Measuring Selective Withdrawal Characteristics using an Argonaut Acoustic Doppler Velocimeter in Folsom Lake, California

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Abstract

During an evaluation of the selective withdrawal structure for a municipal and industrial (M&I) water intake at Folsom Dam, the U.S. Army Corps of Engineers SELECT model was used to compute the near-field velocity profiles in a thermally stratified reservoir. To verify numerical model results, velocity profiles near the M&I intake structure were collected for one flowrate at three different distances from the trashrack structure. In addition, two velocity profiles were collected near the adjacent penstock intake structure for a single flowrate. This paper presents the measurement techniques used to collect the velocity profiles near trashrack structures using an acoustic Doppler velocimeter. In addition, a comparison between the SELECT-computed and field-measured velocity profiles are made.

Introduction

As part of a project to construct a selective withdrawal structure for a M&I water intake at Folsom Dam, the U.S. Army Corps of Engineers SELECT model was used to compute the near-field velocity profiles in a thermally stratified reservoir. Velocity data were requested by the general contractor to prepare a job hazard analysis for diving operations. To verify numerical model results, velocity profiles were collected near the M&I intake structure for one flowrate at three different distances from the trashrack structure. In addition, two velocity profiles were collected near the adjacent penstock intake structure for a single flowrate. Because of the large depths to intake opening and the close proximity to the structure, an ADV (acoustic Doppler velocimeter) was selected to measure the near-field velocity profiles.

Equipment Setup and Data Collection

Along the centerline of the 2.1 m diameter pipe intake structure (M&I intake), a tagline was secured from the safety buoy line to three wire ropes used to lift the access grates off the M&I intake structure (see photo 1). The tagline was oriented perpendicular to the dam face and was used to accurately position the boat while collecting near-field velocity profiles. Maintaining a fixed position was a critical element for this data collection effort because the Argonaut-ADV will include any boat motion in the velocities it measures. With the exception of motion generated by boat wakes, the tagline and calm weather resulted in very little boat motion.

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Figure 1. Picture of three cables attached to the dam's parapet wall. The cables are attached to the M&I access grates. The tagline was tied off between these cables and the safety buoy line located about 100 m from the dam face.

Figure 2. Photo of Argonaut-ADV and anchor line deployment system.

Figure 3. Photo of Unit No.1 trashrack and selective withdrawal shutter structure. The shutters are just above the water surface.

Figure 4. Plan view schematic of Folsom Dam (not to scale). Features pertaining to the velocity measurements are included, such as: the 2.1 m diameter intake, the three penstock intake structures, and velocity measurement locations. To convert distances to meters multiply feet by 0.305.

The profiling system consisted of a vertical anchor line with a 25-kg weight on a 1-cm diameter polypropylene line. An Argonaut-ADV was used to measure three-dimensional velocities (see photo 2). The ADV manufacturer specifies that the instrument is accurate to ±1% of the measured velocity ±0.001 m/sec and has a measurement range of ±0.001 to 6 m/sec (Sontek 2002).

M&I intake profiles were collected 21.1, 10.7, and 7 meters from the face of Folsom Dam. The three dimensional velocities were measured using earth coordinates, that is, velocities were referenced to east, north, and up directions using an internal compass. The ADV was equipped with a pressure sensor and pitch and roll sensors to determine the ADVs depth and orientation, respectively. The Argonaut-ADV was attached to the anchor line using a split section of 2.5 cm diameter PVC conduit that was clamped to the ADV. The ADV was lowered down a taut anchor line using a graduated line; the line was marked at 3.05 m intervals. Velocities were measured at 1.52 and 3.05 meter intervals between elevations 91 and 107 m. The M&I intake centerline elevation is located 96.6 m above mean sea level. Data were collected autonomously because measurement depths were greater than the 10-m-long, RS-232 communications/power cable provided with the instrument. In post-processing the ADV data, instrument depths were verified using internal pressure transducer data. In addition, the standard error of the vertical velocity was used to exclude measurements that were affected by wake-generated boat motion.

Distances from the dam face were measured using a flexible tape measure. Two additional velocity measurements were collected at the intake centerline elevation (El. 96.9 m) at 5.2 and 6.2 m from the dam face or approximately 0 and 1 m away from the trashracks (see figure 4). Because the upstream face of the dam is sloped (0.1H to 1V) the location of the trashrack for the M&I intake was calculated to be 5 m from the dam face for reservoir elevation 134 m. During velocity measurements collected 5.2 m from the dam face, the graduated line vibrated and it felt like the ADV was periodically hitting something — presumably the trashrack. A complete velocity profile was not collected along the trashrack because the probe/lines could have become tangled in the trashracks or with debris. Another problem with measuring close to the trashracks is the effect of the steel structure on the ADV's internal compass. As a result, the direction of the velocities measured near the trashrack may be biased several degrees. In general, this profiling system was very effective at positioning the ADV at known positions and elevations, but data collection was a time consuming process. The Argonaut-ADV pings 10 times per second, but accumulates an average velocity once every second. Furthermore, Sontek recommends that 3 seconds is the minimum effective averaging interval. The reason for this sampling scheme is that acoustic velocimeters are inherently noisy, so it is recommended to average hundreds, if not thousands, of pings to lower the standard error down to acceptable levels. In this regard, the Argonaut-ADV measurements take longer to achieve the same standard error as the laboratory ADV.

During the velocity measurements the reservoir elevation was 133.8 m and the 2.1-m diameter intake was withdrawing about 6.8 m^3/sec from the reservoir. Likewise, penstock No. 1 was reported to have about 65.1 m^3/sec flowing through it. The selective withdrawal shutters on Unit No. 1 were set at El. 110.3 m. It is important to note that velocities measured more than a few meters from the M&I intake are likely a composite of velocity fields generated by both intakes.

After completing measurements at the M&I intake, the tagline and anchors were moved to the centerline of the trashrack structure for Unit No. 1. The tagline was tied off to the trashrack structure, which was located about 7.3 m from the dam face. Velocity profiles near Unit No. 1 were collected in the same manner as previously described. Velocity profiles were collected 6.1 and 9.1 m upstream from the face of the trashrack/shutters. Velocities were collected between elevations 109.7 and 114.3 m to measure the flow associated with penstock withdrawals. Likewise, velocities were collected between elevations 93.0 and 99.1 m to measure the flow associated with the M&I intake withdrawals. During these measurements, Folsom Dam operators reported the reservoir elevation was 133.8 m and the flows through Unit No. 1 and the M&I intake were about 62.3 and 7.6 m^3/sec, respectively.

Throughout the velocity profiling, a temperature string was used to collect forebay temperature profiles at the security buoy line. Temperature data were collected at 15-minute interval. Temperature (density) profiles are required input for the selective withdrawal model. If needed, the ADV's temperature probe, located in the sensor body, could have been used to collect the temperature profile over the entire depth range.

Results

The following tables and graphs summarize the velocity measurements collected on May 31 and June 1, 2001 at Folsom Dam. The velocities were collected every 15 seconds for a period of 5 minutes at each elevation. The horizontal magnitude of the velocity (V_{mag}) is the resultant of the V_{east} and V_{north} component of the 3-D velocities. Vertical velocities are not reported because they were typically much less than the horizontal velocity components and are most likely to be corrupted by boat motion caused by wakes. The directional component of the velocity (V_{dir}) is reported in degrees clockwise from north. The axis of the dam is at 120E clockwise from north. Currents moving into the intake for Unit No. 1 and the M&I intake should be moving nearly perpendicular to the dam's axis or 210E clockwise from north. Some velocities, especially those collected above El. 104 m are probably influenced by flow toward both the M&I and Unit No. 1 intakes and the directional component is in the range of 150E to 200Eclockwise from north.

For brevity, a small sample of the velocities collected in front of both intakes is presented. The velocity statistics (average and standard error) reported in Tables 1 and 2 were determined using a typical sample size of 20 readings collected over five minutes (this is equivalent to 3000 individual acoustic pings). The average velocity represents the best estimate of velocity in a turbulent flow field, and the standard error indicates the amount of variation in either direction around the average velocity measurement. The same statistical descriptions apply to the velocity direction. It is important to note that these velocities only apply to the operational conditions that occurred on May 31 and June 1, 2001. The velocity field will be different if Unit No. 1 is not operating, if flow distributions are modified, or if the penstock shutter configuration is changed.

Table 1. Average velocities and standard errors collected on the M&I intake centerline 7 meters upstream from the intake's trashrack. During these measurements the withdrawals from the M&I and Unit No. 1 intakes were 6.8 and 65.1 m^3/sec, respectively.

Elevation (m)	Vmag (cm/s)	Vdir (° from north)
89.6	2.6 ± 0.3	252.2 ± 18.5
91.1	3.0 ± 0.8	130.6 ± 24.7
92.7	1.7 ± 0.2	194.5 ± 23.2
94.2	2.3 ± 0.3	164.4 ± 14.1
95.7	3.5 ± 0.3	186.5 ± 9.7
97.2	5.3 ± 0.5	214.6 ± 7.6
98.8	2.0 ± 0.2	218.2 ± 18.6
100.3	2.7 ± 0.7	163.0 ± 21.7
101.8	5.7 ± 0.3	173.5 ± 9.9
103.3	7.1 ± 1.1	158.0 ± 7.1
104.9	5.2 ± 0.3	147.8 ± 7.2

Table 2. Velocities collected on the centerline of Unit No. 1 at a distance of 6 meters upstream from the *trashrack face*. During these measurements the withdrawals from the M&I and Unit No. 1 intakes were 7.6 and 62.3 m^3/sec, respectively.

Elevation (m)	Vmag (cm/s)	Vdir (° from north)
92.7	2.9 ± 0.6	180.0 ± 12.2
95.7	3.6 ± 0.4	196.6 ± 3.4
98.7	4.0 ± 0.7	234.7 ± 3.7
101.8	3.8 ± 0.5	206.4 ± 5.6
107.9	6.2 ± 0.5	187.7 ± 2.5
109.4	7.7 ± 0.3	179.9 ± 3.3
110.9	7.5 ± 0.6	172.4 ± 3.0
112.5	8.9 ± 0.4	187.4 ± 3.0
114.0	8.4 ± 0.5	168.2 ± 2.7

Comparison of field velocity measurements to velocities predicted using SELECT

A means of predicting the properties of selective withdrawal was needed to properly design and efficiently operate a selective withdrawal facility. Numerous research projects (Bohan and Grace, 1973 and Smith et al., 1985) have been conducted to determine the characteristics of withdrawal from a stratified impoundment. A product from this research is a numerical model called SELECT, which is a one-dimensional, steady-state model developed to predict withdrawal characteristics from a stratified reservoir (Davis et al. 1987). The model computes the vertical distribution of velocity based upon a user-specified density profile (usually input as temperature). The upper and lower limits of withdrawal are determined from empirically developed relationships for point and line sinks. The discharge, outlet geometry, reservoir elevation, and density profiles are required to estimate the vertical limits of the withdrawal zone.

Analytical Approach - Velocities measured near the El. 96.6 m using a Sontek Argonaut-ADV were used as the centerline approach velocity. The normalized velocity distribution computed by SELECT and the centerline approach velocity were used to compare to the vertical velocity distribution measured in the field. Figure 5 shows the comparisons for a profile collected upstream from the M&I intake for a flow of 6.8 m^3/sec. In general, the agreement is good, except for points in the upper portion of the withdrawal zone. These velocities appear to be affected by the withdrawal zone from Unit No.1. Figure 6 shows the comparisons for a profile collected upstream from the Unit No. 1 intake for a flow of 62.3 m^3/sec. In general, the agreement is very good, except for points in the bottom portion of the withdrawal zone. These velocities appear to be affected by the withdrawal zone from the M&I intake.

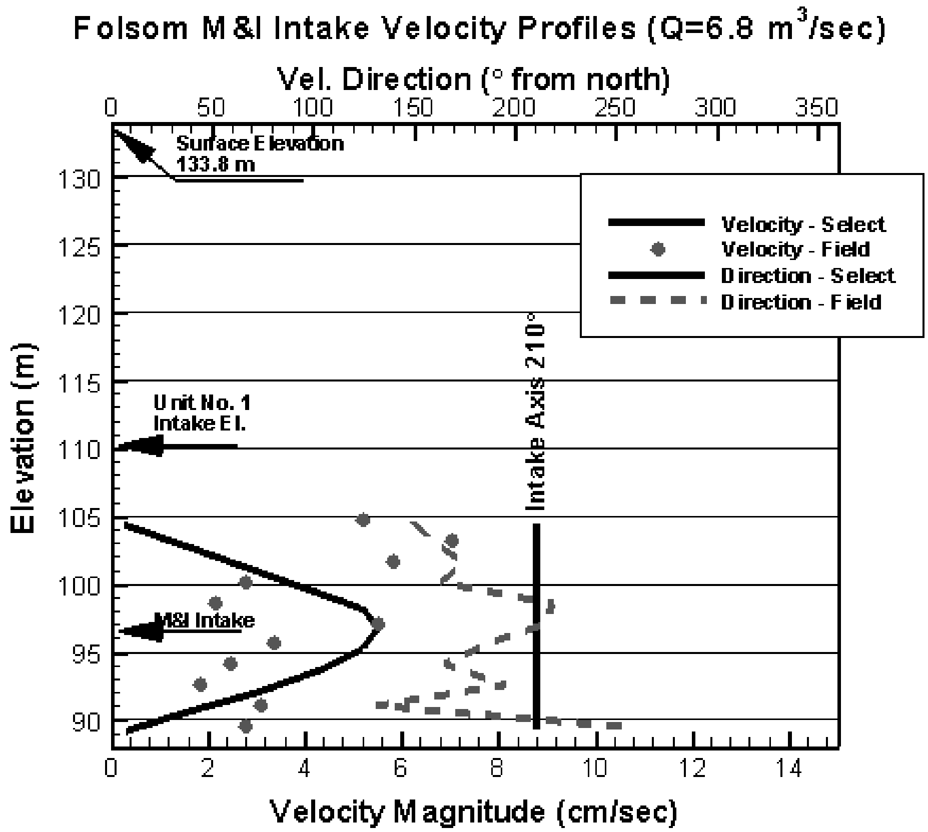

Figure 5. Comparison of velocity profiles measured in the field and those predicted using the SELECT model. Field velocities were collected about 7 meters upstream from the trashrack protecting the M&I intake. Note: the three uppermost field velocities appear to be influenced by flow towards Unit No. 1. which was drawing water from elevation 110.3 m.

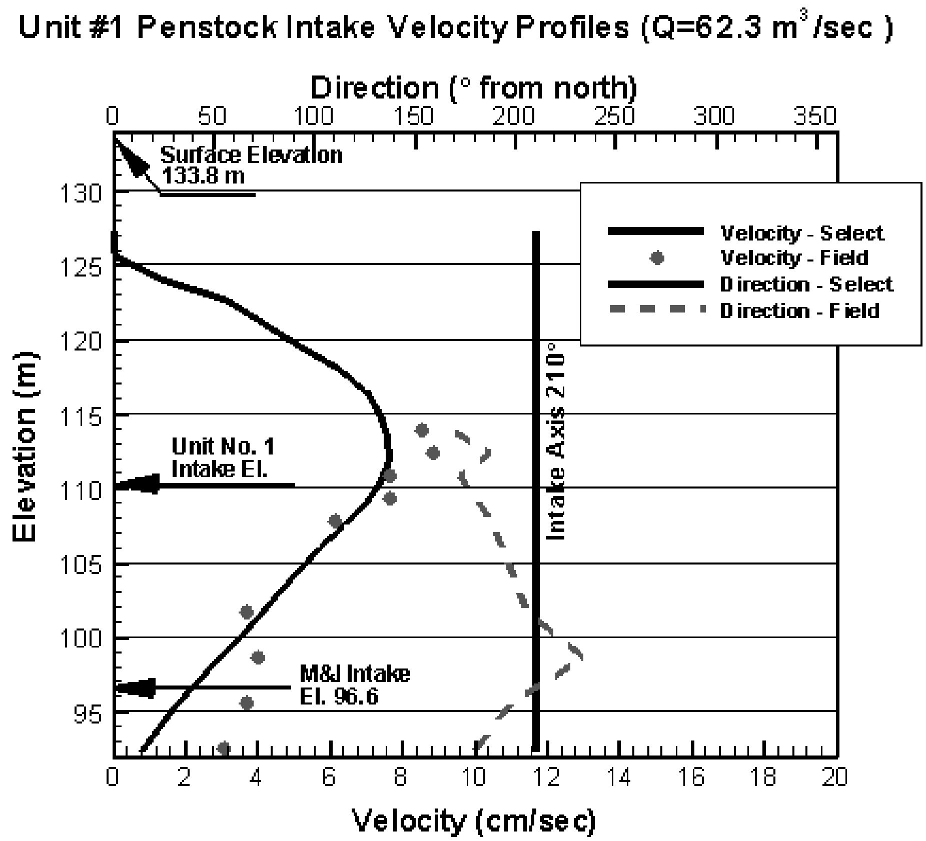

Figure 6. Comparison of velocity profiles measured in the field and those predicted using the SELECT model. Field measured velocities were collected about 6 meters upstream from Unit No. 1's trashrack. Velocities measured at elevations near 96.6m are affected by flows into the M&I intake.

Conclusions and Recommendations

The Argonaut-ADV was found to be an effective tool for making velocity profile measurements near two water intakes under thermally stratified conditions. However, the sampling rate is slower than a standard ADV and may require more time to collect mean velocity data with a comparable standard error. However, velocity accuracies depend more on the measurement environment than the sampling frequency of the instrument.

A useful Argonaut-ADV feature is that the can collect data autonomously, that is, while disconnected from a computer. For example, this application required measurements to be collected at depths beyond the 10-m length of a standard RS-232 communications cable. We have since purchased a 75-m RS-232 communications cable so that real-time data can be observed during data collection. Other useful features include the compass and tilt/roll sensors that compensate for instrument rotation and boat rotation, respectively. These data can be used to filter data that contain large fluctuations in pitch and roll.

An important Argonaut-ADV limitation is that boat translation cannot be resolved from the velocity readings. As a result, the platform deploying the instrument should be securely anchored in calm water to eliminate drifting.

ADVs are very useful field instrument when measurements are necessary in close proximity to a hydraulic structure or some other boundary. The Argonaut-ADV's robust construction makes it well suited for field applications where mean velocities are the primary interest. Because of the relatively slow sampling frequency (0.33 Hz), high frequency turbulence information is not available from this instrument.

The Argonaut-ADV is well suited for making measurement in a thermally stratified reservoir because a temperature sensor in the transducer body is used to compute the sonic velocity at the measurement location. ADCPs depth measurements are not compensated for temperature changes, so there can be a small errors in the ADCP reported depths.

The comparison between field measured and SELECT predicted velocity profiles shows that SELECT adequately computes the normalized velocity profiles for both intakes. However, because SELECT is a one-dimensional model it does not take into account the affects of other intakes operating at a different horizontal location. Both data sets (figures 5 and 6) show how velocities generated by flows into adjacent intakes can influence the velocities measured near the intake.

References

Bohan, J. P., and Grace, J. L., Jr., "Selective Withdrawal from Man-Made Lakes; Hydraulic Laboratory Investigation" Technical Report H-73-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1973.

Davis, J. E., Holland, J. P., Schneider, M. L., and Wilhelms, S. C., "SELECT: A Numerical One-Dimensional Model for Selective Withdrawal" Instruction Report E-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1987.

Smith, D. R., Wilhelms, S. C., Holland, J. P., Dortch, M. S., and Davis, J. E. "Improved Description of Selective Withdrawal Through Point Sinks," Technical Report E-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS., 1985.

Sontek/YSI Inc., "Argonaut-ADV Principles of Operation," http://www.sontek.com/princop/aadv/aadvpo.htm , July 2002.

Sontek/YSI Inc., "Argonaut-ADV Specifications," http://www.sontek.com/download/brochure/arg-adv.pdf, July 2002.