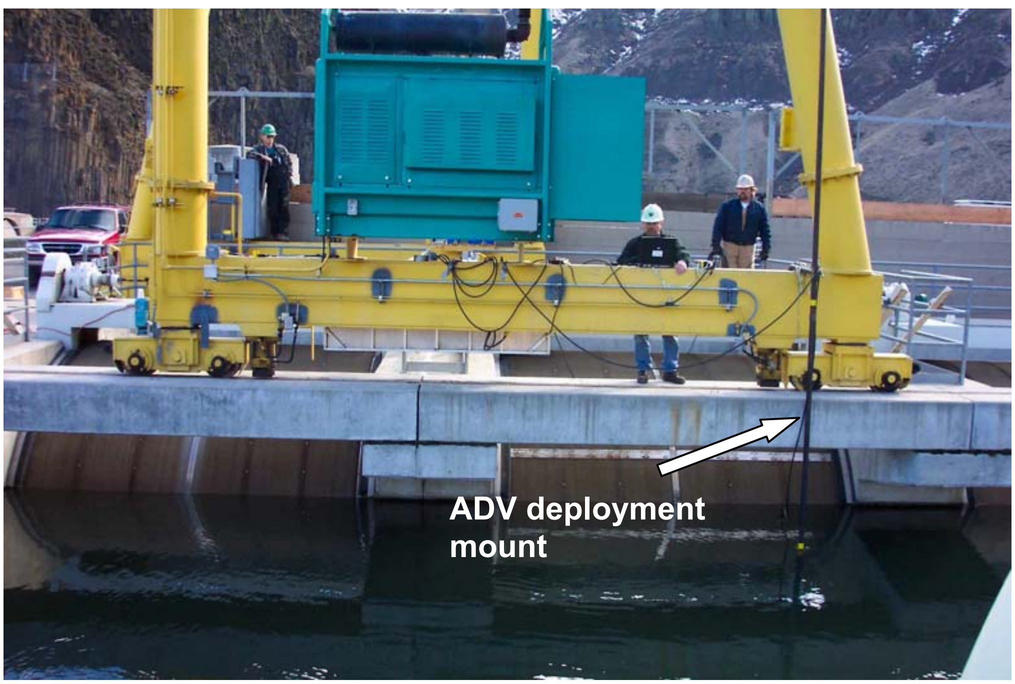

Figure 11. – The deployment mount was attached to a gantry crane that moved laterally across each drum screen in the bay. ADV data were collected at each location.

RESULTS AND DISCUSSION

Primary Fish Bypass Weirs

Results of the primary fish bypass evaluation for Bays 1, 3, and 5 are given in Table 1. Field rating data were collected with a water surface elevation of 1213.0 ft in the secondary screening facility and an upstream water surface elevation of 1220.4 ft at the staff gage in Bay 1. The water depth at the staff gage in Bay 1 was approximately 11.99 ft. Measured leakage rates were 1.2, 1.4, and 1.9 ft^3/s for bypass weirs 1, 3, and 5, respectively. The average leakage rate was approximately 1.5 ft^3/s with zero head above the weir crest.

The bypass weirs cannot be considered suppressed rectangular weirs since the weir crest is partially contracted by 0.15 ft and the vertical sidewalls of the downwell are wider than the sidewalls of the approach channel, allowing for lateral contraction or expansion of the overflow jet. The standard weir rating for a partially contracted weir cannot be applied for several reasons: the adjustable weir blades are not sharp-crested, an aerated nappe is not maintained during operation in a partially submerged condition, and the weirs are typically operated in a submerged condition. Since the standard suppressed weir equation was used to estimate bypass flow rates before field weir ratings were developed, a comparison of the standard suppressed weir equation and the measured field rating data is presented in Figure 12.

The condition of the nappe was difficult to observe due to the site layout. For head values less than 1.5 ft, the nappe appeared to spring free of the weir blade such that free flow conditions existed. For head values between 1.5 ft and 2.8 ft, the nappe did not appear to spring free of the weir blade, but the weir blade was not submerged by the tailwater. Therefore, the weir condition is classified as partially submerged. The onset of weir submergence occurs at approximately 2.8 ft of head on the primary bypass weir when the water surface elevation in the secondary screening facility is 1213.0 ft. For head values greater than 2.8 ft, the weir operates in a submerged condition.

The weir ratings for Bays 1, 3, and 5 are consistent when free flow and partially submerged conditions exist. The Bay 1 bypass weir shows slightly greater efficiency than the bypass weirs in Bays 3 and 5. This could be a result of the weir blade condition or a slightly higher upstream water surface elevation. During the transition from a partially submerged to fully submerged weir, the primary bypass weir becomes less efficient per incremental increase in tailwater level such that the shape of the rating curve changes from the standard power law relationship to a polynomial relationship. Under submerged conditions, the Bay 1 bypass weir becomes less efficient than Bays 3 and 5 since the length of the bypass pipe between the primary screening bay and the secondary screening facility is longest, and therefore has the greatest pipe headloss.

Rating tables, equations, and curve-fit R-squared values are given in Table 2a for data averaged from all primary bypasses, Table 2b for Bay 1 bypass only, Table 2c for Bay 3 bypass only, and Table 2d for Bay 5 bypass only. Although the weir ratings are slightly varied, the average bypass rating equation in Table 2a should be sufficient for calculating primary bypass flow rates or setting bypass weirs. The developed rating curves can be accurately applied when the facility operates with a water surface elevation of 1213.0 ft in the secondary screening facility. When the water surface elevation is operated at 1213.8 ft during juvenile trapping, the onset of submergence can be expected to occur at a lower head value. The change to the weir rating should be minimal. Field testing would be required to determine the extent of the change.

The 1989 NMFS Operating Criteria recommends that the bypass weirs be set to 4.4 ft of head on the weir (Pearce, 1989). The weir is submerged at this setting. From the field ratings, the average bypass flow rate for 4.4 ft of head is 64.9 ft^3/s. This value closely compares to the primary bypass flow rates reported in the July 2003 evaluation. To achieve a reduced primary bypass flow rate of 50 ft^3/s, the bypass weirs should be set at 3.35 ft. Like operation at 65 ft^3/s, the bypass weirs operate in a submerged condition at 50 ft^3/s.

Table 1. – Summary of primary fish bypass data collected in Bays 1, 3, and 5 with a forebay elevation of 1220.4 ft and a water surface elevation of 1213.0 ft in the secondary screening facility.

	Head Above Weir Crest (ft)	Weir Crest Elev. (ft)	Estimated Tailwater Elevation (ft)	Operational Weir Condition	Mean Velocity (ft/s)		Mean Channel Velocity (ft/s)	Measured Bypass Flow Rate (ft^3/s)
					0.2 depth	0.8 depth		
BAY 1	0	1220.44	1212.88	Free flow	0.03	0.07	0.05	1.2
	0.53	1219.86	1213.22	Free flow	0.14	0.08	0.11	2.6
	1.03	1219.36	1214.13	Free flow	0.29	0.35	0.32	7.7
	1.53	1218.86	1215.47	Free flow	0.49	0.68	0.58	13.9
	2.03	1218.36	1217.13	Partially submerged	0.77	1.18	0.97	23.3
	2.53	1217.86	1217.47	Partially submerged	1.47	1.56	1.51	36.3
	3.03	1217.36	1218.30	Submerged	1.91	1.96	1.94	46.4
	3.53	1216.86	1218.80	Submerged	2.32	2.40	2.36	56.5
	4.03	1216.36	1219.55	Submerged	2.44	2.59	2.51	60.2
	4.36	1216.02	1219.63	Submerged	2.58	2.58	2.58	61.8
	4.86	1215.52	1219.97	Submerged	2.74	2.76	2.75	65.8
BAY 3	0	1220.40	1213.05	Free flow	0.06	0.06	0.06	1.4
	0.48	1219.90	1213.38	Free flow	0.14	0.13	0.14	3.3
	0.98	1219.40	1214.22	Free flow	0.39	0.36	0.38	9.0
	1.48	1218.90	1215.13	Free flow	0.57	0.53	0.55	13.2
	1.98	1218.40	1216.30	Partially submerged	1.04	0.88	0.96	23.0
	2.48	1217.90	1216.30	Partially submerged	1.47	1.23	1.35	32.3
	2.98	1217.40	1217.47	Submerged	1.94	1.64	1.79	42.8
	3.48	1216.90	1218.47	Submerged	2.31	2.14	2.23	53.4
	3.98	1216.40	1219.30	Submerged	2.57	2.52	2.54	60.9
	4.31	1216.07	1219.63	Submerged	2.67	2.70	2.69	64.3
	4.90	1215.48	1220.05	Submerged	2.90	2.74	2.82	67.6
BAY 5	0	1220.39	1213.05	Free flow	0.06	0.09	0.08	1.9
	0.41	1219.97	1213.13	Free flow	0.15	0.15	0.15	3.6
	0.91	1219.47	1213.88	Free flow	0.30	0.38	0.34	8.1
	1.41	1218.97	1214.97	Free flow	0.64	0.51	0.58	13.8
	1.91	1218.47	1216.17	Partially submerged	0.93	0.81	0.87	20.9
	2.41	1217.97	1217.38	Partially submerged	1.42	1.14	1.28	30.6
	3.00	1217.39	1217.76	Submerged	1.88	1.58	1.73	41.5
	3.50	1216.89	1218.26	Submerged	2.29	2.06	2.18	52.1
	4.00	1216.39	1218.72	Submerged	2.61	2.48	2.54	60.9
	4.37	1216.01	1219.38	Submerged	2.79	2.59	2.69	64.4
	4.95	1215.43	1219.97	Submerged	3.01	2.85	2.93	70.1

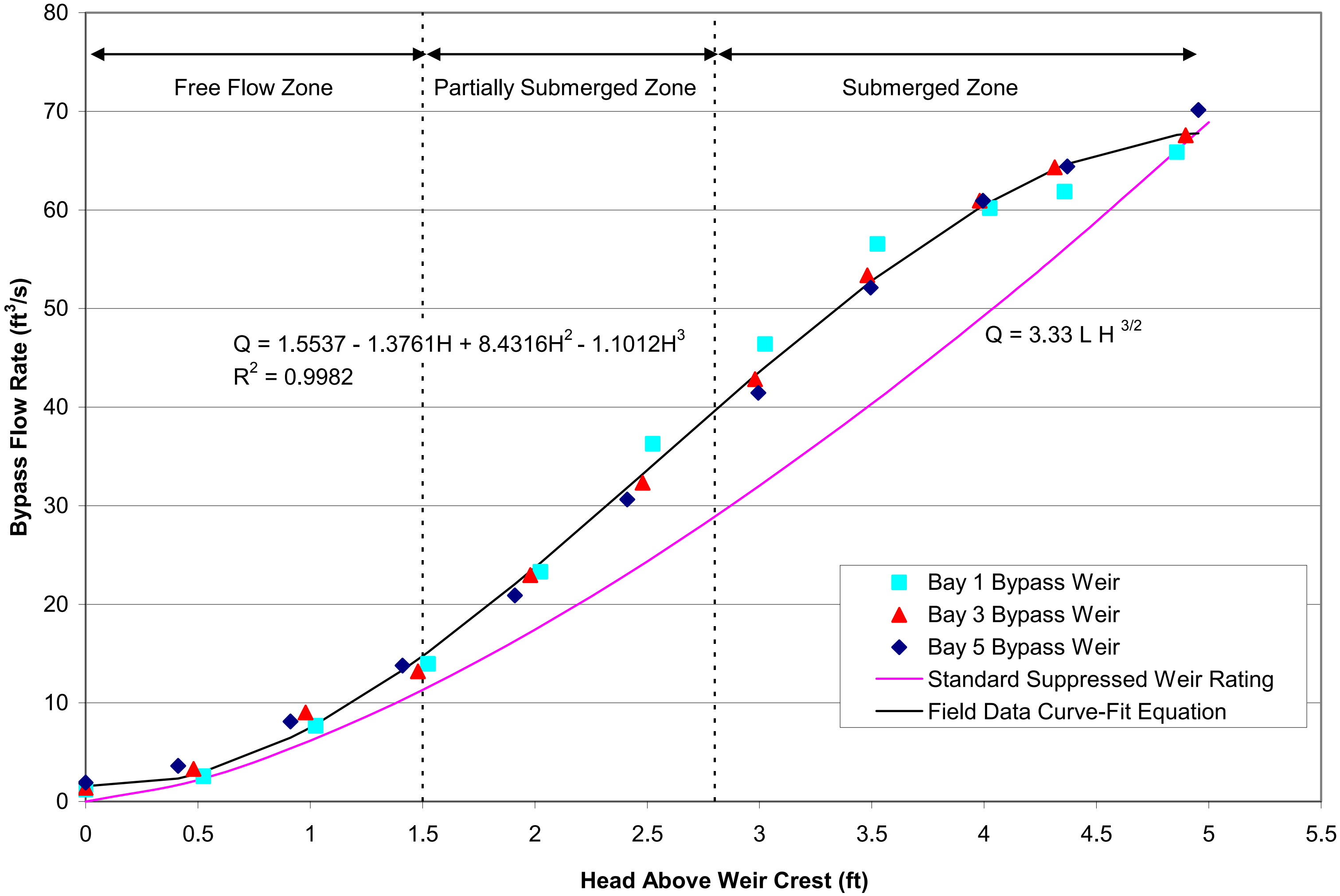

Figure 12. – Primary fish bypass weir rating curve. Measured field data is compared to standard suppressed rectangular weir rating curve for free flow, partially submerged, and submerged conditions. H is the head on the weir crest in feet and Q is the bypass flow rate in ft^3/s.

Table 2a. – Average rating table and equation for all primary bypass weirs. H is the head on the weir crest in feet and Q is the bypass flow rate in ft^3/s. "---" indicates that bypass flow rate cannot be accurately estimated.

$Q = 1.5537 - 1.3761\ H + 8.4316\ H^2 - 1.1012\ H^3$

$R^2 = 0.9982$

Head Above	Primary Bypass Flow Rate (ft^3/s)									
Weir Crest (ft)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	---	---	1.6	1.9	2.3	2.8	3.5	4.3	5.3	6.3
1	7.5	8.8	10.1	11.6	13.1	14.7	16.4	18.2	20.0	21.8
2	23.7	25.6	27.6	29.6	31.6	33.6	35.6	37.6	39.6	41.6
3	43.6	45.5	47.4	49.3	51.1	52.8	54.5	56.1	57.7	59.1
4	60.5	61.8	62.9	64.0	64.9	65.8	66.4	67.0	67.4	67.7

Table 2b. – Bay 1 bypass weir rating table and equation. H is the head on the weir crest in feet and Q is the bypass flow rate in ft^3/s. "---" indicates that bypass flow rate cannot be accurately estimated.

$Q = 1.2064 - 3.2817\ H + 10.1719\ H^2 - 1.4026\ H^3$

$R^2 = 0.9986$

Head Above	Primary Bypass Flow Rate (ft^3/s)									
Weir Crest (ft)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	---	---	---	1.1	1.4	1.9	2.6	3.4	4.4	5.5
1	6.7	8.0	9.5	11.0	12.7	14.4	16.3	18.1	20.1	22.1
2	24.1	26.2	28.3	30.4	32.5	34.7	36.8	38.9	41.0	43.0
3	45.0	47.0	48.9	50.7	52.5	54.2	55.8	57.3	58.7	59.9
4	61.1	62.1	62.9	63.7	64.2	64.6	64.8	64.9	64.7	64.3

Table 2c. – Bay 3 bypass weir rating table and equation. H is the head on the weir crest in feet and Q is the bypass flow rate in ft^3/s. "---" indicates that bypass flow rate cannot be accurately estimated.

$Q = 1.4816 - 1.3849\ H + 8.4372\ H^2 - 1.0988\ H^3$

$R^2 = 0.9994$

Head Above Weir Crest (ft)	Primary Bypass Flow Rate (ft^3/s)									
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0	---	---	1.5	1.8	2.2	2.8	3.5	4.3	5.2	6.3
1	7.4	8.7	10.1	11.5	13.1	14.7	16.4	18.1	19.9	21.8
2	23.7	25.6	27.6	29.6	31.6	33.6	35.6	37.6	39.6	41.6
3	43.6	45.5	47.4	49.3	51.1	52.9	54.6	56.2	57.8	59.2
4	60.6	61.9	63.1	64.2	65.1	66.0	66.7	67.3	67.7	68.0

Table 2d. – Bay 5 bypass weir rating table and equation. H is the head on the weir crest in feet and Q is the bypass flow rate in ft^3/s.

$Q = 1.9808 - 0.0301\ H + 7.0487\ H^2 - 0.8611\ H^3$

$R^2 = 0.9996$

Head Above Weir Crest (ft)	Primary Bypass Flow Rate (ft^3/s)									
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0	2.0	2.0	2.2	2.6	3.0	3.6	4.3	5.1	6.0	7.0
1	8.1	9.3	10.6	12.0	13.4	14.9	16.5	18.1	19.7	21.5
2	23.2	25.0	26.9	28.7	30.6	32.5	34.4	36.3	38.3	40.2
3	42.1	44.0	45.8	47.7	49.5	51.3	53.0	54.7	56.4	58.0
4	59.5	61.0	62.4	63.7	65.0	66.1	67.2	68.1	69.0	69.8

Final Fish Bypass Weirs

Operation of the final bypass weir is subject to operational constraints. Operating criteria requires a minimum of 2.0 ft of head on the final bypass weir. When the water surface elevation in the secondary screening facility is set to the design stage of 1213.0 ft, the final bypass weir can only be set to a head value of 3.0 ft in order to maintain an optimal tailwater pool in the downwell for fish passage. Head values lower than 3.0 ft do not provide an adequate tailwater pool for safe fish passage. Head values greater than 3.0 ft cannot be achieved because the weir cannot be physically lowered any farther.

When the temporary ramp to the juvenile trap is installed, the water surface elevation in front of the traveling screens must be raised to 1213.8 ft to provide flow into the trapping facility. With the ramp installed at a water elevation of 1213.8 ft, the weir can only be set to a head value of 3.6 ft to maintain an optimal tailwater pool in the downwell. Like the previous condition, the weir cannot be physically lowered to pass higher bypass flows.

Results of the final bypass analysis for current operational secondary water surface elevations of 1213.0 ft and 1213.8 ft are shown in Table 3:

Table 3. – Final fish bypass velocities and flow rates with an optimal tailwater pool.

	Head on Weir (ft)	Velocity (ft/s)			Water Depth (ft)	Bypass Flow Rate (ft^3/s)
		0.2 depth	0.8 depth	Mean		
Water Surface Elev. 1213.0 ft No Ramp	3.0	3.73	3.95	3.84	5.26	40.4
Water Surface Elev. 1213.8 ft With Ramp	3.6	3.16	3.32	3.24	6.16	39.9

In August 2004, velocities in the final bypass channel were significantly higher than velocities measured during previous evaluations. In July 2003, the juvenile fish ramp was not installed and the upstream water surface elevation was set to 1213.0 ft. The measured flow rate was 30.0 ft^3/s. During the March 2004 evaluation, the juvenile ramp and trap were installed in the trapping facility with a secondary water surface elevation of 1213.8 ft. The final bypass flow rate was calculated as 28.8 ft^3/s.

It is unclear why this evaluation yields final bypass flow rates that are 25 percent higher than previous measurements. Possible explanations include bypass pipe blockage in previous evaluations or a difference in the downwell condition set by the weir operator. Great care was taken during these experiments to properly set an optimal tailwater pool. The difference between a minimum acceptable tailwater pool and an optimal tailwater pool is subjective. If the weir was not set at a low enough elevation to provide for an optimal tailwater pool, a lower bypass flow rate would be expected.

Drum Screens

Velocity Measurements with Primary Bypass Flows of 65 ft^3/s

Detailed lateral and vertical velocity distributions across the drum screens are displayed in Figures 13-18 and Figures II-1 and II-2 in Appendix II. Figures 13a-18a show the sweep and approach velocity distributions for the operating fish bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s per bay). Figures 13a, 14a, and 15a show velocity data in Bay 2 on Screens 20, 18 and 17, respectively. Figures 16a, 17a, and 18a show velocity data in Bay 5 on Screens 5, 3, and 2, respectively. Approach velocities measured in Bay 2 at 0.05 times the water depth were sufficiently represented by measurements at 0.2 and 0.5 times the depth (Figures 13a, 14a, and 15a). Therefore, these near-surface measurements were not collected for all conditions. Approach velocities measured at 0.8 times the water depth were typically higher than velocities measured at 0.2 and 0.5.

Approach velocities measured at 0.9 times the water depth were significantly higher than velocities measured at shallower depths. Velocities at 0.9 times the depth also contained higher downward vertical velocity components than velocity measurements at other depths (Appendix I). Vertical velocity components were not included in figures for clarity. The forebay floor drops from elevation 1208.39 ft in front of the drum screens to elevation 1207.35 ft at the drum screen seat (Figure 8). Sluice gates installed in the stoplog slots behind the drum screens were placed 1 ft from the channel bottom to promote sediment movement past the screens and 1 ft from the water surface to allow debris and flow to pass over the boards. It is likely that both the recessed floor in front of the drum screens and the placement of the sluice gates contribute to high approach and downward velocities near the drum screens at the bottom of the water column.

Table 4 shows the percent of measurement locations that exceed the current NOAA fish screen approach velocity criteria of 0.4 ft/s and the facility design criteria of 0.5 ft/s. At the operating criteria of 4.4 ft of head on the primary bypass weirs, the approach velocities in Bay 5 are generally higher than the approach velocities in Bay 2 and exceed criteria more frequently. Approach velocities measured at depths below the curvature of the screen (0.8 and 0.9 depths) exceed criteria more frequently than shallower measurements. Approach velocities exceed the 0.4 ft/s NOAA criteria at 75 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth. Approach velocities exceed the 0.5 ft/s design criteria at 58 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth.

Sweep velocity magnitudes were similar between Bays 2 and 5. Sweep velocities do not exhibit a clear acceleration along the screens into the fish bypass channel. Table 5 shows the percent of measurement locations where the sweep-to-approach velocity ratio is less than the current NOAA screen criteria. NOAA requires a 1:1 sweep-to-approach velocity ratio and strongly advocates a 2:1 sweep-to-approach ratio (NOAA draft, 2004).

On all screens, several locations have sweep-to-approach velocity ratios of less than 2:1. Since sweep velocities were often lowest at the 0.9 depth and approach velocities were often highest, ratios were less than criteria on all screens. At the operating criteria of 4.4 ft of head on the primary bypass weirs, 49 percent of 189 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1. For data collected only in Bay 5, 73 percent of 84 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1. For data collected only in Bay 2, 30 percent of 105 total measurement locations and 100 percent of locations at the deepest measurement depth have sweep-to-approach velocity ratios less than 2:1.

Velocity distributions across the screens are nonuniform. NOAA fish passage criterion (Section 16) specifies that a uniform approach velocity is achieved when no individual velocity measurement exceeds 110% of the 0.4 ft/s criteria, or 0.44 ft/s. In this evaluation, approach velocities exceed the 0.5 ft/s criteria at all depths on Screens 2, 3, 5, and 20 and at some depths on Screens 17 and 18. Approach and sweep velocities are highest and least uniform on the most upstream screen in each bay (Screen 20 for Bay 2 and Screen 5 for Bay 5). The highest velocities on these screens occur at the most upstream measurement location (Figures II-1 to II-4 in Appendix II). Approach and sweep velocities are more consistent vertically and laterally across screens in the center of the bays (Screens 18 and 17 in Bay 2 and Screens 3 and 2 in Bay 5). Generally, approach and sweep velocities are slightly higher at the leading edge of each screen and slightly lower at the trailing edge of the screen. The concrete support piers between screens may be a factor in this variability.

Velocity Measurements with Primary Bypass Flows of 50 ft^3/s

Figures 13b, 14b, 15b, 16b, 17b, and 18b and Figures II-1 and II-2 in Appendix II show velocities measured at a primary bypass flow rate of 50 ft^3/s per bay. In Appendix II, Figures II-3 to II-6 show velocity patterns for each screen with iso-velocity lines. When the primary bypass flow rate is reduced from 65 to 50 ft^3/s, approach velocity magnitudes in Bay 2 exceed design criteria more frequently, while approach velocities in Bay 5 do not change considerably (Table 4). Approach velocities exceed 0.4 ft/s at 92 percent of 168 measurement locations.

In Bays 2 and 5, sweep velocities decrease. At a bypass flow rate of 50 ft^3/s, sweep-to-approach velocity ratios are less than 2:1 for 82 percent of all measurement locations, as compared to 49 percent of all measurement locations when the bypass flow rate is 65 ft^3/s. The effect of reducing the bypass flow rate is clearly illustrated in Figure 19 for Bay 2 and Figure 20 for Bay 5. At both 65 and 50 ft^3/s bypass flows, lateral and vertical velocity distributions are nonuniform and flow does not accelerate into the bypass intakes.

In 2003, Battelle measured velocities in Bays 2 and 5 at bypass flow rates of 65 and 32 ft^3/s (McMichael et al., 2003). At approximately 65 ft^3/s, Battelle documented high approach velocities with large vertical and lateral variations over the screen faces in Bay 5. Approach velocities were lower and less variable in Bay 2. This hydraulic evaluation shows a similar pattern at a similar bypass flow rate. When Battelle reduced the bypass flow rate to 32 ft^3/s, Bay 2 sweep velocities decreased and approach velocities increased. In Bay 5, the opposite occurred. This evaluation shows a similar trend to the data collected in Bay 2, but not Bay 5.

BAY 2, SCREEN 20

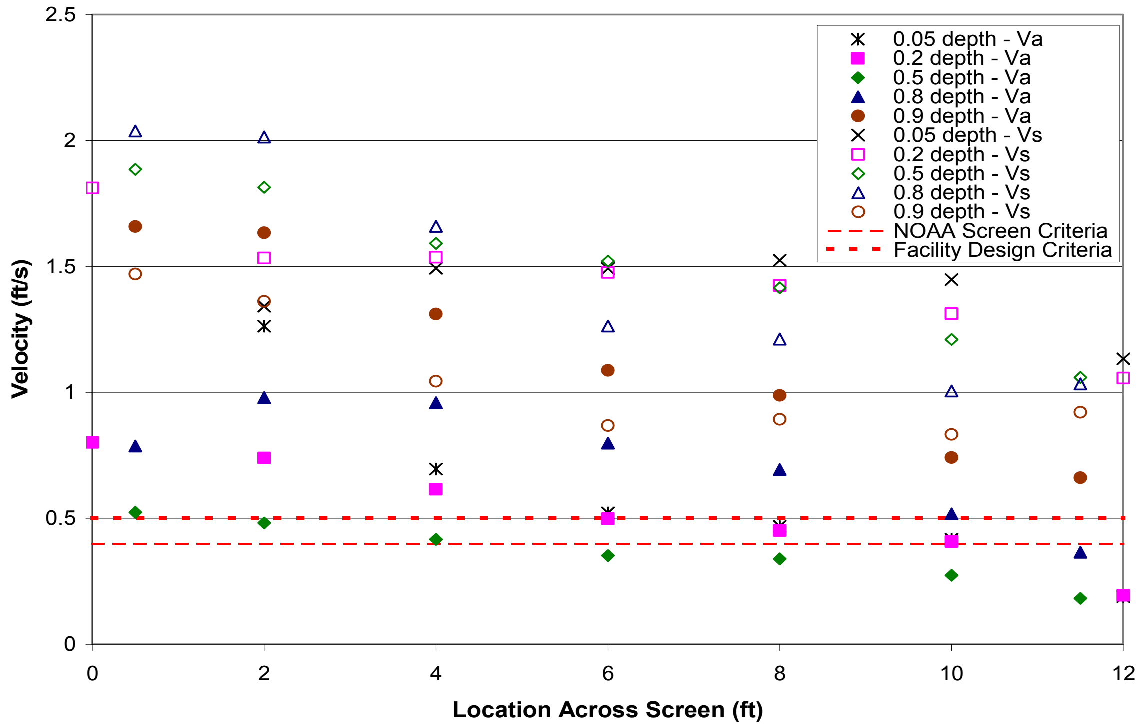

Figure 13a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 20** at a Bay 2 fish bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

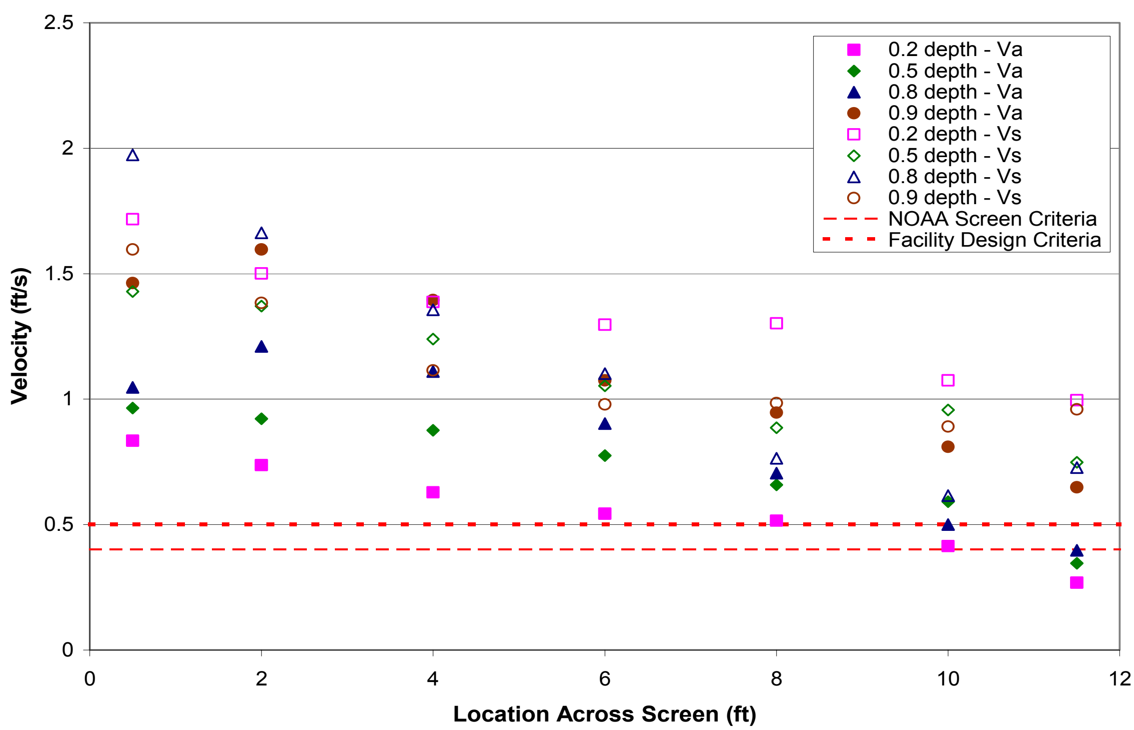

Figure 13b. - Sweep (V_s) and approach (V_a) velocity distributions on **Screen 20** at a Bay 2 fish bypass flow rate of 50 ft^3/s.

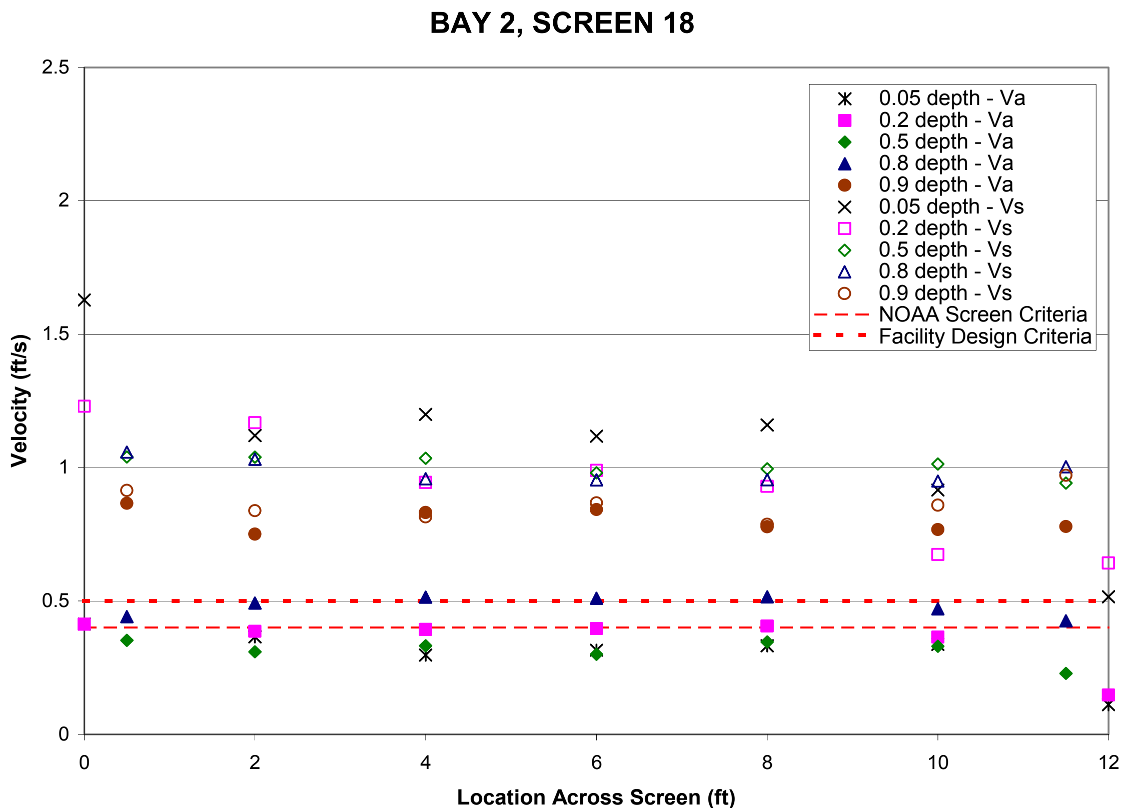

Figure 14a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 18** at a Bay 2 primary bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

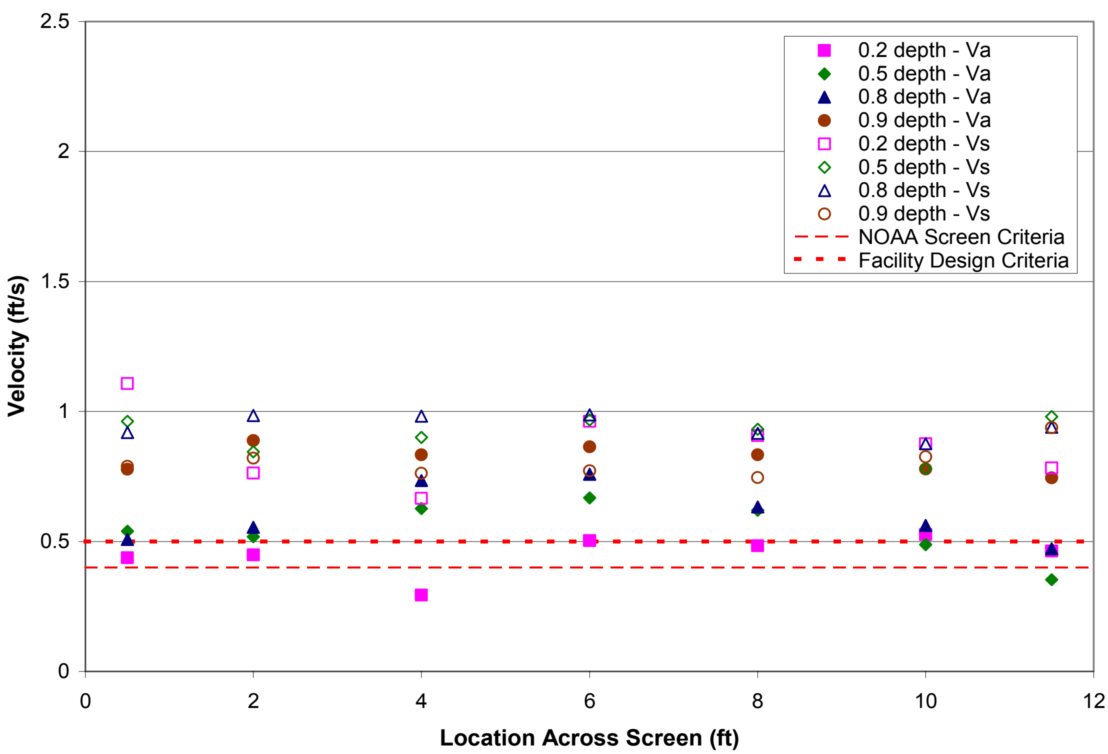

Figure 14b. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 18** at a Bay 2 primary bypass flow rate of 50 ft^3/s.

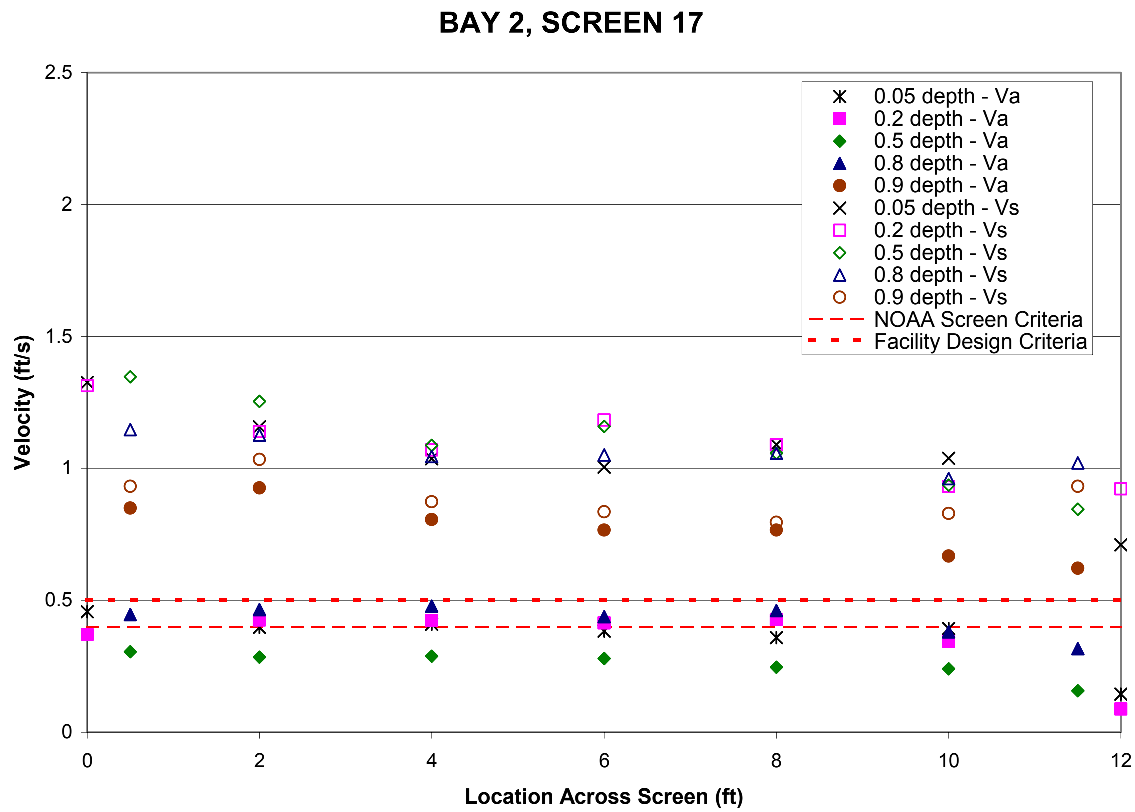

Figure 15a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 17** at a Bay 2 primary bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

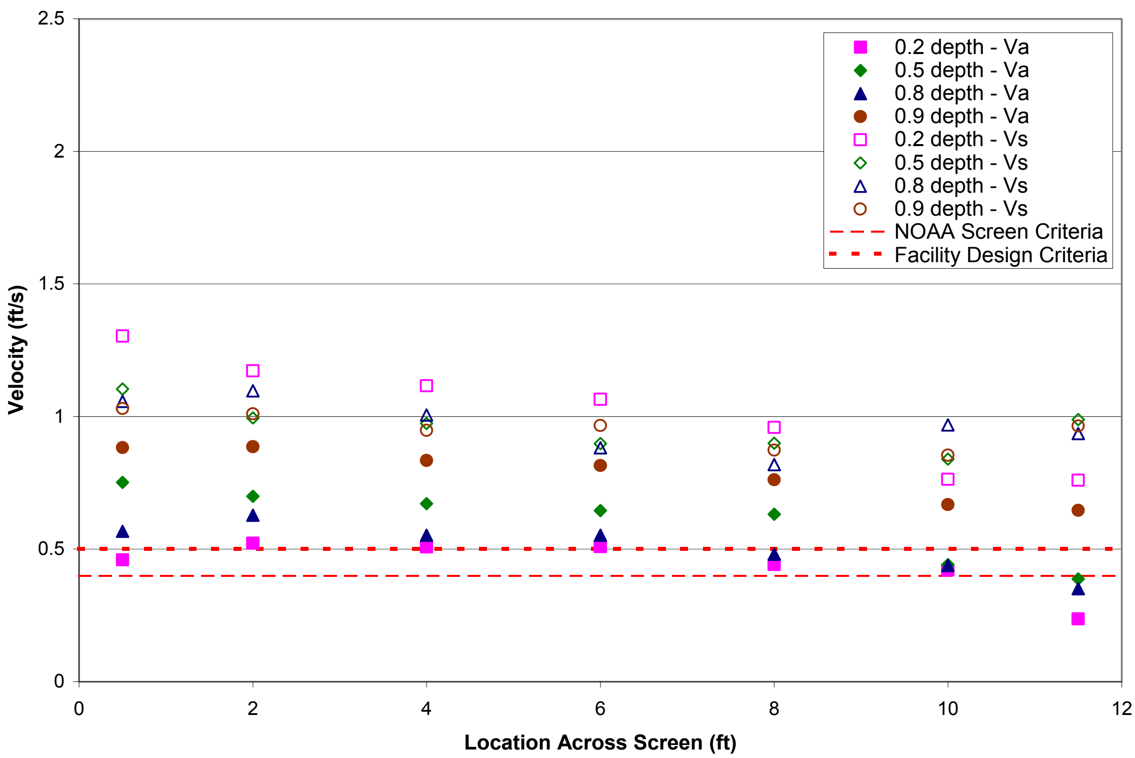

Figure 15b. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 17** at a Bay 2 primary bypass flow rate of 50 ft^3/s.

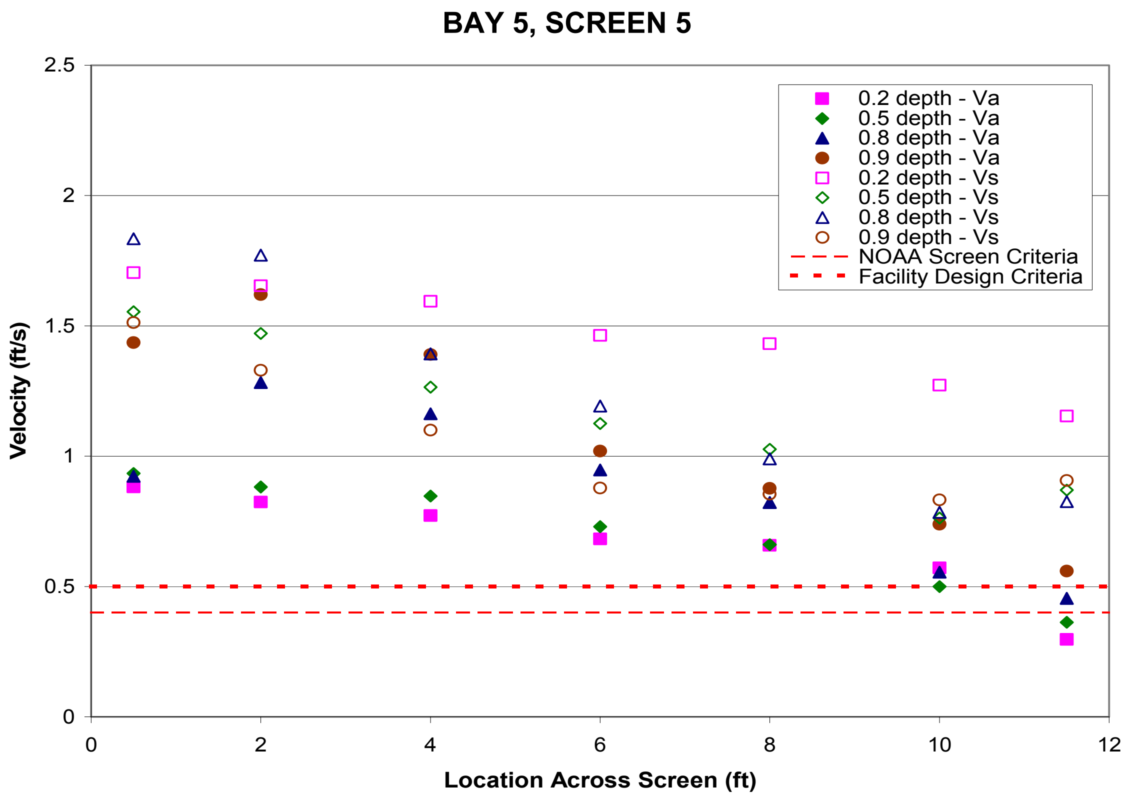

Figure 16a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 5** at a Bay 5 primary bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

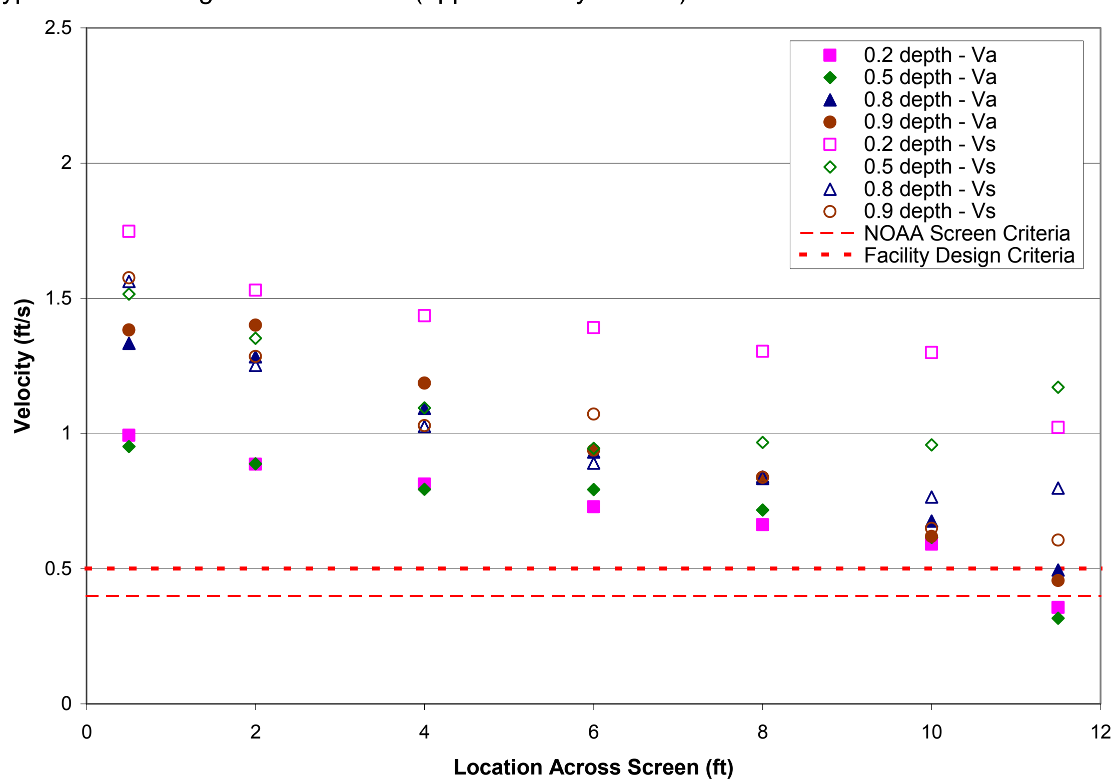

Figure 16b. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 5** at a Bay 5 primary bypass flow rate of 50 ft^3/s.

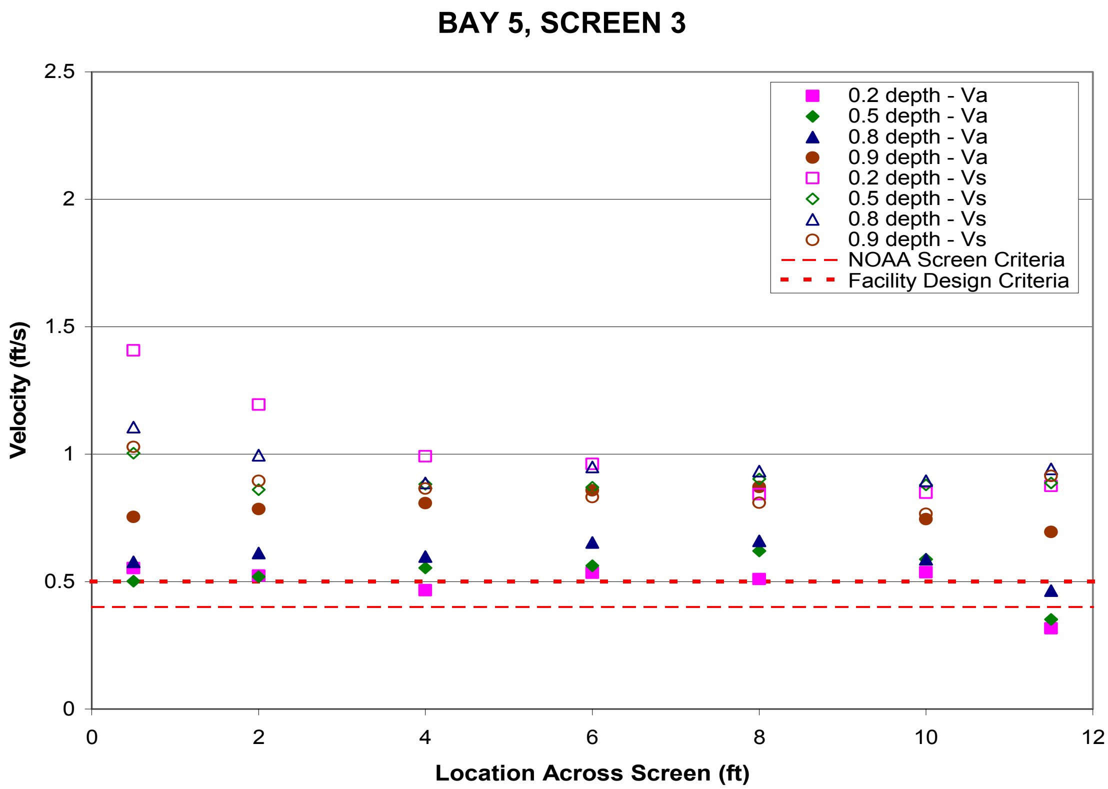

Figure 17a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 3** at a Bay 5 primary bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

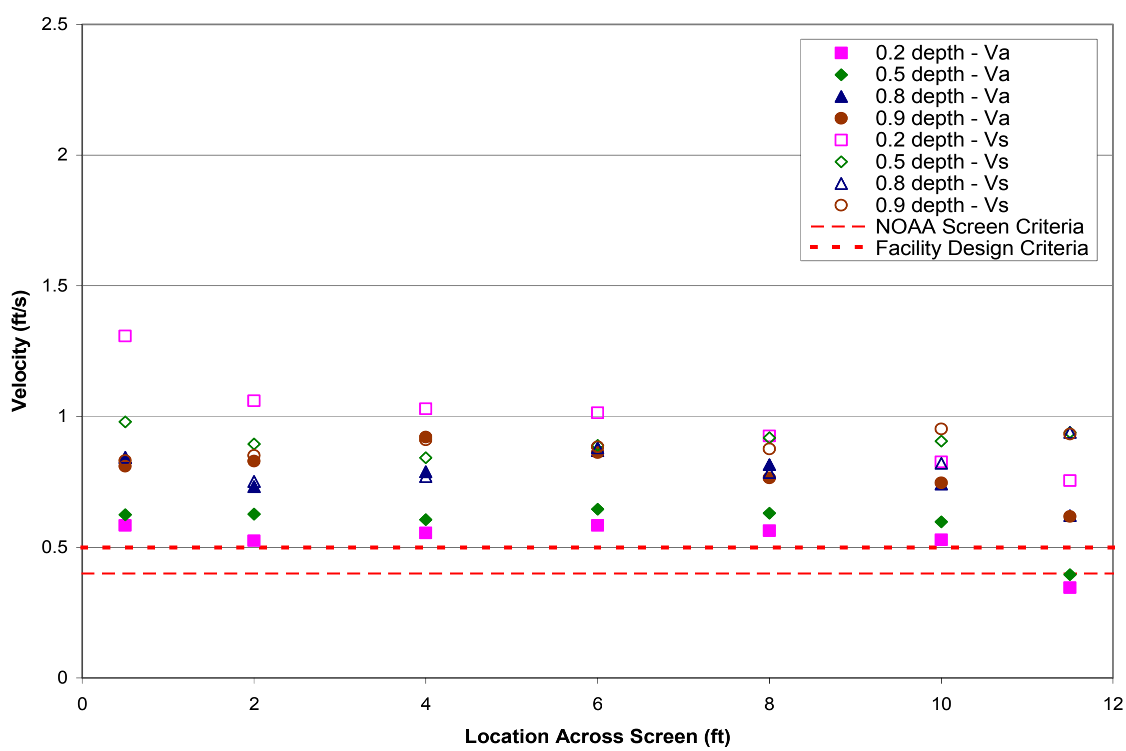

Figure 17b. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 3** at a Bay 5 primary bypass flow rate of 50 ft^3/s.

BAY 5, SCREEN 2

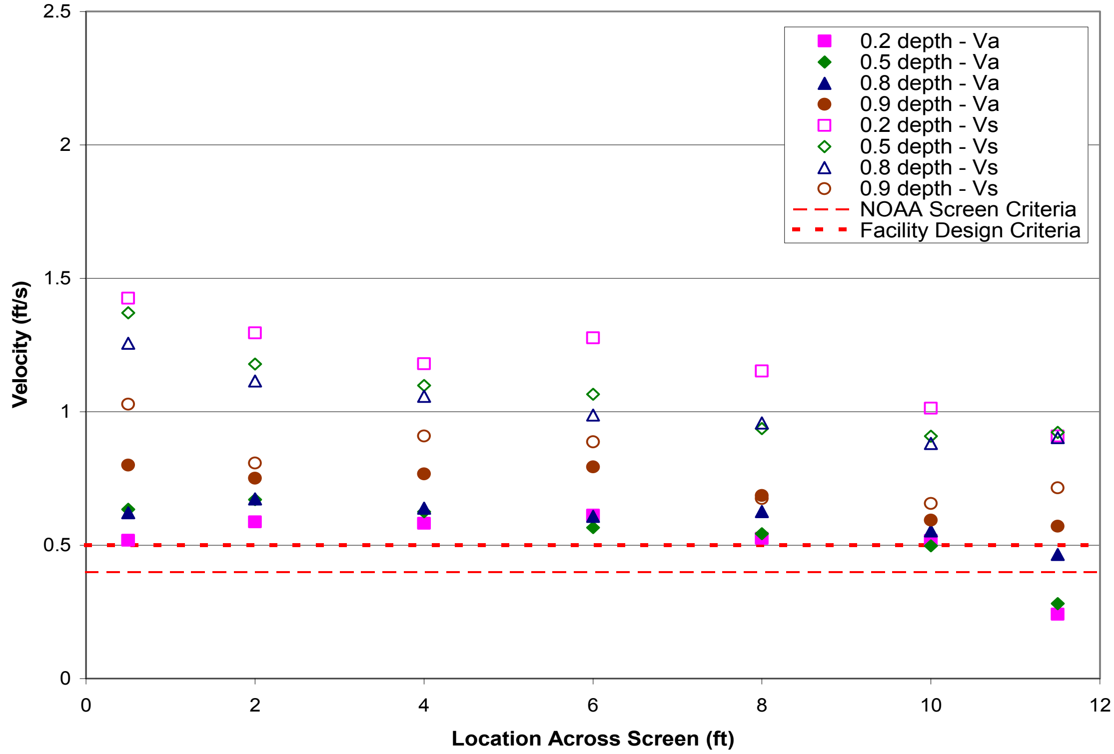

Figure 18a. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 2** at a Bay 5 primary bypass weir setting of 4.4 ft of head (approximately 65 ft^3/s).

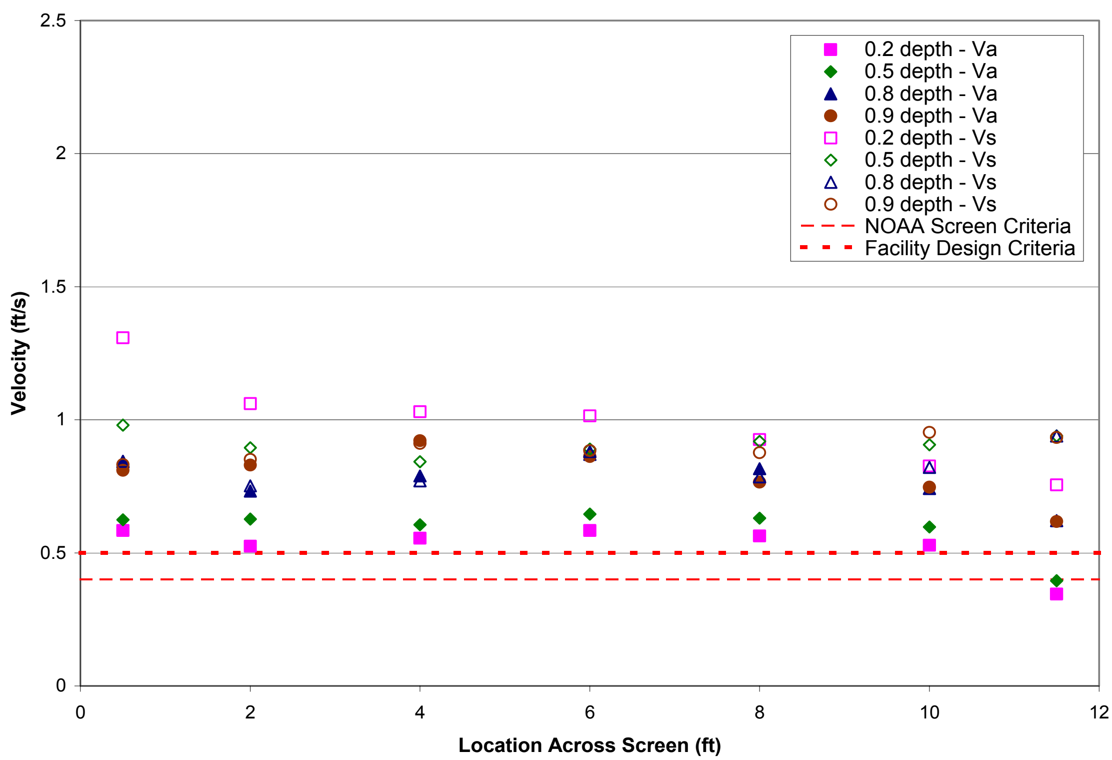

Figure 18b. – Sweep (V_s) and approach (V_a) velocity distributions on **Screen 2** at a Bay 5 primary bypass flow rate of 50 ft^3/s.

Table 4. - Percentage of 7 lateral measurement locations where approach velocity (V_a) measurements exceed NOAA criteria of 0.4 ft/s and facility design criteria of 0.5 ft/s.

Bypass Flow Rate = 65 ft^3/s

	SCREENING BAY 2						SCREENING BAY 5					
	Screen 20		Screen 18		Screen 17		Screen 5		Screen 3		Screen 2	
Depth	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s
0.05	71%	43%	14%	0%	29%	0%	--	--	--	--	--	--
0.2	86%	43%	29%	0%	57%	0%	86%	86%	86%	71%	86%	86%
0.5	57%	14%	0%	0%	0%	0%	86%	86%	86%	86%	86%	71%
0.8	86%	86%	100%	43%	71%	0%	100%	86%	100%	86%	100%	86%
0.9	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Bypass Flow Rate = 50 ft^3/s

	SCREENING BAY 2						SCREENING BAY 5					
	Screen 20		Screen 18		Screen 17		Screen 5		Screen 3		Screen 2	
Depth	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s	$V_a > 0.4$ ft/s	$V_a > 0.5$ ft/s
0.05	--	--	--	--	--	--	--	--	--	--	--	--
0.2	86%	71%	86%	29%	86%	43%	86%	86%	86%	86%	86%	86%
0.5	86%	86%	86%	71%	86%	71%	86%	86%	86%	86%	86%	86%
0.8	86%	86%	100%	86%	86%	57%	100%	86%	100%	100%	100%	71%
0.9	100%	100%	100%	100%	100%	100%	100%	86%	100%	100%	100%	86%

Table 5. – Percentage of 7 lateral measurement locations where the sweep-to-approach velocity ratio (V_s/V_a) does not meet NOAA criteria.

Bypass Flow Rate = 65 ft^3/s

	SCREENING BAY 2						SCREENING BAY 5					
	Screen 20		Screen 18		Screen 17		Screen 5		Screen 3		Screen 2	
Depth	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2.1	V_s/V_a < 1:1	V_s/V_a < 2.1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1
0.05	14%	29%	0%	0%	0%	0%	--	--	--	--	--	--
0.2	0%	0%	0%	14%	0%	0%	0%	14%	0%	43%	0%	14%
0.5	0%	0%	0%	0%	0%	0%	0%	86%	0%	71%	0%	71%
0.8	0%	57%	0%	43%	0%	0%	0%	100%	0%	86%	0%	86%
0.9	71%	100%	14%	100%	0%	100%	57%	100%	29%	100%	14%	100%

Bypass Flow Rate = 50 ft^3/s

	SCREENING BAY 2						SCREENING BAY 5					
	Screen 20		Screen 18		Screen 17		Screen 5		Screen 3		Screen 2	
Depth	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1	V_s/V_a < 1:1	V_s/V_a < 2:1
0.05	--	--	--	--	--	--	--	--	--	--	--	--
0.2	0%	0%	0%	71%	0%	14%	0%	71%	0%	57%	0%	71%
0.5	0%	86%	0%	86%	0%	86%	0%	86%	0%	86%	0%	86%
0.8	0%	100%	0%	100%	0%	71%	43%	100%	29%	100%	14%	100%
0.9	43%	100%	57%	100%	0%	100%	29%	100%	14%	100%	14%	100%

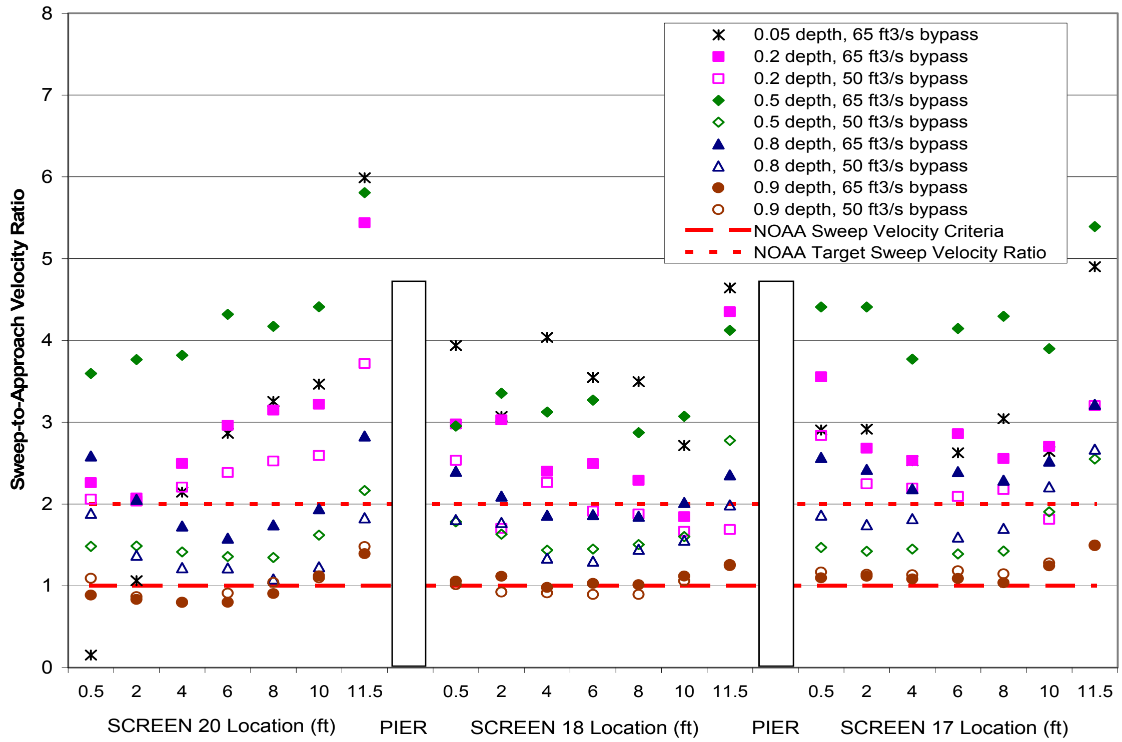

Figure 19. - Ratio of sweep-to-approach velocity in front of Bay 2 screens.

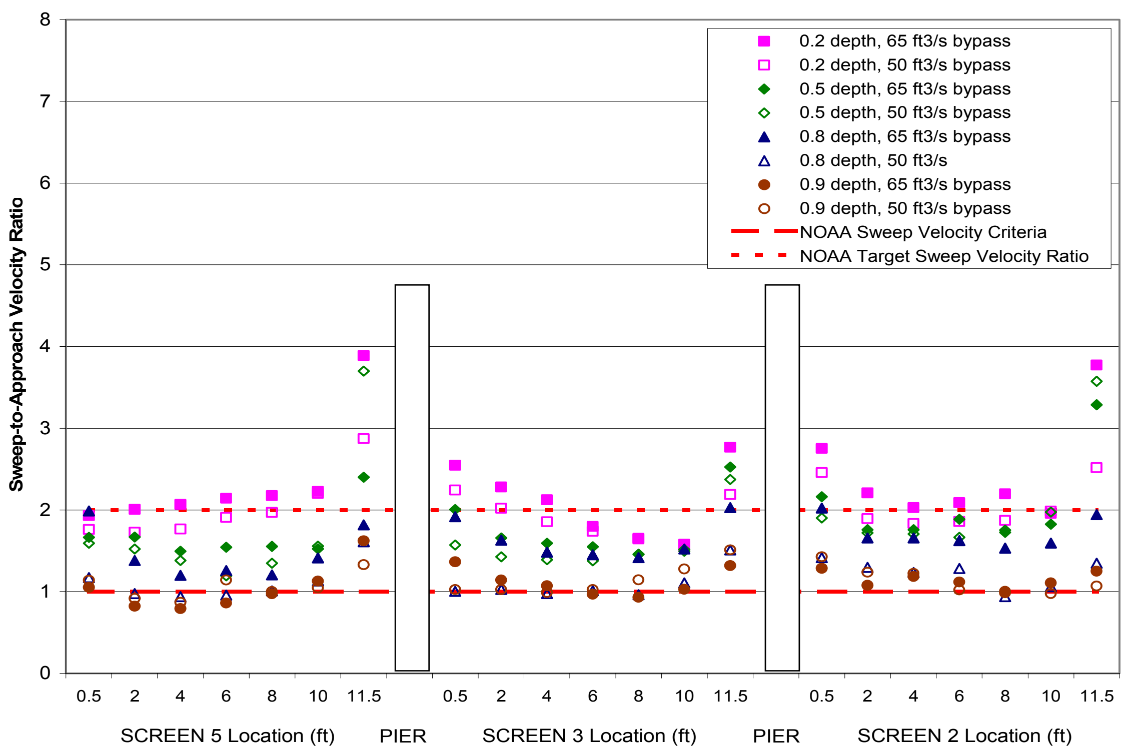

Figure 20. - Ratio of sweep-to-approach velocity in front of Bay 5 screens.

RECOMMENDATIONS

The general weir rating table or equation developed from this evaluation should be used to calculate primary bypass flow rates and set bypass weirs when the forebay water surface elevation is 1220.4 ft and the secondary water surface elevation is 1213.0 ft. The transition between a partially submerged and submerged weir condition should occur at a lower head value when the secondary water surface elevation is set to 1213.8 ft during juvenile trapping. Field testing would be required to quantify the extent of this change on the weir rating. The standard suppressed rectangular weir equation should not be used to set bypass weirs since the adjustable bypass weirs at the facility do not satisfy requirements for application of the equation.

Velocities should be collected near to the drum screens at vertical locations of 0.2, 0.5, 0.8, and 0.9 times the water depth to describe the range of velocities over the water column. Since velocities collected at 0.05 times the water depth were well represented by measurements at 0.2 and 0.5 times the depth, near-surface velocity measurements are not necessary at the Roza drum screens. Velocities collected at 0.9 times the water depth represent the higher velocities present at the bottom of the water column, particularly when sluice gates are installed.

Velocities should be collected laterally near to the concrete divider piers at 0.5 ft and 11.5 ft from the leading edge of the screen. Measuring velocities at three to five other lateral locations across the drum screen face is recommended to show how velocities vary over smaller grid sections. Since flow patterns across the screen face are well defined by seven locations, measuring more locations will most likely not improve knowledge of flow behavior.

The costs and benefits of altering high canal flow operations by reducing the primary bypass flow rate should be carefully considered by fisheries biologists and facility managers. A primary bypass flow reduction from 65 ft^3/s to 50 ft^3/s produces less desirable flow conditions at the drum screens as indicated by an increase in the number of measurement locations that exceed criteria. At 50 ft^3/s, the primary bypass weirs still operate in a submerged condition which does not provide much benefit for improving passage of downstream-migrating salmon.

During the May 2004 hydraulic evaluation at a canal flow rate of 820 ft^3/s, the influence of the sluice gates on drum screen performance at 0.2 and 0.8 times the water depth was neutral, or even favorable. During this evaluation at a canal flow rate of 1911 ft^3/s, velocities collected closer to the bed at 0.9 times the water depth were higher than velocities at shallower depths and exceeded criteria more frequently. Since this evaluation included only velocity measurements with sluice gates installed, the effect of the sluice gates on drum screen performance under these conditions is not known. However, sluice gates were installed at the facility to reduce sediment build-up in front of the screens by increasing near-bed velocities. By improving sediment movement, it is likely that the increased near-bed velocities impact drum screen performance at the deepest locations of the screen.

Since equipment access to measurement locations below the curvature of the drum screens is difficult and numerous measurement locations are needed to fully define velocity fields with and without sluice gates, the effect of the sluice gates on screen performance is not fully described through field evaluations. Numerical modeling of the

Roza drum screens is strongly recommended. Numerical modeling should provide a clear visualization of flow conditions near to the screens including the effects of the sluice gates and recessed floor on the flow field. In the model, the sluice gates can be raised or lowered to identify a configuration that balances sediment movement with reasonable flow conditions near the screen face. To accomplish this, a sediment analysis may need to be conducted. The sluice gates can be repositioned, resized, removed, or redesigned with a different material in the model. Numerical modeling should be less time consuming and less expensive than full-scale field evaluations for various sluice gate configurations.

REFERENCES

Abernathy, C. Scott, Duane A. Neitzel, and E. William Lusty (1989). "Velocity Measurements at Six Fish Screening Facilities in the Yakima River Basin, Summer 1988, Annual Report." Pacific Northwest National Laboratory, Portland, Oregon.

Abernathy, C. Scott, Duane A. Neitzel, and E. William Lusty (1990). "Velocity Measurements at Three Fish Screen Facilities in the Yakima River Basin, Washington, Summer 1989." Pacific Northwest National Laboratory, Portland, Oregon.

Blanton, S.L., G.A. McMichael, and D.A. Neitzel (1998). "Washington Phase II Fish Diversion Screen Evaluations in the Yakima River Basin, 1997." Pacific Northwest National Laboratory, Portland, Oregon.

Blanton, S.L., D.A. Neitzel, and C.S. Abernathy (1999). "Washington Phase II Fish Diversion Screen Evaluations in the Yakima River Basin, 1998." Pacific Northwest National Laboratory, Portland, Oregon.

Bureau of Reclamation (2001). "Water Measurement Manual – Third Edition." U.S. Department of Interior, Bureau of Reclamation, Water Resources Technical Publication, Denver, Colorado.

Carter, J.A., G.A. McMichael, and M.A. Chamness (2002). "Yakima River Basin Phase II Fish Screen Evaluations, 2001." Pacific Northwest National Laboratory, Portland, Oregon.

Chamness, M.A., E.V. Arntzen, G.A. McMichael, and P.S. Titzler (2001). "Washington Phase II Fish Diversion Screen Evaluations in the Yakima River Basin, 2000." Pacific Northwest National Laboratory, Portland, Oregon.

DeMoyer, C.D. and T.B. Vermeyen (2004). "Roza Fish Screens Facility Velocity Measurements With and Without Porosity Boards at an Intermediate Canal Flow Rate." Report No. PAP-928. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado.

McMichael, G.A., J.A. Vucelick, and C.S. Abernathy (2003). "Roza Dam Fish Screen Evaluations, Summer 2003." Battelle-Pacific Northwest Division, Richland, WA.

National Oceanic and Atmospheric Administration (2004). "Anadromous Salmonid Passage Facility Guidelines and Criteria – February 2004 External Review Draft." National Oceanic and Atmospheric Administration, Northwest Region, Portland, Oregon.

Pearce, R. (1989). Operating Criteria: Roza Canal Fish Screens Bypass System. National Marine Fisheries Service, Northwest Region, Portland, Oregon.

APPENDIX I: Velocity Measurements at Drum Screens

BAY 2, SCREEN 20, Bypass Flow Rate = 65 cfs

Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.05	0	-0.073	-0.011	-0.069
0.05	2	1.263	1.342	-0.127
0.05	4	0.696	1.493	-0.051
0.05	6	0.521	1.492	-0.012
0.05	8	0.468	1.524	-0.002
0.05	10	0.418	1.448	-0.003
0.05	12	0.189	1.133	0.003
0.2	0	0.802	1.811	0.178
0.2	2	0.739	1.533	-0.010
0.2	4	0.616	1.537	0.016
0.2	6	0.499	1.476	0.058
0.2	8	0.452	1.424	0.083
0.2	10	0.408	1.313	0.116
0.2	12	0.194	1.057	0.162
0.5	0.5	0.524	1.885	0.244
0.5	2	0.482	1.814	0.275
0.5	4	0.417	1.592	0.242
0.5	6	0.352	1.521	0.216
0.5	8	0.339	1.415	0.212
0.5	10	0.274	1.210	0.148
0.5	11.5	0.182	1.059	0.134
0.8	0.5	0.787	2.037	0.243
0.8	2	0.980	2.014	0.348
0.8	4	0.959	1.659	0.411
0.8	6	0.799	1.263	0.384
0.8	8	0.694	1.211	0.280
0.8	10	0.518	1.006	0.187
0.8	11.5	0.365	1.034	0.139
0.9	0.5	1.658	1.469	0.491
0.9	2	1.633	1.362	0.520
0.9	4	1.311	1.044	0.498
0.9	6	1.087	0.868	0.366
0.9	8	0.988	0.893	0.268
0.9	10	0.742	0.833	0.214
0.9	11.5	0.662	0.921	0.209

BAY 2, SCREEN 18, Bypass Flow Rate = 65 cfs

Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.05	0	0.414	1.629	0.146
0.05	2	0.365	1.120	0.011
0.05	4	0.297	1.200	-0.012
0.05	6	0.315	1.117	-0.018
0.05	8	0.332	1.159	-0.002
0.05	10	0.337	0.915	0.005
0.05	12	0.111	0.515	-0.012
0.2	0	0.413	1.229	0.107
0.2	2	0.386	1.168	0.098
0.2	4	0.393	0.944	0.025
0.2	6	0.397	0.989	0.048
0.2	8	0.406	0.930	0.071
0.2	10	0.365	0.673	0.029
0.2	12	0.148	0.642	-0.007
0.5	0.5	0.352	1.040	0.040
0.5	2	0.310	1.039	-0.010
0.5	4	0.331	1.035	0.076
0.5	6	0.300	0.981	0.029
0.5	8	0.346	0.995	0.103
0.5	10	0.330	1.013	0.110
0.5	11.5	0.228	0.942	0.148
0.8	0.5	0.441	1.058	0.082
0.8	2	0.492	1.032	0.044
0.8	4	0.514	0.958	0.100
0.8	6	0.510	0.954	0.100
0.8	8	0.515	0.954	0.111
0.8	10	0.470	0.949	0.143
0.8	11.5	0.425	1.002	0.196
0.9	0.5	0.866	0.914	0.095
0.9	2	0.750	0.838	0.155
0.9	4	0.831	0.815	0.126
0.9	6	0.842	0.868	0.150
0.9	8	0.778	0.788	0.160
0.9	10	0.767	0.859	0.192
0.9	11.5	0.778	0.971	0.222

BAY 2, SCREEN 17, Bypass Flow Rate = 65 cfs

Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.05	0	0.456	1.326	0.024
0.05	2	0.397	1.158	-0.015
0.05	4	0.410	1.037	-0.008
0.05	6	0.383	1.005	0.007
0.05	8	0.358	1.090	-0.015
0.05	10	0.393	1.039	0.019
0.05	12	0.145	0.710	-0.017
0.2	0	0.370	1.313	0.085
0.2	2	0.425	1.140	0.065
0.2	4	0.423	1.069	0.069
0.2	6	0.414	1.183	0.083
0.2	8	0.427	1.090	0.098
0.2	10	0.345	0.931	0.098
0.2	12	0.088	0.923	0.021
0.5	0.5	0.306	1.347	0.126
0.5	2	0.284	1.254	0.128
0.5	4	0.288	1.087	0.137
0.5	6	0.280	1.159	0.118
0.5	8	0.246	1.058	0.076
0.5	10	0.240	0.937	0.045
0.5	11.5	0.157	0.845	0.119
0.8	0.5	0.446	1.147	0.113
0.8	2	0.465	1.126	0.101
0.8	4	0.478	1.045	0.108
0.8	6	0.439	1.051	0.070
0.8	8	0.461	1.057	0.062
0.8	10	0.381	0.961	0.085
0.8	11.5	0.317	1.020	0.154
0.9	0.5	0.850	0.932	0.191
0.9	2	0.926	1.034	0.179
0.9	4	0.806	0.873	0.172
0.9	6	0.766	0.835	0.163
0.9	8	0.767	0.796	0.124
0.9	10	0.667	0.830	0.148
0.9	11.5	0.622	0.932	0.173

BAY 2, SCREEN 20, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.834	1.717	0.017
0.2	2	0.737	1.501	-0.018
0.2	4	0.629	1.387	0.026
0.2	6	0.543	1.297	0.004
0.2	8	0.516	1.302	0.059
0.2	10	0.414	1.074	0.077
0.2	11.5	0.268	0.996	0.073
0.5	0.5	0.965	1.429	0.225
0.5	2	0.922	1.371	0.212
0.5	4	0.876	1.240	0.243
0.5	6	0.775	1.053	0.224
0.5	8	0.658	0.886	0.209
0.5	10	0.591	0.957	0.152
0.5	11.5	0.345	0.748	0.157
0.8	0.5	1.047	1.974	0.390
0.8	2	1.210	1.664	0.450
0.8	4	1.110	1.356	0.509
0.8	6	0.903	1.102	0.424
0.8	8	0.705	0.764	0.255
0.8	10	0.500	0.616	0.228
0.8	11.5	0.397	0.728	0.211
0.9	0.5	1.463	1.596	0.409
0.9	2	1.596	1.384	0.545
0.9	4	1.395	1.115	0.516
0.9	6	1.074	0.980	0.373
0.9	8	0.946	0.984	0.293
0.9	10	0.810	0.890	0.221
0.9	11.5	0.649	0.959	0.219

BAY 2, SCREEN 18, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.437	1.107	0.027
0.2	2	0.449	0.763	0.058
0.2	4	0.294	0.666	0.041
0.2	6	0.503	0.962	0.044
0.2	8	0.483	0.907	0.000
0.2	10	0.526	0.876	0.021
0.2	11.5	0.464	0.783	0.005
0.5	0.5	0.539	0.962	0.057
0.5	2	0.518	0.845	0.004
0.5	4	0.627	0.901	0.114
0.5	6	0.667	0.968	0.161
0.5	8	0.619	0.931	0.129
0.5	10	0.487	0.781	0.148
0.5	11.5	0.353	0.980	0.191
0.8	0.5	0.507	0.919	0.141
0.8	2	0.554	0.985	0.157
0.8	4	0.734	0.982	0.172
0.8	6	0.759	0.987	0.188
0.8	8	0.633	0.916	0.183
0.8	10	0.562	0.876	0.191
0.8	11.5	0.472	0.939	0.215
0.9	0.5	0.778	0.789	0.099
0.9	2	0.888	0.820	0.181
0.9	4	0.834	0.762	0.134
0.9	6	0.864	0.772	0.165
0.9	8	0.833	0.745	0.159
0.9	10	0.779	0.826	0.210
0.9	11.5	0.745	0.938	0.223

BAY 2, SCREEN 17, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.459	1.304	0.088
0.2	2	0.522	1.173	0.050
0.2	4	0.508	1.116	0.087
0.2	6	0.509	1.065	0.047
0.2	8	0.441	0.960	0.055
0.2	10	0.421	0.763	0.083
0.2	11.5	0.237	0.760	0.064
0.5	0.5	0.752	1.104	0.140
0.5	2	0.699	0.994	0.088
0.5	4	0.671	0.974	0.069
0.5	6	0.645	0.898	0.082
0.5	8	0.631	0.899	0.085
0.5	10	0.441	0.840	0.109
0.5	11.5	0.388	0.989	0.134
0.8	0.5	0.567	1.057	0.185
0.8	2	0.628	1.097	0.159
0.8	4	0.552	1.006	0.188
0.8	6	0.553	0.882	0.132
0.8	8	0.481	0.818	0.144
0.8	10	0.438	0.968	0.129
0.8	11.5	0.350	0.936	0.157
0.9	0.5	0.883	1.030	0.183
0.9	2	0.886	1.010	0.166
0.9	4	0.835	0.947	0.132
0.9	6	0.815	0.966	0.125
0.9	8	0.761	0.873	0.116
0.9	10	0.667	0.854	0.164
0.9	11.5	0.646	0.964	0.161

BAY 5, SCREEN 5, Bypass Flow Rate = 65 cfs
Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.882	1.704	0.033
0.2	2	0.824	1.654	0.000
0.2	4	0.772	1.595	0.067
0.2	6	0.683	1.463	0.096
0.2	8	0.658	1.431	0.104
0.2	10	0.571	1.273	0.086
0.2	11.5	0.297	1.155	0.056
0.5	0.5	0.934	1.554	0.347
0.5	2	0.882	1.471	0.329
0.5	4	0.847	1.265	0.336
0.5	6	0.729	1.126	0.370
0.5	8	0.661	1.026	0.333
0.5	10	0.500	0.762	0.348
0.5	11.5	0.363	0.870	0.158
0.8	0.5	0.922	1.834	0.283
0.8	2	1.282	1.771	0.442
0.8	4	1.163	1.392	0.519
0.8	6	0.948	1.192	0.414
0.8	8	0.822	0.990	0.265
0.8	10	0.555	0.785	0.284
0.8	11.5	0.455	0.826	0.214
0.9	0.5	1.436	1.512	0.306
0.9	2	1.620	1.330	0.472
0.9	4	1.390	1.100	0.500
0.9	6	1.020	0.878	0.350
0.9	8	0.877	0.855	0.293
0.9	10	0.739	0.833	0.222
0.9	11.5	0.559	0.906	0.225

BAY 5, SCREEN 3, Bypass Flow Rate = 65 cfs

Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.553	1.407	0.145
0.2	2	0.524	1.194	0.096
0.2	4	0.467	0.991	0.051
0.2	6	0.535	0.962	0.034
0.2	8	0.510	0.843	0.046
0.2	10	0.537	0.849	0.126
0.2	11.5	0.316	0.876	0.037
0.5	0.5	0.501	1.004	0.047
0.5	2	0.520	0.860	0.031
0.5	4	0.554	0.882	0.101
0.5	6	0.562	0.870	0.097
0.5	8	0.620	0.902	0.091
0.5	10	0.588	0.879	0.109
0.5	11.5	0.351	0.888	0.146
0.8	0.5	0.577	1.106	0.081
0.8	2	0.611	0.996	0.102
0.8	4	0.598	0.888	0.098
0.8	6	0.654	0.950	0.107
0.8	8	0.660	0.934	0.135
0.8	10	0.588	0.896	0.158
0.8	11.5	0.464	0.942	0.188
0.9	0.5	0.754	1.028	0.125
0.9	2	0.784	0.895	0.096
0.9	4	0.808	0.865	0.145
0.9	6	0.858	0.831	0.170
0.9	8	0.871	0.809	0.196
0.9	10	0.746	0.766	0.207
0.9	11.5	0.695	0.915	0.188

BAY 5, SCREEN 2, Bypass Flow Rate = 65 cfs

Velocity data collected with bypass weirs set to the design bypass flow rate at 4.4 ft head.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.518	1.425	0.068
0.2	2	0.586	1.295	0.087
0.2	4	0.581	1.180	0.081
0.2	6	0.612	1.277	0.062
0.2	8	0.525	1.152	0.070
0.2	10	0.517	1.013	0.060
0.2	11.5	0.241	0.909	0.008
0.5	0.5	0.634	1.371	0.208
0.5	2	0.671	1.179	0.122
0.5	4	0.625	1.099	0.083
0.5	6	0.565	1.065	0.050
0.5	8	0.543	0.937	0.066
0.5	10	0.497	0.908	0.119
0.5	11.5	0.281	0.922	0.168
0.8	0.5	0.621	1.256	0.142
0.8	2	0.673	1.116	0.100
0.8	4	0.638	1.058	0.073
0.8	6	0.608	0.988	0.069
0.8	8	0.626	0.958	0.150
0.8	10	0.553	0.881	0.136
0.8	11.5	0.465	0.903	0.170
0.9	0.5	0.800	1.028	0.167
0.9	2	0.751	0.807	0.063
0.9	4	0.767	0.909	0.051
0.9	6	0.793	0.887	0.093
0.9	8	0.686	0.675	0.114
0.9	10	0.594	0.656	0.144
0.9	11.5	0.571	0.714	0.174

BAY 5, SCREEN 5, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.994	1.748	-0.090
0.2	2	0.886	1.530	-0.096
0.2	4	0.813	1.435	-0.035
0.2	6	0.729	1.391	-0.003
0.2	8	0.662	1.304	0.011
0.2	10	0.590	1.300	-0.005
0.2	11.5	0.356	1.022	0.026
0.5	0.5	0.951	1.515	0.381
0.5	2	0.888	1.352	0.375
0.5	4	0.793	1.094	0.390
0.5	6	0.793	0.945	0.342
0.5	8	0.717	0.967	0.007
0.5	10	0.616	0.957	0.011
0.5	11.5	0.317	1.171	0.071
0.8	0.5	1.333	1.562	0.582
0.8	2	1.283	1.252	0.642
0.8	4	1.092	1.025	0.592
0.8	6	0.931	0.891	0.372
0.8	8	0.833	0.840	0.229
0.8	10	0.676	0.764	0.010
0.8	11.5	0.495	0.798	0.061
0.9	0.5	1.383	1.576	0.471
0.9	2	1.401	1.285	0.564
0.9	4	1.187	1.029	0.501
0.9	6	0.938	1.071	0.201
0.9	8	0.837	0.838	0.163
0.9	10	0.619	0.649	0.093
0.9	11.5	0.456	0.605	0.057

BAY 5, SCREEN 3, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.584	1.308	-0.036
0.2	2	0.525	1.060	-0.059
0.2	4	0.555	1.030	-0.006
0.2	6	0.583	1.015	-0.059
0.2	8	0.563	0.925	-0.047
0.2	10	0.529	0.826	-0.092
0.2	11.5	0.345	0.755	-0.007
0.5	0.5	0.624	0.980	-0.058
0.5	2	0.627	0.895	-0.133
0.5	4	0.606	0.842	-0.156
0.5	6	0.646	0.890	-0.125
0.5	8	0.631	0.919	-0.100
0.5	10	0.597	0.906	-0.153
0.5	11.5	0.396	0.939	-0.171
0.8	0.5	0.842	0.844	-0.228
0.8	2	0.732	0.751	-0.247
0.8	4	0.789	0.770	-0.237
0.8	6	0.870	0.881	-0.201
0.8	8	0.816	0.786	-0.229
0.8	10	0.742	0.821	-0.231
0.8	11.5	0.621	0.939	-0.248
0.9	0.5	0.810	0.831	-0.208
0.9	2	0.829	0.851	-0.225
0.9	4	0.921	0.912	-0.222
0.9	6	0.862	0.884	-0.194
0.9	8	0.765	0.876	-0.186
0.9	10	0.746	0.953	-0.223
0.9	11.5	0.617	0.933	-0.215

BAY 5, SCREEN 2, Bypass Flow Rate = 50 cfs

Velocity data collected with a bypass flow rate of 50 cfs.

Measurement Depth (fraction of total)	Distance from Upstream Edge of Screen (ft)	Approach Velocity Toward Screen (ft/s)	Sweep Velocity Toward Bypass (ft/s)	Vertical Velocity Downward (ft/s)
0.2	0.5	0.566	1.390	0.066
0.2	2	0.676	1.279	0.052
0.2	4	0.649	1.191	0.033
0.2	6	0.589	1.093	0.025
0.2	8	0.597	1.118	0.022
0.2	10	0.507	1.006	0.013
0.2	11.5	0.360	0.907	0.035
0.5	0.5	0.662	1.257	0.060
0.5	2	0.626	1.076	0.037
0.5	4	0.633	1.079	0.015
0.5	6	0.593	0.987	0.053
0.5	8	0.525	0.919	0.025
0.5	10	0.442	0.871	0.044
0.5	11.5	0.257	0.920	0.117
0.8	0.5	0.768	1.087	0.096
0.8	2	0.757	0.980	0.111
0.8	4	0.660	0.815	0.020
0.8	6	0.665	0.852	0.077
0.8	8	0.670	0.629	0.102
0.8	10	0.446	0.472	0.052
0.8	11.5	0.436	0.587	0.184
0.9	0.5	0.754	1.077	0.150
0.9	2	0.640	0.792	0.087
0.9	4	0.578	0.706	-0.005
0.9	6	0.563	0.573	0.016
0.9	8	0.552	0.554	0.082
0.9	10	0.521	0.510	0.118
0.9	11.5	0.445	0.475	0.120

APPENDIX II: Velocity Distributions in Front of Drum Screens

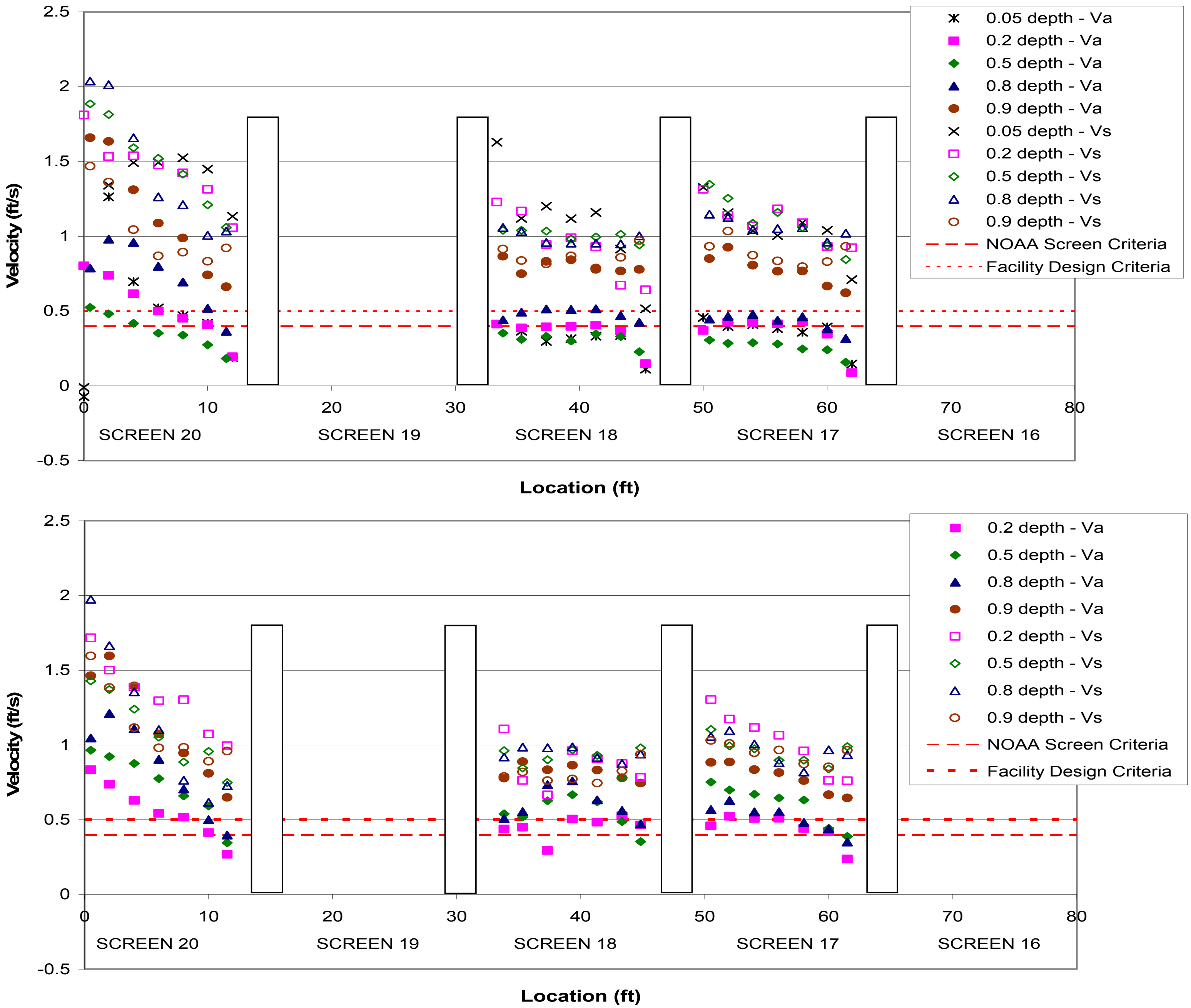

Figure II-1. - Comparison of sweep (V_s) and approach (V_a) velocity distributions on screens in Bay 2 at a fish bypass weir setting of 65 ft^3/s (top) and 50 ft^3/s (bottom).

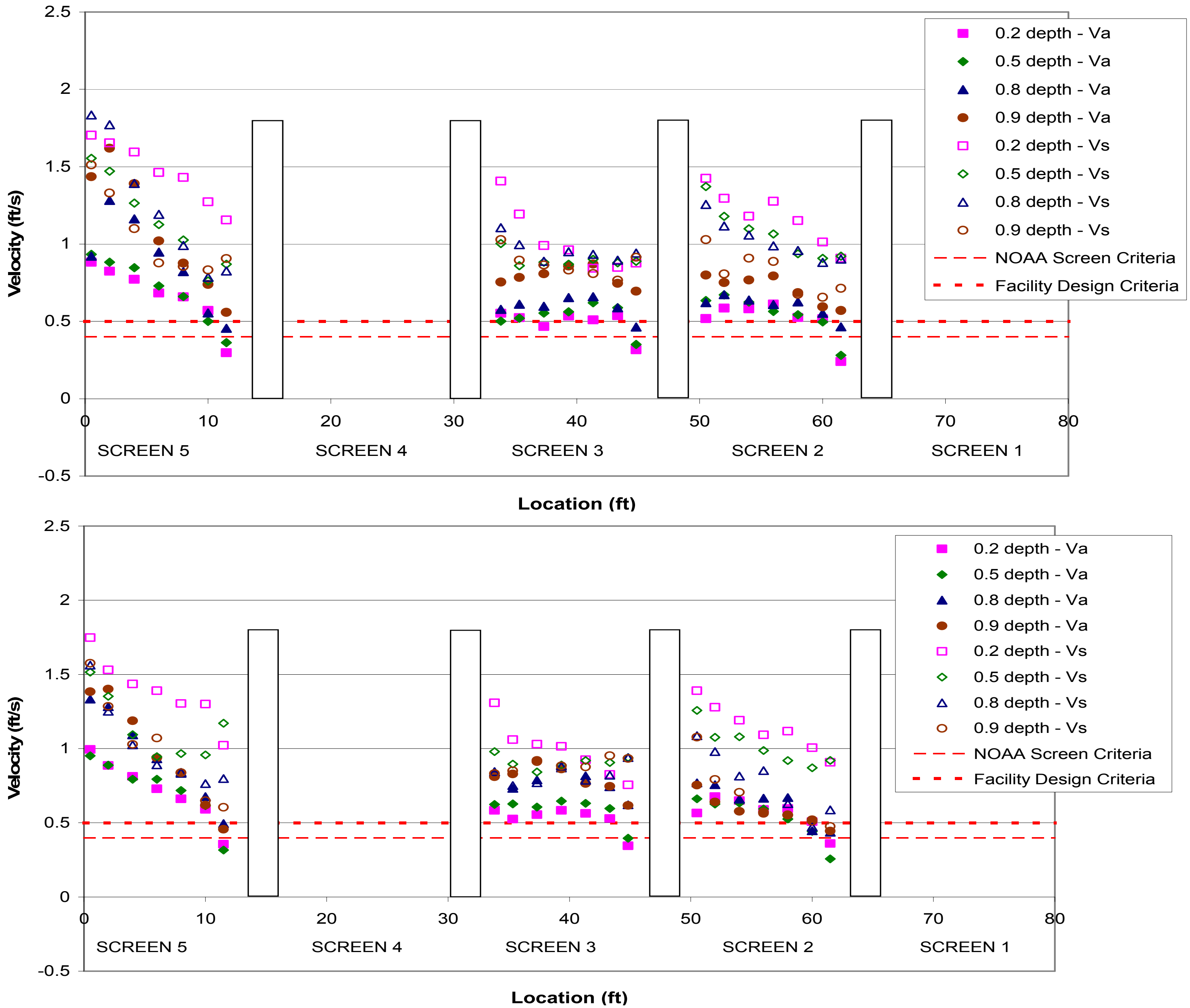

Figure II-2. – Comparison of sweep (V_s) and approach (V_a) velocity distributions on screens in Bay 5 at a fish bypass weir setting of 65 ft^3/s (top) and 50 ft^3/s (bottom).

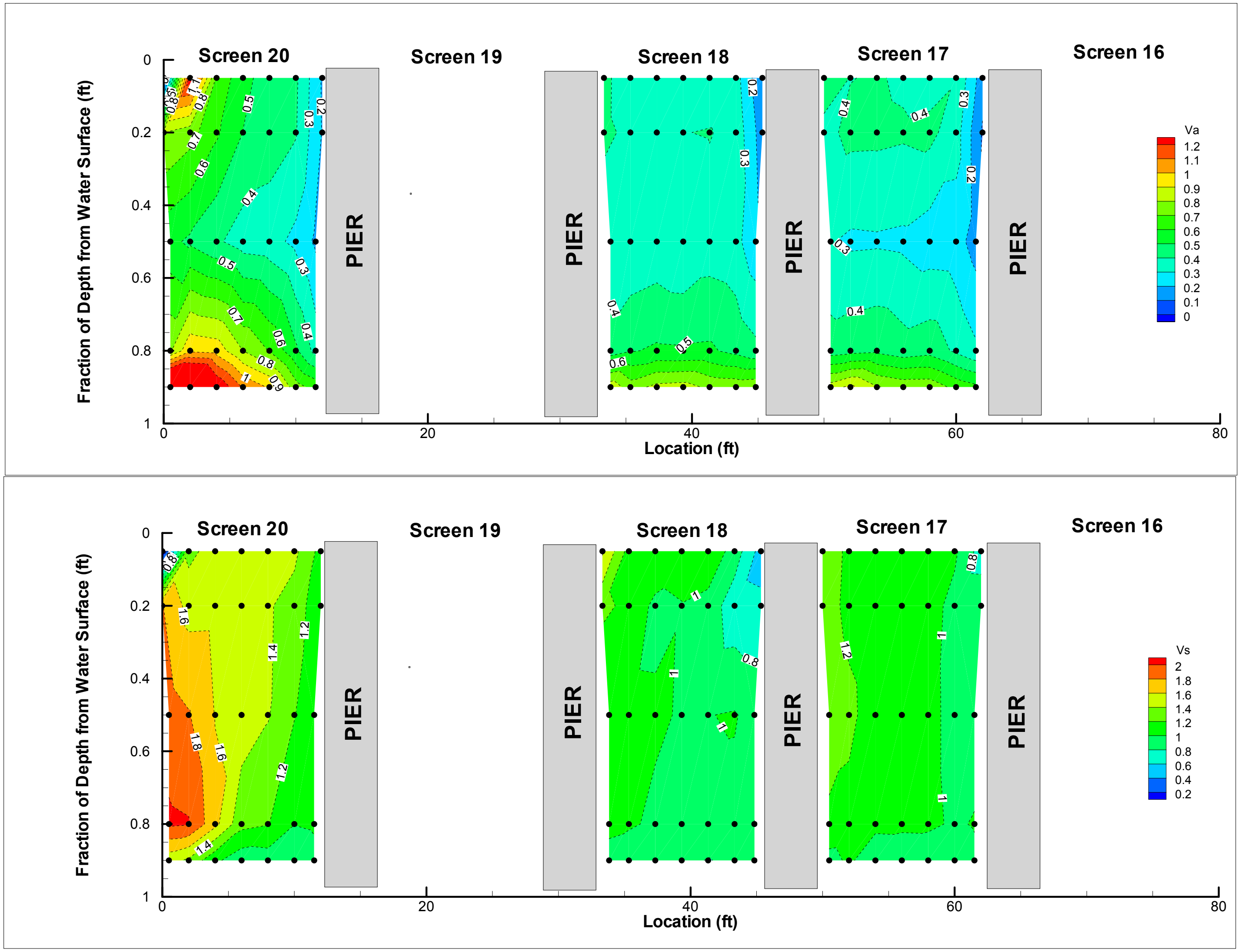

Figure II-3. –Approach (V_a, top) and sweep (V_s, bottom) velocity distributions in Bay 2 at a primary bypass flow rate of 65 ft^3/s. Black dots represent measurement locations at fractional water depths of 0.05, 0.2, 0.5, 0.8, and 0.9.

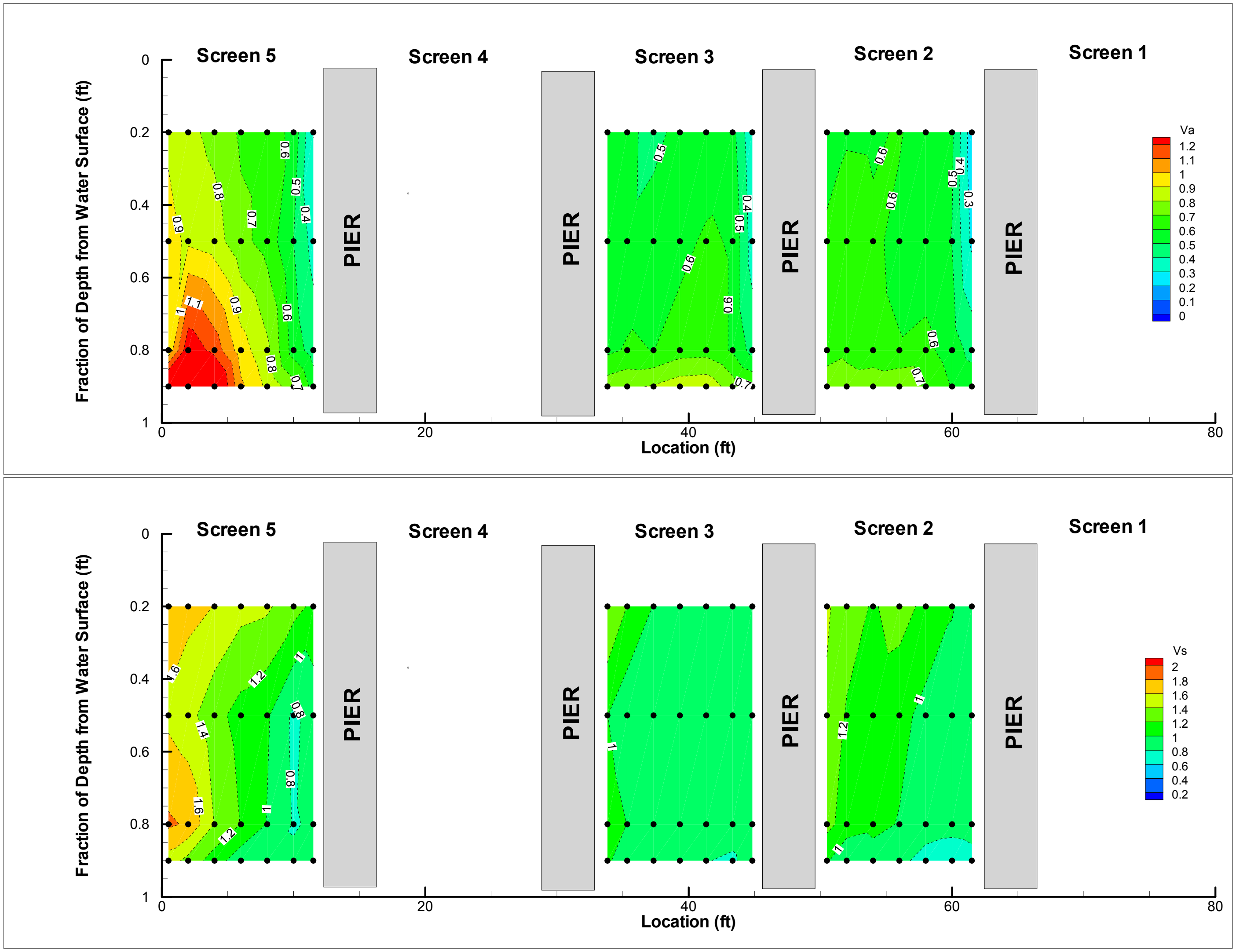

Figure II-4. –Approach (V_a, top) and sweep (V_s, bottom) velocity distributions in Bay 5 at a primary bypass flow rate of 65 ft^3/s. Black dots represent measurement locations at fractional water depths of 0.2, 0.5, 0.8, and 0.9.

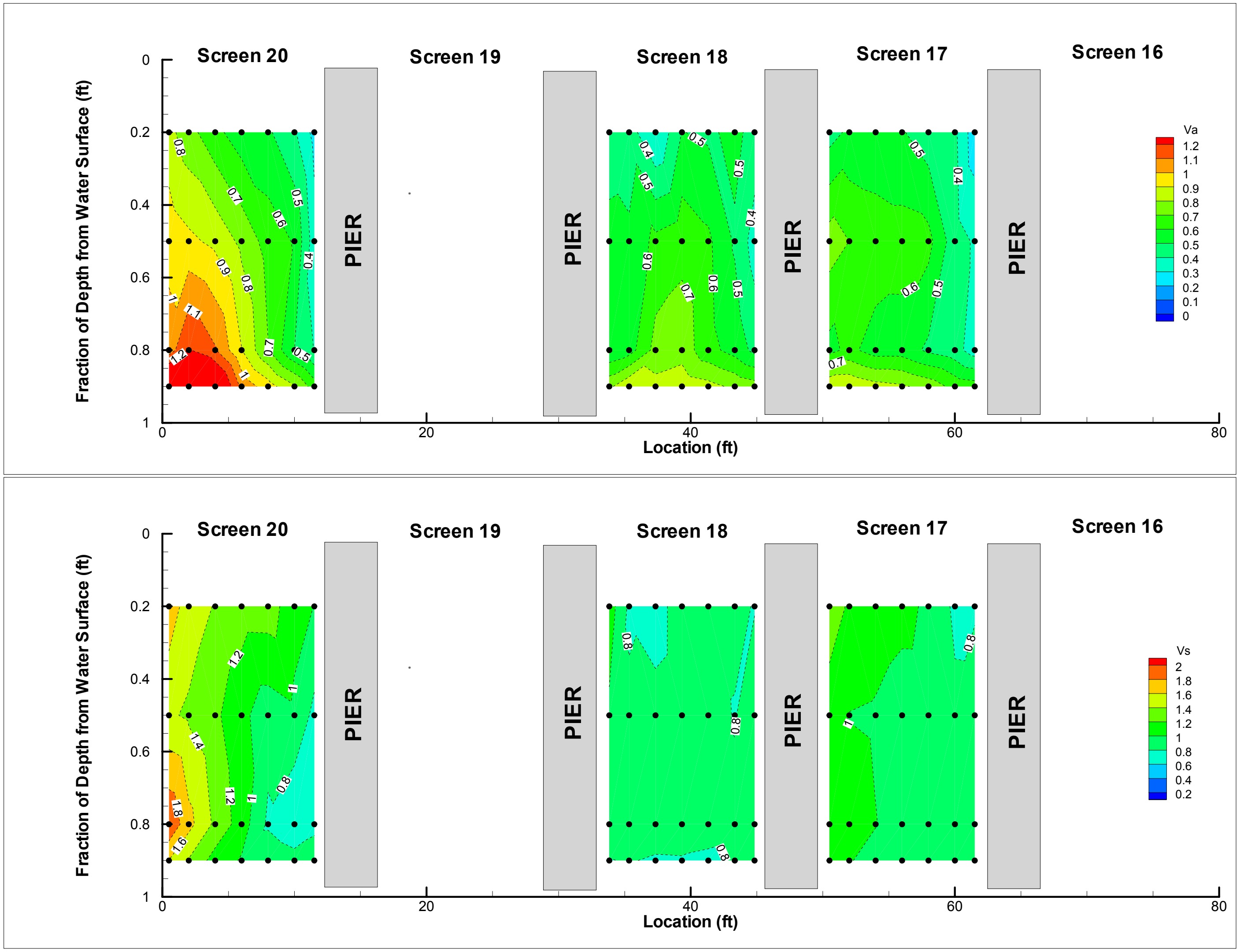

Figure II-5. –Approach (V_a, top) and sweep (V_s, bottom) velocity distributions in Bay 2 at a primary bypass flow rate of 50 ft^3/s. Black dots represent measurement locations at fractional water depths of 0.2, 0.5, 0.8, and 0.9.

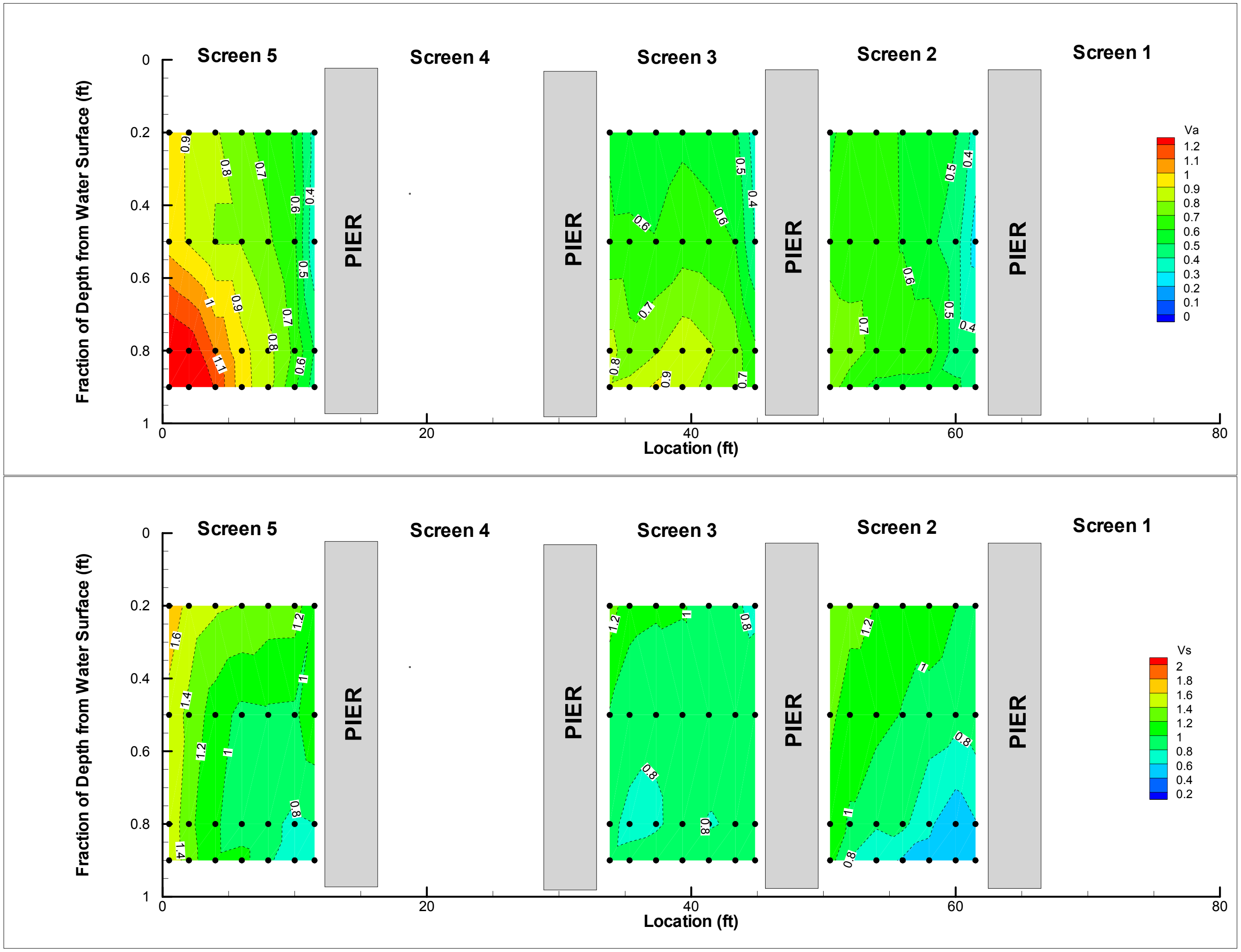

Figure II-6. –Approach (V_a, top) and sweep (V_s, bottom) velocity distributions in Bay 5 at a primary bypass flow rate of 50 ft^3/s. Black dots represent measurement locations at fractional water depths of 0.2, 0.5, 0.8, and 0.9.