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Hydraulic Laboratory Technical Memorandum PAP-1112

Cle Elum Dam - Interim Flume Approach Velocity Mapping

Yakima Project, Pacific Northwest Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
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Denver, Colorado

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Introduction

The interim fish passage flume at Cle Elum Dam is a fish bypass system that was installed to facilitate downstream passage of juvenile salmon. The objective of this site visit was to measure the approach velocities to the interim flume for model-prototype comparisons with physical and computational fluid dynamics (CFD) modeling of the flume approach velocities.

Interim Fish Passage Flume Description

In 2005, Reclamation completed construction of an interim (experimental) downstream juvenile fish passage facility at Cle Elum Dam. The fish passage features include an overflow section and plunge pool installed in the second radial gate bay from the left side of the spillway. The overflow section consists of 3 bays with stop logs to control the flow into the plunge pool and flume entrance. During velocity measurements, only the middle bay was operating. The flume is constructed of marine plywood and lumber and was built on the existing concrete spillway.

The approach channel to the Cle Elum spillway gates is a sloped channel that is about 300 ft wide and up to 20 ft deep. The invert elevation at the stop log structure is El. 2223.0 ft.

Velocity Data Collection and Analyses

Two instruments were used to collect approach velocities in the forebay. A QLiner (acoustic Doppler profiling) system was used to collect far-field velocities while a Sontek acoustic Doppler velocimeter (ADV) was used to measure near-field velocities within the stop-log bay that serves as the flume's intake.

During data collection Cle Elum reservoir's water surface elevation was 2239.85 ft. The flume intake was set up with about 2 ft of head on the stop logs and about 150 ft^3/sec flowing into the flume. The dam operator reported that 15 stop logs were installed for this flow condition.

A second data set was collected with 14 stop logs installed or about 3 ft of head on the stop logs and an estimated 250 ft^3/sec flowing into the flume.

QLiner velocity profile measurements

The QLiner measures a 2-D vertical velocity profile along with the depth under the transducer. The QLiner uses three acoustic beams to determine a 2-dimensional velocity profile. Figure 1 shows the angle of the three beams and their orientation to the float. Beams 1 and 2 are used together to calculate the vertical velocity profile. Beam 3 is used to collect near-surface data out in front of the float. Beam 3 velocity data can be used to supplement near surface velocities that cannot be measured by beams 1 and 2. For this study, the beam 3 velocities are not used because they are not representative of the surface velocities at the profiling station (i.e. the beam 3 velocities are spatially removed from the location of interest). Figure 2 illustrates how the QLiner system is used to measure velocity profiles at several verticals along a cross section. The QLiner's 2.0 MHz Doppler profiler has an accuracy of ±1% of the measured velocity ±0.02 ft/sec with a velocity range from ±32 ft/sec. Velocity profiles are acquired at a sampling rate of 1 Hz. The averaging time for each velocity measurement was 60 seconds.

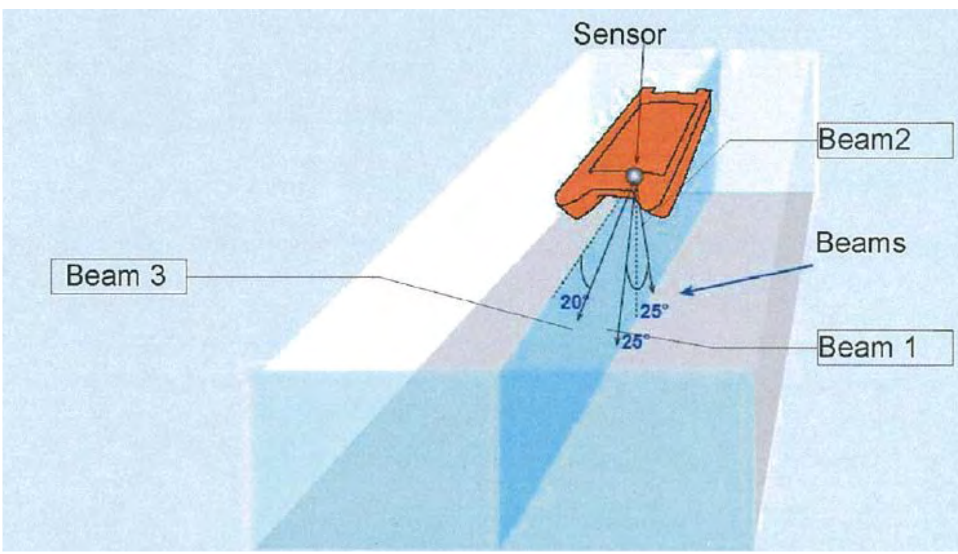

Figure 1. Schematic of three acoustic beams and their orientation to the acoustic Doppler sensor. (Image was taken from the QLiner manual)

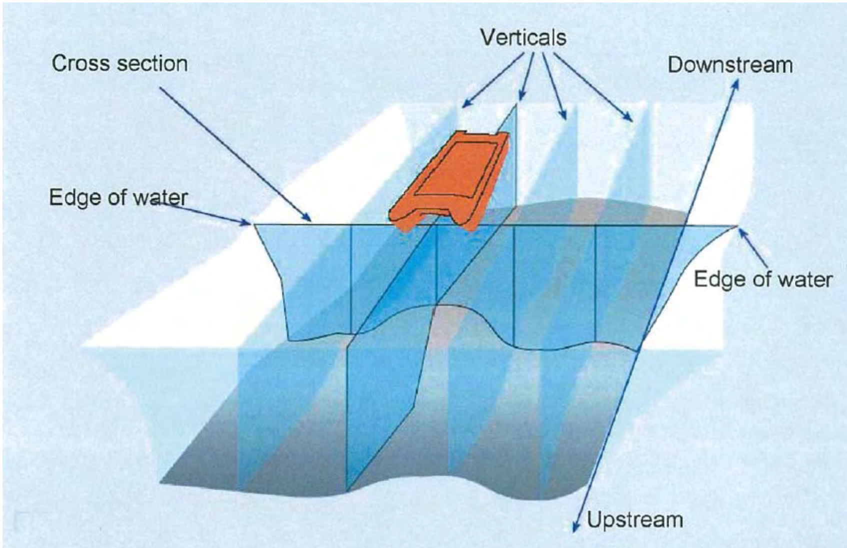

Figure 2. Illustration of measurement verticals along a channel cross section. (Image was taken from the QLiner manual)

ADV point velocity measurements

The Sontek ADV is a 10 MHz instrument with an accuracy of ±1% of the measured velocity with a velocity range from ±0.03 to 8.2 ft/s (figure 3). Data can be acquired at sampling rates up to 25 Hz which allows the measurement of turbulence characteristics of the flow.

Figure 3 Sontek/YSI Field ADV probe and splash-proof signal processing module.

ADV Theory of Operation

An ADV is a high-resolution acoustic Doppler velocimeter that measures 3-dimensional velocity vectors in a remotely sampled volume. The ADV is a bi-static Doppler current meter which means the ADV uses separate acoustic transducers for transmitter and receivers (figure 4). The transducers are mounted such that their respective beams intersect over a volume of water located some distance away, called the sampling volume. ADVs normally report velocity data in a Cartesian (X,Y,Z) coordinate system relative to the probe's orientation. The field probe used for this project was serial number A254A and the probe configuration used throughout testing is summarized in Table 1.

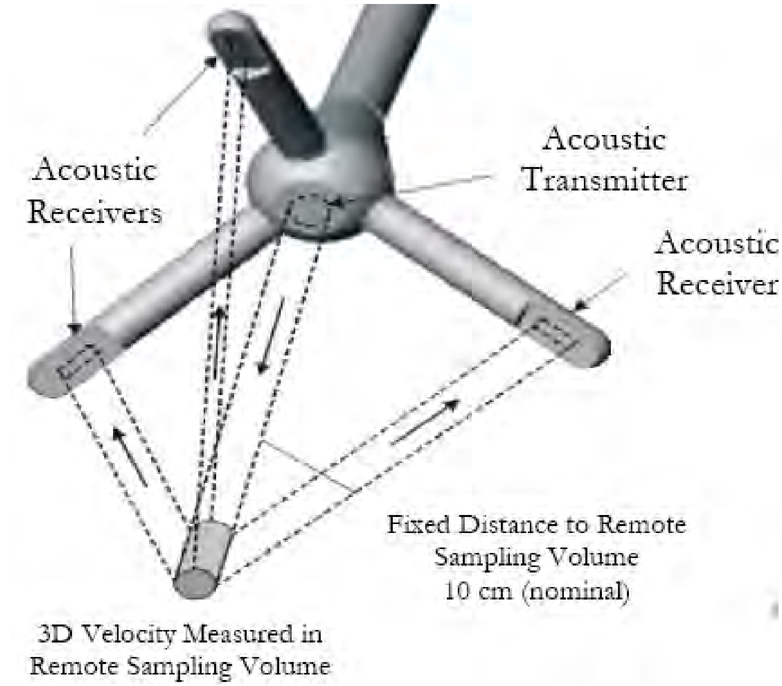

Figure 4. Schematic of ADV probe head orientation and sampling volume. (Image provided by Sontek/YSI Inc.).

Table 1. Sontek ADV instrument specifications and configuration

Parameter	Value
Instrument Model	Field ADV
Instrument Serial Numbers	A254A
Operating Acoustic Frequency	10 Megahertz (MHz)
Sampling Volume	0.25 cm^3 (0.015 in^3)
Distance to Sampling Volume (from acoustic transmitter)	10 cm (3.94 inches)
Resolution	0.01 cm/sec (0.003 ft/sec)
Accuracy	±1 % of measured velocity
Instrument Configuration	
Sampling rate	25 Hz
Max Velocity Range Setting	250cm/s (8.2 ft/s)
Data Collection Period (per burst)	30 seconds
Salinity	1 part per thousand
Water temperature	13.5° C

ADV Mounting Configuration

The ADV was mounted securely to a pole and lowered into the water at two locations: 1) about 3 inches upstream from the stop logs and 2) about 6 ft upstream from the stop logs. Care was taken to align the ADV with the x-velocity component perpendicular and y-velocity component parallel to the stop logs.

Velocity Measurement Locations

Velocity mapping was performed in the approach channel to the Cle Elum Dam spillway using the QLiner for far-field measurements and an ADV for near-field measurements. A tagline was temporarily setup across the approach channel to allow the velocity measurement float to be located at points in the measurement grid (figure 5). The measurement locations were on 6 ft x 5 ft grid centered on the centerline of the flume entrance. Figure 6 is an aerial photograph with the velocity measurement grid points superimposed on the image.

Two sets of velocity data were collected on June 4, 2014. The first data set (CLE) was collected while there was 2 ft of head on the stop logs. Appendix table A1 contains the measurement locations and the instrument that was used at each location. The origin for the measurement grid was at the right-most concrete pier (looking downstream) and the stop-log guide (figure 6). Each bay is 11 ft wide and the concrete piers are about 2 ft wide (figure 7). The center bay was passing flow into the flume, but the left and right bays were completely blocked which kept water from passing down the spillway.

The second data set (CLE2) was collected with 3 ft of head on the stop logs (one stop log was removed by the dam operator). Because of deteriorating weather conditions (increasing wind and waves), fewer velocity measurement locations were sampled. Velocity measurements were taken at sections through the middle bay’s left and right piers, and along the bay’s centerline. Appendix table A1 shows the measurement locations and the instrument that was used at that location.

Figure 5. Aerial photograph of the Cle Elum interim flume intake and tagline location. During the measurements the log boom was spanning the approach channel. The box indicates the extents of figure 6. (Image date: November 6, 2012).

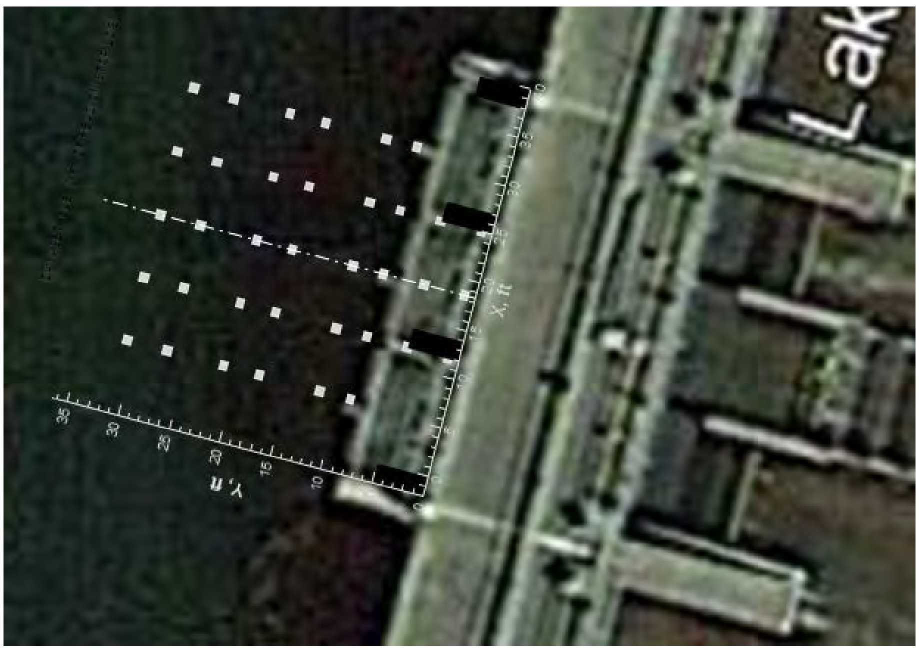

Figure 6. Aerial image of velocity measurement grid used for CLE velocity mapping. The CLE2 measurement grid (not shown) only covered the middle bay centerline and adjacent piers.

Figure 7. Photograph of Interim Flume intake in the dry (looking downstream).

Figure 8. Photograph of tagline across forebay and QLiner float with guidance ropes. The buoys are part of a safety line across the forebay.

Data Collection Period

On June 4, 2014, data collection for the CLE data set began at 9:05 a.m. and concluded at 12:04 p.m. The dam operator said 15 stop-logs were in-place during this test. Prior to starting the CLE2 data collection, one stop-log was removed from the center bay, leaving 14 one-ft-high stop-logs in-place. The CLE2 data collection began at 2:21 p.m. and concluded at 3:15 p.m.

Velocity Data Analyses

QLiner data were reviewed with a software package named QLiner Review. Velocity data were exported to a text file for import to Microsoft Excel for data analysis. Excel was used to compute near-surface average velocities. Velocity data collected between depths of 2 and 4 ft were averaged to get the near-surface approach velocity to the flume entrance. ADV data were analyzed using WinADV which is a Windows-based viewing and post-processing utility for ADV files that was developed by Reclamation (Wahl, 2000). WinADV provides an integrated environment for viewing, reviewing, and processing data collected using Sontek acoustic Doppler velocimeters (ADV's). Time series velocity data were processed to determine the average velocity components (x,y,z) and summary statistics for each measurement location. Data were filtered to remove measurements with signal-to-noise ratios (SNR) less than 5 and correlation (COR) values less than 70.

Results and Discussion

CLE Test Results

Velocity mapping data for 2 feet of head on the stop log intake was contoured to illustrate the near-surface approach velocity conditions. Near-surface velocity for QLiner measurements is defined as the average of velocities measured from 2 to 4 ft below the water surface. The dam tender stated that the flow was about 150ft^3/sec. Figure 9 shows contours for the near-surface approach velocities and the boxes contain the approach velocity values. Velocities for y-values greater than 6 were measured using the QLiner and velocities measured inside the flume intake structure are based on the average of ADV measurements collected at several depths along the intake centerline (x=18.5 ft). Velocities near the piers were assigned the same magnitude as the centerline velocity because making measurements near the piers could have damaged the ADV probe. Table 2 contains the 3-dimensional ADV data collected within the intake structure at y=0.5 (above stop logs) and 6 ft (along upstream face of intake structure).The

Vmag values are the magnitude of the x, y, and z velocity components and represent the total velocity at that location and depth. *NOTE: Velocity components (Vx and Vy) are not in the same coordinate system as the measurement grid. For both the ADV and QLiner measurements Vx is parallel to the y-axis in figures 9 and 10.*

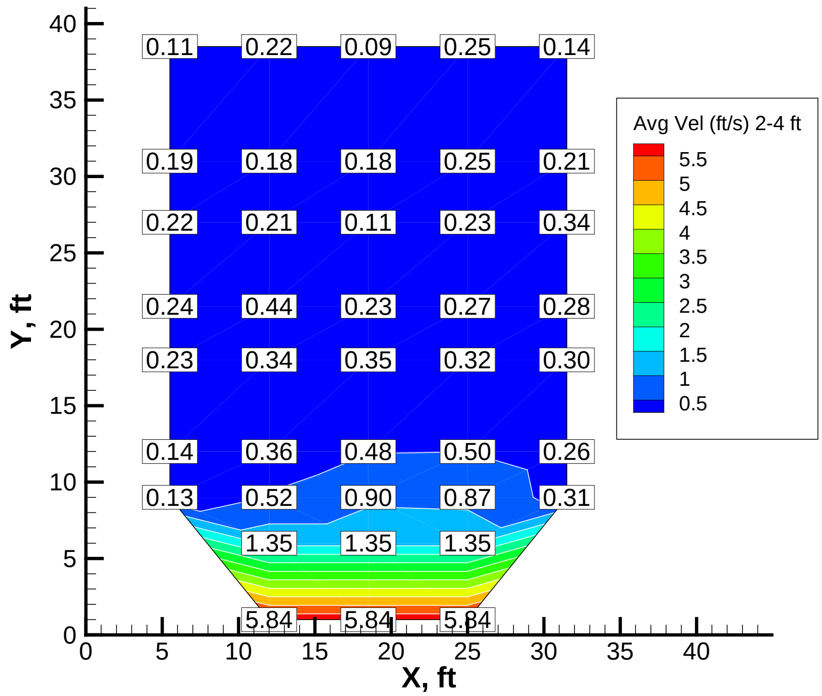

Figure 9. CLE approach velocity contours for 2 ft of head on the flume intake stop logs. The boxes contain the near-surface velocity values (ft/sec) at the location they were measured. Velocities inside the intake structure were measured with an ADV and the rest of the data were collected with the QLiner.

Table 2. ADV 3-D velocity data (CLE) for 2 ft of head on the stop logs measured on the middle bay centerline. RMS values are an indication of the turbulence intensity for each velocity component. Note: negative Vx values are in the downstream direction, positive Vy values are toward the right pier, and positive Vz values are directed upward. *All velocities values are in ft/sec.*

X, ft	Y, ft	Z, ft	Vx	Vy	Vz	Vmag	RMS[Vx']	RMS[Vy']	RMS[Vz']
18.5	0.5	-0.3	-5.64	-0.44	0.23	5.66	0.15	0.21	0.11
18.5	0.5	-1	-6.35	-0.14	1.73	6.6	0.15	0.35	0.29
18.5	6	-0.1	-1.38	0.03	0.11	1.42	0.15	0.2	0.24
18.5	6	-1	-1.35	0.01	0.21	1.39	0.16	0.18	0.17
18.5	6	-2	-1.32	0.03	0.37	1.38	0.11	0.14	0.12
18.5	6	-3	-1.22	0.23	0.38	1.31	0.1	0.13	0.1
18.5	6	-4	-1.11	0.11	0.49	1.23	0.12	0.13	0.08
18.5	6	-5	-0.96	0.25	0.53	1.13	0.1	0.13	0.06
18.5	6	-6	-0.88	0.21	0.5	1.04	0.1	0.09	0.04

CLE2 Test Results

Velocity mapping data for 3 feet of head on the stop log intake was contoured to illustrate the near-surface approach velocity conditions. As expected, the approach velocities increased with more flow going over the stop logs. The dam tender estimated that the flow into the flume was between 240 to 250 ft^3/sec. Figure 10 shows contours for the near-surface approach velocities and the boxes contain the approach velocity values. Velocity contours inside the intake structure are based on the average of ADV measurements collected at several depths along the intake centerline (x=18.5 ft). Velocities near the piers were not measured because of the potential to damage the ADV probe. Table 3 contains the 3-dimensional ADV data collected within the intake structure, at y=0.5 and 6 ft.

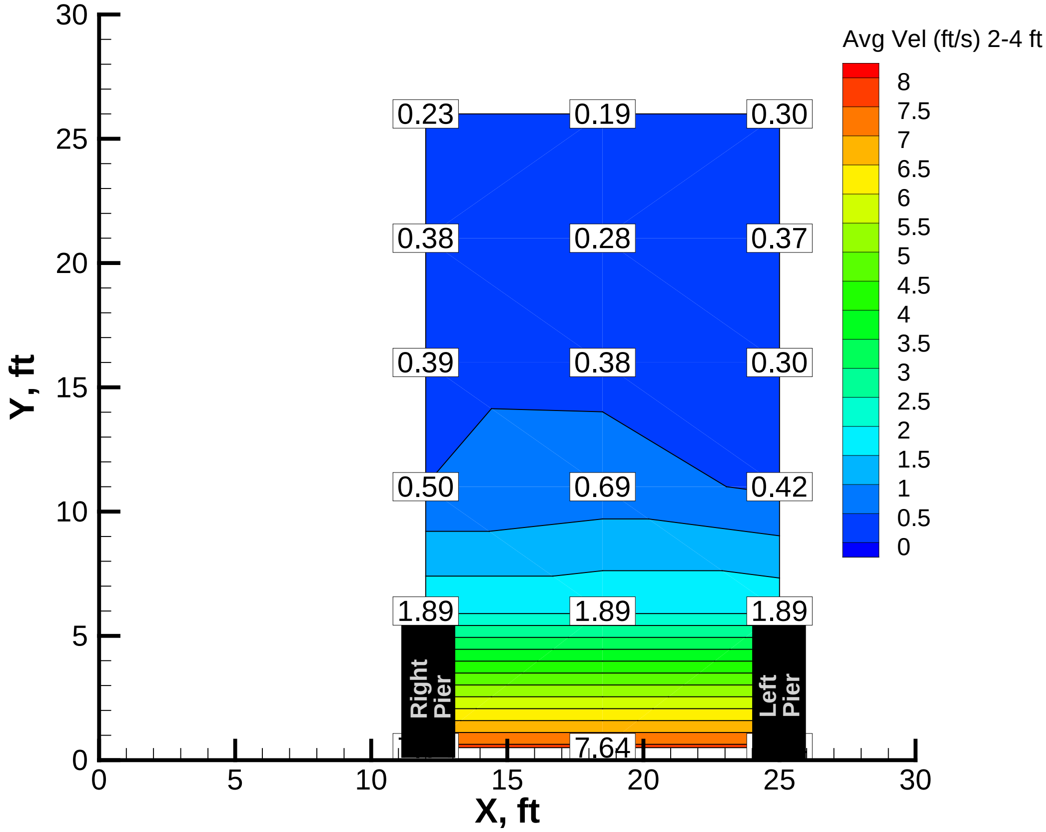

Figure 10. CLE2 approach velocity contours for 3 ft of head on the flume intake stop logs. The boxes contain the near-surface Vx values (ft/sec) at the location they were measured. Velocities inside the intake structure were measured with an ADV and the rest of the data were collected using the QLiner.

Table 3. ADV 3-D velocity data (CLE2) for 3 ft of head on the stop logs measured at the middle bay centerline. RMS values are an indication of the turbulence intensity for each velocity component. Note: negative Vx values are in the downstream direction, positive Vy values are toward the right pier, and positive Vz values are directed upward. *Velocity units are in ft/sec.*

X, ft	Y, ft	Z, ft	Vx	Vy	Vz	Vmag	RMS[Vx']	RMS[Vy']	RMS[Vz']
18.5	0.5	-0.3	-6.92	-0.72	-1.08	7.09	0.59	0.94	0.14
18.5	0.5	-1	-7.22	-0.67	-0.41	7.27	0.15	0.33	0.12
18.5	0.5	-1.5	-7.64	-0.15	-0.06	7.65	0.15	0.21	0.08
18.5	0.5	-2	-8.76	-0.9	0.49	8.83	0.22	0.3	0.11
18.5	6	-0.3	-1.94	0.2	0.07	1.98	0.13	0.25	0.22
18.5	6	-1	-1.94	0.06	0.23	1.96	0.11	0.16	0.14
18.5	6	-2	-1.87	-0.02	0.36	1.91	0.09	0.13	0.15
18.5	6	-3	-1.83	0	0.39	1.88	0.08	0.11	0.08
18.5	6	-4	-1.79	0.14	0.4	1.85	0.08	0.14	0.06
18.5	6	-5	-1.55	0.19	0.55	1.66	0.1	0.1	0.06
18.5	6	-5	-1.55	0.38	0.53	1.68	0.09	0.1	0.05
18.5	6	-6	-1.47	0.23	0.48	1.57	0.13	0.12	0.13

Approach Velocity Gradients

Approach velocity gradients are important characteristics of a fish passage structure because they describe the attraction flow to the intake. Approach velocity profiles were collected at several sections across the interim flume intake structure to illustrate the variation in approach velocities for data sets CLE and CLE2.

It is important to note that the QLiner is a 2-dimensional velocity profiler that was used in a 3-dimensional flow field. For velocity measurement sections on either side of the intake centerline (e.g. left bay centerline) the QLiner will only measure the Vx and Vz velocity components. For these measurements, the QLiner was oriented so the measurement plane was the same at all profiling locations. This limitation results in lower velocity measurements along the centerlines of the left and right bays. As a result, velocities measured outside the extents of the middle bay are not representative of the approach velocity vector and will not be discussed.

Figure 11 presents the interim flume centerline approach velocity profiles for CLE and CLE2 data sets. These profiles illustrate that the near-surface flow is accelerating in the first 10 ft upstream from the stop logs. Beyond 10 ft upstream, the approach velocities are very similar in magnitude. As expected, 3 ft of head on the stop logs creates a stronger velocity gradient near the overflow weir. The maximum near-surface velocity gradient for 2 ft of head on the stop logs was 0.79 ft/sec/ft. The maximum near-surface velocity gradient for 3 ft of head on the stop logs was 1.01 ft/sec/ft. These velocity gradients were calculated using average near surface velocities plotted in figures 9 and 10. Table 4 contains the middle bay centerline approach velocities and the velocity gradients for CLE and CLE2 data sets.

Figure 12 is a plot of QLiner velocity data collected in front of the left and right piers of the interim flume intake. The close agreement between data sets CLE and CLE2 velocities indicates that the flow distribution is relatively uniform across the intake bay.

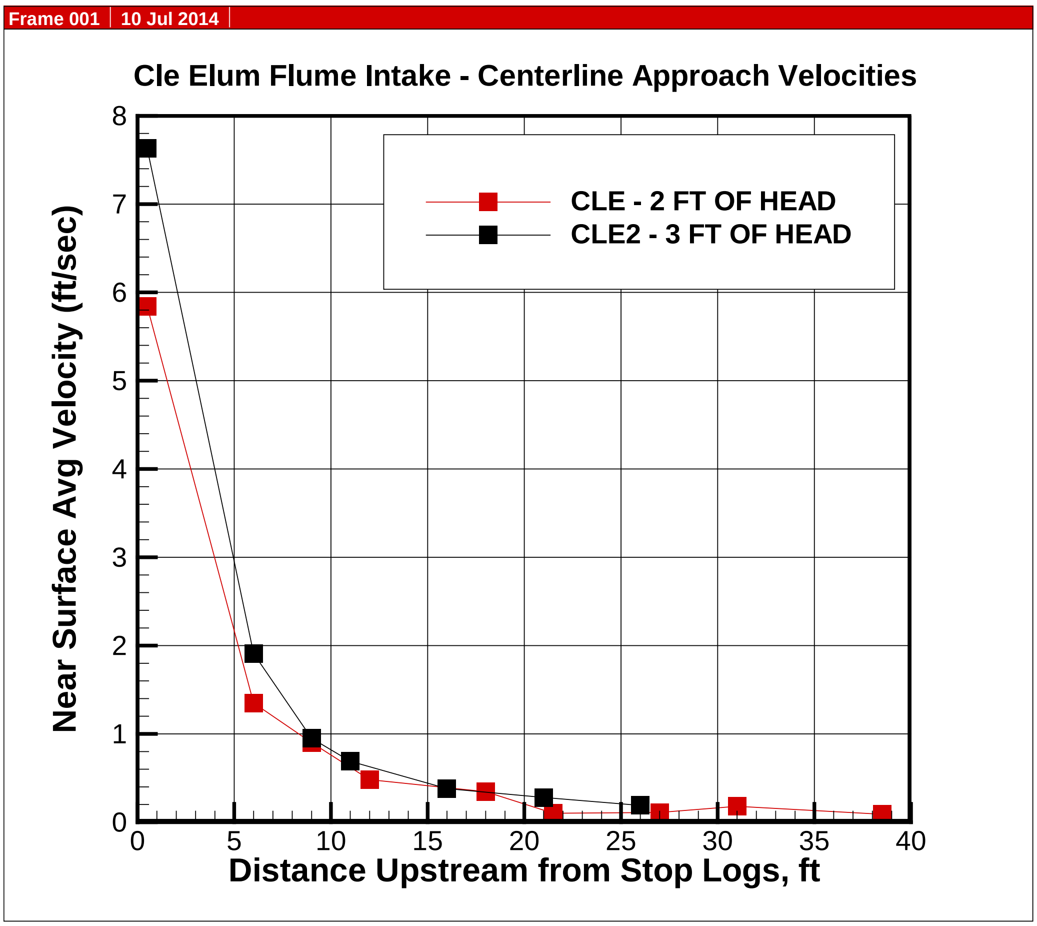

Figure 11. Interim flume centerline approach velocity profiles for CLE and CLE2 data sets. These profiles illustrate that the flow is accelerating rapidly in the first 10 ft upstream from the stop logs.

Table 4. Middle bay centerline (x=18.5 ft) approach velocities and velocity gradients for CLE and CLE2 data sets.

X, ft	Y, ft	Velocity, ft/sec	Velocity. Gradient, ft/sec per ft
CLE Data			
18.50	0.33	5.84	
			0.79
18.50	6.00	1.35	
			0.15
18.50	9.00	0.90	
			0.14
18.50	12.00	0.48	
			0.02
18.50	18.00	0.35	
			0.03
18.50	21.50	0.23	
			0.02
18.50	27.00	0.11	
			-0.02
18.50	31.00	0.18	
			0.01
18.50	38.50	0.09	
CLE2 Data			
18.50	0.33	7.64	
			1.01
18.50	6.00	1.89	
			0.24
18.50	11.00	0.69	
			0.06
18.50	16.00	0.38	
			0.02
18.50	21.00	0.28	
			0.02
18.50	26.00	0.19	

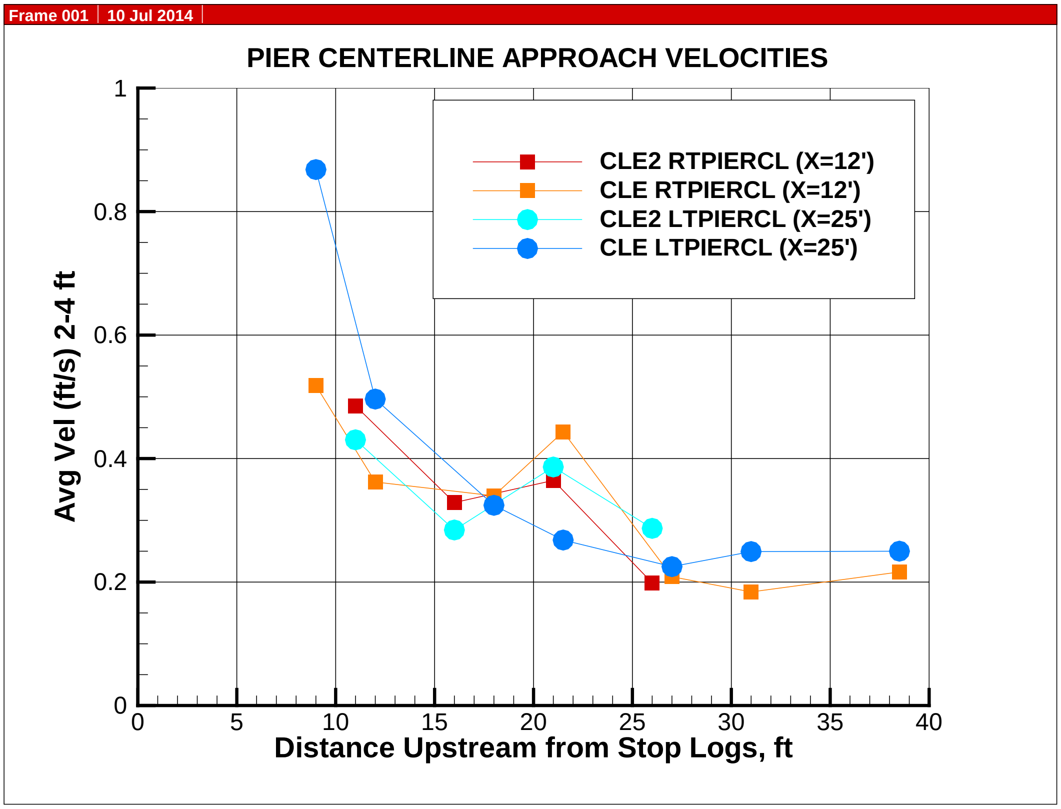

Figure 12. Plot of QLiner velocity data collected in front of the left and right pier of the interim flume intake. The close agreement between data sets CLE and CLE2 indicated that the forebay flow distribution is uniformly approaching the interim flume intake structure.

Conclusions

Approach velocities to the Cle Elum interim fish passage flume were measured using a 2-D acoustic Doppler profiler and a 3-D acoustic Doppler velocimeter for two flow conditions: 1) 2 ft of head and 2) 3 ft of head on the middle bay stop logs.

Velocity measurements confirmed a uniform approach velocity distribution upstream from the intake structure for both flow conditions tested.

For 2 ft of head on the stop logs the maximum near-surface velocity gradient was 0.79 ft/sec/ft. For 3 ft of head on the stop logs the maximum near-surface velocity gradient was 1.01 ft/sec/ft.

The velocity gradients measured on the Cle Elum interim flume at these operational configurations are at or below a velocity acceleration gradient of 1.0

ft/sec/ft, which has been shown to cause avoidance behavior in migratory Atlantic and Chinook salmon smolts (Haro et al. 1997, Enders et al. 2012). Studies on the migratory behavior of other salmon species have not been published, although the 1.0 ft/sec/ft acceleration is currently considered a design consideration for the operation of juvenile fish passage facilities, rather than design criteria.

References

Enders, E.C., M.H. Gessel, J.J. Anderson, and J.G. Williams. 2012. Effects of Decelerating and Accelerating Flows on Juvenile Salmonid Behavior. Transactions of the American Fisheries Society 141:357–364.Haro, A., M. Odeh, J. Noreika, and T. Castro-Santos. 1998. Effect of water acceleration on downstream migratory behavior and passage of Atlantic salmon smolts and juvenile American shad at surface bypasses. Transactions of the American Fisheries Society 127:118–127.

Wahl, T. (2000). Analyzing ADV Data using WinADV. *Joint Conference on Water Resources Engineering and Water Resources Planning & Management.* Minneapolis.

Appendix

Table A1. Locations of for QLiner and ADV measurement for first set of measurements with 2 ft of overtopping head on the stop logs

CLE Data Set			CLE2 Data Set		
X, ft	**Y, ft**	**Instrument**	**X, ft**	**Y, ft**	**Instrument**
12.0	0.5	ADV	12.0	0.5	ADV
18.5	0.5	ADV	18.5	0.5	ADV
25.0	0.5	ADV	25.0	0.5	ADV
12.0	6.0	ADV	12.0	6.0	ADV
18.5	6.0	ADV	18.5	6.0	ADV
25.0	6.0	ADV	25.0	6.0	ADV
5.5	9.0	QLiner	25.0	6.5	QLiner
12.0	9.0	QLiner	18.5	6.5	QLiner
18.5	9.0	QLiner	12.0	6.5	QLiner
25.0	9.0	QLiner	12.0	11.0	QLiner
31.5	9.0	QLiner	18.5	11.0	QLiner
5.5	12.0	QLiner	25.0	11.0	QLiner
12.0	12.0	QLiner	12.0	16.0	QLiner
18.5	12.0	QLiner	18.5	16.0	QLiner
25.0	12.0	QLiner	25.0	16.0	QLiner
31.5	12.0	QLiner	12.0	21.0	QLiner
5.5	18.0	QLiner	18.5	21.0	QLiner
12.0	18.0	QLiner	25.0	21.0	QLiner
18.5	18.0	QLiner	12.0	26.0	QLiner
25.0	18.0	QLiner	18.5	26.0	QLiner
31.5	18.0	QLiner	25.0	26.0	QLiner
5.5	21.5	QLiner			
12.0	21.5	QLiner			
18.5	21.5	QLiner			
25.0	21.5	QLiner			
31.5	21.5	QLiner			
5.5	27.0	QLiner			
12.0	27.0	QLiner			
18.5	27.0	QLiner			
25.0	27.0	QLiner			
31.5	27.0	QLiner			
5.5	31.0	QLiner			
12.0	31.0	QLiner			
18.5	31.0	QLiner			

25.0	31.0	QLiner			
31.5	31.0	QLiner			
18.5	38.5	QLiner			
12.0	38.5	QLiner			
5.5	38.5	QLiner			
25.0	38.5	QLiner			
31.5	38.5	QLiner			