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Managing Water in the West

Improving Data Collection Methods for Hydraulic Evaluations of Fish Screens

Research and Development Office
Science and Technology Program
Final Report ST-2017-6504-01

Hydraulic Laboratory Report HL-2017-03

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Research and Development Office
Bureau of Reclamation
U.S. Department of the Interior

March 2017

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
T1. REPORT DATE March 2017	**T2. REPORT TYPE** Research	**T3. DATES COVERED** October 2015 – March 2017
T4. TITLE AND SUBTITLE Improving Data Collection Methods for Hydraulic Evaluations of Fish Screens		**5a. CONTRACT NUMBER** RY1541EN201626504 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation Hydraulic Investigations and Laboratory Services Group, 86-68560 Denver, CO 80225-0007		**8. PERFORMING ORGANIZATION REPORT NUMBER** HL-2017-03
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research and Development Office U.S. Department of the Interior, Bureau of Reclamation PO Box 25007, Denver CO 80225-0007 Anadromous Fish Screen Program U.S. Fish and Wildlife Service and Bureau of Reclamation Sacramento, CA		**10. SPONSOR/MONITOR'S ACRONYM(S)** R&D: Research and Development Office BOR/USBR: Bureau of Reclamation DOI: Department of the Interior **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** ST-2016-6504-01

12. DISTRIBUTION / AVAILABILITY STATEMENT
Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 words)*
The purpose of this research project was to determine if methods for collecting hydraulic data on vertical flat plate fish screens can be improved to reduce post-construction evaluation cost and increase measurement quality. Testing was performed on a full scale four-bay vertical flat plate fish screen diversion model. This project investigated the effect of velocity probe distance from the screen face on approach velocity measurements, evaluated the effects of velocity measurement locations on describing approach velocity distribution on a screen bay, and compared velocity measurements using a traversing system to stationary measurements. The study also examined the effects of probe vibrations on approach and sweeping velocities and turbulence measurements for stationary and traversing methods and compared the performance of wedge wire and perforated plate screen material for a wide range of porosities.

15. SUBJECT TERMS
Fish screen, fish protection, hydraulic evaluation, acoustic Doppler velocimetry, vibration, turbulence, wedge wire, perforated plate, fish screen evaluation criteria

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Connie Svoboda
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	U	51	**19b. TELEPHONE NUMBER** 303-445-2152

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

BUREAU OF RECLAMATION

Research and Development Office
Science and Technology Program

Technical Service Center, Hydraulic Investigations and Laboratory Services, 86-68560

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Improving Data Collection Methods for Hydraulic Evaluations of Fish Screens

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Acknowledgments

This study was funded by the Bureau of Reclamation's Research and Development Office - Science and Technology Program and by the Bureau of Reclamation Mid-Pacific Region's Anadromous Fish Screening Program. Levi Johnson (Bureau of Reclamation, Project Manager), Dan Meier (USFWS, Program Manager), and Steve Thomas (NMFS, Hydraulic Engineer) provided technical direction and review. Review comments were also provided by Mark Gard (USFWS, Senior Fish and Wildlife Biologist). Jason Black, Jimmy Hastings, and Marty Poos (Craftsmen) and Dane Cheek (Machinist) constructed the physical model.

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Executive Summary

Fish screens are installed at water diversions to physically protect fish from entrainment into a water diversion structure. Reclamation is required by federal and state regulatory agencies to conduct post-construction hydraulic evaluations of all new fish screen facilities to ensure that fish screens are in compliance with fish screening criteria. The purpose of this research project was to determine if methods for collecting hydraulic data on vertical flat plate fish screens can be improved to reduce evaluation cost and increase measurement quality.

Testing was performed on a full scale four-bay vertical flat plate fish screen physical model in the Bureau of Reclamation's Hydraulics Laboratory in Denver, Colorado. Velocity measurements were collected in the approach (perpendicular to screen face) and sweeping (parallel to screen face) component directions at various distances (1.5, 3, 4, 6, and 12 inches) from the front of the screen face, at multiple water depths, and numerous locations along the length of the screen. Velocity data were collected at specified points with a stationary measurement system and also with a continuously traversing data collection system.

Model results indicate that as probe distance from the screen increases, the average approach velocity decreases. An average approach velocity measurement measured 3 inches from the screen face should be approximately 20% lower than theoretical average approach velocity computed with facility flowmeters. A review of past fish screen field evaluations showed a wide range in the percent difference between the theoretical average approach velocity calculated from the measured diversion rate and wetted screen area and the average approach velocity measured near the screen face.

Several data collection grids were analyzed to determine which configurations best describe the approach velocity distribution across the screen. Model results showed which configurations may be good alternatives for reducing data collection efforts on long screens while sufficiently describing velocities at the screen face.

Velocity measurements collected using a continuously traversing system were compared to stationary velocity measurements. Traversing data collection provided velocity measurement across the entire screen face and this technique can be used on long screens to reduce the data collection effort. For the range of traverse speeds tested in the model (0.07-0.9 ft/s), traversing speed did not have a notable effect on measured approach velocities.

The effects of probe vibrations on approach and sweeping velocities and turbulence measurements were analyzed in the model by inducing probe vibration. Vibration test results indicate that ADV probe vibrations did not significantly influence average velocity measurements for stationary or traversing system data for vibration frequencies up to one-half of the ADV sampling frequency (e.g. 25 Hz). It is recommended that traversing speed be as slow as practical and that the ADV probe mount be constructed to minimize vibration to under 10 Hz. This vibration criterion will allow an ADV sampling at 25 Hz to properly capture probe vibration effects in the ADV turbulence measurements.

The performance of wedge wire (57% porosity) and perforated plate (58% porosity) screen material were compared. Approach velocities were low near the intermediate piers for both wedge wire and perforated plate screens of the same porosity, but there was a shift in the location of the highest velocities with more flow entering the perforated plate screen in the first half of each screen, while the wedge wire screen had more flow through the downstream half of each screen. The performance of perforated plate screens with 58%, 40%, and 33% porosity was also compared in the model. Model results showed that approach velocities were more uniform over the screen face when the porosity was lower. Fish screens with 33% and 40% porosity did not have hot spots like the fish screens with 58% porosity because lower screen porosity requires more head to drive flow through the screen which reduces the low velocity areas near the screen support piers.

Introduction

Fish screens are installed at water diversions to physically protect fish from entrainment into a water diversion structure. There are many different types of positive barrier fish screen designs such as flat plate screens, inclined screens, drum screens, cylindrical and cone screens, traveling screens, Coanda screens, and closed conduit Eicher and MIS screens (Bureau of Reclamation 2006). After construction of a new fish screen, post-construction hydraulic evaluations are required by federal and state regulatory agencies to ensure that fish screens are in compliance with fish screening criteria. Follow-up hydraulic evaluations are required if there are changes in diversion operations, screening operations, or baffle settings.

Current National Marine Fisheries Service SW Region Anadromous Fish Screen Criteria for California (NMFS 1997) states:

- Approach velocity (velocity component perpendicular to the screen face) shall not exceed 0.33 ft/s for on-river screens and 0.4 ft/s for canals. Approach velocity shall be measured approximately three inches in front of the screen surface.
- Screen design must provide for uniform flow distribution over the surface of the screen, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of the screens.
- Sweeping velocity (velocity component parallel to the screen face) shall be greater than approach velocity.

Current National Marine Fisheries Service NW Region Anadromous Fish Passage Criteria for Washington, Oregon, and Idaho (NMFS 2011) provides more definition on post-construction evaluation requirements in Section 15:

- Evaluation must consist of a series of velocity measurements encompassing the entire screen face, divided into a grid with each grid section representing no more than 5% of the total diverted flow through the screen (i.e., at least 20 grid points must be measured).
- The approach and sweeping velocity should be measured at the center point of each grid section, as close as possible to the screen face without entering the boundary layer turbulence at the screen face.
- Uniformity of approach velocity is defined as being achieved when no individual approach velocity measurement exceeds 110% of the criteria.

Field evaluation of large fish screens requires significant effort in designing an appropriate velocity probe deployment system, collecting hydraulic data, and analyzing results. There may be situations where physical (structure geometry, features, and access), hydraulic (approach velocity magnitude or uniformity), or environmental (debris loading, algal growth, and sediment accumulation) conditions make it difficult to meet criteria or can produce unknown errors in data quality.

Federal fish screening criteria require velocity data to be collected 3 inches from the fish screen face or as close as possible to the screen face. Historically, the measurement distance of 3 inches was chosen to minimize interference between electromagnetic velocity meters and ferrous metal screens. For the last two decades, hydraulic screen evaluations have been conducted with acoustic Doppler velocimeters. Measuring velocities 3 inches from the screen without damaging the velocity meter may not be possible in some locations due to physical limitations of the screen structure, instrument geometry, or the instrument mount. In other locations, it may be possible to measure closer to the screen than 3 inches. Therefore, it is important to understand how approach velocity changes with distance from the screen when interpreting hydraulic evaluation results.

To provide confidence in the quality of velocity data collected during a hydraulic screen evaluation, the overall average approach velocity measured during the hydraulic field evaluation is often compared to the computed theoretical average approach velocity using permanent flow measurement instrumentation in the diversion. The theoretical average approach velocity is calculated as the measured diversion flow rate divided by the wetted screen area. The relationship between measured near-screen approach velocities and computed theoretical approach velocities needs to be better defined.

On long, flat plate fish screens it may not be feasible to collect stationary data at 20 points on each screen (representing 5% of the total diverted flow through each screen). By better understanding how approach velocities vary across the screen laterally and vertically (particularly near the water surface, bed, and intermediate support piers), it may be possible to collect fewer data points while maintaining confidence that the velocity distribution (particularly hot spots or higher velocity zones) are captured by the velocity measurement grid. It may also be beneficial to collect velocity data using a traversing system in lieu of stationary data points to collect more data in a significantly shorter time period. Collecting data more quickly can minimize the effects of changing environmental conditions such as tidal variations, accumulation of debris, and the ability to maintain a constant diversion rate during the evaluation period. Effects of traversing direction or speed of travel should be assessed to determine if instrument vibration, deflection, or rotational movement affect velocity data quality. Furthermore, care must be taken to locate the velocity probe clear of any flow disturbance from submerged traversing system infrastructure (e.g., brush cleaner arm or trash rake mast).

During field evaluations, the mount that holds the velocity measurement instrument may experience flow-induced vibrations. The effects of instrument vibration on velocity measurements for stationary and traversing measurements is not well understood. Tests should be conducted to determine whether vibrations average out over the sample period and whether vibration frequency and amplitude affect data. Instrument mounts are often fixed to another system such as a traveling screen cleaner trolley such that probe vibration can occur in the approach or sweeping velocity directions. To minimize vibration of the instrument, it may be possible to design the mount to travel directly against the screen. Indexing the probe directly off the screen also maintains probe orientation in relation to the screen to minimize misalignment errors.

Several physical model studies of fish screens revealed the need to investigate the effect of screen porosity on fish screen approach velocity uniformity. Fish screening criteria requires a minimum of 27% porosity for any screen material. Results from a physical model study of flat plate fish screens at Roza Dam (Svoboda and Heiner 2015) indicated that porosity of the screen notably affected velocity distributions at the screen face and screens with 40% porosity or less produced the most uniform velocity distribution at the screen face.

Model Objectives

The purpose of this research project was to determine if methods for collecting hydraulic data on vertical flat plate fish screens can be improved to reduce evaluation cost and increase measurement quality. Constructing a physical model in a hydraulics laboratory provided a controlled environment for collecting accurate, repeatable data with consistent approach flow conditions, good visibility for instrument positioning, and no debris accumulation or algal growth. Inclined screens, drum screens, and traveling screens were not examined in this investigation, but many of the results can be directly applied to those types of designs. Some results may be applied to cylindrical or cone screens, but the unique challenges for evaluation of these screens should be studied separately.

Several questions related to current methods for making velocity measurements on fish screens were addressed in this study.

1. What is the effect of velocity measurement distance from the screen face on approach velocity? Are velocity measurements collected at distances other than 3 inches from the screen representative of near-screen conditions?

2. What are the ideal number and best measurement locations to accurately represent velocity distribution on the screen panels?

3. Can a traversing data collection system be used in place of collecting stationary velocity data points at the screen face? What is the effect of traversing speed on approach and sweeping velocities?

4. Are the velocity measurements affected by vibrations induced on the velocity measurement probe?

5. What is the effect of screen porosity on screen approach velocity uniformity?

Model Description

Figure 1 is a plan view layout of the fish screening model constructed at the Bureau of Reclamation's (Reclamation) Hydraulics Laboratory in Denver, Colorado. Figure 2 shows pertinent features of the physical model. The physical model was constructed at full scale with a vertical flat plate fish screen angled 10 degrees to the flow. Flow passed through the fish screen into the diversion or continued into a fish bypass system at the downstream end of the screen. Testing was performed with a channel flow rate of 20 ft^3/s, diversion flow rate of 18 ft^3/s, and fish bypass flow rate of 2 ft^3/s. The diversion flow rate was calculated as the measured inflow discharge minus the measured fish bypass flow. The average water depth in front of the screen was 3.604 ft.

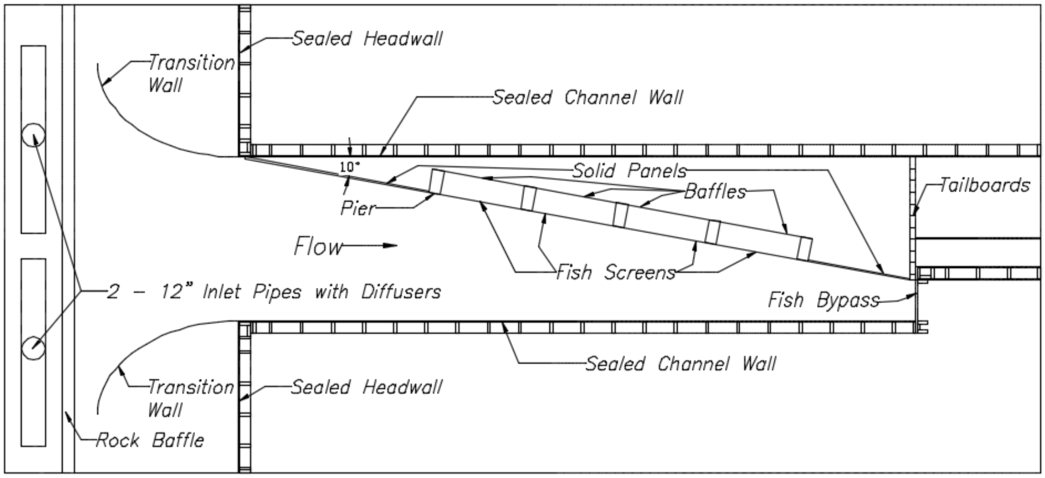

Figure 1. Fish screening model layout, plan view.

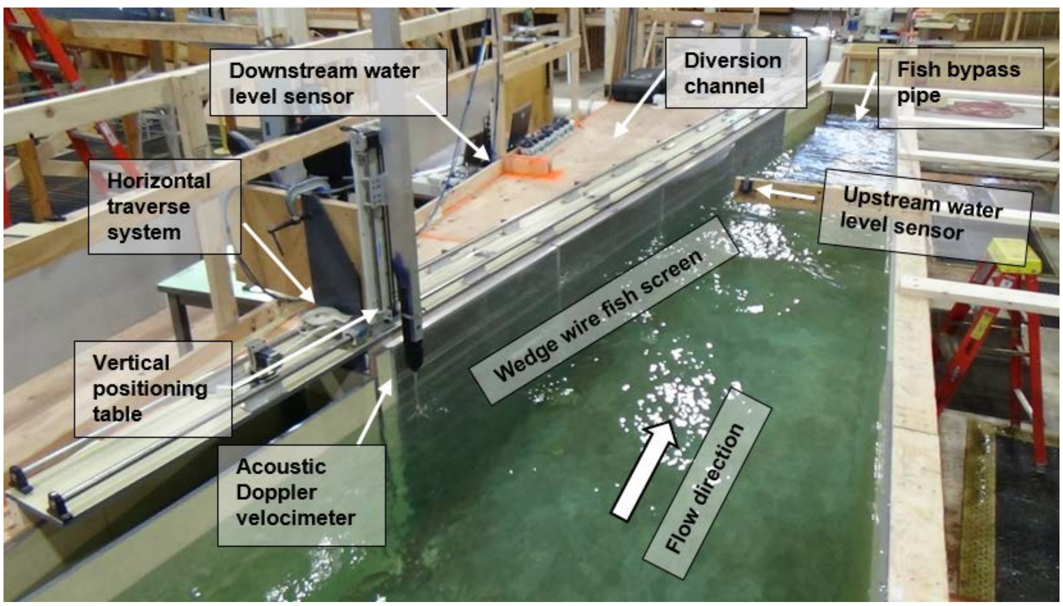

Figure 2. Major features of the fish screen physical hydraulic model.

Water was conveyed to the model with the laboratory 12-inch horizontal pump system connected to a 240,000 gallon reservoir. Flow to the model was measured with the laboratory venturi meters. A 44,000 pound (678 ft^3) volumetric/weigh tank was used to calibrate the laboratory venturi meters at regular intervals to an accuracy of ± 0.25%. Water was supplied to the model through two 12-inch-diameter inlet pipes and passed through a rock baffle to make the flow more uniformly distributed across the channel and less turbulent.

Curved transition walls directed flow into the test section. Four 4-foot-wide by 4-foot-tall wedge wire fish screens with 3/32-inch slot openings (57% porosity) were installed with wires oriented vertically. The screens were mounted to 0.5-ft-wide by 1-ft-deep by

4-ft-tall piers and rested on a 0.25-ft-high bottom sill. The screens overlapped the piers by 0.25 ft on each side, yielding an effective wetted width of screen of 3.5 ft per screen or 14 ft total. Solid panels were installed at the upstream and downstream ends of the fish screen. A thin layer of concrete sand was glued to the approach channel floor to simulate a typical channel bottom roughness.

Perforated plate baffles were installed 1 ft behind the fish screen to control the amount of flow entering through each fish screen bay. Two perforated plates mounted to the downstream face of the fish screen piers were used to adjust the baffle porosity from 5% to 44% using spacer blocks.

Tailboards were used to set target diversion channel water levels behind the fish screen. The fish bypass system consisted of a 1-ft-diameter pipe installed just above the bypass channel invert in the wall downstream from the fish screen. The pipe was equipped with a Controlotron transit-time acoustic flowmeter set up with a pair of Controlotron 1011 transducers mounted in reflect mode to monitor fish bypass flow rates with an uncertainty of ± 2.0%. A butterfly valve at the end of the fish bypass pipe was used to set and maintain steady bypass flows. Due to space limitations in the model, the bypass pipe was placed 4 ft downstream of the end of the screen. Therefore, the sweeping velocity decreased from the upstream to downstream end of the screen face for the flow conditions operated in the model.

Water surface elevations were measured upstream of the screen and downstream of the screen and flow control baffles with MassaSonic™ M-5000/200 ultrasonic downlooking sensors with an uncertainty of ± 0.25% at a full scale range of 3.33 ft. Headloss across the fish screen was computed as the difference between the upstream and downstream water surface elevations. The upstream average water depth (upstream water surface elevation minus the sill elevation) and the effective screen width were used to calculate the effective wetted area of the fish screen.

Three-dimensional velocity measurements were collected at a sample rate of 25 Hz using a Nortek Vectrino Acoustic Doppler Velocimeter (ADV) to an accuracy of ± 0.5% of measured value ± 1 mm/s. The Nortek ADV was set up with the approach velocity component on the y-axis (perpendicular to the screen face), sweeping velocity component on the x-axis (parallel to the screen face), and vertical velocity component on the z-axis. The instrument was accurately aligned with the fish screen using a carpenter square. Figure 3 shows the ADV on a sliding sled mounted to a vertical mast. The mast sled was attached to a vertical positioning table mounted on the trolley cart with a securing clamp. The mast sled was used to vary the ADV probe-to-screen offset from 1.5 inches to 12 inches from the screen face. The trolley cart was attached to rails which allowed the ADV to traverse the horizontal length of the screen (Figure 4). For stationary measurements, the trolley cart system was used to position the ADV. The traversing measurement tests were performed with a continuous traverse in the downstream then upstream directions over a range of traversing speeds from 0.07 to 0.89 ft/s.

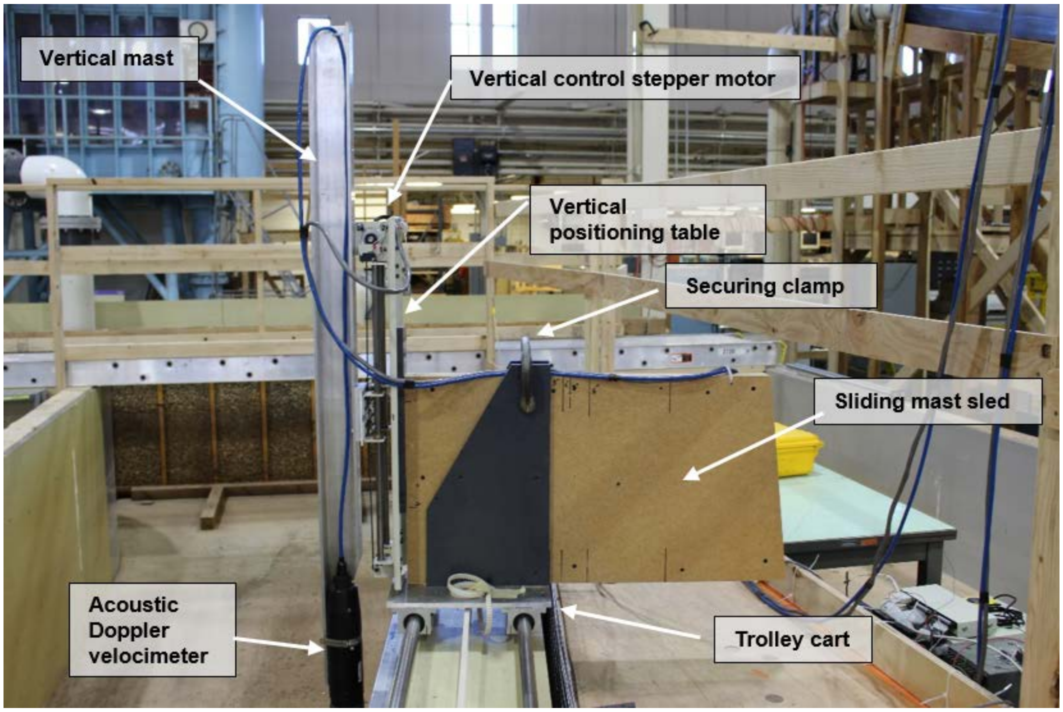

Figure 3. A trolley cart allowed the ADV to traverse along the entire screen length and at offset distances of 1.5 to 12 inches from the screen face.

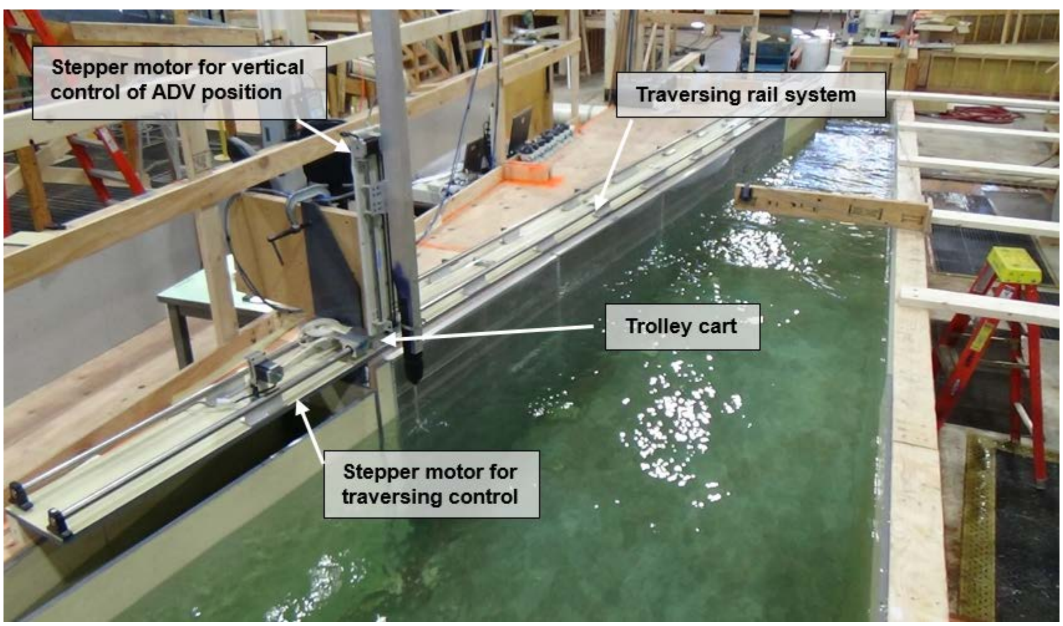

Figure 4. Major features of the automated traversing and probe positioning system.

Results

Effect of Distance from Screen on Approach Velocity

Velocity measurements were collected at 1.5, 3, 4, 6, and 12 inches in front of the vertically oriented wedge wire screen face for 40 seconds at a sampling rate of 25 Hz. Due to physical limitations of the field ADV, a Nortek Vectrino laboratory ADV with shorter transducer arms was used to collect measurements 1.5 inches from the fish screen. A Nortek Vectrino Plus field ADV was used to obtain velocity measurements at all other distances in front of the screen.

Prior to testing, the baffles behind the screen were adjusted to improve uniformity of approach velocities across all four screens. The baffle porosities were set at 44%, 20%, 15% and 15% for screen bays 1 through 4 (numbered upstream to downstream), respectively. Stationary velocity measurements were collected at five horizontal locations (2, 26, 50, 74, and 98% from leading edge of screen) and five vertical positions (2, 17, 32, 62, and 84% from bottom of screen panel, Figure 5) on each screen (Configuration A). The horizontal extents of each screen were considered as the distance between the support piers. The average water depth in front of the screen was 3.604 ft with a wetted screen depth of 3.354 ft. Dividing the wetted screen area (14 ft x 3.354 ft = 46.958 ft^2) by the diversion rate of 18 ft^3/s, the theoretical average approach velocity was calculated as 0.383 ft/s.

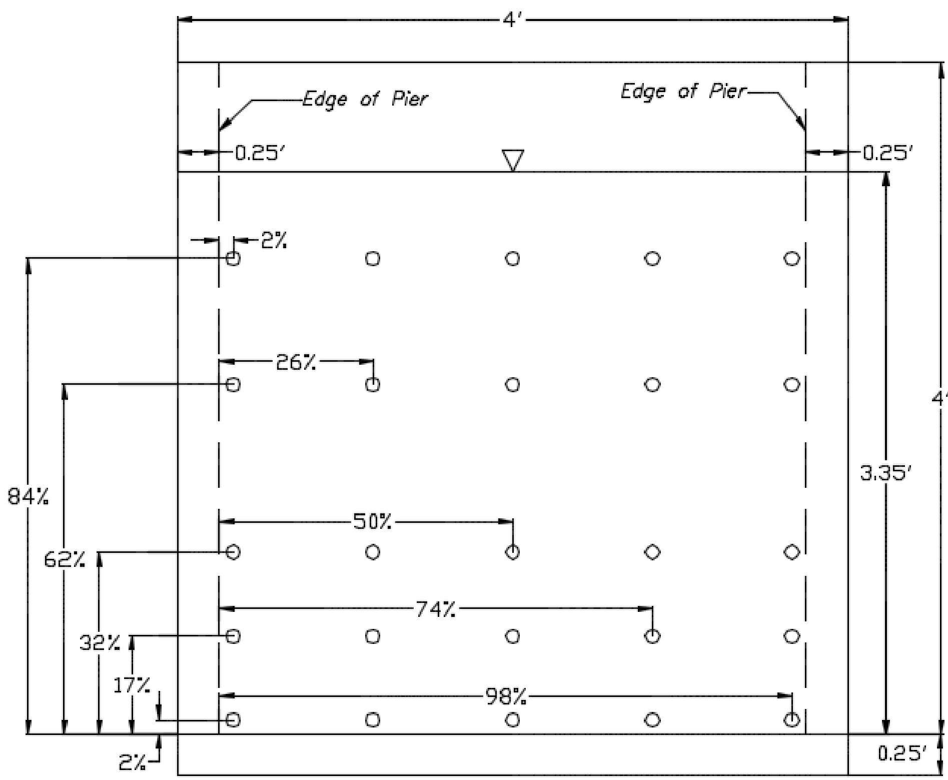

Figure 5. Location of 25 data points at 5 depths for stationary velocity measurements (Configuration A).

Laboratory model results indicate that as the probe distance from the screen increases, the average approach velocity decreases. Table 1 shows the average approach velocity for stationary measurements versus the probe offset from the screen face where velocities were collected. Since the measurement grid shown in Figure 5 included data points close the piers and channel bottom in an effort to fully describe approach velocities at the screen face, average area-weighted approach velocities were calculated (Table 1). The area represented by each data point is divided by the total screen area to prevent data points at the piers and channel bottom from skewing the overall average approach velocity. Appendix A further describes the area-weighting process.

To generalize the results, the ratio of the average approach velocity from measured area-weighted model data to the computed theoretical average approach velocity from laboratory flow instrumentation and the wetted screen area was plotted against the measurement distance from the screen (Figure 6). A best-fit curve using TableCurve 2D v5.01 was fit to the average approach velocity data in generalized form:

$$y = (1.0+0.243x) / (1.0+0.385x)$$

$$r^2 = 0.997$$

where y is expressed as an approach velocity ratio and x is the probe offset expressed in inches.

The computed theoretical approach velocity can be multiplied by the ratio specified in Figure 6 to estimate the expected average approach velocity at the distance from the screen where field data is measured. This relationship should be applicable to different channel velocities and flow splits between diversion rate and bypass rate. However, if approach conditions are not uniform or if the screen is not baffled properly, the equation cannot be applied.

Table 1. Average measured approach velocities and average area-weighted approach velocities for stationary data collected across all 4 screens (25 points per screen) versus distance from the screen face. At the screen face, the theoretical approach velocity should be 0.383 ft/s.

Distance from Screen (in)	Average Approach Velocity (ft/s)	Average Area-Weighted Approach Velocity (ft/s)
1.5	0.312	0.331
3	0.280	0.304
4	0.273	0.299
6	0.256	0.287
12	0.236	0.265

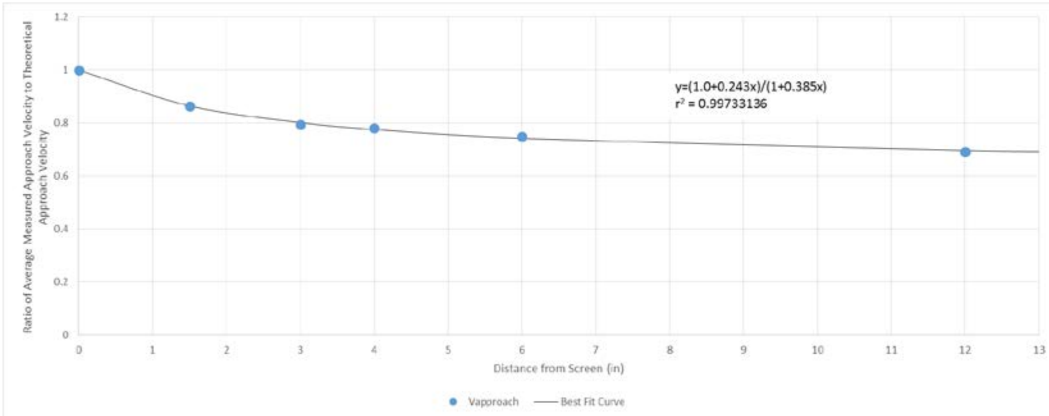

Figure 6. Plot of the ratio of average area-weighted approach velocity for measured laboratory data to computed theoretical approach velocity from flow measurement instrumentation versus distance from screen face. At a distance of 0 inches from the screen, the ratio should be 1.0 assuming that the average approach velocity for measured field data is equivalent to the theoretical approach velocity.

Approach velocity contour plots developed for velocity measurements at 1.5, 3, 4, 6, and 12 inches from the screen are included in Figure 7 through Figure 11, respectively. Approach velocity plots indicate the effect of measurement distance from the screen on velocity distribution. The hotspot near the bottom of screen 4 is a due to the bypass pipe intake. High velocity areas (hotspots) are seen when data is measured close to the screen, but hotspots are not well defined when measurements are collected farther from the screen.

Sweeping velocity contour plots developed for velocity measurements at 1.5, 3, 4, 6, and 12 inches from the screen are included in Figure 12 through Figure 16, respectively. Negative velocities were measured near the bottom of screen 4 due to flow recirculation at the downstream wall of the model near the bypass pipe. Sweeping velocity magnitudes and distributions were similar between various distances from the screen.

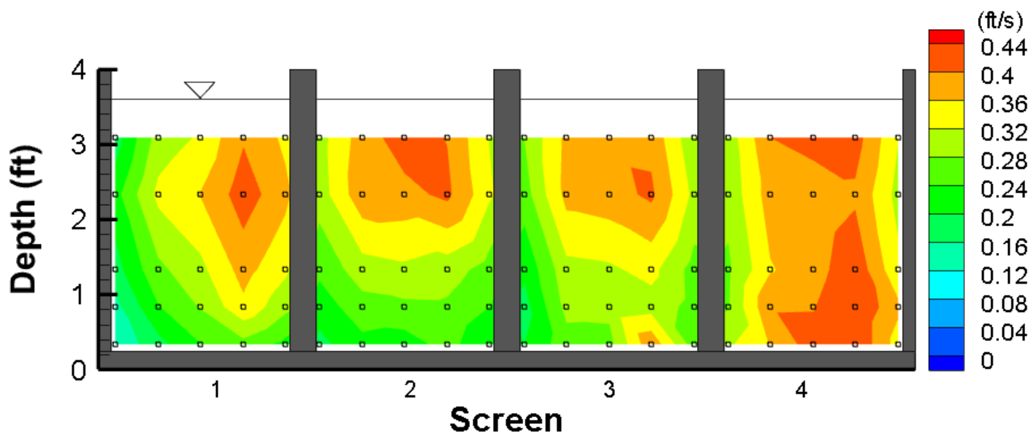

Figure 7. Approach velocity contour plot measured 1.5 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

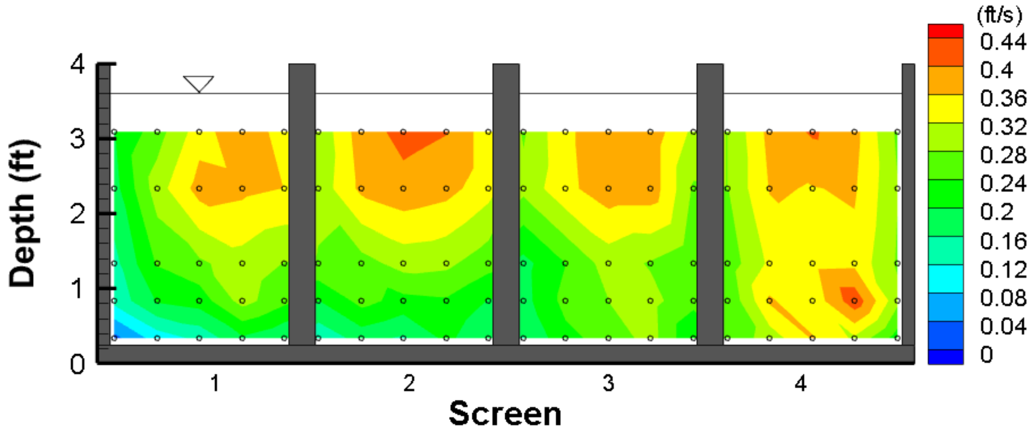

Figure 8. Approach velocity contour plot measured 3 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

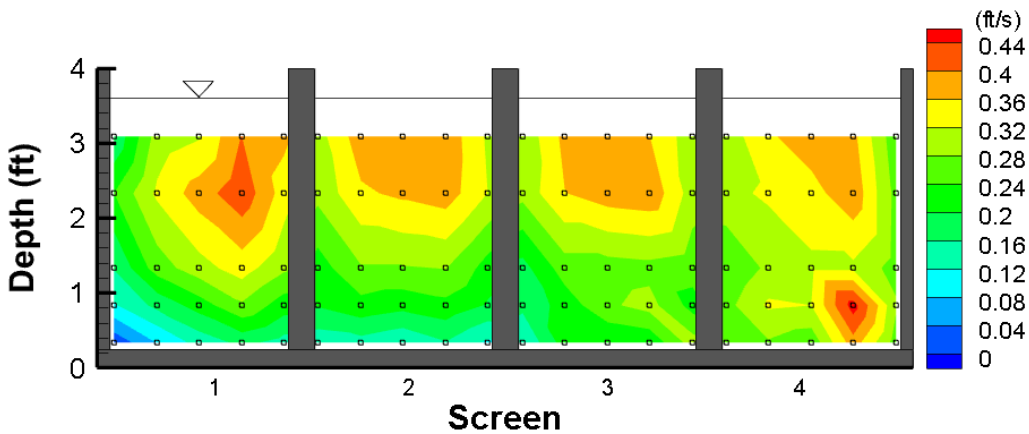

Figure 9. Approach velocity contour plot measured 4 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

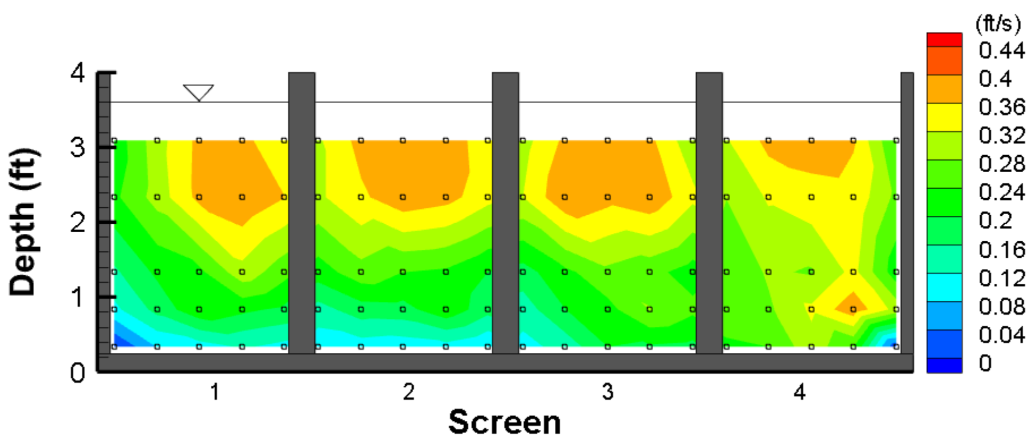

Figure 10. Approach velocity contour plot measured 6 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

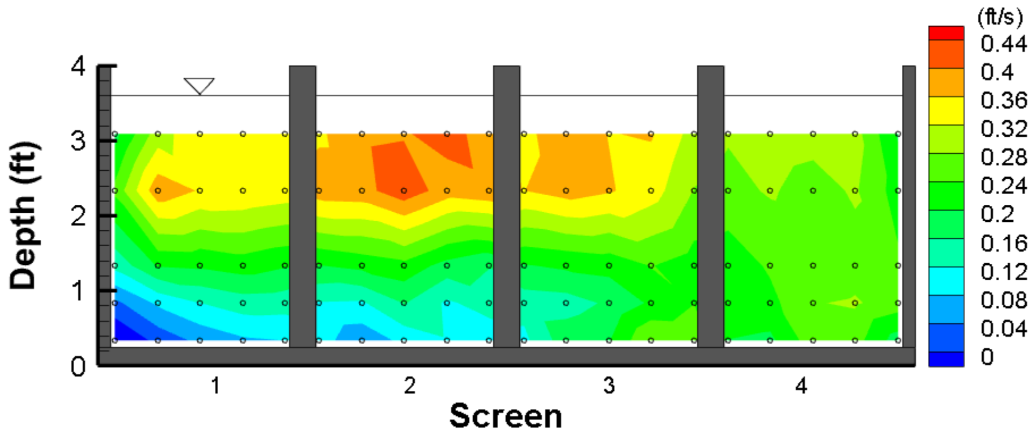

Figure 11. Approach velocity contour plot measured 12 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

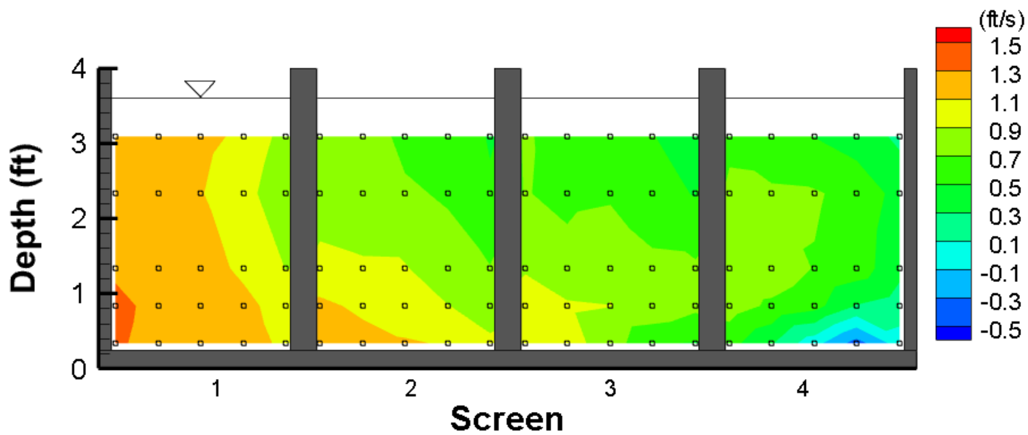

Figure 12. Sweeping velocity contour plot measured 1.5 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

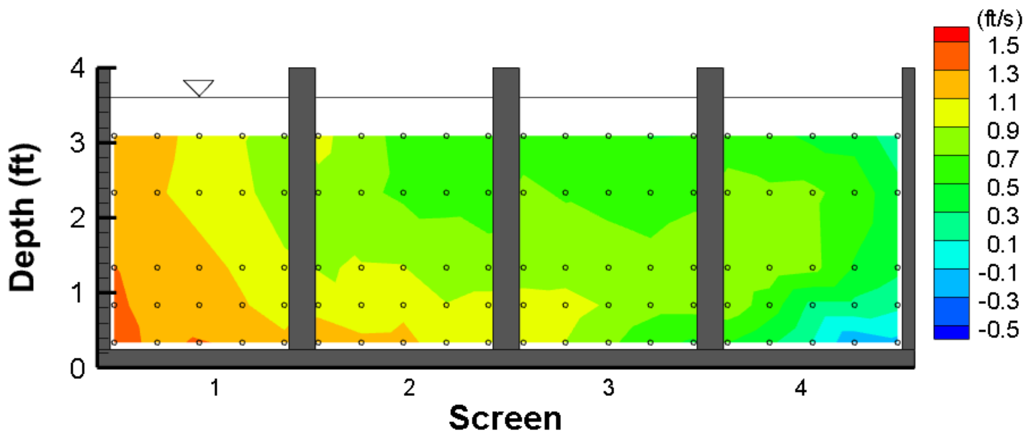

Figure 13. Sweeping velocity contour plot measured 3 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

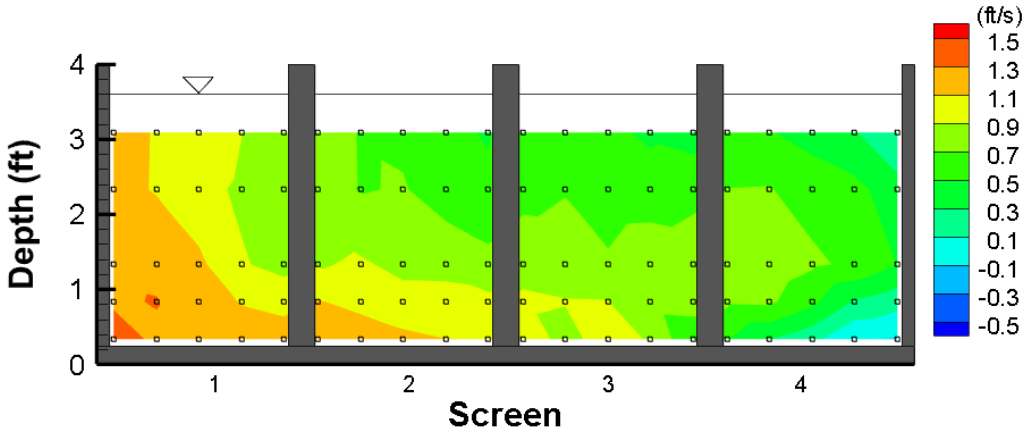

Figure 14. Sweeping velocity contour plot measured 4 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

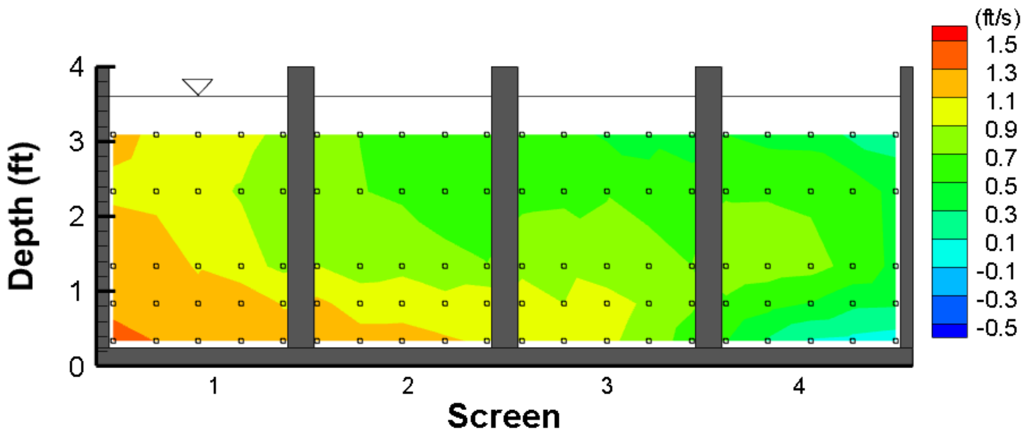

Figure 15. Sweeping velocity contour plot measured 6 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

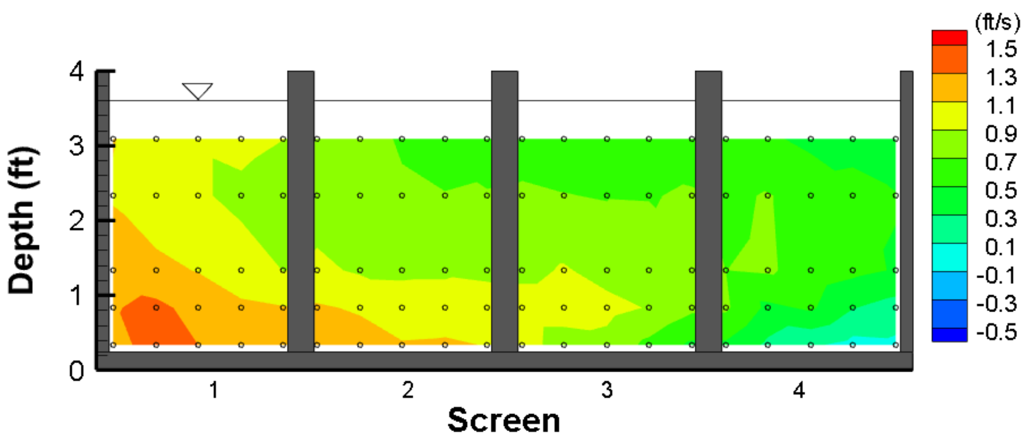

Figure 16. Sweeping velocity contour plot measured 12 inches in front of the screen. Vertical gray rectangles show pier locations. Flow is from left to right.

In “Guidelines for Performing Hydraulic Evaluations of Fish Screens”, it is recommended that measured screen velocities and total wetted area be used to calculate the diversion rate. The calculated diversion rate should be compared with facility recorded diversion rates as a continuity check (Thomas 2013). From Figure 6, it can be seen that an approach velocity measurement collected 3 inches from the screen face should be approximately 20% lower than the theoretical average approach velocity computed using facility flowmeters.

Table 2 shows that there is wide range in the percent difference between the theoretical approach velocity and overall approach velocities measured near the screen face. For these separate evaluations, data were collected with various levels of resolution on each screen (number of stationary data points per screen). It is possible that lower velocity regions near to the intermediate piers and the screen invert were not represented in the field velocity data, thereby making the average measured field velocities higher. Furthermore, aquatic debris and/or sediment clogging of the screen or accumulation along the bottom of the screen can reduce the effective wetted area of the screen, thereby increasing the measured approach velocities at the screen. Probe misalignment is another potential source of error. When the sweeping velocity is an order of magnitude greater than the approach velocity (e.g. sweeping velocity 3.0 ft/s and approach velocity 0.3 ft/s), a probe misalignment of 3 degrees results is a 50% error in the approach velocity measurement (Thomas 2013).

Comparing the theoretical approach velocity to the measured approach velocity may help identify if a potential error or bias has occurred in the field data (e.g. probe misalignment, damaged instrument, inadequate number of data points). However, there are other reasons why differences can occur which are independent of the field study (e.g. debris/sediment clogging, poor calibration of facility instrumentation, poor facility approach conditions), so this comparison cannot be used to definitively validate velocity data sets.

Table 2. Results from several fish screen hydraulic evaluations showing the percent difference between approach velocities measured during the field evaluation and approach velocities computed from diversion facility instrumentation.

	Durango Pumping Plant Fish Screens[1]*	Contra Costa Water District Old River Facility Fish Screen (5 pump test, 3 pump test)[2]**	Reclamation District 2035 and Woodland-Davis Clean Water Agency's Sacramento River Joint Intake Project (8-point course grid, 16-point fine grid)[3]	Browns Valley Irrigation District Fish Screen (First/Second Data Set)[4]	Freeport Regional Water Authority Water Intake Screen (Screens 1-8, Screens 9-16)[5]**	Sankey Diversion Fish Screen[6]	Patterson Irrigation District Fish Screen[7]
Theoretical Approach Velocity or Discharge from Facility Instrumentation	0.36 ft/s	0.257 ft/s, 0.176 ft/s	397.4 ft^3/s, 397.8 ft^3/s	0.235 ft/s, 0.235 ft/s	139.3 ft/s, 139.3 ft^3/s	381 ft^3/s	175 ft^3/s
Measured Approach Velocity or Discharge from Field Data	0.42 ft/s	0.267 ft/s, 0.189 ft/s	495.0 ft^3/s, 438.7 ft^3/s	0.329 ft/s, 0.338 ft/s	139.6 ft/s, 147.6 ft^3/s	423 ft^3/s	170 ft^3/s
Percent Difference from Theoretical Approach Velocity	17%	4%, 7%	25%, 10%	40%, 44%	<1%, 6%	10%	-3%

* Velocity data collected 6-9 inches from the screen face.
** Tidal variations occurred during testing program.

[1] (DeMoyer and Vermeyen 2009)
[2] (Hansen 2010)
[3] (MWH 2016)
[4] (Thomas et al. no date)
[5] (ICF International 2015)
[6] (CH2M 2016)
[7] (MWH 2012)

Best Locations for Stationary Velocity Measurement Points

Data were collected 3 inches from the screen face at 25 locations on each fish screen to fully describe the approach velocities at the screen face (Configuration A, Figure 5). Figure 18 shows the corresponding approach velocity contour plot for data collected in Configuration A. Several data collection grids were then analyzed using the laboratory data to determine if there are specific configurations that can reduce data collection effort while sufficiently describing velocities at the screen face (Figure 17).

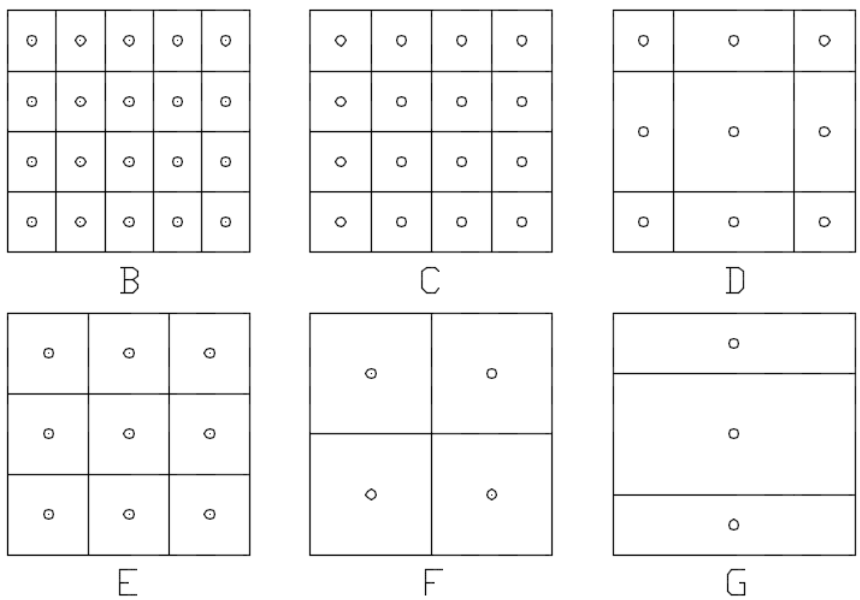

Figure 17. Data collection grid for Configurations B-G which were analyzed with laboratory data collected for Configuration A.

Configuration B was based on the 2011 Northwest region Anadromous Salmonid NMFS criteria which requires measurements for every 5% of the flow area (i.e., at least 20 points) with measurements at the center point of each grid section created by equally spaced grid lines (NMFS 2011). Figure 19 shows the corresponding approach velocity contour plot if data were collected in Configuration B.

Configuration C was included in the NMFS document "Guidelines for Performing Hydraulic Evaluations of Fish Screens" as a good coarse grid for performing velocity measurements on large screens, which is a 16-point grid with measurement locations at the centers of sections of equally spaced grid lines (Thomas 2013). Configuration D was a 9-point grid with one central point and the 8 outer points weighted toward the water surface, screen invert, and piers. It was also included in the NMFS guidelines as "may be acceptable" for larger screens, specifically for situations with relatively uniform mid-water depth approach velocities (Thomas 2013). Figure 20 and Figure 21 show the corresponding approach velocity contour plots if data were collected in Configurations C and D, respectively.

Configuration E was also a 9-point grid consisting of measurement locations at the center of sections divided by equally spaced grid lines. Configuration F was a 4-point grid with measurement locations in the center of equally space grid sections. Both of these configurations were used in tuning the flow control baffles on Browns Valley Irrigation District's fish screens on the Yuba River (Thomas et al. no date). Figure 22 and Figure 23 show the corresponding approach velocity contour plots if data were collected in Configurations E and F, respectively.

Configuration G was a 3-point per screen configuration with measurement locations at the center of the screen laterally at 3 depths (17%, 50%, and 83% of the water depth). This configuration was recommended by CH2M for the fish screen evaluation at Sankey Diversion for 7 of the 10 screens (CH2M 2016). Figure 24 shows the corresponding approach velocity contour plot if data were collected in Configuration G.

The ADV probe sample volume prevented measurement of velocities close to the water surface. Therefore, near-surface velocity measurements were 0.1 ft below the recommended measurement location for Configurations B, C, D, and G due to instrument limitations.

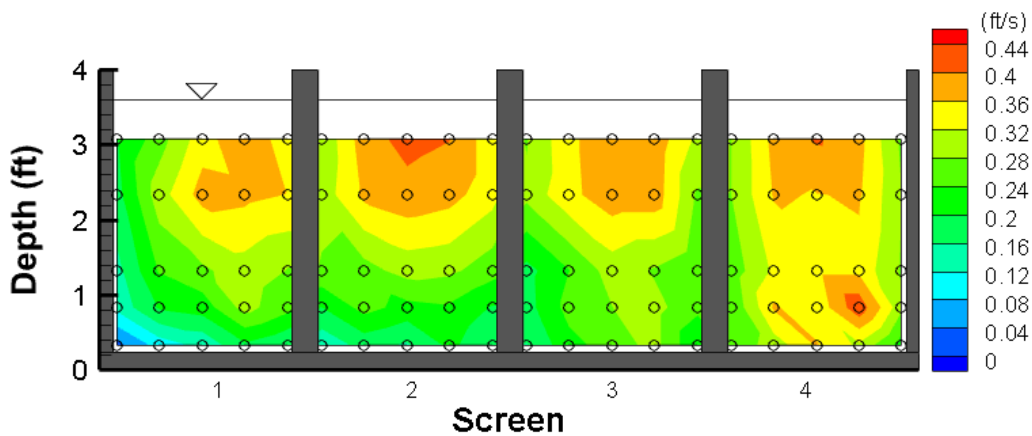

Figure 18. Approach velocity contour plot of stationary data collected at 25 points per screen (Configuration A).

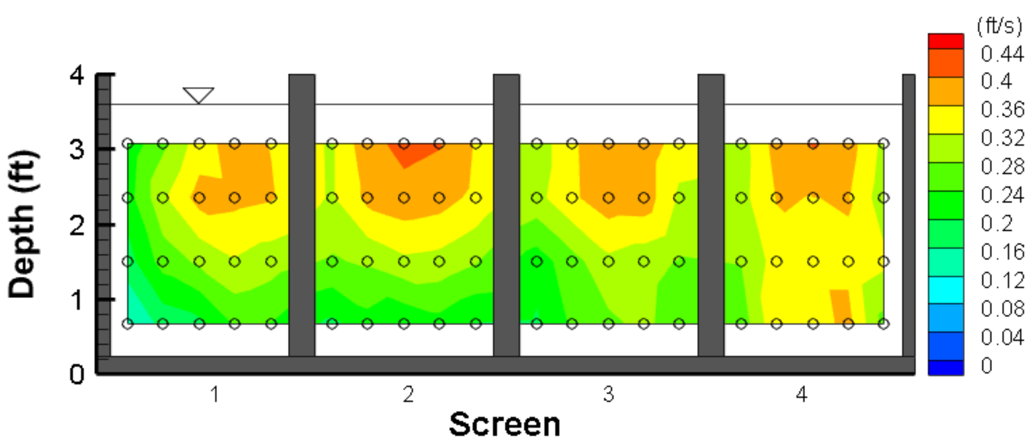

Figure 19. Approach velocity contour plot using an interpolated data grid of 20 points per screen (Configuration B).

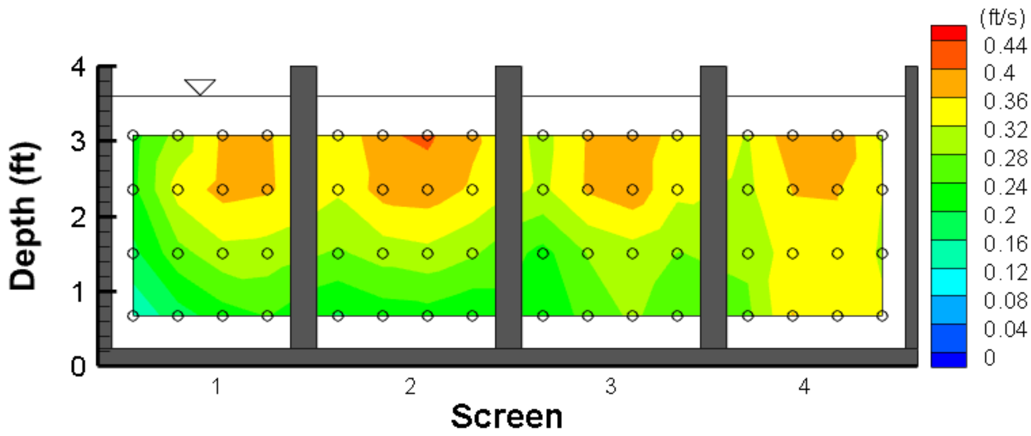

Figure 20. Approach velocity contour plot using an interpolated data grid of 16 points per screen (Configuration C).

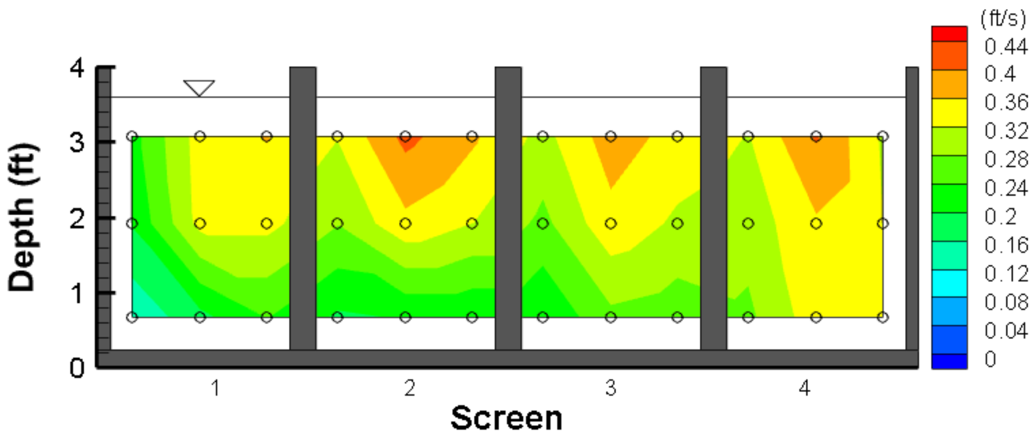

Figure 21. Approach velocity contour plot using an interpolated data grid of 9 points per screen, with one central point and 8 outer points weighted toward the water surface, screen invert, and piers (Configuration D).

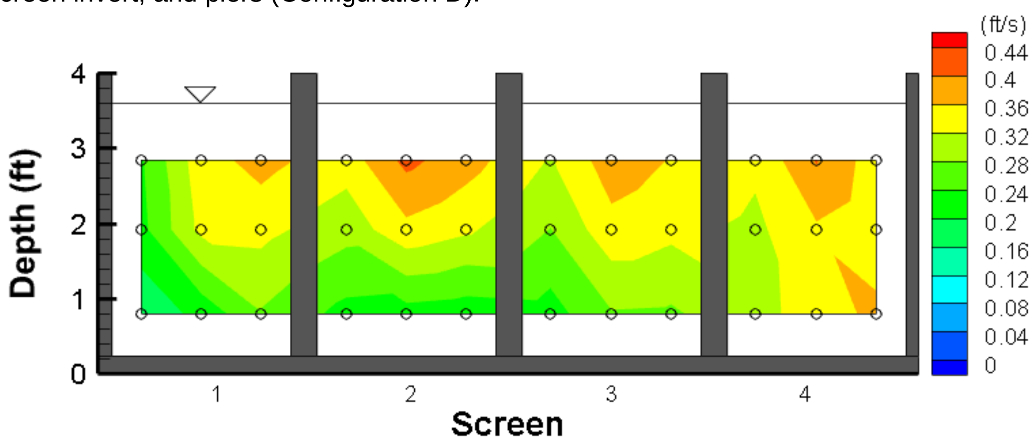

Figure 22. Approach velocity contour plot using an interpolated data grid of 9 points per screen at the center of sections on a 9 square grid (Configuration E).

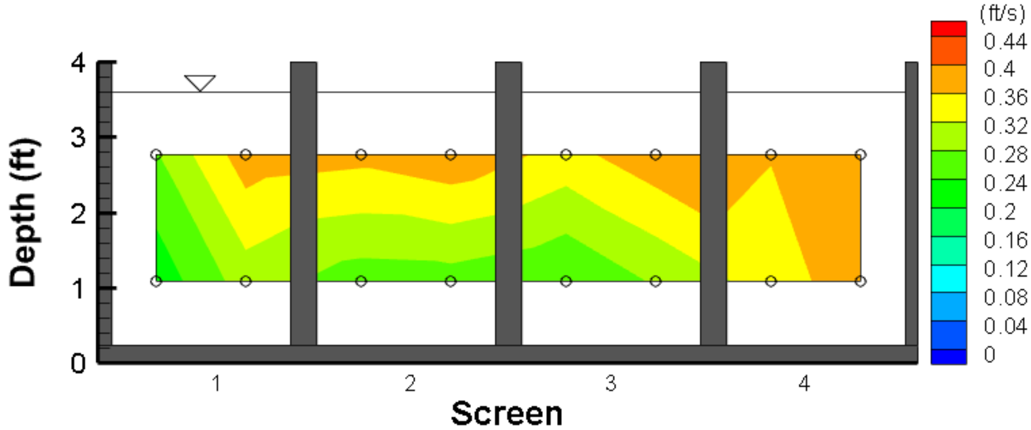

Figure 23. Approach velocity contour plot using an interpolated data grid of 4 points per screen at the center of sections on a 4 square grid (Configuration F).

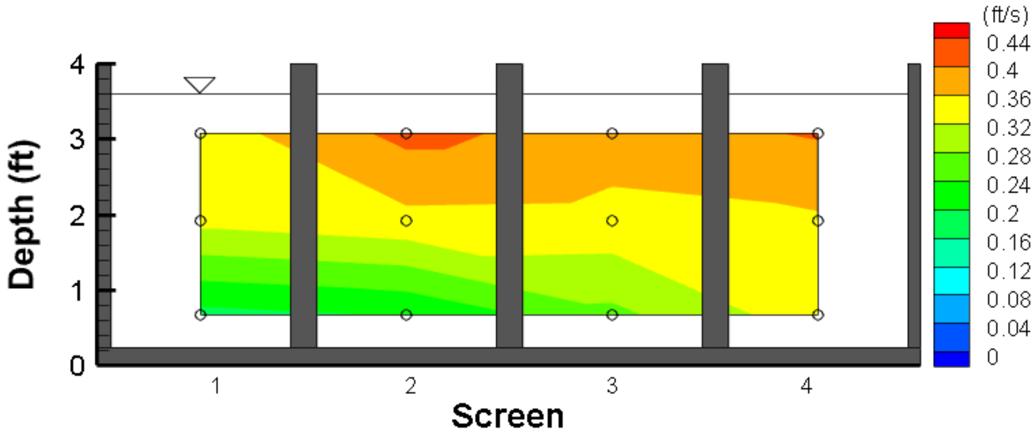

Figure 24. Approach velocity contour plot with an interpolated data grid of 3 points per screen, centered on the screen laterally at 3 depths (17%, 50%, and 83% of the water depth, Configuration G).

Approach velocity contour plots for Configurations B, C, D, and E resembled the contour plot for Configuration A, but none were able to capture the magnitude of the hot spot on the bottom right corner of screen 4. As expected, the coarser grid patterns of Configurations F and G were unable to successfully identify higher and lower velocity zones. Table 3 shows a comparison of average area-weighted approach velocities for each configuration. Configurations B, C, D, and E were within +1.6% of Configuration A while Configurations F and G were +6.3 and +9.2% different, respectively. The maximum approach velocity is also provided in Table 3. Data show that reduced point density is able to capture some, but not all, of the hotspots on the screen.

Table 3. Comparison of average area-weighted approach velocity for Configurations A-G. At the screen face, the theoretical approach velocity should be 0.383 ft/s.

Data Collection Grid Configuration	Number of Data Collection Points	Average Area-Weighted Approach Velocity (ft/s)	Percent Difference in Average Approach Velocity from Configuration A (%)	Maximum Approach Velocity (ft/s)
A	25	0.304	N/A	0.428
B	20	0.306	+0.6	0.412
C	16	0.306	+0.6	0.407
D	9	0.307	+1.0	0.412
E	9	0.309	+1.6	0.411
F	4	0.323	+6.3	0.390
G	3	0.332	+9.2	0.412

Comparison of Stationary and Traversing Velocity Data Collection

Stationary velocity data collected 3 inches from the screen face were compared to data collected 3 inches from the screen face with a traversing measurement system. Stationary velocity measurements were collected for 40 seconds per location at 25 points per screen for Configuration A (Figure 5). Traversing velocity measurements were continuously collected at the same 5 vertical depths as Configuration A while traveling at 0.07 ft/s in both the downstream and upstream directions. To compensate for traversing speed, the sweeping velocity data were adjusted by adding traverse speed to the downstream traverse data and subtracting it from the upstream traverse data.

Figure 25 shows a comparison of approach velocity data collected with stationary and traversing methods at a water depth of 2.083 ft from the bottom of the screen. Variations in the traversing velocity measurements were smoothed using a moving average of 20 data points. Stationary and traversing data follow the same general trend with most traversing data falling within the 95% confidence interval of the stationary data. This agreement is quite good when considering the traversing data were moving averages of 20 measurements while the stationary velocities were an average of 1,000 measurements (40 sec at 25 Hz).

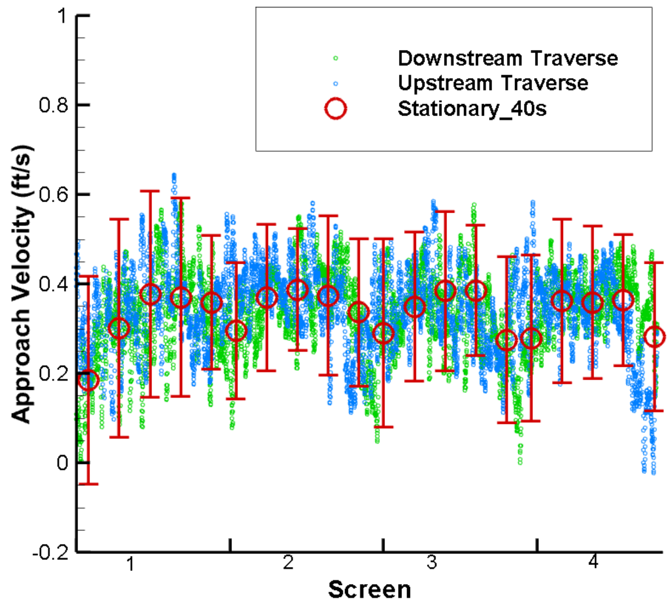

Figure 25. Comparison of stationary and traversing approach velocity data at 62% of screen wetted depth (± 95% CI).

Averaging the upstream and downstream traverses across all screens provided approach velocity values that are higher than the stationary data by 4.6%, while the sweeping velocities values were 1.9% lower for the laboratory tests (Table 4 and Table 5). Approach velocities may be higher with the traversing system because 2 of the 5 lateral locations for the stationary points were measured 1 inch from the piers. It is possible that the stationary data weighted the slower approach data near the piers more, thereby lowering the average approach velocity.

Table 4. Comparison of continuously traversing average approach velocity data to stationary point data. Note: average velocities reported in this table are not area-weighted. However, the area-weighting technique could be applied to traversing data if traverses are collected at unequal vertical spacing.

	Average Approach Velocity (ft/s)				
Screen Number	**Stationary**	**Downstream Traverse**	**Upstream Traverse**	**Average of Upstream and Downstream Traverses**	**Percent Difference Between Stationary and Averaged Traverses (%)**
Screen 1	0.243	0.26	0.263	0.262	7.8
Screen 2	0.276	0.286	0.283	0.285	3.3
Screen 3	0.282	0.291	0.29	0.291	3.2
Screen 4	0.32	0.336	0.33	0.333	4.1

Table 5. Comparison of continuously traversing average sweeping velocity data to stationary point data. Note: data were adjusted to account for speed of the traversing system.

	Average Sweeping Velocity (ft/s)				
Screen Number	**Stationary**	**Downstream Traverse**	**Upstream Traverse**	**Average of Upstream and Downstream Traverses**	**Percent Difference Between Stationary and Averaged Traverses (%)**
Screen 1	1.126	1.113	1.093	1.103	-2.0
Screen 2	0.868	0.894	0.809	0.852	-1.8
Screen 3	0.731	0.718	0.717	0.718	-1.8
Screen 4	0.453	0.492	0.403	0.447	-1.3
All Screens	0.795	0.804	0.756	0.780	-1.9

Velocity data collected with stationary and traversing methods were compared by using velocity contour plots. Figure 27 presents traversing data which has numerous high and low velocities throughout the water column that are not reflected with the stationary data shown in Figure 26. This difference is a result of comparing highly averaged data (stationary) with nearly instantaneous traversing velocity measurements. In other words, the traversing data contain turbulent fluctuations whereas the stationary data do not. The traversing data provide useful information about the presence of high and low approach velocities throughout the water column and adequately represents the velocity distribution from the stationary data in Figure 26. Traversing data collection includes velocity measurements across the entire screen face, but data should be presented carefully to provide the most useful visualization of measured velocities.

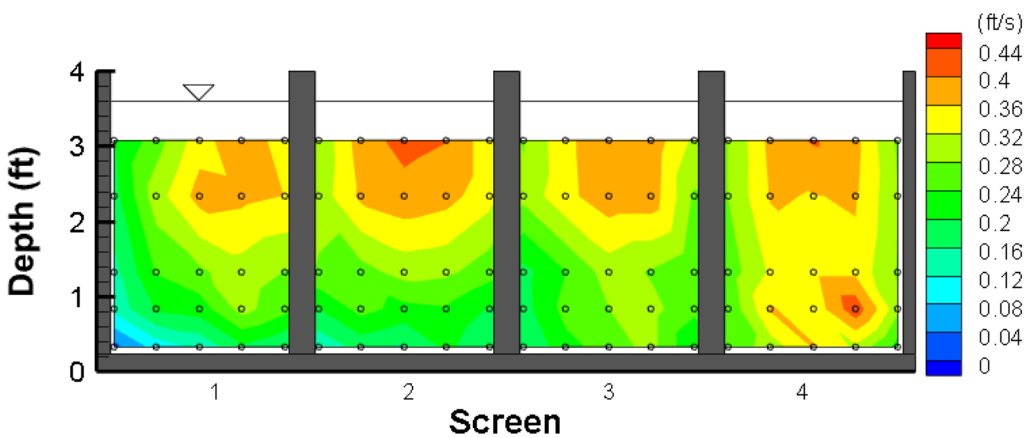

Figure 26. Approach velocity contour plot of stationary data collected at 25 points per screen (Configuration A, same as Figure 19).

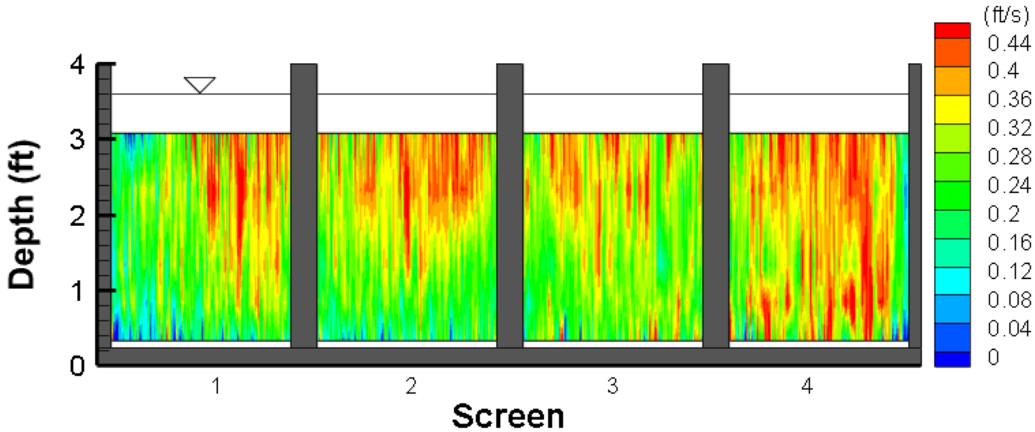

Figure 27. Average velocity contour plot for traversing data at a traverse speed of 0.07 ft/s at 5 depths. Traversing velocity measurements were smoothed with a 20-point moving average.

Effect of Traversing Speed on Data Quality

The effect of traversing speed on velocity data quality was analyzed to determine if there is a practical upper limit. Velocity measurements were made over a range of traversing speeds from 0.07 to 0.9 ft/s across all four screens with data collected at a single water depth of 2.083 ft from the bottom of the screen. Data were compared to average stationary data collected at five points on each screen at the same depth as the traversing data (shown at zero traverse speed in Figure 28). Over the range of speeds tested, traversing speed did not have a notable effect on measured approach velocities. It was assumed that faster traversing speeds may adversely affect data quality, but a breakpoint in the data was not detected at these low traverse speeds.

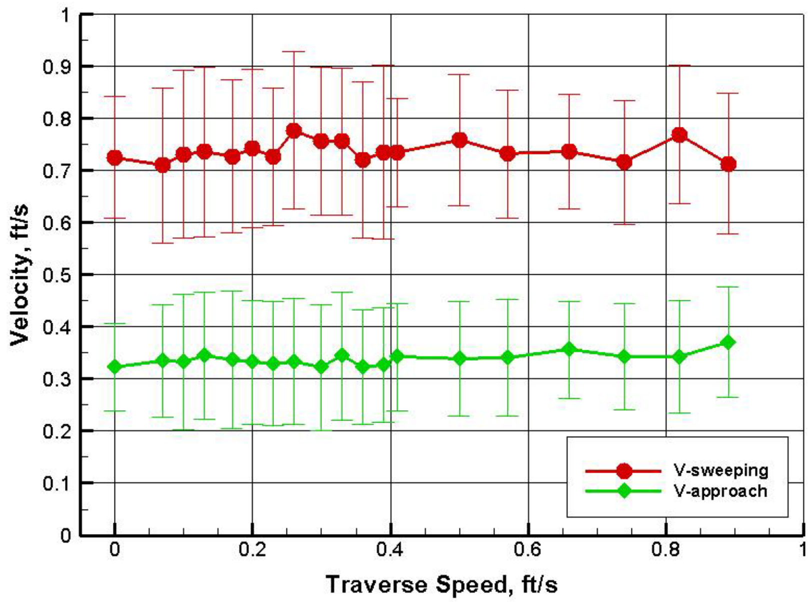

Figure 28. Comparison of average approach and sweeping velocities collected with stationary point data and a traversing system moving at 0.07—0.9 ft/s. Error bars are the RMS deviations from the average screen velocity component. Note: average stationary velocities are shown at zero traverse speed.

Evaluation of Probe Vibrations on Approach and Sweeping Velocities for Stationary and Traversing ADV Measurements

Vibrations were measured at 100 Hz using an Onset HOBO Pendant g logger (UA-0004-64) which is a three-axis accelerometer with a range of ± 3 g with an uncertainty of ±0.075 g. The resolution of the accelerometer is 0.025 g. Velocities were measured with a Nortek Vectrino field ADV and a Vectrino Plus laboratory ADV. The Vectrino Plus is capable of measuring velocities up to 200 Hz, whereas the Vectrino field ADV can sample up to 25 Hz.

The following tests were conducted:

1. Evaluate baseline vibration characteristics for stationary and traversing measurements in the physical hydraulic model.
2. Document acceleration and velocity measurements for stationary data collection with artificially induced vibration.
3. Document acceleration and velocity measurements for traversing data collection with artificially induced vibration.

Baseline Acceleration Measurements

A series of three tests were conducted to evaluate baseline accelerations for the ADV probe mount with the ADV out of the water. An accelerometer was mounted to the ADV probe just above the transducers to measure probe vibrations nearest the point of the velocity measurement. Accelerations in the x-axis were in the direction of sweeping flow and accelerations in the y-axis were in the direction of approach flow. These tests did not include any influence of flow on the ADV probe.

During the first baseline test, the ADV probe was held stationary. During the next two tests, the ADV probe was traversing along the screen. These tests were performed to determine if traverse speed had an impact on vibrations generated on the ADV probe since potential flow disturbances could extend into the ADV sampling volume. Traversing tests were performed with a traverse speed of 0.07 ft/s which was used for the majority of fish screen velocity measurements in this report and a faster traverse speed of 0.26 ft/s. The out-of-water measurements documented probe vibrations generated by the traversing system only.

Average accelerations and standard deviations of the time series of accelerations are summarized in Table 6. Accelerations in the vertical (z-axis) were not considered for baseline tests. The standard deviations represent the intensity of vibration. The average accelerations were similar for all tests. These test results indicate that there is minimal vibration generated by the laboratory traversing system over a range of traversing speeds.

Table 6. Summary of average, standard deviations (SD), and peak acceleration for baseline testing with the ADV probe out of the water.

Test	Acceleration in Sweeping Direction ± SD (g)	Acceleration in Approach Direction ± SD (g)	Peak Acceleration in Approach Direction (g)
Stationary	0.029 ± 0.009	-0.080 ± 0.052	-0.250
Traverse Speed 0.07 ft/s	0.035 ± 0.026	-0.093 ± 0.119	-0.675
Traverse Speed 0.26 ft/s	0.034 ± 0.059	-0.088 ± 0.148	-0.800

Stationary Acceleration and Velocity Measurements with Induced Vibration

Since the laboratory traversing system was relatively free of vibrations, it was necessary to artificially induce vibration to be more representative of a field situation. For stationary measurements, probe vibration was induced using stepper motors attached to the vertical positioning table. The ADV probe was submerged in flowing water for these tests.

A program was developed to repeatedly send a HOME command to the probe's vertical positioning table while the traversing system was held stationary. A series of HOME commands were repeatedly executed, thereby repeatedly sending the probe mount to the home position. This operation created motion in the vertical direction and strong vibrations perpendicular to the fish screen face which would impact approach velocity measurements. These induced vibration tests showed that the laboratory ADV mount was more susceptible to vibrations perpendicular to the screen than parallel to the screen.

Figure 29 is an example of the accelerations generated using this technique. Note that vertical accelerations include 1 g of gravitational acceleration. Table 7 summarizes the average accelerations for a submerged stationary ADV probe with and without induced vibration. For the induced vibration test, the peak acceleration was -3.20 g and the dominant frequency was 27 Hz. It is important to note that the average accelerations for baseline and induced vibrations are not significantly different which indicates that high vibration does not significantly change the average accelerations for all three components.

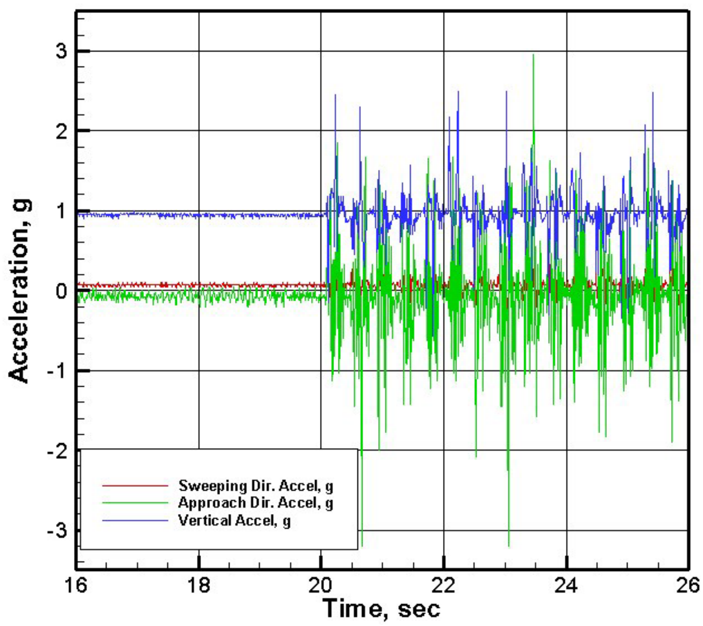

Figure 29. Plot of accelerations in the sweeping, approach, and vertical directions for bursts of vertical accelerations inducing vibration in the approach direction with a peak of -3.20 g and a dominant frequency of 27 Hz.

Table 7. Summary of average acceleration components and standard deviations for a stationary probe with and without induced vibration. Accelerometer measurements were collected at 100 Hz.

Test	Acceleration in Sweeping Direction ± SD (g)	Acceleration in Approach Direction ± SD (g)	Acceleration in Vertical Direction ± SD (g)
Stationary, without Induced Vibration	0.070 ± 0.019	- 0.072 ± 0.053	0.947 ± 0.024
Stationary, with Induced Vibration	0.069 ± 0.091	- 0.065 ± 0.549	0.951 ± 0.257

The next objective was to determine if probe vibrations affected stationary ADV measurements by collecting data with and without induced vibration. Velocities were measured using a Nortek Vectrino field probe using a 25 Hz sampling frequency. Table 8 summarizes the average velocities for a stationary ADV probe and the same probe with induced vibration. These ADV data were collected at the same time as accelerations presented in Table 7. ADV data were processed using WinADV without filtering to create a worst-case scenario for incorporating vibration-caused velocity spikes. The sweeping velocity measurements were about 6% higher with induced vibration. The average approach velocities were similar for both tests which indicates that induced vibration does not significantly influence the stationary approach velocity measurements over time regardless of the magnitude or dominant frequency of the probe accelerations.

Table 8. Summary of average ADV velocity components and standard deviations for a stationary probe with and without induced probe vibration. ADV measurements were sampled at 25 Hz.

Test	Average Sweeping Velocity ± SD (ft/s)	Average Approach Velocity ± SD (ft/s)	Average Vertical Velocity ± SD (ft/s)
Stationary, without Induced Vibration	0.974 ± 0.154	0.336 ± 0.107	0.039 ± 0.080
Stationary, with Induced Vibration	1.034 ± 0.152	0.313 ± 0.115	0.011 ± 0.104

Traversing Acceleration and Velocity Measurements with Induced Vibration

The last objective was to determine if probe vibrations during traversing affected ADV measurements for ambient and induced vibration. Accelerometer and ADV data were collected simultaneously while traversing the fish screen at a speed of 0.07 ft/s with and without induced vibration. Data were collected with a Nortek Vectrino field ADV at a sampling rate of 25 Hz. Probe vibrations were induced by manually tapping the ADV probe mast in the y-direction for the duration of the traverse.

Table 9 summarizes the average accelerations for the sweeping, approach, and vertical directions and their respective standard deviations. The accelerometer sampled vibrations at 100 Hz. Note that vertical accelerations include 1 g of gravitational acceleration. For the ambient vibration test, the peak acceleration was -0.50 g and the dominant frequency was at 27 Hz. For the induced vibration test, the peak acceleration was -2.125 g and the dominant frequency was at 10 Hz. These statistics indicate that ADV probe vibrations do not affect the average acceleration values measured for ambient and high vibration traverses, which is quantified by the standard deviations in the approach direction.

Table 10 presents similar data for average sweeping, approach, and vertical velocities measured with an ADV and their respective standard deviations. The average approach velocities measured with induced vibration were 5% lower while the standard deviations were 46% higher. These data illustrate that ambient and induced vibrations are effectively averaged out in the average ADV velocity measurements.

Table 9. Summary of average acceleration components and standard deviations for traverses with the ADV probe submerged in water flowing at 0.93 ft/s. Accelerometer measurements were collected at 100 Hz.

Test	Acceleration in Sweeping Direction ± SD (g)	Acceleration in Approach Direction ± SD (g)	Acceleration in Vertical Direction ± SD (g)
Traverse with ambient vibration	0.002 ± 0.029	-0.054 ± 0.090	0.959 ± 0.048
Traverse with induced vibration	-0.003 ± 0.091	-0.054 ± 0.457	0.951 ± 0.183

Table 10. Summary of average ADV velocity components and standard deviations for 0.07 ft/sec traverses with the ADV probe submerged in water flowing at 0.93 ft/sec. ADV measurements were sampled at 25 Hz.

Test	Average Sweeping Velocity ± SD (ft/s)	Average Approach Velocity ± SD (ft/s)	Average Vertical Velocity ± SD (ft/s)
Traverse with ambient vibration	0.935 ± 0.142	0.337 ± 0.096	0.029 ± 0.066
Traverse with induced vibration	0.916 ± 0.150	0.321 ± 0.140	0.022 ± 0.087

Effects of Vibration on Turbulent Velocity Fluctuations

A comparison of standard deviations of acceleration and velocity shows that the standard deviation of accelerations are many times higher with induced vibration, but this is not the case with the standard deviation of velocities with induced vibrations. Figure 30 presents a summary of average ADV velocities measured for stationary and traverse plots with and without induced vibration.

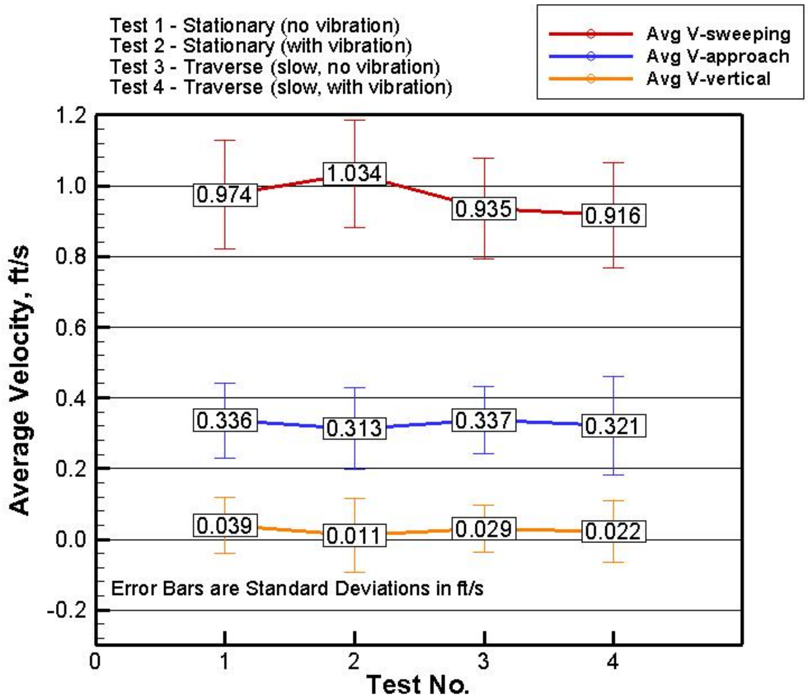

Figure 30. Results from induced vibration tests for a 0.07 ft/s traverse speed sampled using a Nortek Vectrino Field probe at 25 Hz.
Note: Stationary measurements were included to illustrate background standard deviations of the 3 velocity components, but the velocity magnitudes are not comparable to the average traverse velocities which are taken over a length of screen number 1.

Dynamic events, such as vibration frequency, that are to be accurately measured should be sampled at 2 times the dominant frequency. For example, an accelerometer logging at a frequency of 100 Hz will accurately capture vibration frequencies up to 50 Hz. Similarly, an ADV sampling frequency of 25 Hz will only capture the effects of probe vibrations (or velocity fluctuations) up to 12.5 Hz. This is important for these induced vibration tests because the dominant frequency of accelerations was computed to be around 25 to 30 Hz.

To better capture the effects of vibrations on velocity fluctuations, a Nortek Vectrino Plus ADV was used with a sampling rate of 200 Hz. Velocities were measured while traversing at 0.07 and 0.35 ft/s with and without induced vibration. Figure 31 illustrates the close agreement of average velocities for a wide range of test conditions. However, the ADV sampling rate of 200 Hz was able to capture the variation in velocity fluctuations as illustrated by the error bars on Figure 31.

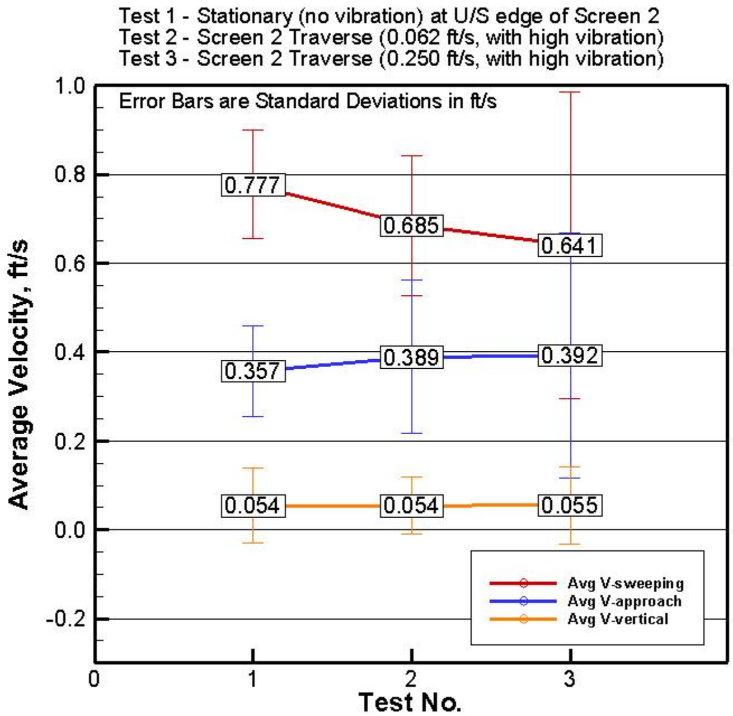

Figure 31. Results from a high vibration traverse test for two traverse speeds (0.07 and 0.35 ft/sec) sampled at 200 Hz using a Nortek Vectrino Plus. Note: Stationary averages were included to illustrate background standard deviations of the 3 velocity components. However, stationary velocity magnitudes are not comparable to the traverse velocities which are taken over a length of screen number 2.

Effect of Screen Type and Porosity on Approach Velocity Uniformity

Four different screens were installed in the physical model to determine if screen type or porosity (percent open area) affected approach velocity uniformity. The original screen was wedge wire with 3/32-inch slot openings with a 57% porosity. The wedge wire screen (Figure 32) was compared to a perforated plate screen (Figure 33) of about the same porosity (1/4-inch diameter holes staggered 5/16-inch diagonally, 58% porosity) to determine if screen type affected velocity distribution.

To determine the effect of porosity on approach velocity uniformity, velocity data were also collected with stationary and traversing systems with perforated plate screens at 40% porosity (with 1/8-inch diameter holes staggered on 3/16-inch diagonal spacing, Figure 34) and 33% porosity (with 3/32-inch diameter holes staggered on 5/32-inch diagonal spacing, Figure 35). All perforated plate screens tested were 14-gauge aluminum.

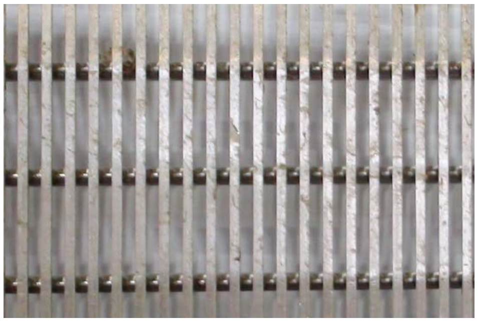

Figure 32. Wedge wire with 3/32-inch slot opening (57% porosity).

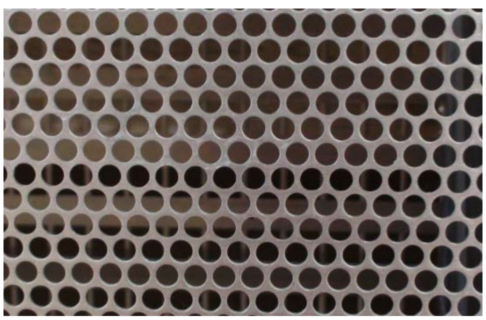

Figure 33. Perforated plate with 1/4-inch holes at 5/16-inch spacing (58% porosity).

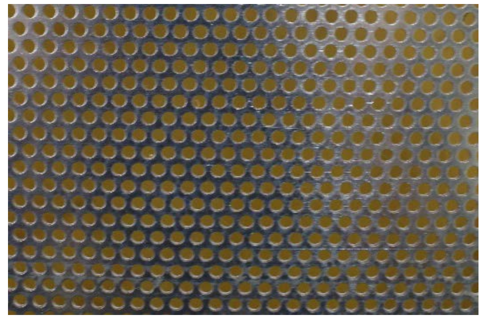

Figure 34. Perforated plate with 1/8-inch holes at 3/16-inch spacing (40% porosity).

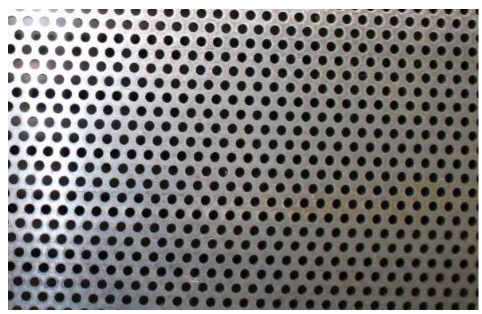

Figure 35. Perforated plate with 3/32-inch holes at 5/32-inch spacing (33% porosity).

Table 11 shows that average approach velocities for wedge wire were within 2.5% of perforated plate screens for stationary and traversing data collection. Figure 36 shows that approach velocities are low near the intermediate piers for wedge wire and perforated plate screens with the same porosity, but there is shift in the location of the highest velocities with more flow entering the perforated plate screen in the first half of each screen, while the wedge wire screen has more flow through the downstream half of each screen.

Table 11. Summary of average approach velocities for wedge wire and perforated plate screens, measured 3 inches in front of the screen using stationary and traversing data collection methods. The traversing system data are the average of the upstream and downstream traverses. Note: average velocities reported in this table are not area-weighted.

Type of Screen	Average Approach Velocity (ft/s)		
	Stationary	Traversing System	Average Headloss (in)
Wedge wire (57% porosity)	0.280	0.289	1.09
Perforated Plate (58% porosity)	0.273	0.285	1.03
Perforated Plate (40% porosity)	0.282	0.291	1.20
Perforated Plate (33% porosity)	0.281	0.288	1.32

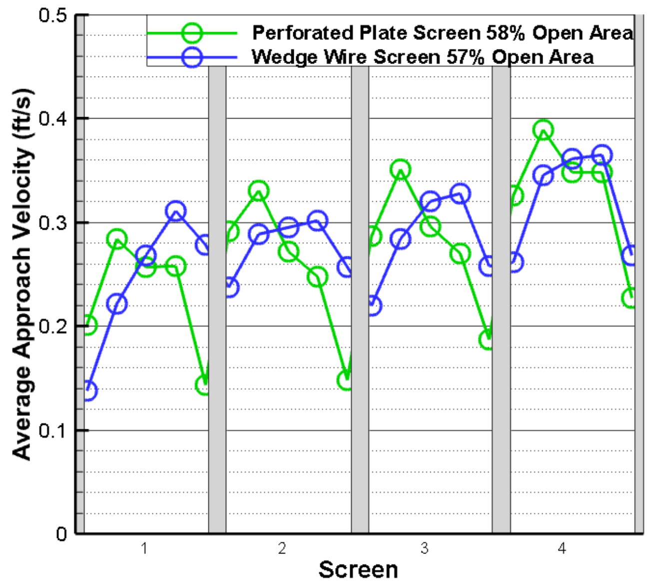

Figure 36. Comparison of average approach velocities collected 3 inches in front of wedge wire and perforated plate screens with approximately the same porosity.

Approach velocity contour plots for wedge wire (57% porosity) and perforated plate (58%, 40%, and 33% porosity) are shown in Figure 37 through Figure 40. Contour plots show that approach velocities were more uniform over the screen face when the porosity is lower. Fish screens of 33% and 40% porosity did not have hot spots like the fish screens with 58% porosity. Similar results were found in the Roza Dam flat plate fish screen model (Svoboda and Heiner 2015). Lower screen porosity requires more head to drive flow through the screen which produces more uniform flow through the screen and reduces the low velocity areas near the screen support piers (Table 11).

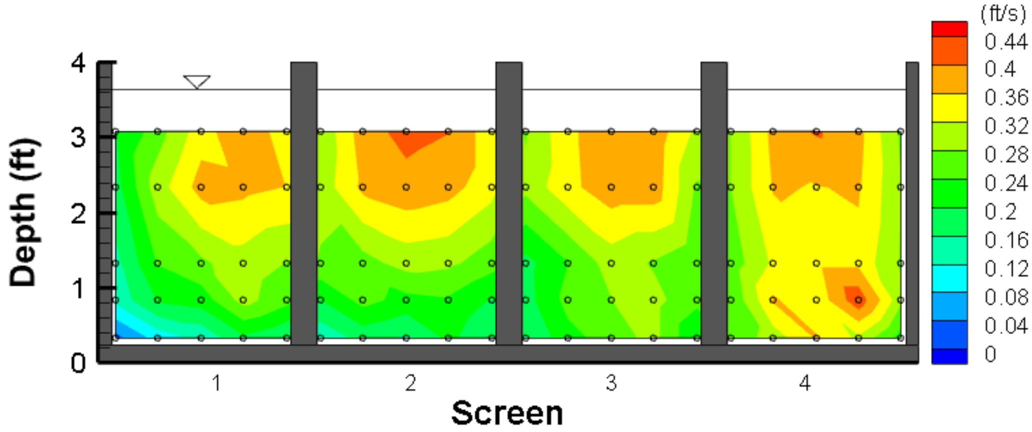

Figure 37. Approach velocity contour plot of stationary data collected on wedge wire screen with 57% porosity. Flow is from left to right.

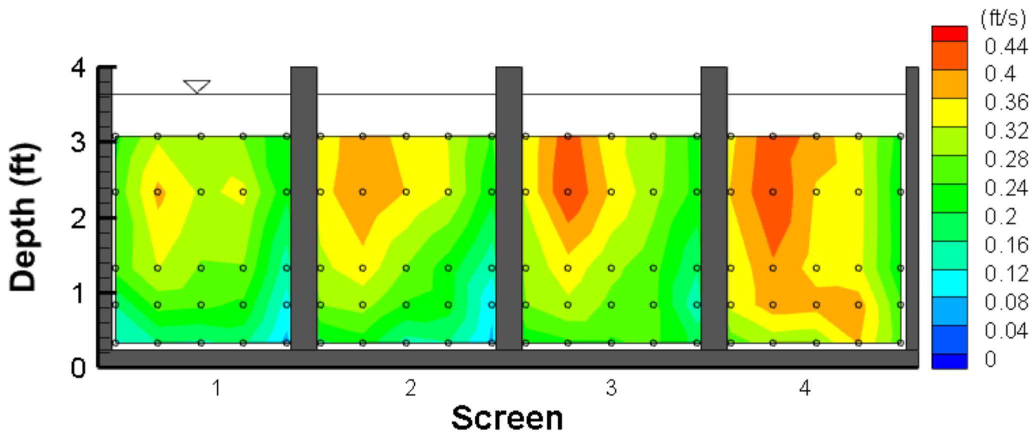

Figure 38. Approach velocity contour plot of stationary data collected on perforated plate screen with 58% porosity. Flow is from left to right.

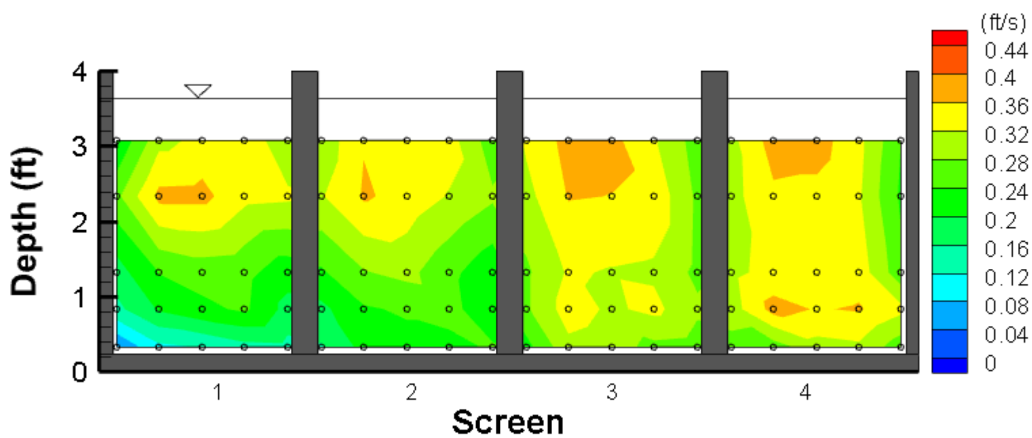

Figure 39. Approach velocity contour plot of stationary data collected on perforated plate screen with 40% porosity. Flow is from left to right.

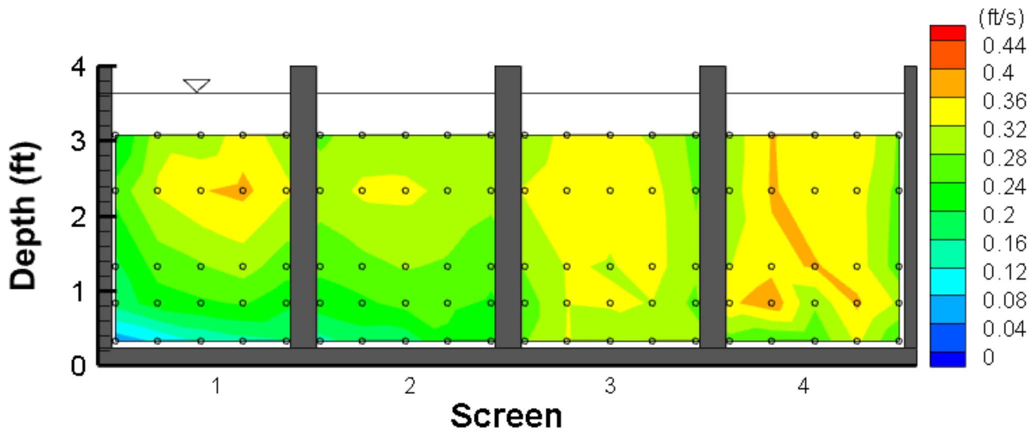

Figure 40. Approach velocity contour plot of stationary data collected on perforated plate screen with 33% porosity. Flow is from left to right.

Conclusions

A physical hydraulic model was constructed and tested to determine if methods for collecting hydraulic data on vertical flat plate fish screens can be improved to reduce evaluation cost and increase measurement quality. Notable conclusions and recommendations are listed below:

- Model data show that approach velocities are higher at the center of the screen and near the water surface, but are lower near the intermediate piers and at the screen invert.
- Laboratory model results indicate that as the probe distance from the screen increases, the average approach velocity decreases.
- An approach velocity measurement collected 3 inches from the screen face should be approximately 20% lower than theoretical average approach velocity computed using facility flowmeters.
- A review of past fish screen field evaluations shows a wide range in the percent difference between the computed theoretical approach velocity and approach velocities measured near the screen face (from measured approach velocities being 44% higher to 3% lower than theoretical approach velocities). Aquatic debris/sediment accumulation, probe misalignment, damaged or poorly calibrated instruments, inadequate number or location of data points, or poor facility approach conditions may all be factors when considering the difference between computed and measured approach velocities.
- Comparing the theoretical approach velocity to the measured approach velocity may help identify if a potential error or bias has occurred in the field data. This method, however, cannot be used to definitively validate velocity data sets because there may be other reasons that differences occur which are independent of the field study.
- Configurations B (20 points per screen) and C (16 points per screen) closely resembled a full data collection effort. For long screens, Configuration D (9 points per screen with 1 central point and 8 outer points weighted toward the

water surface, screen invert, and piers) may be a good alternative for minimizing the data collection effort on all screens. Configuration E (9 points per screen on a square grid) did not capture velocities near the edges as well, but still provided a reasonable representation of the velocity distribution. Coarser grid patterns like Configurations F (4 points per screen) and G (3 points per screen) were unable to successfully identify higher and lower velocity zones and did not provide enough data to be useful, except for an initial evaluation of baffle performance.

- Traversing data collection included velocity measurements across the entire screen face and this technique can be used on long screens to significantly reduce the data collection effort. For the laboratory tests, averaging the upstream and downstream traverses provided approach velocity values that are higher than the stationary data by 4.6%, while the sweeping velocities values were 1.9% lower.
- For the range of traverse speeds tested (0.07-0.9 ft/s), traversing speed did not have a notable effect on measured approach velocities. To be conservative, it is recommended that traversing systems should move as slowly as practical to ensure that traversing speed does not adversely affect data quality.
- Vibration test results indicate that ADV probe vibrations did not significantly influence average velocity measurements for stationary or traversing system data for vibration frequencies up to one-half of the ADV sampling frequency (e.g. 25 Hz).
- For the laboratory probe mount, flow-induced (ambient) vibrations in the sweeping flow direction did not significantly affect average sweeping velocities measured with an ADV; however, the sweeping velocity was limited to 1.0 ft/s for these tests. It is possible that high sweeping velocities will create additional vibrations from vortex shedding or from flow disturbances that excite the ADV probe.
- Vibration frequencies greater than one half of the ADV sampling frequency of 25 Hz (i.e. 12.5 Hz) were not captured in the turbulent fluctuations (the RMS deviations of the velocities) which affects the accuracy of turbulence measurements.
- It is recommended that traversing speed be as slow as practical and that the ADV probe mount be constructed to minimize vibration to under 10 Hz. This vibration criteria will allow an ADV sampling at 25 Hz to properly capture probe vibration effects in the ADV turbulence measurements.
- If probe vibrations are a concern, a low-cost 3-axis accelerometer (up to 100 Hz) can be used to measure vibration characteristics (dominant frequencies and affected axes). As a note, the accelerometer can also measure tilt angles which might be useful for monitoring probe orientation over the course of the traverse or at various probe elevations.
- Approach velocities were low near the intermediate piers for wedge wire and perforated plate screens of the same porosity, but there was a shift in the location of the highest velocities with more flow entering the perforated plate screen in the first half of each screen, while the wedge wire screen had more flow through downstream half of each screen.
- Model results show that approach velocities were more uniform over the screen face when the porosity was lower. Fish screens of 33% and 40% porosity did not have hot spots like the fish screens with 58% porosity because lower screen porosity requires more head to drive flow through the screen which reduces the low velocity areas near the screen support piers.

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Appendix A. Average Area-Weighted Approach Velocities

The technique of area-weighting ensures that each data point is given an appropriate level of influence on the total average approach velocity based on the area that it represents. Stationary data points collected for Configuration A are shown in Figure A1. After a grid was drawn, the area surrounding each data point was calculated and multiplied by the measured approach velocity in that grid section. Data in each grid section were summed and then divided by the total screen area. This method prevents data points representing a smaller area from skewing the overall average approach velocity.

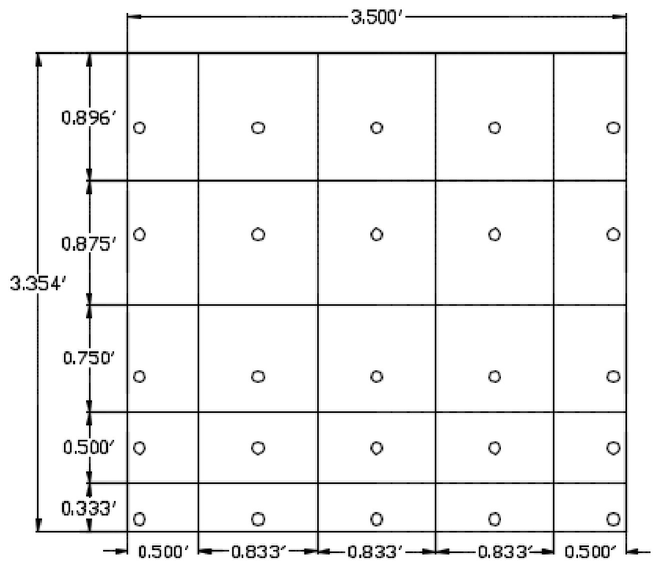

Figure A1. Location of 25 stationary approach velocity points in Configuration A. Data collected at each location were area-weighted to ensure that the average approach velocity was not disproportionally influenced by measurements representing a smaller screen area.