RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1091

Tehama-Colusa Canal Authority (TCCA) Red Bluff Pumping Plant Post-Construction Fish Screen Hydraulic Evaluation

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

May 2014

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Introduction

Background

Red Bluff Diversion Dam (RBDD) is located on the Sacramento River approximately 2 miles southeast of Red Bluff, California (Figure 1). Completed in the mid-1960s, the diversion dam raised the water surface of the Sacramento River enabling gravity diversion into Tehama Colusa Canal Authority's (TCCA) canal system. Fish ladders were constructed at the dam to allow for fish passage during dam operations, but fish passage was unreliable and inefficient for species of concern. The National Marine Fisheries Service's (NMFS) 2009 Biological Opinion for the Central Valley Project required that the RBDD gates be raised year-round after 2011 (NMFS, 2009).

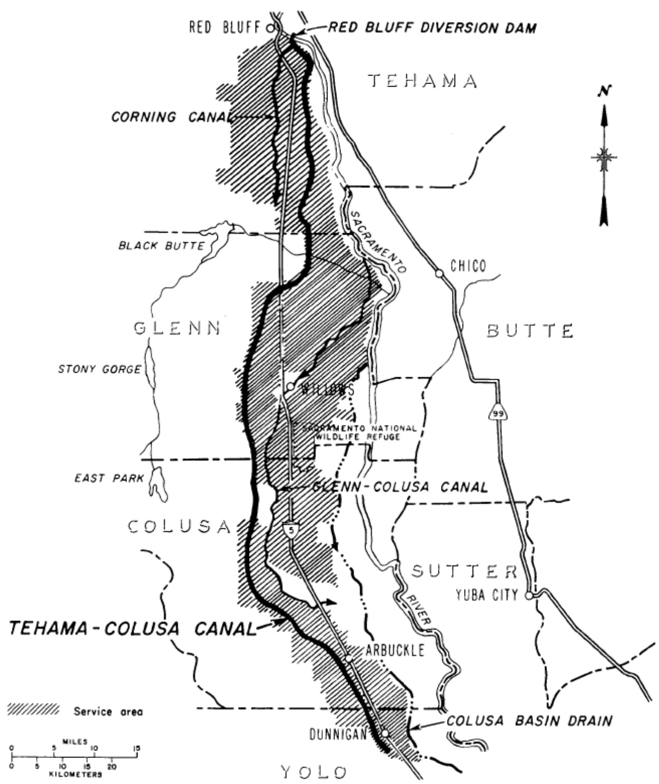


Figure 1. General location map of Red Bluff Diversion Dam and project area extents.

The Red Bluff Diversion Dam Fish Passage Improvement Project addresses the dual concerns of providing fish passage at RBDD while ensuring reliable water deliveries to the TCCA service area. The project involved construction of a positive barrier fish screen structure, forebay, pumping plant, switchyard, canal, and siphon to reduce or eliminate reliance on the RBDD. The project allows TCCA to ensure water deliveries while avoiding regulatory constraints associated with operation of the RBDD.

The 1,100-ft-long fish screen is located on the west bank of the Sacramento River approximately 1,500 ft upstream of the RBDD (Figure 2). The flat-panel fish screen structure has 60 screen bays with four sections containing 15 screen bays (screen bay 1 is most upstream and screen bay 60 is most downstream). Each section is separated by blowout panels that include small fish refuge areas. The effective width and depth of each screen bay is 14.92 ft and 9.83 ft, respectively, for a total effective flow area of 8,800 ft^2. The fish screen panels are constructed of stainless steel profile-wire with 1.75 mm gaps.

Figure 2. Aerial view of Red Bluff fish screen, forebay, and pumping plant (photo from website of Balfour Beatty Infrastructure, Inc.)

The initial pumping plant capacity is limited to 2,000 cfs with a build-out capacity of 2,500 cfs. Screen section 1, consisting of screen bays 1-15, is currently blocked with solid panels until full build-out occurs. Screen section 2 (bays 16-30), screen section 3 (bays 31-45), and screen section 4 (bays 46-60) are currently operational. The normal peak diversion rate during June and July is generally 1,300 cfs or less.

The fish screen structure includes an automated screen cleaning system along with a sediment jetting system to mitigate sediment build-up behind the screen panels. Ten adjustable tuning baffles are located behind each fish screen panel to produce uniform flow through the screen. Tuning baffles rotate through 90 degrees – from fully open to fully closed. Baffles behind each screen panel will be set to the same percent opening. However, baffle settings will vary from screen to screen.

Federally listed species of concern include winter-run and spring-run Chinook salmon, Central Valley steelhead, and green sturgeon. The fish screen was designed to comply with NMFS and California Department of Fish and Wildlife (CDFW) criteria for salmon and steelhead fry. It is generally accepted that these criteria for salmonids are also protective of green sturgeon.

Purpose

This technical memorandum describes the post-construction hydraulic evaluation of the fish screen at Red Bluff Pumping Plant. A Post-Construction Fish Screen Hydraulic Evaluation Plan (referred to as "Hydraulic Evaluation Plan") was prepared by CH2MHILL (2011). The goal of this evaluation is to document the as-built fish screen performance and identify where tuning baffle modifications may be warranted. Velocity data will be evaluated by CH2MHILL and regulatory staff to determine the best possible tuning strategy. Once baffle adjustments have been made, a second hydraulic evaluation will be performed to verify the tuning baffle performance and document final compliance with federal and state fish screening criteria.

Regulatory Agency Fish Screening Criteria

Approach velocity is the velocity vector perpendicular to the screen face. NMFS Southwest Region Fish Screening Criteria for Anadromous Salmonids require that the approach velocity not exceed 0.33 ft/s for on-river screens at a point approximately 3 inches in front of the screen surface (NMFS, 1997). This approach velocity criterion is intended to prevent impingement of juvenile salmonids on the screens. In addition, CDFW criteria state that sweeping velocity (velocity vector parallel and adjacent to the screen face) should be at least two times the allowable approach velocity which is more stringent than the NMFS requirement that sweeping velocity must be greater than approach velocity (CDFW, no date). High sweeping velocities allow for better movement of fish and debris past the screen and better cleaning of the screen face. NMFS criteria state that flow should be uniformly distributed across the screen surface to prevent localized areas of higher velocity. Adjustable baffles are commonly used behind the fish screen to fine tune screen panels with nonuniform velocities.

There is currently no formal guidance for design and performance of fish refugia structures. Refugia features were not examined as part of this post-construction hydraulic evaluation.

Methodology

The Hydraulic Evaluation Plan (CH2MHILL, 2011) states that data should be collected when the river stage is between 244.5 and 247.0 at screen bay 1. The required diversion rate is 80 to 100 percent of the design diversion capacity, corresponding to 1,600 to 2,000 cfs. Since the peak diversion rate during the test period is typically 1,300 cfs or less, water will likely need to be spilled back into the Sacramento River through the headworks. Tuning baffles were initially set at 4 percent porosity (mostly closed) in fish screen bay 16 and 98 percent porosity (mostly open) in fish screen bay 60. All 10 tuning baffles were set to the same porosity within each screen bay. Baffle porosities between bays 16 and 60 were evenly distributed between 4 and 98 percent open.

Velocity data were collected with a Nortek Vectrino Plus, a three-dimensional downlooking Acoustic Doppler Velocimeter (ADV). Data can be collected in the velocity range of 0.01 to 4 m/s with a sampling rate of up to 200 Hz at a sample volume distance of 10 cm from the probe face. Nortek Vectrino Plus specifications are included in Appendix A. The ADV was oriented such that the x-axis was parallel to the screen face to measure sweeping velocity (positive values were in the upstream direction). The y-axis was perpendicular to the screen velocity to measure approach velocity (positive readings were toward the screen face). The z-axis was vertically oriented (positive readings in the upward direction). The ADV sample volume was positioned 3 inches from the screen face.

Velocity data were collected using two methods: stationary measurements and traversing data collection from a moving trolley. For stationary measurements, the ADV instrument was fixed during data collection. During traversing data collection, the trolley was used to move the probe from one end of the screen section to the other – covering a total of 15 screen bays. Stationary ADV measurements were collected using a 50 Hz sampling frequency for a period of 60 seconds for a total of 3,000 measurements. During traversing data collection, the ADV moved across 15 screen bays using the screen cleaning system. A traverse was made in the upstream and downstream direction at the 3 elevations specified in the Hydraulic Evaluation Plan (CH2MHILL, 2011). From the moving trolley, ADV data were collected at a 50 Hz sampling frequency as the instrument was moved laterally along the screen at 0.54 ft/s.

A laptop computer was used to store raw velocity measurement data. Nortek velocity data files were converted to a file format that is compatible with WinADV data processing software (version 2.031). WinADV was used to compute averages and standard deviations of the collected velocity measurements. Processed data were filtered to remove spikes and points with correlations less than 70. For moving trolley data, concrete piers between screen bays and fish refugia bays were excluded by using flags in WinADV. Approach velocities measured in front of piers and fish refugia bays were very low and they were not averaged with velocities measured in front of the screen face. Velocity data collected at the very beginning and ending of each bay were discarded so that hydraulic influence from piers did not skew average approach velocities. The center 1,000 velocity measurements on each screen bay were processed. Approximately 250 measurements near the edge of each screen bay were excluded.

Several types of mounting systems for the ADV instrument were considered. Due to expected high sweeping velocities and a large number of data points required in the testing protocol, a probe mounting system was designed to attach to the screen cleaning system. A metal platform was attached on top of the screen cleaner counterweight platform. A 6-ft-long stationary steel mast (3-in.-square structural tubing) hung vertically off the upstream side of the platform above the water surface. A 10.75-ft-long moveable mounting arm (4 in. x 2.25 in. rectangular structural tubing) hung vertically upstream of the stationary mast such that the ADV mount could be raised and lowered with a pulley and winch system. The probe mounting arm extended below the water surface. A 16.5-in.-long L-shaped arm (4 in. x 2.25 in. rectangular structural tubing) at the bottom of the moveable mounting arm was designed to hold the instrument at a position 3 inches from the screen face when the probe clamp was resting against the screen (Figures 3-4). Ratchet straps were used to secure the probe in the proper position. Probe orientation with respect to the screen face was checked regularly using an alignment template (Figure 5).

Figure 3. ADV mounting system attached to screen cleaner counterweight platform.

Figure 4. A plastic probe clamp positioned the ADV 3 inches from the screen face.

Figure 5. ADV probe orientation was regularly checked with a template to ensure proper alignment and a 3-inch offset from screen face.

The ADV probe could be positioned laterally across the screen by moving the screen cleaner trolley along its track. The probe was positioned at measurement elevations by raising or lowering the mounting arm with an electric winch. The instrument mount was designed so that velocity data would be collected 5.6 ft upstream from the leading edge of the screen cleaner arm to minimize hydraulic influence from the screen cleaner arm. A two-dimensional (2-D) computational fluid dynamics (CFD) model was used during mount design to ensure that a 5.6 ft distance was sufficient in preventing velocity interference (Figure 6). To validate CFD model results, NMFS required field tests to confirm that the mount was outside of the zone of influence of the screen cleaner arm. These tests were conducted during the July 2013 field trip described below in “Data Collection”.

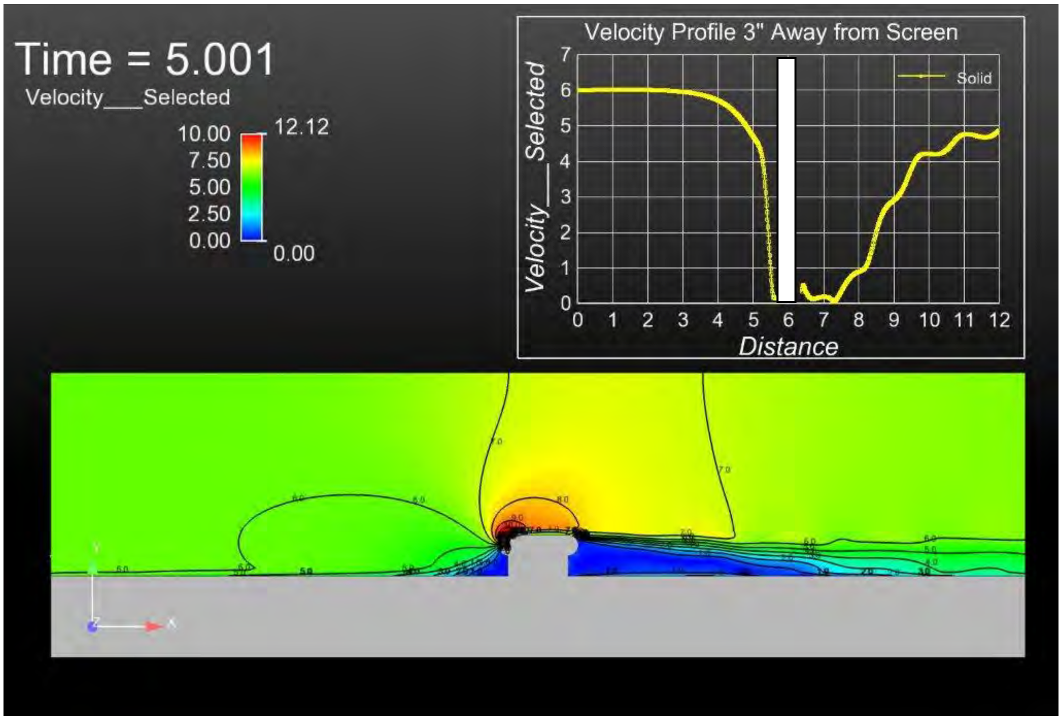


Figure 6. Results from the 2-D CFD model assuming a solid fish screen panel. Flow is from left to right. The bottom graph shows expected velocities (ft/s) near the screen cleaner arm. The white rectangle in the upper graph shows the location of the screen cleaner arm. Flow disturbance can be seen approximately 3 ft upstream and for over 6 ft downstream of the brush arm.

A velocity sampling protocol recommended in the Hydraulic Evaluation Plan (CH2MHILL, 2011) was the basis for this testing. Approach and sweeping velocities were measured and recorded for a minimum of 60 seconds per test location at the 45 operational screen bays (bays 16-60). Data were collected at 3 elevations: 0.17, 0.5, and 0.83 times the water depth, corresponding to row A, B, and C, respectively (Figure 7). The proposed evaluation plan recommended 9 stationary test points on 9 screen panels (3 panels per 15-bay section) and 3 test points on the remaining 36 screen panels (12 panels per 15-bay section). In addition, the evaluation plan specified that river flow, river stage, forebay stage, and measured diversion rate be recorded during field testing.

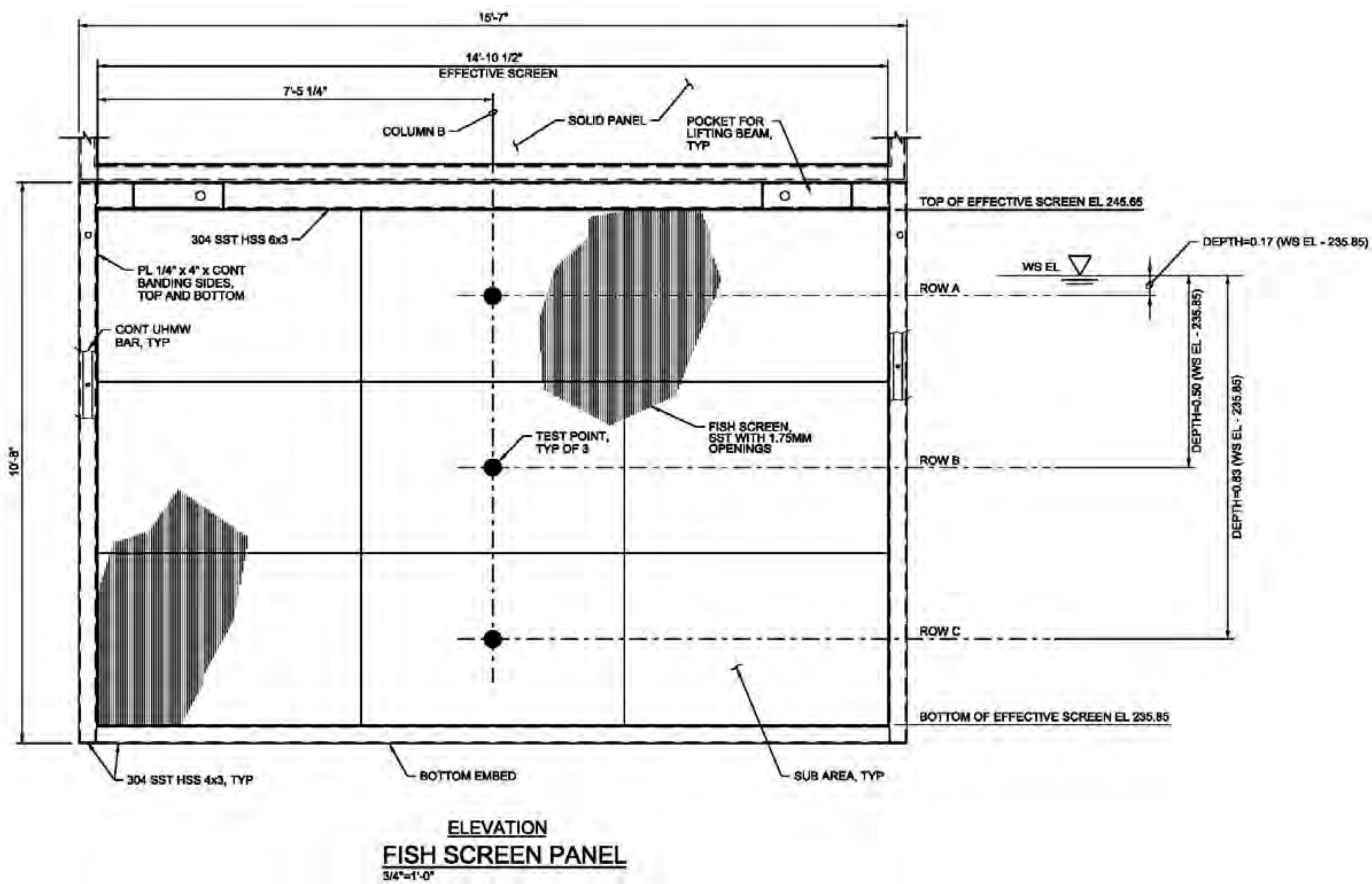


Figure 7. Location of 3 centerline data points at 0.17, 0.5 and 0.83 times the water depth (CH2MHILL, 2011).

During initial field testing, a concept of collecting measurements from a traversing data collection system was developed. With a traversing system, data would be collected continuously across the width of a screen bay at the 3 measurement elevations (rows A, B, and C) specified in the hydraulic evaluation plan. Velocity data would be measured while traversing the trolley upstream and downstream to cover all 15 bays served by the screen cleaning system in each screen section. Using this approach, velocities would be collected across the full width of the screen rather than at discreet points.

Data Collection

July 2013 Field Trip: Installation and Assessment

Objectives

The first field trip to Red Bluff fish screen was conducted July 15-18, 2013. The objectives of this initial trip were to:

- Install ADV instrument mount on screen cleaner system.
- Collect initial velocity data to ensure that instrument mount was operating properly.
- Determine the influence of the screen cleaner on velocity data collected upstream of the screen cleaner arm.
- Develop alternatives for improving speed of data collection.

Probe Mount Installation

The instrument mount was installed by project personnel using a National crane and Genie man-lift. Before installation, eight 50-lb counterweight plates were removed from the counterweight platform to account for the additional weight of the probe mounting system. The ADV mount was moved upstream and downstream using the screen cleaner trolley system and up and down with the electric winch. Several trolley passes were made at different probe elevations to ensure that the instrument tracked well laterally and vertically. Some initial velocity data were collected with the ADV mount system to ensure that all equipment was working properly.

Velocity Interference Testing

To examine the influence of the screen cleaner's brush arm on velocity data collected upstream from the brush arm, an ADV was attached to the steel blanking panel directly above the fish screen with a temporary magnetic mount

(Figure 8). A 14-ft-long jon boat was used to gain access to the screen face. The magnetic mount consisted of two 660-lb on/off magnets to anchor the system to the blanking panels. A vertical steel pipe clamped to the magnets held the ADV three inches from the screen face. The pipe was moved vertically by hand to position to the ADV at the desired elevation. Velocities were measured at depths of 3.1 and 0.85 ft from the water surface. The probe orientation with respect to the screen face was set using a template (see figure 5).

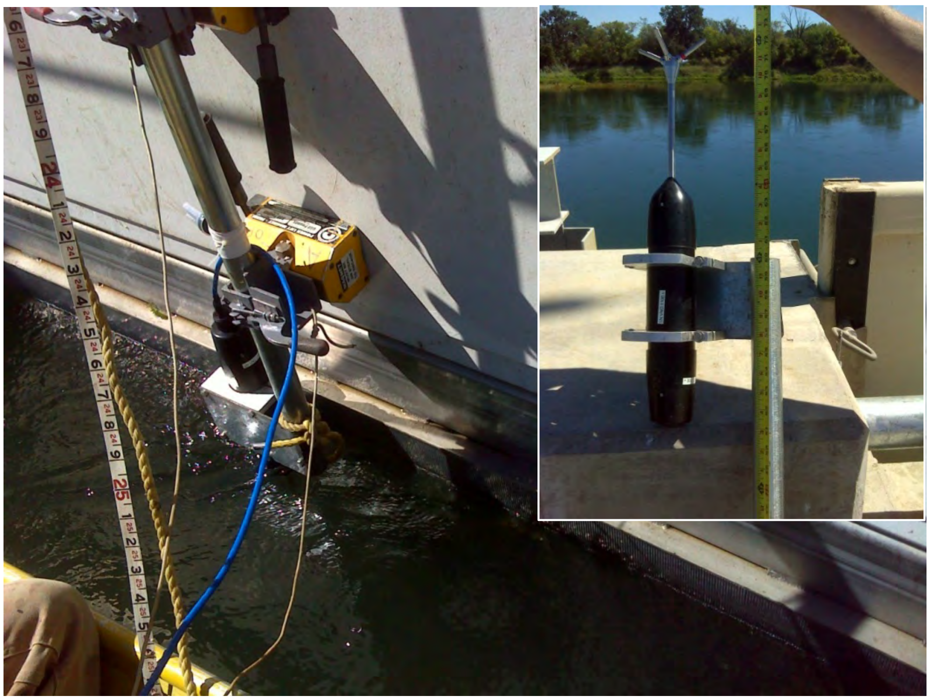


Figure 8. Temporary magnetic mount used to collect ADV data upstream from the screen cleaner’s brush arm to verify that the probe (inset photo) was positioned outside of the hydraulic influence of the brush arm.

The ADV was attached to the screen at the midpoint of bay 17 which is about 24 ft downstream from the screen cleaner’s parking bay. Three sets of velocity measurements were made at 2 different depths. Data were collected 3 to 20 ft upstream from the screen cleaner arm.

Prior to velocity testing, TCCA staff power-washed the fish screen panels for bays 16 through 30. The screen cleaner was operating normally until it was taken out of service for velocity measurements. During velocity testing, the Sacramento River at Bend Bridge was flowing at 14,300 cfs and the Red Bluff pumping plant was delivering 1,000 cfs to the Tehama-Colusa Canal. The top of the fish screen was about 0.33 ft above water surface elevation at 245.32 ft. The river water temperature was 14.8 °C (58.7 °F) during velocity measurements.

Approach velocity data measured at bay 17 showed no influence of the cleaner arm for all three tests (Figure 9). Sweeping velocity data show a small influence when the probe was 3 to 4 ft upstream. For velocity measurements collected at a distance greater than 4 ft from the cleaner arm, sweeping velocities were very consistent. Results indicate that velocities collected with the cantilevered mount system will not be significantly affected by the screen cleaner arm because the ADV will be located 5.6 ft upstream. Test data agrees with results from a 2-D CFD model which indicated the screen cleaner arm would not alter the flow field more than 3 ft upstream. Details of the July 2013 field data collection effort were documented in a technical memorandum (Vermeyen, 2013).

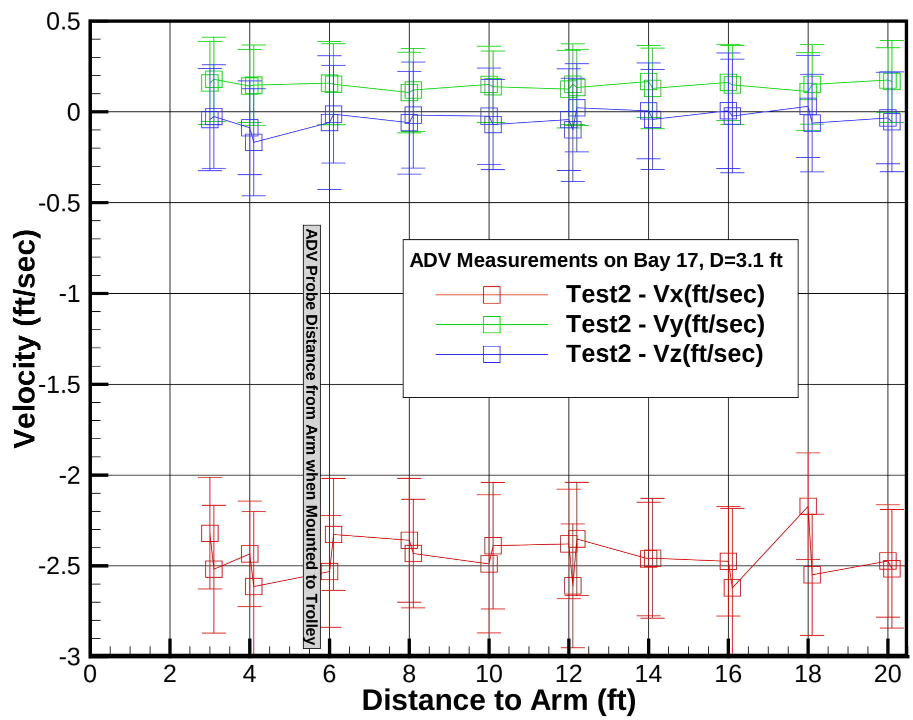


Figure 9. Velocity measurements collected near the mid span of bay 17 at a depth of 3.1 ft. Vx = sweeping velocity, Vy = approach velocity, and Vz = vertical velocity. Measurements were repeated twice at each distance. Error bars represent the standard deviation of each velocity component.

The last objective of the July 2013 field visit was to develop alternatives for improving the efficiency of data collection. Hydraulics Laboratory personnel developed the idea of collecting velocity data from a moving trolley instead of taking stationary measurements along the screen. This technique was used for the full suite of velocity data collected in August 2013.

August 2013 Field Trip: Data Collection

Objectives

A second field trip to Red Bluff fish screen was conducted August 19-21, 2013. The objectives of this trip were to:

- Collect a full suite of velocity data at screen bays 16-60 at three depths using the moving trolley method.

- Collect stationary velocity measurements for comparison to ensure that the moving trolley method was collecting representative velocity data.

Probe Mount Installation

The ADV probe was clamped to the cantilevered instrument mount. The mount and winch system was bolted to the counterweight platform. Warning: It was necessary to offset the platform about 3 inches away from the screen so the mast cleared the steel pulley covers (Figure 10). <u>Failure to provide clearance could damage the pulley covers, trolley, or ADV mount</u>.

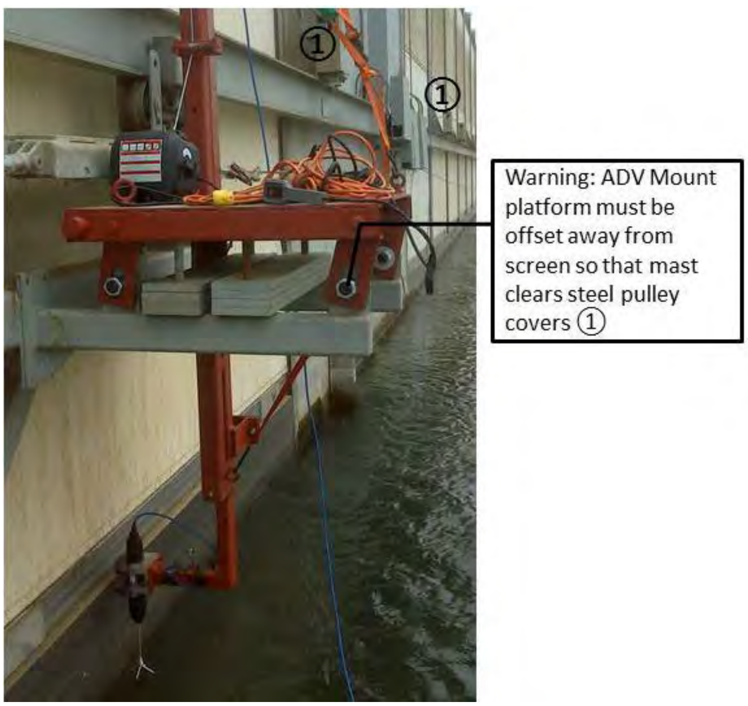


Figure 10. Photograph of platform offset to provide mast clearance by the steel pulley covers. The platform was leveled and the mast was held in a vertical position using ratchet straps.

Prior to data collection, the variable frequency drive (VFD) controlling the screen cleaner's drive motor was reduced from 60 Hz to 15 Hz to decrease the trolley speed. Aquatic debris was removed from the fish refugia bays using a long-handled rake. Velocity data were collected with the screen cleaner trolley moving in both the downstream and upstream directions. The distance traveled by the trolley was measured to be 248.75 ft and the travel time was 461 seconds. The trolley speed was computed to be 0.54 ft/s. The trolley speed is needed to adjust sweeping velocities to actual water velocity. When moving in the downstream direction, the trolley speed was added to the measured sweeping velocity (Vx). In the upstream direction, the trolley speed was subtracted from the measured sweeping velocity. For downstream traverses, velocities were measured from the upstream edge of the fish screen panel. Velocities could not be collected in the last 6 ft of the final screen bay in each section because the cleaner system reached the end of its track where it would trip a stop limit switch.

Traverse data were collected continuously at row A and row B elevations. At row C elevation, the traverse was stopped before the fish refugia bay and raised to the surface before moving past the refugia bay. Once past the fish refugia bay, the probe was lowered to row C elevation and the traverse was completed. ADV data collection was stopped during the refugia bay bypass operation. This operation was deemed necessary to protect the probe from hitting debris on the refugia bars which could not be reached using the rake.

For comparison analyses, stationary velocity data were collected at the centerline of select screen bays at the same elevations as the moving trolley measurements (rows A, B, and C).

Hydraulic Evaluation Results

Hydraulic Parameters

River discharge in the Sacramento River during the test period from August 19-21, 2013 was recorded by the California Data Exchange Center (Station Name: Sacramento River at Bend Bridge, Station ID: BND, Figure 11). Hydraulic parameters collected from facility instrumentation during testing are shown in Table 1.

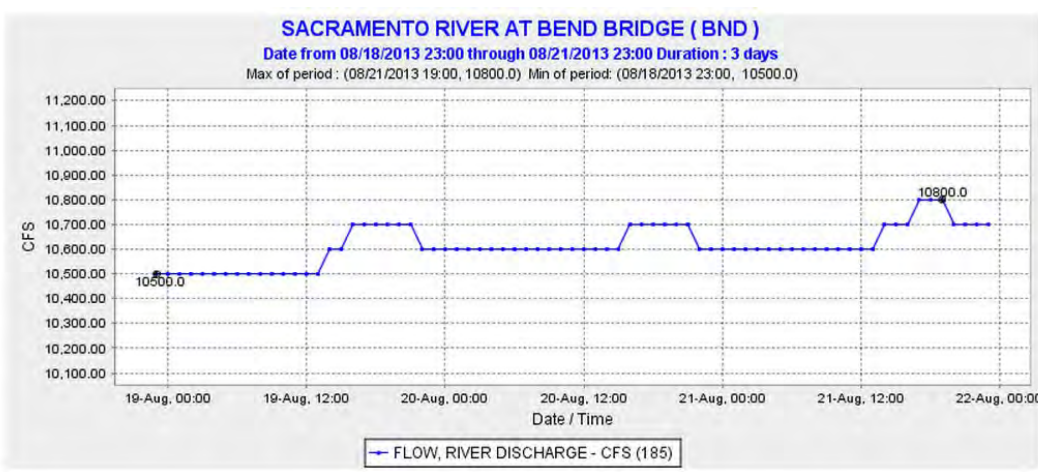


Figure 11. Sacramento River flow at Bend Bridge during hydraulic evaluation.

Table 1. Hydraulic parameters during data collection period. Note: top of effective screen is at elevation 245.65 ft.

Date	River Flow (cfs)	TCCA Pumped Diversion Rate (cfs)	River Stage (ft)	Forebay Stage (ft)	Distance from Top of Eff. Screen to Water Level (ft)
8/19/2013	10,500	1,757	244.38	244.32	1.27
8/20/2013	10,600	1,771	244.46	244.43	1.19
8/21/2013	10,600	1,761	244.39	244.25	1.26

Statistical Analyses of Velocity Data

Velocity data were collected in three ways: 1) stationary measurement, 2) instrument traversing downstream, and 3) instrument traversing upstream. Potential variations between stationary, upstream, and downstream traverse measurement methods can be attributed to several factors:

1. Relative velocity between the water and the ADV. Water velocity relative to the ADV probe is lowest during the downstream traverse because the probe was moving with the flow. Conversely, the highest relative velocity occurs during the upstream traverse because the probe was moving into the flow. Stationary measurements were collected with the actual water velocity moving past the probe. The effect of relative velocity can be removed by adding or subtracting the trolley speed from the sweeping velocity measurement depending on the trolley direction.

2. Vibration and small variances in deflection and rotational movement in the probe mount hardware between upstream and downstream travel.

3. Slight variations in probe orientation with respect to the screen face, including distance from the screen face and x-axis of the probe not being parallel to the screen face.

4. Location of data collected. Stationary data were only collected at the lateral centerline of each screen bay and traversing data were collected continuously across the screen.

5. Differing quantities of debris on the screen face or aquatic debris that may have accumulated on the probe itself.

6. Variation in wake conditions at ADV sampling location caused by direction of trolley travel (upstream or downstream).

7. Smoothness of trolley movement along its track.

Statistical analyses of ADV data were conducted for three randomly selected screen locations to determine differences between the data collection methods. Statistics were computed for sweeping (Vx), approach (Vy), and vertical (Vz) velocity components. ADV velocities in this report have the following orientation: Vx is positive in the upstream direction, Vy is positive toward the fish screen, and Vz is positive in the upward direction. Statistics reported are mean, standard error (standard deviation of the mean), standard deviation, velocity range, and the filtered data sample size. The standard error (standard deviation of the mean) is only reported for stationary measurements because it is a measure of uncertainty in repeated measurements of the same quantity (velocity) which is not the case for traversing velocity measurements.

In Table 2, upstream and downstream sweeping velocity data were adjusted to account for trolley traverse speed and direction. In general, average velocities agreed closely for stationary, upstream traverse, and downstream traverse methods. The average of the upstream and downstream traverse velocity data are also presented in Table 2.

Table 2. Summary velocity statistics for three sets of velocity data collected at different screen sections and elevations. DS = downstream and US = upstream.

SECTION 2, BAY 19 ROW B	STATIONARY*			DS TRAVERSE			US TRAVERSE			AVERAGE OF US AND DS		
STATISTICS	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*
Mean Velocity (ft/s)	-2.73	0.26	-0.07	-2.71	0.21	-0.09	-2.72	0.25	-0.18	-2.72	0.23	-0.14
Standard Error (ft/s)	0.005	0.004	0.005									
Standard Deviation (ft/s)	0.14	0.11	0.14	0.15	0.10	0.15	0.19	0.09	0.12			
Range (ft/s)	0.82	0.59	0.85	0.97	0.59	0.93	0.84	0.55	0.69			
Sample size (filtered from 1000)	905	905	905	866	866	866	894	894	894			

SECTION 3, BAY 33 ROW A	STATIONARY*			DS TRAVERSE			US TRAVERSE			AVERAGE OF US AND DS		
STATISTICS	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*
Mean Velocity (ft/s)	-2.68	0.33	-0.08	-2.84	0.30	-0.09	-2.66	0.41	-0.15	-2.75	0.36	-0.12
Standard Error (ft/s)	0.006	0.002	0.003									
Standard Deviation (ft/s)	0.18	0.07	0.09	0.15	0.08	0.08	0.14	0.08	0.12			
Range (ft/s)	0.81	0.41	0.53	0.78	0.54	0.48	0.67	0.45	0.70			
Sample size (filtered from 1000)	941	941	941	913	913	913	924	924	924			

SECTION 4, BAY 51 ROW C	STATIONARY*			DS TRAVERSE			US TRAVERSE			AVERAGE OF US AND DS		
STATISTICS	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*	*Vx*	*Vy*	*Vz*
Mean Velocity (ft/s)	-1.85	0.50	-0.02	-1.68	0.51	0.00	-2.05	0.47	-0.19	-1.87	0.49	-0.10
Standard Error (ft/s)	0.014	0.00	0.008									
Standard Deviation (ft/s)	0.42	0.20	0.26	0.27	0.19	0.25	0.40	0.16	0.25			
Range (ft/s)	2.13	1.20	1.45	1.54	1.15	1.51	1.89	1.00	1.37			
Sample size (filtered from 1000)	946	946	946	887	887	887	880	880	880			

Note: Stationary data statistics were calculated from a subsample of 1,000 measurements. Data presented in Appendix B includes statistics for all 3,000 collected measurements.

To take this analysis further, Figures 12 and 13 show a comparison of approach velocity data collected using the stationary and traversing measurement methods on screen section 3 (bays 31-45) and section 4 (bays 46-60), respectively. Approach velocities shown are the average of the 3 vertical locations (rows A, B, and C) on each bay. These figures show a difference between the upstream and downstream traverse data. This bias is likely caused by a minor rotation in the probe orientation caused by torque on the probe mount. A counter clockwise torque would result in an increase in approach velocity and a reduction in sweeping velocity. For example, for a sweeping velocity of 2.9 ft/s, a 1 degree counter clockwise rotation in the probe body caused by torque on the mount system would increase the approach velocity by 0.05 ft/s. This increase is directly related to the magnitude of the sweeping velocity.

A vector analysis for upstream and downstream trolley speed effects on approach velocity bias showed that averaging the upstream and downstream traverse data cancels any bias related to trolley speed. The averaged traverse approach velocities are graphed on Figures 12 and 13. A comparison of stationary and averaged traverse approach velocities shows an average difference of +0.03 ft/s and +0.04 ft/s for screen sections 3 and 4, respectively. It is likely that stationary approach velocities were higher than traversing approach velocities because they were measured at the midpoint of the screen panel, whereas traversing approach velocities include lower velocities near the leading and trailing edges of the screen panels. Figure 14 is a similar plot showing the close agreement of the sweeping velocities measured along Section 4.

Based on this analysis, the average of the upstream and downstream traverse data was selected for data presentation because it minimizes bias due to traverse direction and maximizes the number of velocity measurements used in the analysis. Appendix B reports all average velocity data (mean) and turbulent fluctuations (root mean square, RMS) collected with the averaged traversing and stationary measurement methods.

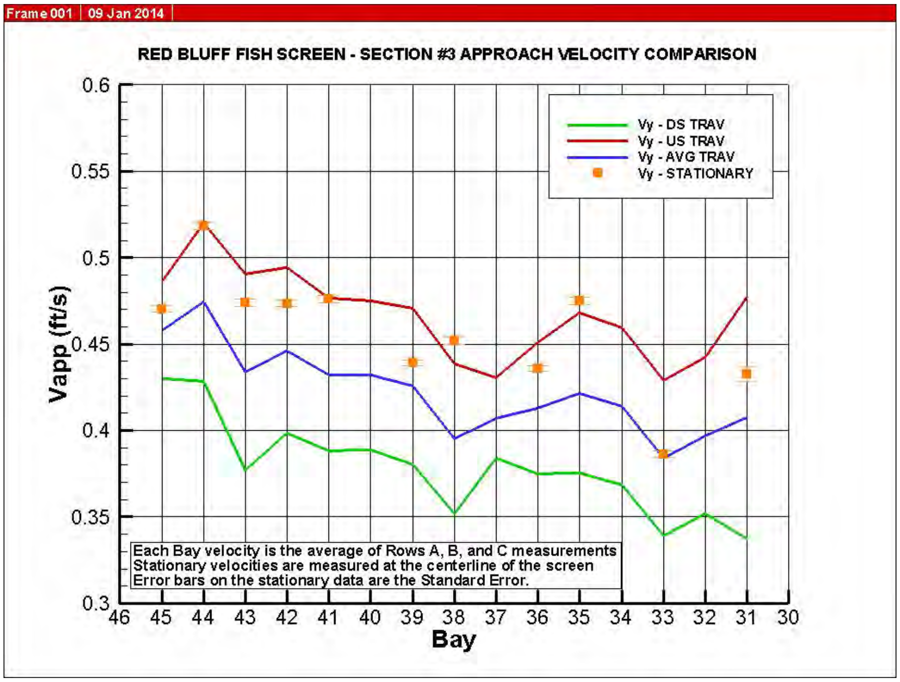


Figure 12. Plot of section 3 approach velocities demonstrating close agreement between stationary and traversing measurements. Data used for these plots are the average of measurements taken along rows A, B, and C.

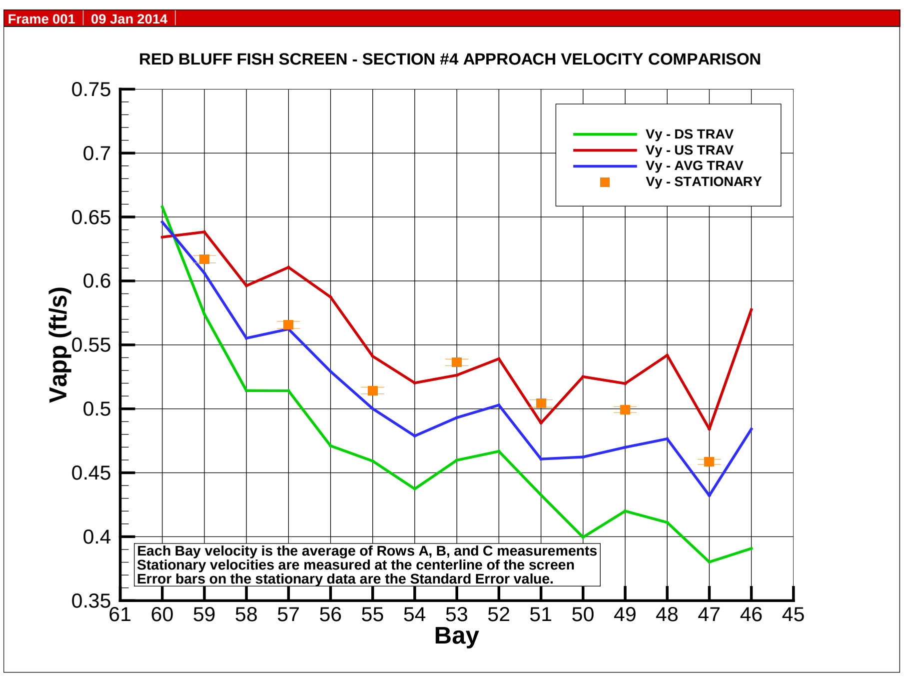


Figure 13. Plot of section 4 approach velocities demonstrating close agreement between stationary and traversing measurements. Data used for these plots are the average of measurements taken along rows A, B, and C.

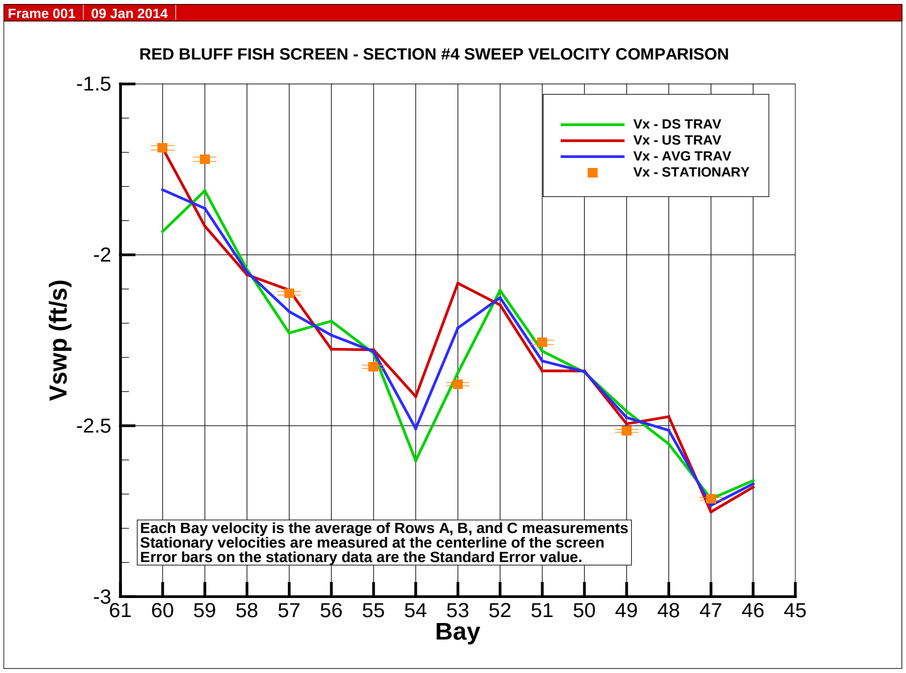


Figure 14. Plot of section 4 sweeping velocities demonstrating close agreement between stationary and traversing measurements. Data used for these plots are the average of measurements taken along row A, B, and C.

Turbulence for stationary and moving traverse measurements is not significantly different. Error bars for approach and sweeping velocities for averaged traversing data and stationary data are displayed in Table 3. Figure 15 compares the root mean square of approach velocities between averaged traversing data and stationary data in Section 3. Figure 16 compares the root mean square of sweeping velocities between averaged traversing data and stationary data in Section 3.

Table 3. Comparison of average root mean square deviations for screen section 3 and 4.

	Root Mean Square of Approach Velocity (ft/s)		Root Mean Square of Sweeping Velocity (ft/s)	
	Section 3	Section 4	Section 3	Section 4
Average of Upstream and Downstream Traverse Data	0.10	0.15	0.20	0.26
Stationary Data	0.10	0.15	0.24	0.28

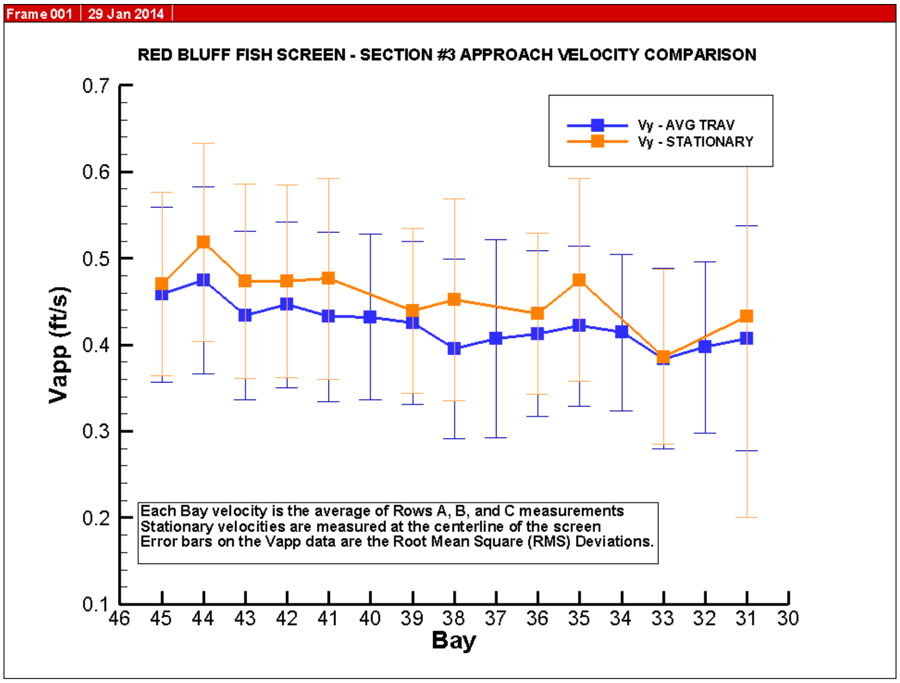


Figure 15. Comparison of approach velocities and root mean square deviations (error bars) between averaged traversing data and stationary data for screen section 3.

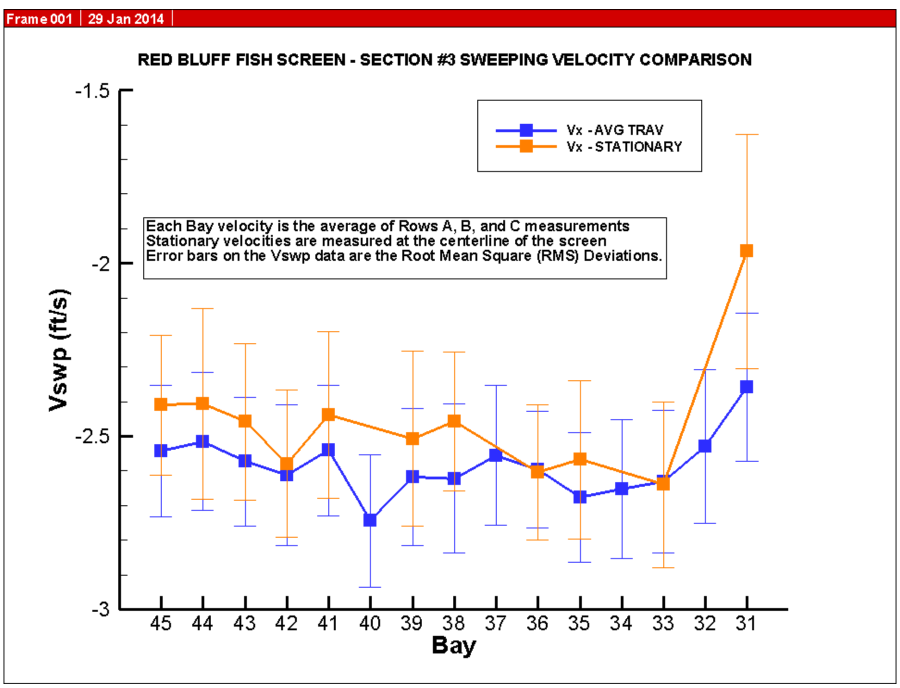


Figure 16. Comparison of sweeping velocities and root mean square deviations (error bars) between averaged traversing data and stationary data for screen section 3.

Fish Screen Velocities

Screen Section 2 (Bays 16-30)

In screen section 2, velocity data were collected by traversing in the upstream and downstream directions. Average approach velocity data are presented in Figure 17. Data labeled on the graph are averaged over the screen bay at that particular elevation. Contours extend between average velocity information. Tabular data are presented in Appendix B. Few stationary data points were measured in section 2, so stationary data are not presented in graphical or tabular form.

Approach velocities were lowest in the first few screen bays and highest in the last few screen bays. Approach velocity criteria of 0.33 ft/s was only exceeded at the bottom elevation in bays 29 and 30.

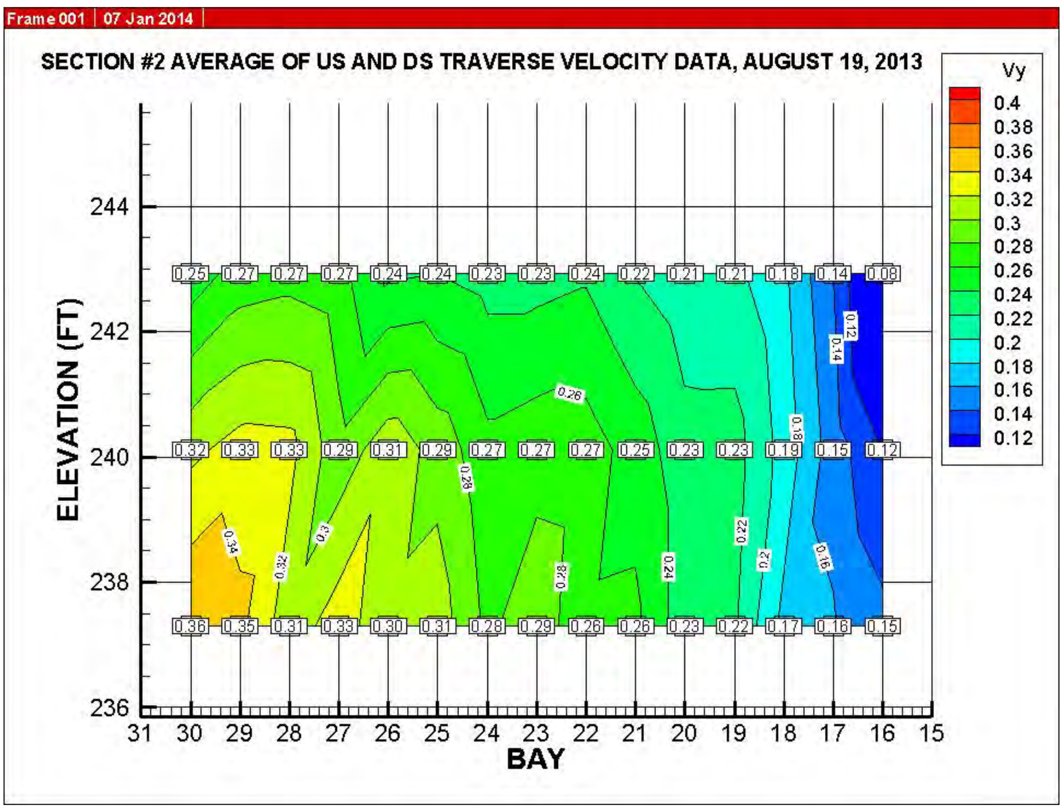


Figure 17. Isovel plot of average approach velocities (Vy, ft/s) between downstream and upstream traverses along screen section 2 (bays 16-30).

Screen Section 3 (Bays 31-45)

In screen section 3, velocity data were collected by traversing in the upstream and downstream directions. Average approach velocity data are presented in Figure 18. Data labeled on the graphs are averaged over the screen bay at that particular elevation. Contours extend between average velocity information. Stationary data points were measured at the centerline of several bays at multiple elevations in screen section 3 for comparison (Figure 19). Tabular data are presented in Appendix B.

Approach velocity criteria of 0.33 ft/s were exceeded at all locations. Approach velocities were highest in the last few screen bays of section 3. Baffle adjustments will be needed in screen section 3 to reduce approach velocities.

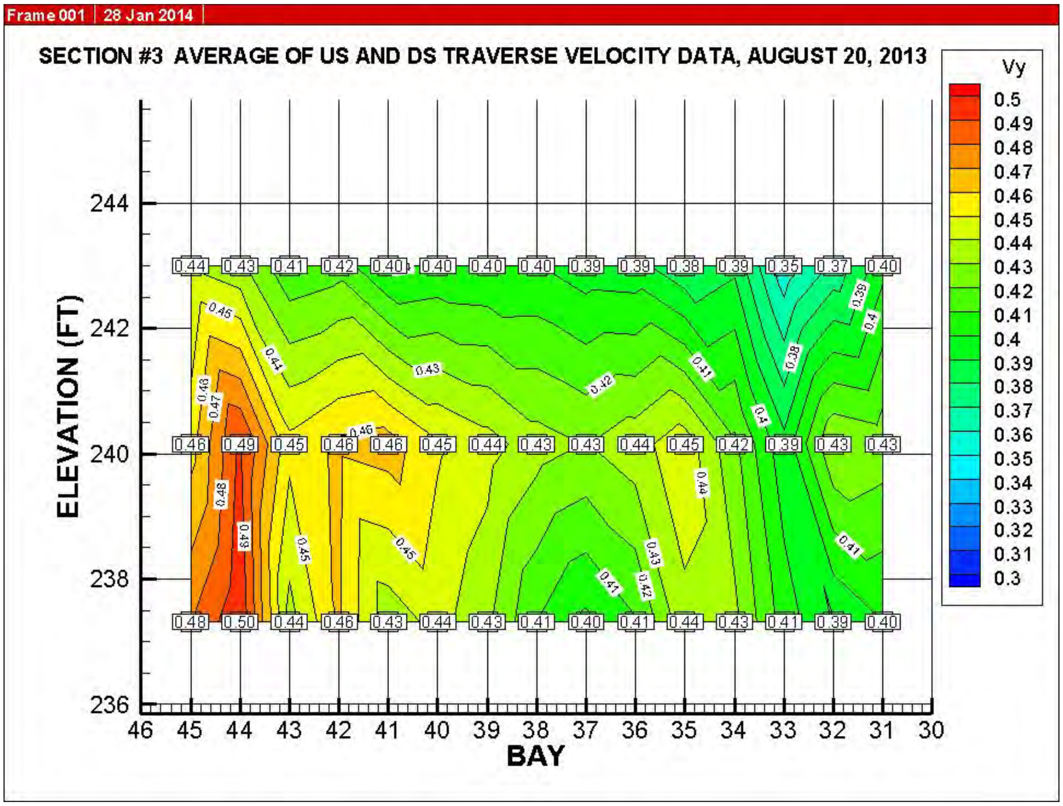


Figure 18. Isovel plot of average approach velocities (Vy, ft/s) between downstream and upstream traverses along screen section 3 (bays 31-45).

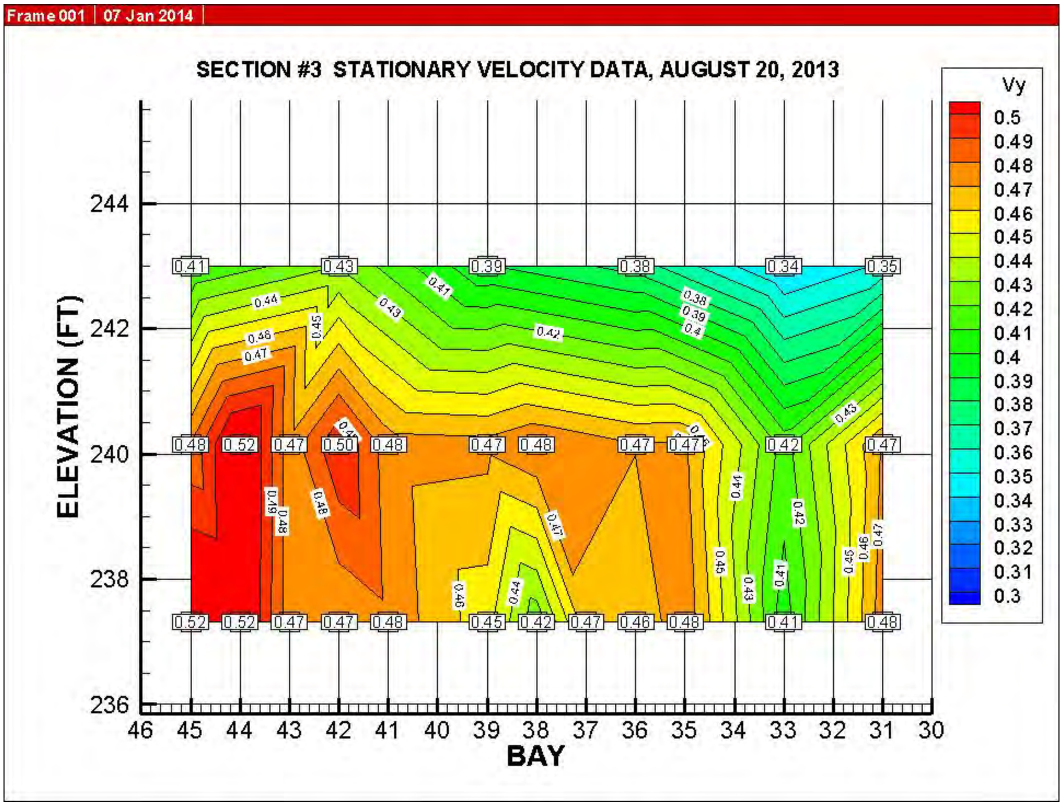


Figure 19. Isovel plot of stationary approach velocities (Vy, ft/s) collected along screen section 3 (bays 31-45).

Screen Section 4 (Bays 46-60)

In screen section 4, velocity data were collected by traversing in the upstream and downstream directions. Average approach velocity data are presented in Figure 20. Data labeled on the graphs are averaged over the screen bay at that particular elevation. Contours extend between average velocity information. Stationary data points were measured at the centerline of many bays in screen section 4 for comparison (Figure 21). Tabular data are presented in Appendix B.

Approach velocity criteria of 0.33 ft/s were exceeded at all locations. Velocities at the middle and bottom of the screen were notably higher than velocities at the top. Approach velocities were lowest in the first few screen bays and highest in the last few screen bays. Baffle adjustments will be needed in screen section 4 to reduce approach velocities.

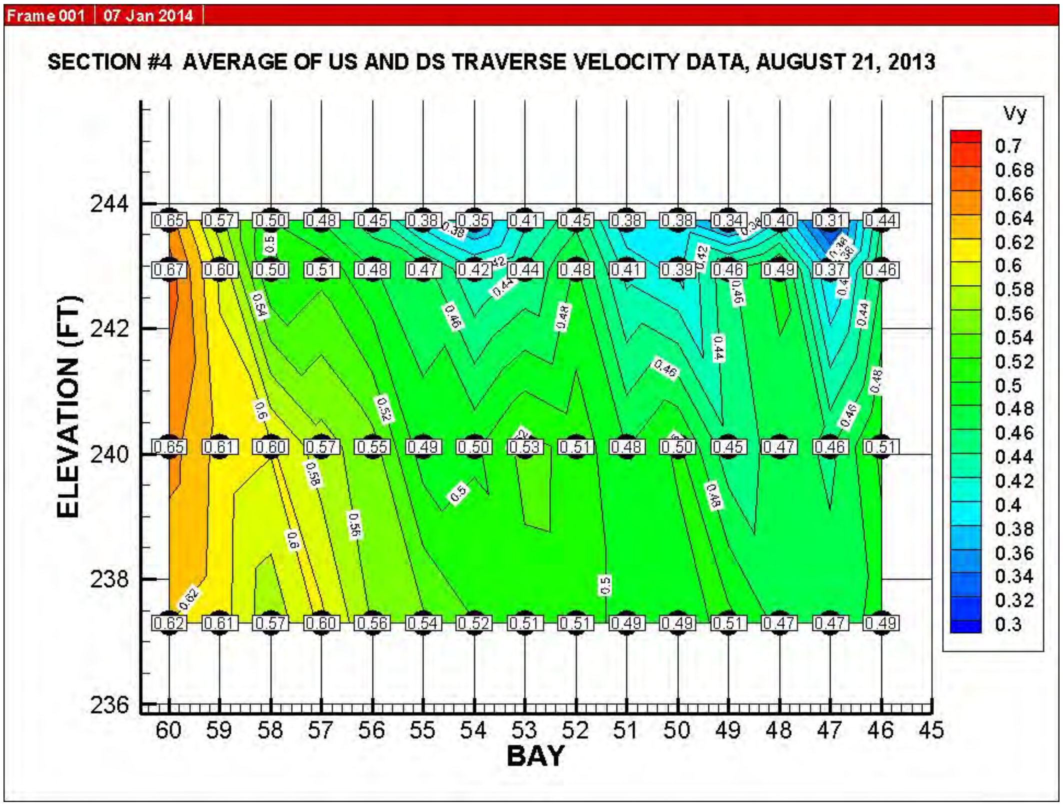


Figure 20. Isovel plot of average approach velocities (Vy, ft/s) between downstream and upstream traverses along screen section 4 (bays 46-60).

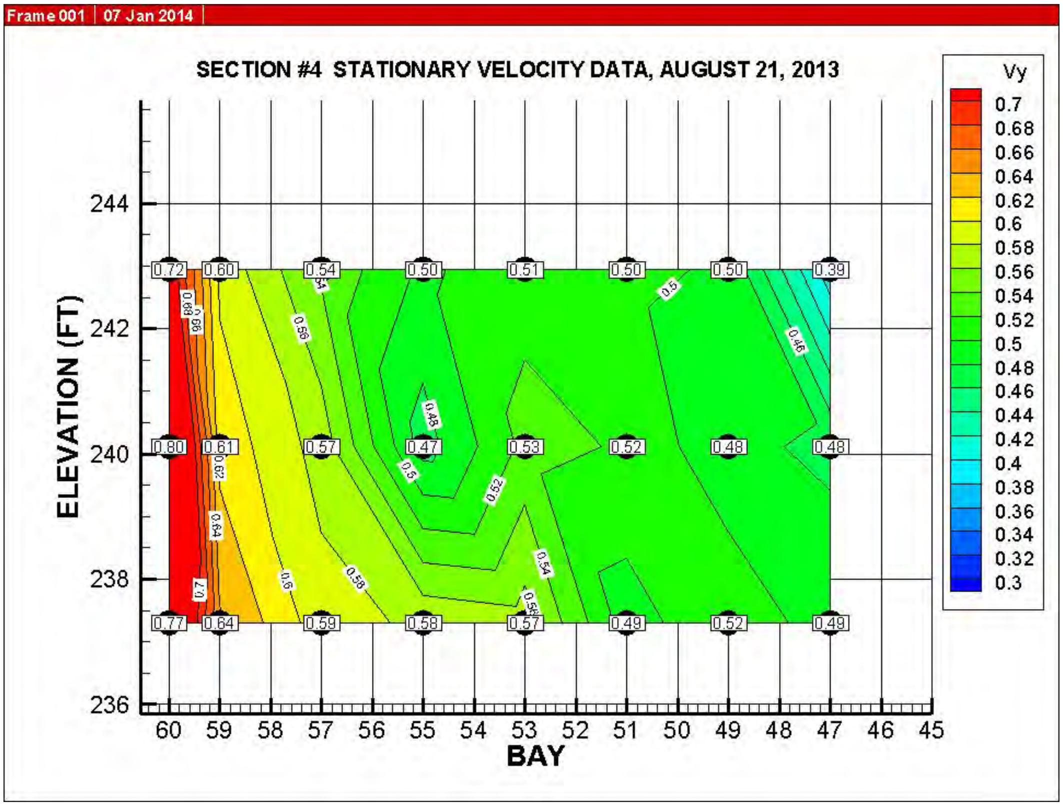


Figure 21. Isovel plot of stationary approach velocities (Vy, ft/s) collected along screen section 4 (bays 47-60).

Composite Velocity Data across All Screens

Composite isovel plots using average traverse velocity data across all screen bays are shown in Figures 22 and 23. These graphs include the locations of the screen cleaner parking area and small fish refugia panels.

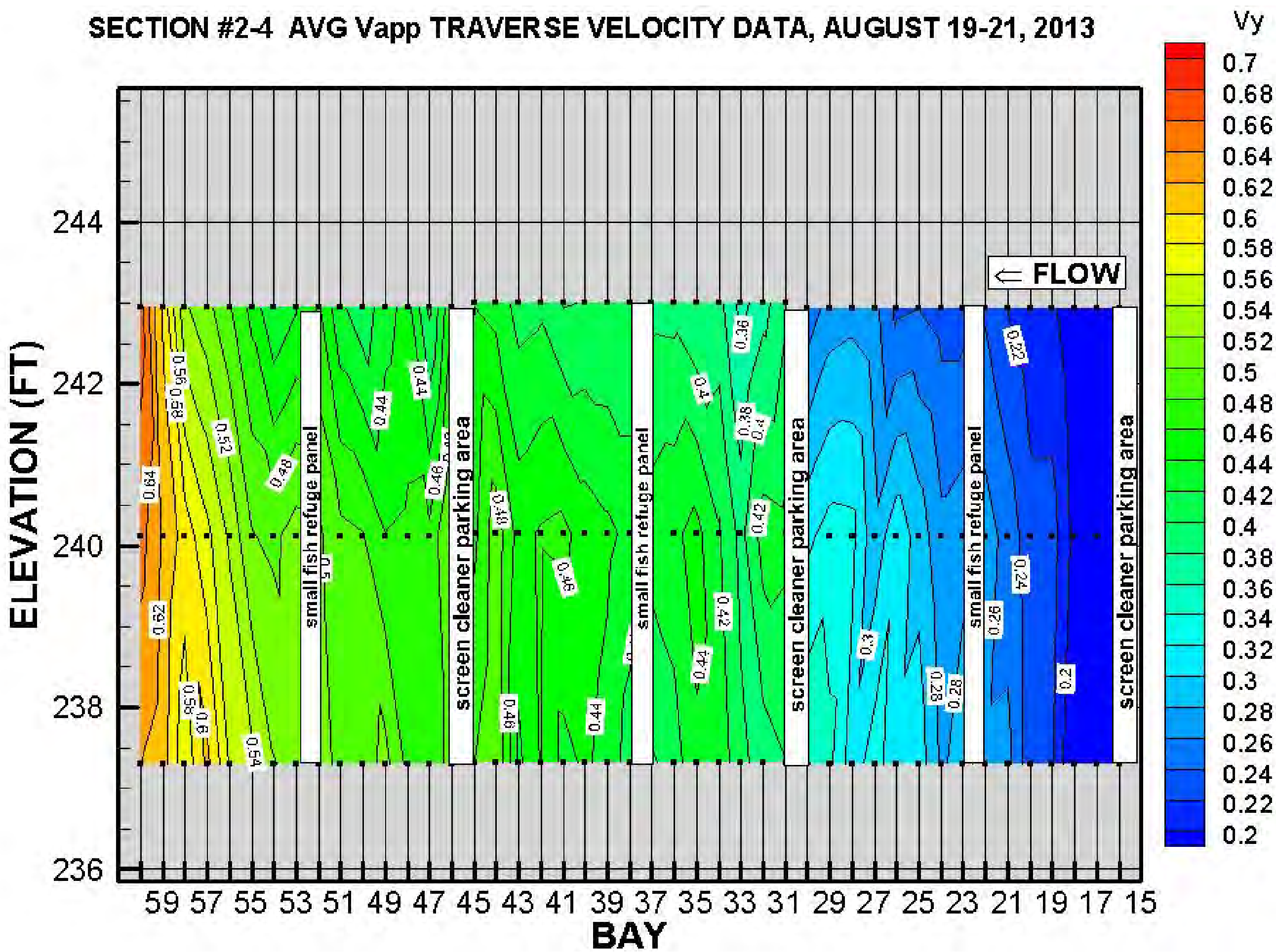


Figure 22. Composite isovel plot of approach velocities (Vy, ft/s) across Red Bluff fish screen using moving traverse method. Note: Fisheries criteria specify that approach velocities must not exceed 0.33 ft/s.

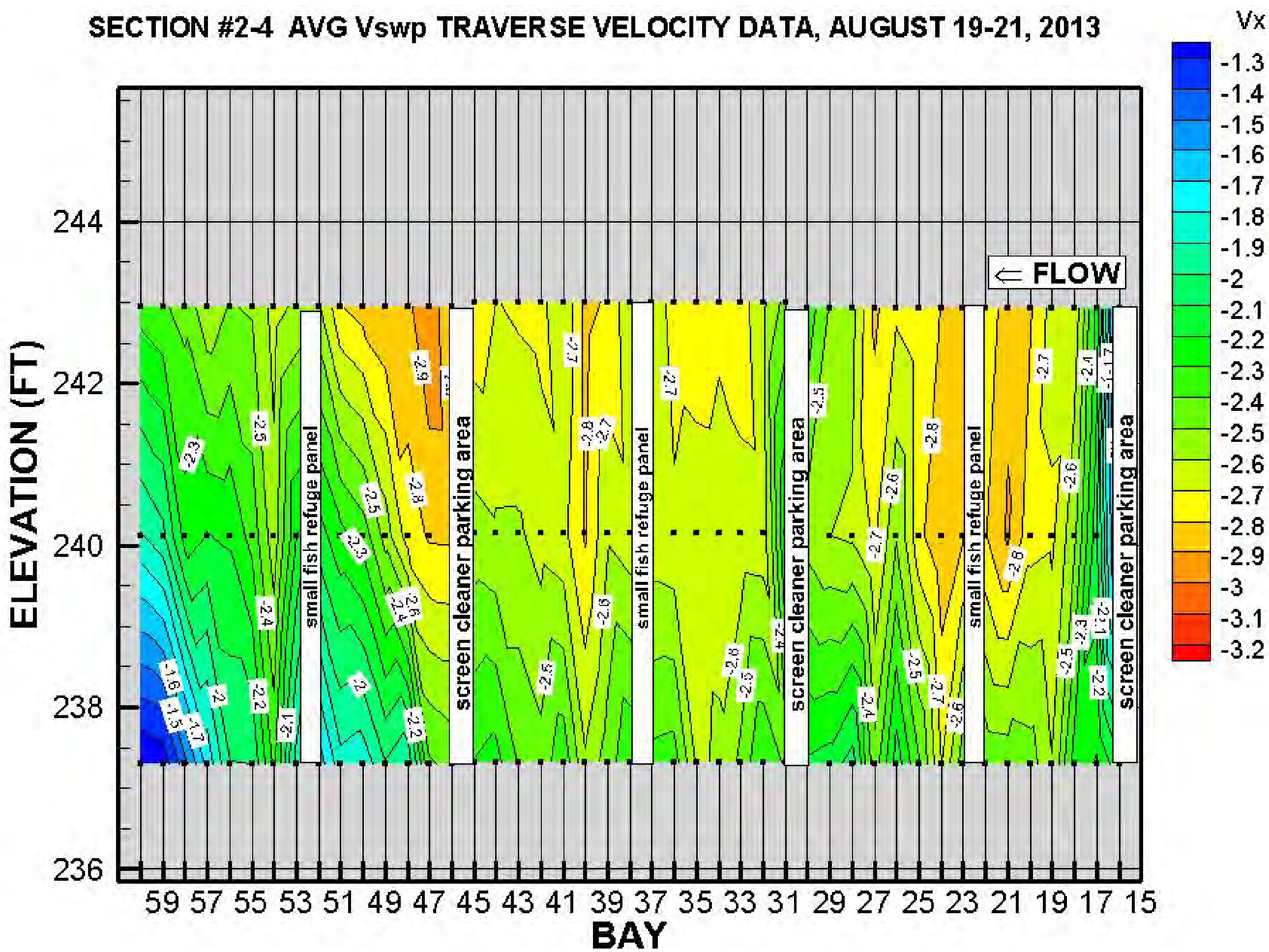


Figure 23. Composite isovel plot of sweeping velocities (Vx, ft/s) across Red Bluff fish screen using moving traverse method. Note: Fisheries criteria specify that sweeping velocity should be 2 times the approach velocity.

Table 4 compares measured moving traverse velocities in screen sections 2, 3, and 4. The table contains the average of all velocity data collected at each elevation in the screen section along with an average of velocities measured at all elevations. Table 4 shows that velocities vary with measurement depth. In all screen sections, the lowest approach velocities occurred near the water surface and the lowest sweeping velocities occurred at the deepest depth.

Table 4. Comparison of approach, sweeping, and vertical velocities collected for each screen section. Shaded data indicate exceedance of fisheries velocity criteria.

	SECTION 2 (BAYS 16-30)			SECTION 3 (BAYS 31-45)			SECTION 4 (BAYS 46-60)		
Average of Upstream and Downstream Traverses	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)
Row A	-2.58	0.22	-0.11	-2.70	0.40	-0.14	-2.65	0.48	-0.13
Row B	-2.58	0.26	-0.11	-2.62	0.44	-0.09	-2.35	0.52	-0.12
Row C	-2.34	0.27	-0.09	-2.42	0.43	-0.06	-1.86	0.53	-0.04
All Elevations	-2.50	0.25	-0.10	-2.58	0.42	-0.10	-2.29	0.51	-0.10

Approach velocities are lowest at the upstream screen bays and highest at the downstream screen bays. Approach velocity criteria are achieved at all bays in screen section 2. The average approach velocity for all elevations in screen section 2 is 0.25 ft/s. Baffles in screen sections 3 and 4 will need to be adjusted to meet federal and state fish screening criteria. The average approach velocity for all elevations in screen sections 3 and 4 is 0.42 and 0.51 ft/s, respectively.

Sweeping velocities are generally uniform across all screen bays. The lowest sweeping velocities occur at the most upstream screen, bay 16, and the most downstream screens, bays 58-60. The average sweeping velocity for all elevations in screen sections 2, 3, and 4 is -2.50, -2.58, and -2.29 ft/s, respectively. Sweeping velocities are more than 2 times the approach velocities in all bays. As a result, sweeping velocity criteria is met for screen bays 16-60.

A flow continuity check was conducted to compare the measured diversion discharge using the pumping plant flow meters and the flow rate through the screen using the measured approach velocities. During testing, the average measured diversion rate from the pumping plant flow meters was 1,763 cfs. With an average water surface elevation of 244.41 ft, the wetted area of each screen panel is 127.33 sq ft or 5,730 sq ft total for all 45 screen panels. The computed average approach velocity is 0.31 ft/s. Using the average of the upstream and downstream traverses, the average measured approach velocity is 0.39 ft/s which is 26% higher than the computed value.

This discrepancy may be attributed to several factors. There may have been slight changes in probe orientation (x-y plane rotation) after the velocity probe was submerged. A small rotation in probe orientation from torque on the probe arm can make a significant difference in measured velocities. For example, for a sweeping velocity of 2.7 ft/s, a 1.5 degree counterclockwise rotation in the probe body caused by torque on the mount system would increase the approach velocity by 0.08 ft/s which is the difference between measured and expected approach velocities.

Furthermore, velocity data near the screen edges were excluded to minimize error from hydraulic influence of the piers. Excluding the near-pier velocity data is consistent with the 9 test point locations recommended in the Hydraulic Evaluation Plan (CH2MHILL, 2011). Since the edge data were lower, the average approach velocity data on the screen would be lower than reported.

Lastly, approach velocities measured along Row A and near the water surface (see Appendix B, Table 8) were lower than those measured along Rows B and C. As a result, it is probable that sampling only 3 rows will produce a higher average approach velocity than the calculated value.

Conclusions

The following conclusions are drawn from the hydraulic field evaluation:

- Approach velocity data measured in screen section 2 do not exceed federal and state fish screening criteria of 0.33 ft/s.

- Approach velocity data measured in screen sections 3 and 4 exceed federal and state fish screening criteria of 0.33 ft/s.

- Baffles need to be adjusted in sections 2, 3, and 4 to modify approach velocities and improve uniformity across the screen face. It is recommended that guidance from the Red Bluff fish screen physical hydraulic model report (Vermeyen, 2013) be considered when selecting battle settings. Physical model results indicated that baffling bays 1-30 to 5% open and bays 31-60 to 7.5% open will provide the most uniform approach velocities within federal and state criteria.

- Sweeping velocities at the screen face are generally uniform. Sweeping velocities are more than 2 times the approach velocities at all locations, thereby meeting fisheries criteria.

- Approach velocities are lower at the top of the screen and higher near the bottom of the screen. Sweeping velocities are lowest at the bottom of the screen and highest at the top of the screen.

- A flow continuity check showed that measured approach velocities are 26% higher than anticipated based on calculating the average through-screen velocity from the canal flow meter reading.

References

California Department of Fish and Wildlife (no date). “Fish Screening Criteria”. Retrieved January 2014 from http://www.dfg.ca.gov/fish/Resources/Projects/Engin/Engin_ScreenCriteria.asp

CH2MHILL (2011). Post-construction Fish Screen Hydraulic Evaluation Plan – Tehama Colusa Canal Authority Fish Passage Improvement Project at the Red Bluff Diversion Dam.

National Marine Fisheries Service (2009). Biological Opinion for the Central Valley Project

National Marine Fisheries Service Southwest Region (1997). Fish Screening Criteria for Anadromous Salmonids.

Vermeyen, Tracy. 2013. Tehama-Colusa Canal Authority (TCCA) - Red Bluff Pumping Plant and Fish Screen Hydraulic Evaluation – *Velocity Measurement Interference Testing.*

APPENDIX A

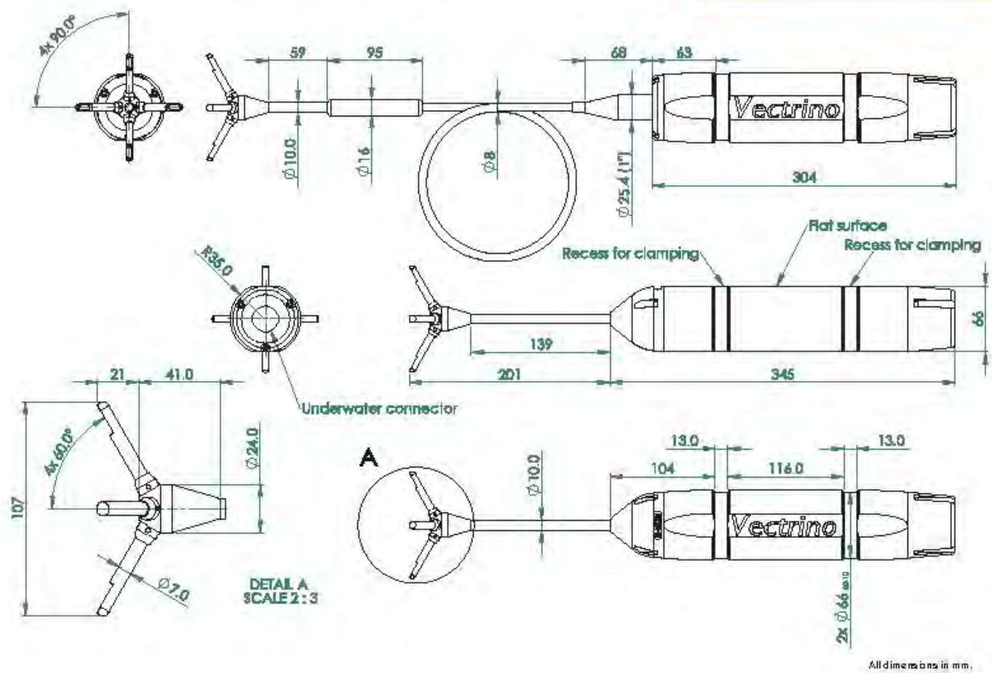
Nortek Vectrino Field Probe Specifications[1]

[1] Specifications were taken from website: http://www.nortek.no/lib/data-sheets/datasheet-vectrino-fieldprobe

The Vectrino is a high-resolution acoustic velocimeter used to measure 3D water velocity in a wide variety of applications from the laboratory to the ocean in order to study rapid velocity fluctuations. The basis measurement technology is coherent Doppler processing, which is characterized by accurate data with no appreciable zero offset.

Vectrino

Field Probe



Technical Specifications

Water Velocity Measurements	
Range:	±0.01, 0.1, 0.3, 1, 2, 4 m/s*) (user selectable)
Accuracy:	±0.5% of measured value ±1 mm/s
Sampling rate (output):	1–25 Hz (standard firmware), 1–200 Hz (plus firmware)

*) The velocity range is not the same in the horizontal and vertical direction. Please refer to the configuration software.

Sampling Volume	
Distance from probe:	0.1 m
Diameter:	6 mm
Height (user selectable):	3–15 mm

Echo Intensity	
Acoustic frequency:	10 MHz
Resolution:	Linear scale
Dynamic range:	25 dB

Sensors	
Temperature:	Thermistor embedded in probe
Range:	–4°C to 40°C
Accuracy/Resolution:	1°C/0.1°C
Time response:	5 min

Data Communication	
I/O:	RS 232. The software supports most commercially available USB–RS 232 converters.
Communication Baud rate:	300–115 200 baud
User control:	Handled via Vectrino Win32® software, ActiveX® function calls, or direct commands.
Analog outputs:	3 channels standard, one for each velocity component.
Output range:	0–5 V, scaling is user selectable.
Synchronization:	SynchIn and SynchOut

Multi Unit Operation	
Software:	Polysync
I/O:	RS 232–USB support for devices with 1, 2, 4, and 8 serial ports.

Software ("Vectrino")	
Operating system:	Windows® XP, Windows® 7
Functions:	Instrument configuration, data collection, data storage. Probe test modes.

Power	
DC Input:	12–48 VDC
Peak current:	2.5 A at 12 VDC (user selectable)
Max. consumption:	200 Hz 1.5 W

Connectors	
Bulkhead:	MCBH-12-FS, bronze (Impulse)
Cable:	PMCIL-12-MP – see also options below.

Materials	
Standard model:	Delrin® housing, Stainles steel (316) probe and screws.

Environmental	
Operating temperature:	–4°C to 40°C
Storage temperature:	–15°C to 60°C
Shock and vibration:	IEC 721-3-2

Dimensions	
See drawing on front page	
Weight in air:	1.3 kg
Weight in water:	0.1 kg

Options

- Standard or Vectrino Plus firmware
- Fixed stem or flexible cable
- 10, 20, 30 or 50 m cable with Impulse underwater connector
- RS 232–USB converter (one-to-one, four-to-one or eight-to-one)
- Combined transportation and storage case

The Vectrino consists of two basic elements: the probe attached to a cylindrical housing and the processor inside the housing. From here the processed data is sent over a serial line or analog signals can be sent to an A/D converter.

TS-081-en-052013

APPENDIX B

Measured Fish Screen Velocity Data

Table 5. Velocity data in screen section 2 (bays 16-30) at 3 elevations using moving traverse method. Reported velocities are the average of upstream and downstream traverse data over the measured screen width.

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
16	A	242.93	-1.335	0.076	-0.035	1.340	1.426	0.487	0.303	0.333
16	B	240.12	-1.454	0.119	0.108	1.463	1.557	0.561	0.306	0.343
16	C	237.30	-2.117	0.146	-0.044	2.124	2.147	0.330	0.199	0.231
17	A	242.93	-2.261	0.140	-0.029	2.266	2.283	0.264	0.177	0.207
17	B	240.12	-2.123	0.150	-0.029	2.129	2.143	0.223	0.155	0.191
17	C	237.30	-2.308	0.162	-0.093	2.315	2.326	0.209	0.134	0.172
18	A	242.93	-2.667	0.184	-0.073	2.674	2.680	0.173	0.106	0.132
18	B	240.12	-2.526	0.192	-0.086	2.535	2.543	0.201	0.116	0.161
18	C	237.30	-2.258	0.174	-0.078	2.268	2.277	0.217	0.126	0.148
19	A	242.93	-2.658	0.205	-0.106	2.669	2.672	0.179	0.086	0.088
19	B	240.12	-2.718	0.228	-0.135	2.732	2.737	0.172	0.095	0.138
19	C	237.30	-2.594	0.222	-0.116	2.606	2.611	0.163	0.101	0.121
20	A	242.93	-2.808	0.206	-0.073	2.817	2.820	0.157	0.079	0.103
20	B	240.12	-2.739	0.228	-0.125	2.752	2.756	0.136	0.083	0.108
20	C	237.30	-2.457	0.228	-0.119	2.470	2.476	0.200	0.099	0.134
21	A	242.93	-2.862	0.219	-0.153	2.875	2.877	0.122	0.077	0.088
21	B	240.12	-2.917	0.252	-0.186	2.934	2.938	0.223	0.088	0.123
21	C	237.30	-2.440	0.264	-0.079	2.457	2.466	0.257	0.112	0.178
22	A	242.93	-2.728	0.237	-0.160	2.743	2.748	0.281	0.101	0.119
22	B	240.12	-2.790	0.269	-0.139	2.806	2.809	0.171	0.090	0.096
22	C	237.30	-2.429	0.263	-0.104	2.446	2.455	0.245	0.133	0.165
23	A	242.93	-2.871	0.232	-0.139	2.884	2.889	0.199	0.102	0.134
23	B	240.12	-2.804	0.272	-0.183	2.823	2.829	0.192	0.104	0.146
23	C	237.30	-2.450	0.293	-0.142	2.473	2.483	0.297	0.133	0.171
24	A	242.93	-2.804	0.232	-0.175	2.819	2.822	0.181	0.083	0.093
24	B	240.12	-2.875	0.266	-0.178	2.893	2.896	0.193	0.083	0.094
24	C	237.30	-2.703	0.276	-0.207	2.725	2.731	0.197	0.103	0.144
25	A	242.93	-2.757	0.240	-0.145	2.772	2.775	0.178	0.078	0.100
25	B	240.12	-2.773	0.293	-0.164	2.794	2.798	0.179	0.080	0.109

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
25	C	237.30	-2.388	0.310	-0.131	2.412	2.419	0.254	0.117	0.153
26	A	242.93	-2.717	0.236	-0.134	2.730	2.734	0.142	0.081	0.116
26	B	240.12	-2.510	0.313	-0.112	2.532	2.538	0.232	0.097	0.142
26	C	237.30	-2.143	0.305	-0.026	2.166	2.176	0.224	0.115	0.161
27	A	242.93	-2.821	0.266	-0.106	2.836	2.839	0.151	0.083	0.100
27	B	240.12	-2.720	0.287	-0.119	2.738	2.743	0.282	0.092	0.130
27	C	237.30	-2.462	0.331	-0.099	2.487	2.498	0.264	0.134	0.182
28	A	242.93	-2.565	0.273	-0.118	2.582	2.585	0.139	0.077	0.095
28	B	240.12	-2.614	0.327	-0.132	2.638	2.643	0.249	0.102	0.132
28	C	237.30	-2.055	0.307	-0.019	2.078	2.088	0.290	0.116	0.160
29	A	242.93	-2.518	0.269	-0.082	2.534	2.538	0.223	0.081	0.115
29	B	240.12	-2.599	0.328	-0.106	2.622	2.627	0.172	0.091	0.129
29	C	237.30	-2.161	0.345	-0.015	2.188	2.196	0.178	0.117	0.140
30	A	242.93	-2.335	0.248	-0.068	2.349	2.353	0.246	0.076	0.092
30	B	240.12	-2.539	0.315	-0.073	2.559	2.568	0.224	0.133	0.158
30	C	237.30	-2.184	0.361	-0.028	2.214	2.223	0.248	0.131	0.146

Table 6. Velocity data in screen section 3 (bays 31-45) at 3 elevations using moving traverse method. Reported velocities are the average of upstream and downstream traverse data over the measured screen width.

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
31	A	243.00	-2.460	0.397	-0.097	2.496	2.503	0.176	0.112	0.143
31	B	240.16	-2.188	0.426	0.007	2.230	2.241	0.269	0.148	0.167
31	C	237.31	-2.423	0.400	-0.064	2.458	2.464	0.198	0.130	0.124
32	A	243.00	-2.615	0.372	-0.124	2.645	2.649	0.178	0.078	0.121
32	B	240.16	-2.670	0.430	-0.102	2.707	2.713	0.241	0.103	0.152
32	C	237.31	-2.306	0.389	-0.027	2.339	2.348	0.247	0.117	0.164
33	A	243.00	-2.754	0.353	-0.116	2.780	2.783	0.147	0.080	0.101
33	B	240.16	-2.661	0.393	-0.089	2.692	2.698	0.202	0.105	0.152
33	C	237.31	-2.477	0.406	-0.105	2.513	2.523	0.273	0.128	0.177
34	A	243.00	-2.727	0.388	-0.169	2.760	2.763	0.174	0.078	0.109
34	B	240.16	-2.645	0.422	-0.110	2.682	2.686	0.201	0.084	0.128
34	C	237.31	-2.583	0.432	-0.091	2.621	2.630	0.227	0.109	0.187
35	A	243.00	-2.767	0.382	-0.161	2.799	2.801	0.167	0.074	0.093
35	B	240.16	-2.639	0.446	-0.122	2.680	2.684	0.139	0.096	0.123
35	C	237.31	-2.623	0.438	-0.104	2.662	2.668	0.258	0.109	0.137
36	A	243.00	-2.750	0.393	-0.158	2.782	2.785	0.197	0.075	0.101
36	B	240.16	-2.679	0.436	-0.113	2.717	2.722	0.140	0.091	0.138
36	C	237.31	-2.359	0.409	-0.069	2.396	2.402	0.167	0.122	0.131
37	A	243.00	-2.630	0.394	-0.134	2.664	2.668	0.141	0.091	0.113
37	B	240.16	-2.665	0.430	-0.105	2.702	2.707	0.173	0.112	0.124
37	C	237.31	-2.371	0.398	-0.038	2.404	2.414	0.294	0.141	0.157
38	A	243.00	-2.624	0.400	-0.166	2.660	2.664	0.182	0.089	0.119
38	B	240.16	-2.662	0.434	-0.076	2.698	2.704	0.239	0.101	0.136
38	C	237.31	-2.314	0.410	-0.068	2.352	2.361	0.215	0.111	0.166
39	A	243.00	-2.787	0.400	-0.128	2.819	2.823	0.178	0.077	0.128
39	B	240.16	-2.617	0.444	-0.094	2.657	2.662	0.204	0.092	0.139
39	C	237.31	-2.449	0.432	-0.088	2.489	2.497	0.210	0.113	0.160
40	A	243.00	-2.830	0.401	-0.097	2.861	2.863	0.191	0.079	0.099
40	B	240.16	-2.815	0.452	-0.097	2.853	2.857	0.155	0.087	0.120

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
40	C	237.31	-2.586	0.444	-0.065	2.625	2.633	0.228	0.122	0.145
41	A	243.00	-2.618	0.399	-0.104	2.651	2.655	0.147	0.071	0.114
41	B	240.16	-2.673	0.465	-0.111	2.717	2.722	0.175	0.096	0.132
41	C	237.31	-2.332	0.434	-0.041	2.374	2.382	0.246	0.128	0.146
42	A	243.00	-2.732	0.416	-0.132	2.768	2.771	0.155	0.080	0.106
42	B	240.16	-2.642	0.462	-0.088	2.684	2.688	0.192	0.086	0.100
42	C	237.31	-2.464	0.461	-0.037	2.508	2.515	0.264	0.120	0.149
43	A	243.00	-2.717	0.412	-0.099	2.751	2.755	0.177	0.077	0.124
43	B	240.16	-2.587	0.453	-0.069	2.628	2.633	0.141	0.091	0.128
43	C	237.31	-2.413	0.436	-0.052	2.454	2.464	0.241	0.125	0.173
44	A	243.00	-2.697	0.432	-0.173	2.738	2.742	0.166	0.093	0.127
44	B	240.16	-2.588	0.492	-0.109	2.637	2.642	0.229	0.099	0.135
44	C	237.31	-2.261	0.498	-0.041	2.316	2.325	0.203	0.132	0.158
45	A	243.00	-2.772	0.439	-0.163	2.812	2.817	0.150	0.102	0.139
45	B	240.16	-2.562	0.456	-0.095	2.604	2.610	0.186	0.088	0.145
45	C	237.31	-2.294	0.479	-0.069	2.345	2.354	0.234	0.114	0.148

Table 7. Velocity data for screen section 3 (bays 31-45) at 3 elevations using stationary measurement method. Velocity data were collected at the centerline of the screen.

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
31	A	243.00	-1.051	0.352	0.105	1.113	1.262	0.507	0.425	0.402
31	B	240.16	-2.409	0.471	-0.061	2.456	2.465	0.279	0.137	0.164
31	C	237.31	-2.437	0.475	-0.036	2.483	2.491	0.231	0.134	0.145
33	A	243.00	-2.818	0.338	-0.068	2.839	2.842	0.212	0.069	0.111
33	B	240.16	-2.742	0.416	-0.121	2.776	2.781	0.182	0.100	0.136
33	C	237.31	-2.359	0.405	-0.030	2.394	2.407	0.322	0.134	0.207
35	B	240.16	-2.684	0.472	-0.099	2.727	2.732	0.223	0.098	0.132
35	C	237.31	-2.451	0.478	-0.076	2.498	2.507	0.236	0.138	0.156
36	A	243.00	-2.723	0.376	-0.082	2.750	2.754	0.211	0.074	0.115
36	B	240.16	-2.604	0.471	-0.082	2.647	2.652	0.178	0.098	0.134
36	C	237.31	-2.483	0.461	-0.113	2.528	2.534	0.197	0.108	0.146
37	C	237.31	-2.353	0.466	-0.058	2.399	2.409	0.253	0.119	0.164
38	B	240.16	-2.695	0.481	-0.072	2.739	2.744	0.203	0.101	0.137
38	C	237.31	-2.217	0.423	0.015	2.257	2.267	0.198	0.133	0.170
39	A	243.00	-2.630	0.391	-0.074	2.659	2.663	0.265	0.069	0.114
39	B	240.16	-2.602	0.473	-0.055	2.645	2.652	0.288	0.103	0.158
39	C	237.31	-2.288	0.454	-0.046	2.333	2.341	0.203	0.114	0.147
41	B	240.16	-2.620	0.475	-0.072	2.664	2.670	0.239	0.103	0.153
41	C	237.31	-2.256	0.477	0.030	2.306	2.317	0.244	0.128	0.182
42	A	243.00	-2.794	0.430	-0.097	2.828	2.832	0.157	0.077	0.123
42	B	240.16	-2.729	0.499	-0.077	2.775	2.781	0.168	0.102	0.149
42	C	237.31	-2.429	0.470	-0.065	2.475	2.483	0.220	0.122	0.158
43	B	240.16	-2.632	0.474	-0.090	2.676	2.680	0.165	0.093	0.122
43	C	237.31	-2.283	0.474	-0.005	2.331	2.341	0.287	0.132	0.163
44	B	240.16	-2.588	0.520	-0.076	2.640	2.645	0.209	0.099	0.120
44	C	237.31	-2.225	0.517	-0.041	2.285	2.298	0.343	0.131	0.190
45	A	243.00	-2.560	0.409	-0.118	2.595	2.599	0.169	0.081	0.113
45	B	240.16	-2.462	0.481	-0.051	2.509	2.516	0.177	0.103	0.150
45	C	237.31	-2.208	0.521	-0.047	2.269	2.279	0.258	0.134	0.158

Table 8. Velocity data in screen section 4 (bays 46-60) at 3 elevations using moving traverse method. Reported velocities are the average of upstream and downstream traverse data over the measured screen width. WS = near water surface measurement.

Bay #	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
46	WS	243.73	-2.615	0.441	-0.001	2.654	2.664	0.289	0.179	0.138
46	A	242.94	-2.768	0.459	-0.035	2.807	2.818	0.232	0.165	0.172
46	B	240.12	-2.817	0.505	-0.012	2.863	2.869	0.185	0.130	0.118
46	C	237.30	-2.426	0.488	0.037	2.477	2.492	0.354	0.144	0.199
47	WS	243.73	-2.899	0.309	-0.076	2.917	2.921	0.138	0.121	0.087
47	A	242.94	-2.997	0.374	-0.099	3.022	3.027	0.160	0.113	0.117
47	B	240.12	-2.814	0.457	-0.161	2.856	2.860	0.185	0.088	0.098
47	C	237.30	-2.388	0.466	-0.063	2.435	2.449	0.284	0.151	0.200
48	WS	243.73	-2.583	0.400	-0.085	2.615	2.620	0.149	0.116	0.111
48	A	242.94	-2.873	0.487	-0.103	2.916	2.919	0.143	0.094	0.104
48	B	240.12	-2.752	0.469	-0.145	2.798	2.804	0.202	0.119	0.138
48	C	237.30	-1.916	0.474	-0.064	1.975	1.998	0.260	0.195	0.221
49	WS	243.73	-2.824	0.343	-0.112	2.847	2.851	0.165	0.123	0.078
49	A	242.94	-2.896	0.457	-0.140	2.935	2.939	0.162	0.090	0.111
49	B	240.12	-2.541	0.446	-0.152	2.586	2.595	0.206	0.149	0.147
49	C	237.30	-1.992	0.507	-0.101	2.058	2.086	0.410	0.203	0.255
50	WS	243.73	-2.729	0.382	-0.120	2.758	2.763	0.226	0.124	0.104
50	A	242.94	-2.843	0.394	-0.160	2.876	2.881	0.181	0.122	0.120
50	B	240.12	-2.345	0.504	-0.137	2.403	2.417	0.332	0.153	0.207
50	C	237.30	-1.837	0.489	-0.049	1.904	1.936	0.353	0.194	0.280
51	WS	243.73	-2.745	0.384	-0.098	2.773	2.781	0.230	0.137	0.150
51	A	242.94	-2.794	0.413	-0.149	2.829	2.835	0.187	0.126	0.124
51	B	240.12	-2.270	0.479	-0.180	2.329	2.344	0.364	0.145	0.203
51	C	237.30	-1.868	0.490	-0.095	1.936	1.962	0.336	0.177	0.247
52	WS	243.73	-2.618	0.454	-0.096	2.659	2.667	0.284	0.134	0.132
52	A	242.94	-2.580	0.483	-0.142	2.629	2.636	0.276	0.138	0.123
52	B	240.12	-2.152	0.513	-0.122	2.217	2.232	0.234	0.158	0.212
52	C	237.30	-1.645	0.513	-0.056	1.725	1.755	0.327	0.189	0.233

Bay #	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
53	WS	243.73	-2.521	0.415	-0.039	2.556	2.563	0.198	0.132	0.142
53	A	242.94	-2.576	0.441	-0.117	2.616	2.623	0.265	0.126	0.138
53	B	240.12	-2.198	0.527	-0.066	2.263	2.284	0.232	0.170	0.253
53	C	237.30	-1.868	0.512	-0.006	1.940	1.961	0.229	0.164	0.228
54	WS	243.73	-2.653	0.355	-0.080	2.678	2.685	0.182	0.133	0.132
54	A	242.94	-2.639	0.420	-0.168	2.678	2.686	0.188	0.133	0.165
54	B	240.12	-2.561	0.496	-0.140	2.613	2.623	0.215	0.134	0.181
54	C	237.30	-2.325	0.521	-0.168	2.391	2.405	0.295	0.145	0.196
55	WS	243.73	-2.569	0.385	-0.037	2.598	2.605	0.175	0.134	0.140
55	A	242.94	-2.510	0.468	-0.128	2.557	2.563	0.158	0.113	0.132
55	B	240.12	-2.338	0.488	-0.133	2.393	2.406	0.234	0.143	0.199
55	C	237.30	-2.000	0.544	-0.080	2.075	2.093	0.279	0.143	0.211
56	WS	243.73	-2.577	0.449	-0.058	2.616	2.621	0.157	0.116	0.107
56	A	242.94	-2.493	0.481	-0.143	2.544	2.550	0.192	0.110	0.124
56	B	240.12	-2.215	0.548	-0.079	2.284	2.297	0.226	0.140	0.184
56	C	237.30	-1.997	0.559	-0.096	2.077	2.091	0.246	0.133	0.196
57	WS	243.73	-2.345	0.478	-0.058	2.394	2.400	0.201	0.127	0.119
57	A	242.94	-2.573	0.514	-0.101	2.626	2.633	0.178	0.123	0.145
57	B	240.12	-2.197	0.569	-0.121	2.273	2.288	0.214	0.151	0.199
57	C	237.30	-1.728	0.605	-0.054	1.835	1.867	0.334	0.182	0.263
58	WS	243.73	-2.477	0.499	-0.085	2.529	2.535	0.216	0.124	0.128
58	A	242.94	-2.431	0.498	-0.154	2.487	2.494	0.168	0.132	0.141
58	B	240.12	-2.251	0.602	-0.126	2.334	2.353	0.292	0.168	0.235
58	C	237.30	-1.468	0.566	0.035	1.575	1.614	0.347	0.207	0.266
59	WS	243.73	-2.137	0.568	-0.065	2.212	2.230	0.284	0.149	0.173
59	A	242.94	-2.390	0.596	-0.123	2.466	2.477	0.181	0.142	0.173
59	B	240.12	-1.969	0.613	-0.078	2.066	2.089	0.302	0.177	0.244
59	C	237.30	-1.234	0.610	0.004	1.379	1.429	0.385	0.178	0.242
60	WS	243.73	-2.114	0.650	-0.097	2.213	2.227	0.254	0.177	0.142
60	A	242.94	-2.341	0.670	-0.166	2.441	2.461	0.324	0.191	0.210
60	B	240.12	-1.889	0.648	-0.083	1.999	2.029	0.319	0.231	0.250
60	C	237.30	-1.200	0.620	0.091	1.355	1.415	0.365	0.233	0.286

Table 9. Velocity data for screen section 4 (bays 46-60) at 3 elevations using stationary measurement method. Velocity data were collected at the centerline of the screen.

Bay#	Row	Elevation (ft)	Vx (ft/s)	Vy (ft/s)	Vz (ft/s)	V-Avg (ft/s)	Vmag (ft/s)	RMS[Vx'] (ft/s)	RMS[Vy'] (ft/s)	RMS[Vz'] (ft/s)
47	A	242.94	-2.868	0.387	-0.193	2.900	2.903	0.166	0.088	0.093
47	B	240.12	-2.791	0.478	-0.113	2.834	2.840	0.218	0.098	0.144
47	C	237.30	-2.425	0.488	-0.062	2.475	2.485	0.285	0.140	0.175
49	A	242.94	-2.832	0.497	-0.138	2.878	2.881	0.117	0.072	0.100
49	B	240.12	-2.730	0.483	-0.201	2.779	2.786	0.206	0.120	0.152
49	C	237.30	-1.984	0.518	-0.137	2.055	2.081	0.355	0.188	0.261
51	A	242.94	-2.805	0.505	-0.161	2.855	2.859	0.223	0.097	0.124
51	B	240.12	-2.216	0.518	-0.126	2.279	2.301	0.344	0.181	0.250
51	C	237.30	-1.747	0.490	-0.018	1.815	1.849	0.444	0.199	0.285
53	A	242.94	-2.615	0.514	-0.111	2.667	2.674	0.201	0.112	0.160
53	B	240.12	-2.361	0.526	-0.130	2.422	2.438	0.243	0.147	0.230
53	C	237.30	-2.159	0.569	0.020	2.233	2.253	0.301	0.165	0.237
55	A	242.94	-2.658	0.496	-0.133	2.707	2.712	0.200	0.098	0.126
55	B	240.12	-2.299	0.471	-0.109	2.350	2.363	0.273	0.159	0.192
55	C	237.30	-2.026	0.576	-0.054	2.107	2.131	0.314	0.173	0.247
57	A	242.94	-2.430	0.537	-0.107	2.490	2.496	0.195	0.108	0.129
57	B	240.12	-2.225	0.572	-0.135	2.301	2.314	0.288	0.145	0.172
57	C	237.30	-1.683	0.588	0.001	1.783	1.814	0.372	0.200	0.241
59	A	242.94	-2.459	0.595	-0.122	2.533	2.542	0.252	0.115	0.162
59	B	240.12	-1.730	0.613	-0.027	1.836	1.862	0.383	0.157	0.231
59	C	237.30	-0.971	0.643	0.152	1.175	1.246	0.415	0.197	0.281
60	A	242.94	-2.134	0.723	-0.120	2.257	2.268	0.278	0.131	0.169
60	B	240.12	-1.629	0.797	-0.064	1.814	1.852	0.375	0.214	0.277
60	C	237.30	-1.297	0.774	0.057	1.512	1.573	0.456	0.234	0.281