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Managing Water in the West

Hydraulic Laboratory Report HL-2006-07

Penstock Intake Velocity Survey at Glen Canyon Dam, September 2006

MIDDLE RIVER DIVISION – GLEN CANYON UNIT
COLORADO RIVER STORAGE PROJECT, ARIZONA-UTAH

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory
Denver, Colorado

November 2006

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14. ABSTRACT

A survey of the actual water currents around unit no. 6 during normal (2600 ft^3/sec) and high (3600 ft^3/sec) flows into unit nos. 5 and no. 7 at Glen Canyon Dam was performed in September 2006. The strongest horizontal currents were measured at the trashracks of the operational units (no. 5 and no. 7). Under steady flows, the maximum current measured was 1.64 ft/sec at El. 3458.8 ft near unit no.7 which was withdrawing 3600 ft^3/sec. For all 4 test conditions, there was at least a 48 ft envelope on either side of the unit no. 6 centerline where velocities were less than 0.4 ft/sec. Current magnitudes quickly dropped with distance from the operating unit's trashrack. Currents decreased to less than 0.4 ft/sec at a distance of 20 ft from the operating intake for high flows (3600 ft^3/sec). Similarly, currents decreased to less than 0.4 ft/sec at a distance of 15 ft from the operating intake for normal flows (2600 ft^3/sec).

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

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Cover Photograph: A view of Glen Canyon Dam and its penstock intake structures taken from the safety boom. Photograph was taken by the author.

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Executive Summary

A constructability review of the Glen Canyon Dam Temperature Control Device (TCD) recommended an underwater velocity survey be performed around proposed TCD intakes with adjacent units operating to determine water currents at the proposed TCD/dam connection elevations. Water current measurements were collected for normal and high flows into the penstock intakes adjacent to unit no. 6. The purpose of this survey was to provide contract bidders with water current data for the underwater environment that they may encounter during normal and high flow conditions. This data report will provide contract bidders with information to assist them in developing a safe and efficient diving plan.

There are five proposed TCD/dam connection points located between elevations 3562 ft and 3423 ft where velocities were of interest. Water current data will give the contract bidders critical information to plan their underwater work within the constraints of scheduled power unit outages. The Constructability Review Team recommended the current speed criteria of 0.4 ft/sec or lower as an acceptable working current for safe diving operations.

Based on the similarity of the spacing between adjacent penstock intakes at Glen Canyon Dam, the design team decided that current measurements around unit nos. 3, 4 and 5 were not necessary because the currents would be very similar to those measured around unit nos. 5, 6 and 7. A survey of the actual water currents around an offline unit no. 6 during normal (2600 ft^3/sec) and high (3600 ft^3/sec) flows into unit nos. 5 and 7 will be included in the construction specifications. The high flow was based on the reservoir water surface elevation at the time of the survey (El. 3601.8 ft - which was almost 100 ft below the full pool elevation) resulting in a high flow of 3600 ft^3/sec. The maximum flow for a single unit under full reservoir head is 4000 ft^3/sec.

The strongest horizontal currents were measured at or very near the trashracks of the operational unit nos. 5 and no. 7. Under steady flows, the maximum current measured was 1.64 ft/sec at El. 3458.8 ft near the unit no.7 intake which was withdrawing 3600 ft^3/sec. The highest current speeds were usually measured 61 ft in front of the dam face (as measured from the boat) and were progressively higher with proximity to the operating units. Currents decreased to less than 0.4 ft/sec at a distance of 20 ft from the operating intake trashracks for high flows (3600 ft^3/sec). Similarly, currents decreased to less than 0.4 ft/sec at a distance of 15 ft from the operating intake trashracks for normal flows (2600 ft^3/sec).

For all 4 test conditions, there was at least a 48 ft envelope on either side of the unit no. 6 centerline where currents were less than 0.4 ft/sec. Because of similarity in the spacing between units, this same 48 ft envelope can be expected around unit no. 4 centerline for similar flow conditions. These currents may vary a small degree for higher flow rates or different thermal stratification in Lake Powell.

Introduction

A constructability review of the Glen Canyon Dam Temperature Control Device (TCD) recommended that an underwater current survey be performed around proposed TCD intakes (unit nos. 4 and 6) with adjacent power units operating at high and normal flows to determine water currents at dam connection elevations. Constructing the TCD/dam connections will require the bulk of the diving effort. The review team felt the contract bidders would need this information to determine whether they could safely dive between elevations 3562 and 3423 without requiring outages for adjacent units. Likewise, the review team thought this velocity data would give the bidders the necessary information for planning underwater work around the constraints of scheduled unit outages.

The Glen Canyon TCD Design Team Leader requested the TSC's Water Resources Research Laboratory (WRRL) perform an underwater velocity survey around penstock intake no. 6 at Glen Canyon Dam. The WRRL provided the necessary equipment and personnel to collect the velocity data and the Glen Canyon Field Office provided a boat and operator during the data collection. The data collection plan was based on recommendations from the *Constructability Review Report Glen Canyon Dam Temperature Control Device* (Reclamation 2006). Based on the similarity of the spacing between adjacent penstock intakes at Glen Canyon Dam and experience gained collecting similar data at other Reclamation facilities, it was decided that current measurements around unit nos. 3, 4 and 5 were not necessary. See figure A1 in the appendix for a general plan view of Glen Canyon Dam.

The data presented in this report were collected near unit nos. 5, 6 and 7 over the period of September 26-28, 2006.

Background

Reclamation has constructed several temperature control devices over the past two decades. Typically, these are retro-fit structures which require extensive deep water diving operations during construction. As a result, it is common to collect current data around the penstock intake structures while the hydro-electric units are operating to provide diving contractors with information to develop safe diving plans. For example, in May 1994 Reclamation hired a contractor to collect water current velocity measurements at the Shasta Dam Penstocks (Deepsea Development Services, July 1994). Based on past experience and recommendations from the Constructability Review Team, it was decided that a similar data set be collected at Glen Canyon Dam in preparation for construction of two temperature control devices (two TCDs were determined to be the minimum number necessary to meet the Colorado River temperature goals).

Methods and Materials

Prior to shipping the velocity measurement equipment to Glen Canyon Dam, the equipment was checked for proper operation. During the system check, a new internal battery pack was installed and the system software was upgraded to the most recent version.

To collect data at the desired locations, a tagline was secured between adjacent trashrack structures using clamps attached to the trashrack guides. The tagline was oriented parallel to the dam face and was used to accurately position the velocity probe while collecting near-field velocity profiles. Maintaining a fixed position was a critical element for this data collection effort because the velocity probe will include any boat motion in the velocities it measures. With the exception of boat motion generated by boat wakes, the tagline and calm weather resulted in very little boat motion.

The profiling system consisted of a vertical anchor line with a 42-lb weight attached to a ¾-inch diameter nylon line. The anchor line was extended to a depth of approximately 300 ft. A Sontek/YSI® Argonaut-ADV was used to measure three-dimensional water velocities around the intakes (see figure 1). The manufacturer's specifications for the Argonaut ADV are listed in table 1.

A series of current profiles were collected at locations spaced 15, 31 and 61 ft from the face of Glen Canyon Dam as measured from the boat at reservoir elevation El. 3601.8 ft. Velocity measurements collected 61 ft from the dam were collected by positioning the boat using a two-point anchorage and maintaining position using the boat motor.

Table 1. Sontek/YSI® Argonaut-ADV specifications

Velocity
- Range: ±0.003 to 15 ft/sec
- Resolution: 0.0003 ft/sec
- Accuracy ±1% of measured velocity, ±0.003 ft/sec
- User programmable data output rate
- 3-D water velocity measurement

Temperature Sensor
- Resolution 0.01°C
- Accuracy ±0.1°C

Pressure Sensor
- Strain Gage (0.1 % accuracy)

The three-dimensional velocities were measured in earth coordinates, that is, velocities were referenced to east, north, and up directions using an internal flux-gate compass. The ADV is equipped with a pressure sensor and tilt sensors that are used to determine the ADV's depth and orientation, respectively. The Argonaut ADV was attached to the anchor line using a split section of 1-inch diameter PVC conduit that was clamped to the ADV (figure 1). The ADV was fitted with a 6-inch diameter disk which was used to prevent the ADV probe from passing through the trashrack openings. The ADV was lowered down the anchor line using a graduated line; the line was marked at the 5 TCD/dam connection depths to facilitate repeatable elevations during the measurements. Data were collected and monitored on a laptop computer. During post processing the data, the depths were also verified using

data from the ADV's internal pressure transducer. Likewise, velocity data were corrected for a local magnetic variation of 12.1° east during post processing. Throughout the velocity profiling, an integral temperature sensor was used to measure water temperature to perform real-time speed-of-sound corrections.

The penstock intake centerline elevation is located at 3470 ft above mean sea level or at a depth of 131 ft below the reservoir surface elevation (El. 3601.8 ft) during data collection.

Distances from the profiling location to the dam face and between trashrack structures were measured using an Impulse laser range finder. This range finder was accurate to the nearest 0.1 ft. Because the trashrack structure is sloped (0.17H to 1V) the location of the probe with respect to the trashrack structure varied depending on the measurement elevation (figure A2 in appendix).

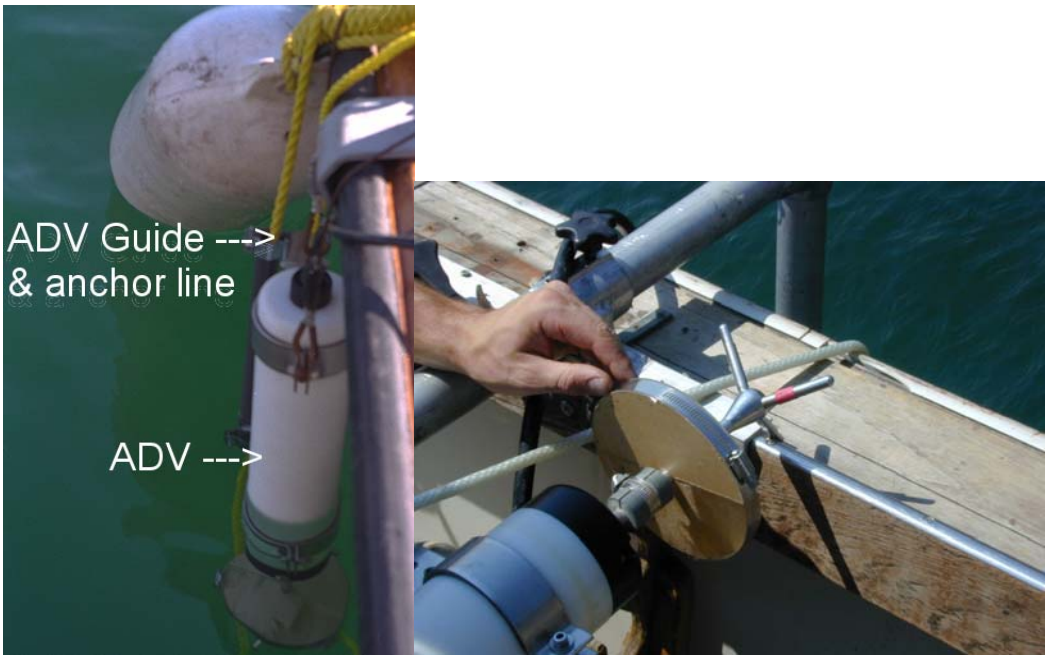

Figure 1. Photograph of the ADV and guide attached to the anchor line (left) and the ADV with a 6-inch diameter disk used to prevent the probe from entering the trashracks (right).

In general, this profiling system was effective at positioning the ADV at known positions and elevations. Data collection was time consuming because the Argonaut-ADV samples at a frequency of 10 times per second and accumulates 1-second averages over a user-defined averaging interval. The averaging interval used for this project was 30 seconds. Furthermore, because a single ADV measurement is inherently noisy it is good practice to average 100s, if not 1000s of acoustic pings to bring the velocity standard error (uncertainty) down to acceptable levels. For this project, at least 90 seconds (three data points) of data were averaged to determine the water velocity at each point.

Powerplant Operation

During the field data collection, Lake Powell's water surface elevation was constant at 3601.8 ft. Powerplant operations for the 4 data sets are summarized in table 2. Unit flowrates were held constant during the testing. As a result, steady flow conditions were maintained throughout each survey. Penstock flows for unit no. 5 and no. 7 were measured by Accusonic flowmeters (model 7500) mounted on the penstocks just upstream from the turbine scroll cases.

Table 2. Summary of powerplant operations for the 4 velocity data sets.

Date/Data Set	Unit No. 5 Flows (ft^3/sec)	Unit No. 6 Flows (ft^3/sec)	Unit No. 7 Flows (ft^3/sec)	Survey Location
9/26/2006 p.m. / No. 1	3600	0	2600	Between Unit nos. 6 and 7
9/27/2006 a.m. / No. 2	2600	0	3600	Between Unit nos. 6 and 7
9/27/2006 p.m. / No. 3	2600	0	3600	Between Unit nos. 5 and 6
9/28/2006 a.m. / No. 4	3600	0	2600	Between Unit nos. 5 and 6

Data Collection

A grid of velocity measurement points was developed based on the recommendations of the Constructability Review Team (Reclamation 2006). The grid consisted of 4 locations between two trashrack structures and five TCD/dam connection elevations (extending from El. 3562.8 down to El. 3423.8 ft, see figure 2). The spacing between verticals depended on distance between adjacent units. The clear distance between unit no. 5 and no. 6 trashrack structures is approximately 65.2 ft. Where clear distance is the spacing between two adjacent trashrack structures. Similarly, the clear distance between unit no. 6 and no. 7 trashrack structures is approximately 39 ft. The vertical measurement grid was repeated at 3 distances (15, 31, and 61 ft) normal to the dam face. A total of 60 velocity measurement locations made up the three-dimensional data grid for each of the four operational conditions tested. Table 3 contains a summary of the measurement locations and the distance from the dam face for dam connections between El. 3562.8 and El. 3423.8 ft. A drawing with the measurement locations and cross sectional profiles of the dam and trashrack structures is included in figure A2 in the appendix. It is important to note that because of the curve of the dam face some of the deeper measurements are much closer to the dam face than those collected higher in the water column. In fact, the three measurements collected 15 feet from the dam face for elevations 3493.8 to 3423.8 ft were

actually on the dam face. This observation was supported by the probe's pitch/roll readings for those particular measurements.

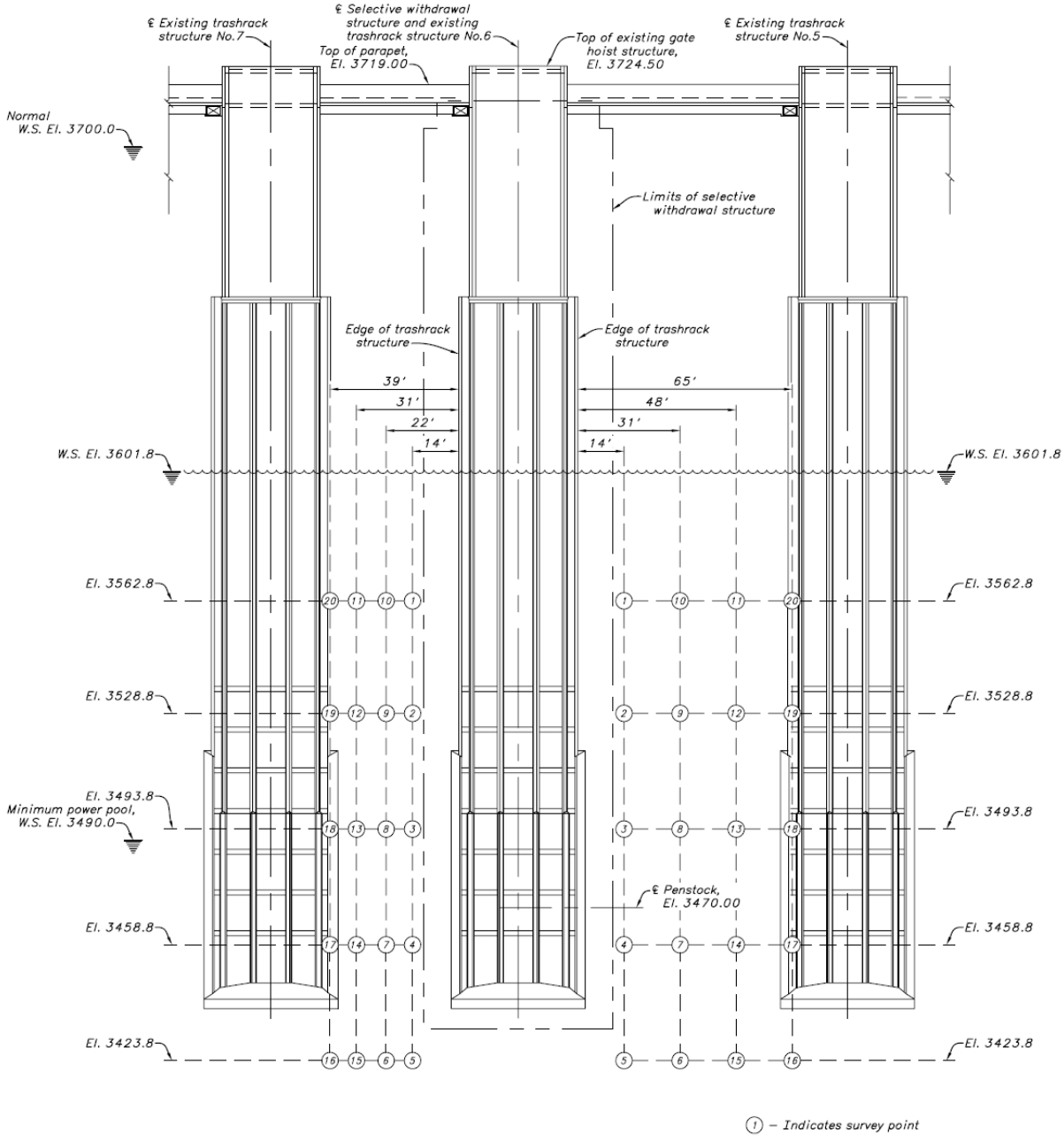

Figure 2. Illustration of velocity survey points collected on both sides of unit no. 6. These sampling grids represent two vertical planes of measurements collected. A total of three planes of data were collected at distances of 15, 31 and 61 ft away from the dam face (measured at El. 3601.8 ft). Each velocity survey point is numbered and represents the order in which measurements were collected.

Table 3. Summary of the 5 velocity measurement elevations and horizontal distances from the dam face at each TCD/dam connection elevation for 3 offset distances from the dam face. Figure A2 in the appendix shows these distances.

Measurement Elevation (ft)	Offset distance from the dam face for reservoir water surface El. 3601.8 ft		
	15 ft	31 ft	61 ft
3562.8	7.8	23.8	53.8
3528.8	2.4	18.4	48.4
3493.8	On dam face	13.6	43.6
3458.8	On dam face	9.6	39.6
3423.8	On dam face	6.4	36.4

During velocity measurements collected at El. 3458.8 ft, the ADV often got hung up on the unit nos. 5 and 7 trashracks. As a result, velocity measurements at deeper locations were aborted because of the risk the probe/cables could have become tangled in the trashracks. Another potential problem with measuring close to the trashracks is the effect of the steel trashracks on the accuracy of the ADV's internal flux-gate compass. As a result, the direction of the velocities measured near the trashrack may be biased, but the velocity magnitudes would not be affected. In general, horizontal current directions measured 61 ft away from dam face agreed with the radial direction toward the nearest operational unit.

A typical output screen from the Sontek/YSI® data acquisition software is shown in figure 3. This screen shows the three-dimensional velocity components in ft/sec. The upper graph shows east [red line], north [blue], and up [green] velocity components and the horizontal current speed (dashed line). Water pressure in lb/in^2 (psi) is plotted in the lower graph. This data sub-set is for a down cast and an upward cast between unit no. 6 and no. 7. Note how the vertical velocity component (green line) spikes when lowering (or raising) the probe. Velocity data collected during periods of constant pressure were processed to determine the average water current at those depths.

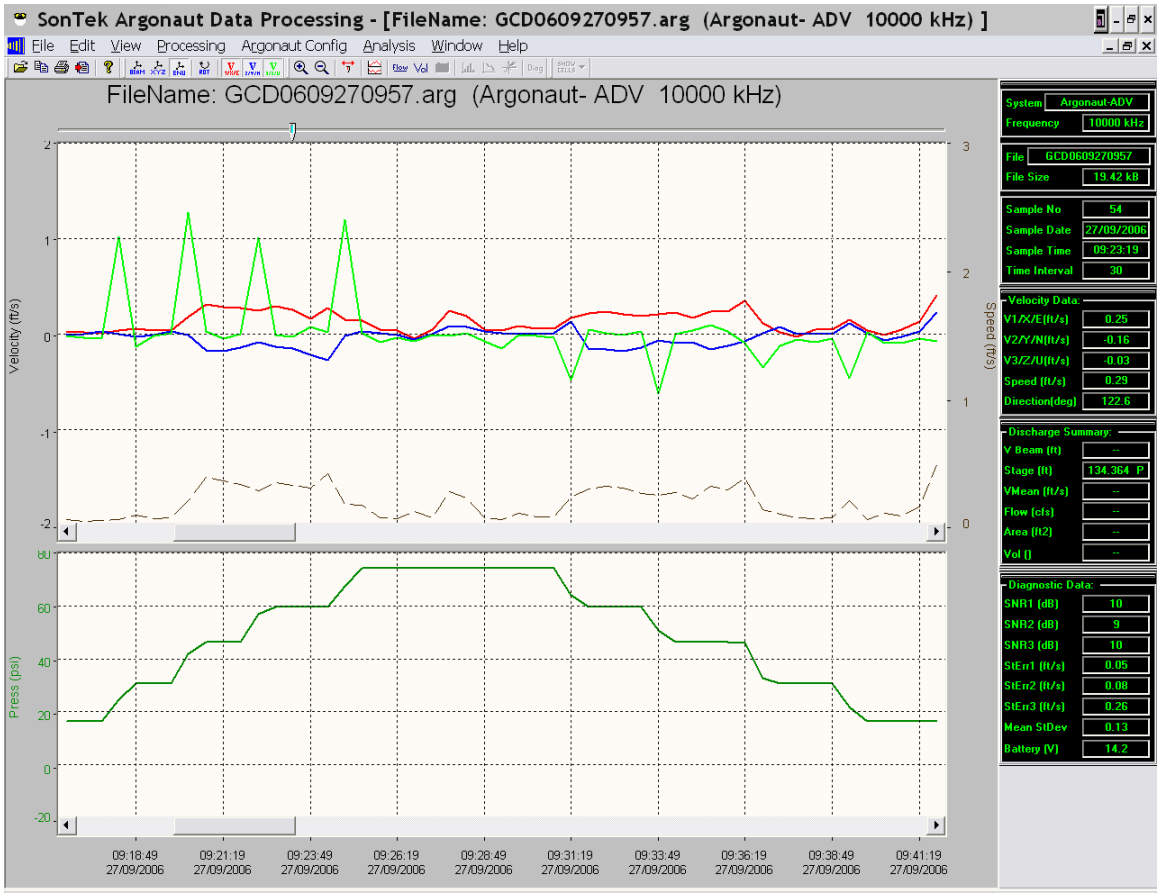

Figure 3. A view of the Sontek/YSI® View Argonaut data collection software showing velocities in the upper graph and pressure in the lower graph. The data shown in the right panels are for a single data point. This data is a subset of data set No. 2 collected the morning of 9/27/2006 between unit nos. 6 and no. 7.

On September 27, 2006 at 4:00 p.m., a far-field current profile was collected at the safety boom located about 1000 ft uplake from Glen Canyon Dam. The reason for collecting this velocity profile was to document the reservoir temperature profile (figure 4) and to identify any significant ambient currents that may influence velocities measured near the dam. The reservoir temperature profile (stratification) can be an important factor in the development of the velocity field (withdrawal zone) around the penstock intake structures. Thermal stratification can influence withdrawal zone characteristics, such as velocity distribution and the upper and lower limits of the withdrawal zone. As a result, currents near the operational penstock intakes may vary a small degree for higher flow rates or a different reservoir stratification.

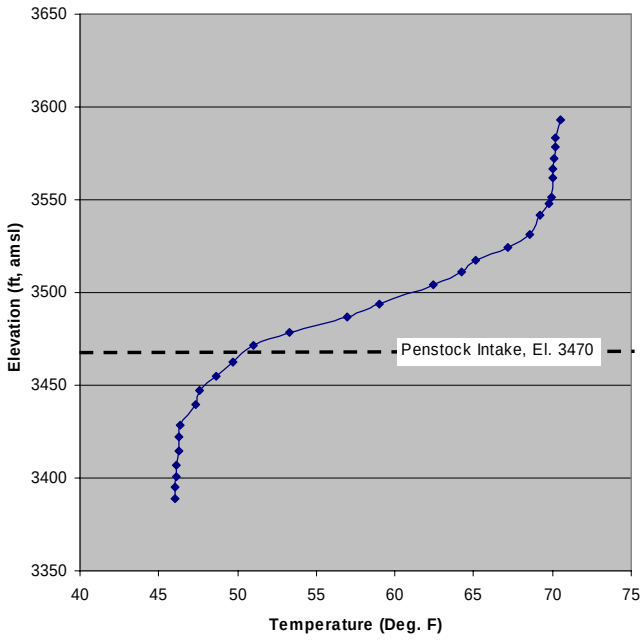

Figure 4. Plot of Glen Canyon Dam forebay temperature profile. This profile was collected while moored to the safety boom located about 1000 ft uplake from Glen Canyon Dam.

Results

Intake Velocities

A total of 4 data sets were collected and each set consisted of about 60 point velocity measurements. Two data sets were collected between unit nos. 6 and 7 for two flow rates - 2600 (normal) and 3600 ft^3/sec (high). Similarly, two data sets were collected between unit no. 5 and no. 6 for flow rates 2600 and 3600 ft^3/sec. Three-dimensional velocities measured are presented as horizontal current speeds. North and east velocities were combined to produce a resultant horizontal water speed and direction. The resultant speeds were combined into a 2-dimensional representation for three vertical planes offset from the dam face. Each figure contains three panels which represent current speeds at three distances (15, 31, and 61 ft) from the dam face. As previously discussed, the dam face is curved, so with increasing depth the probe is located closer to the dam face and penstock intake structure(s). The x-axis is the distance measured away from the edge of the unit no. 6 intake structure toward the adjacent unit. Consequently, the horizontal current speed increases with distance toward the operating adjacent unit. The y-axis is the elevation in feet above mean sea level (amsl). For clarity, contour ranges are identical for all three panels.

Plots of the velocity direction are not presented graphically since they are difficult to interpret because water moves into the penstock intakes in a radial direction, so the direction changes with every position. Furthermore, velocities measured outside the withdrawal zone have small magnitudes and their directions are more a function of boat motion and acoustic noise than actual water motion. If current direction is of interest, all velocity data are included in tables A1 to A4 in the appendix.

Horizontal Currents Measured Near Unit No. 6

Data Set No. 1

The horizontal currents for data set no. 1 are presented in figure 5. The figure contains three panels which represent 2-dimensional views of water currents at three distances offset by 15, 31 and 61 ft from the dam face. The first plot is for data collected 15 ft from the dam which shows water speeds at all elevations were less than 0.2 ft/sec. At a distance 31 ft from the dam face, the water speeds increase in the vicinity of penstock intake (El. 3470) for locations nearest to unit no. 7. Speeds approach 0.8 ft/sec near the unit no. 7 trashrack (x=39 ft), but quickly decrease to below 0.3 ft/sec at a distance of 31 ft from unit no. 6. The third contour plot shows that the strongest currents were measured at a distance of 61 ft from the dam face. A maximum current on this plot was 1.56 ft/sec at El. 3458.8 ft. This current was measured very close to the trashrack because the probe was hung up for a short period when we attempted to lower it to El. 3423.8 ft. Once again, the speeds decreased to about 0.3 ft/sec at a distance of 31 ft from unit no. 6 trashrack. However, water currents measured 61 ft from the dam face at elevations 3458.8 and 3493.8 ft were about 0.2 ft/sec all the way to within 14 ft of unit no. 6 trashrack.

Data Set No. 2

The currents for data set no. 2 are presented in figure 6. The first plot is for data collected 15 ft from the dam. This plot shows that water speeds at all elevations were less than 0.2 ft/sec. At a distance 31 ft from the dam face, the water speeds were about 0.2 ft/sec at El. 3458.8 and El. 3493.8 ft for locations nearest to unit no. 7. The reason why these velocities were less than those in data set no. 1 is not known, but was likely attributed to uncertainty in the probe location with respect to distance from the unit no. 7 trashrack. The third contour plot illustrates that the strongest currents were measured at a distance of 61 ft from the dam face and closest to the unit no. 7 trashrack. The maximum speed measured was 1.64 ft/sec at El. 3458.8 ft. This speed was only slightly higher than the data set no.1 speed even though inflow was significantly higher. Again, this may be related to the uncertainty in the distance from the unit no. 7 trashrack structure. The water speeds decreased to less than 0.4 ft/sec at a distance of 31 ft from unit no. 6. Similar to data set no. 1, water currents at elevations 3458.8 and 3493.8 were about 0.2 ft/sec all the way to within 14 ft of the unit no. 6 trashrack.

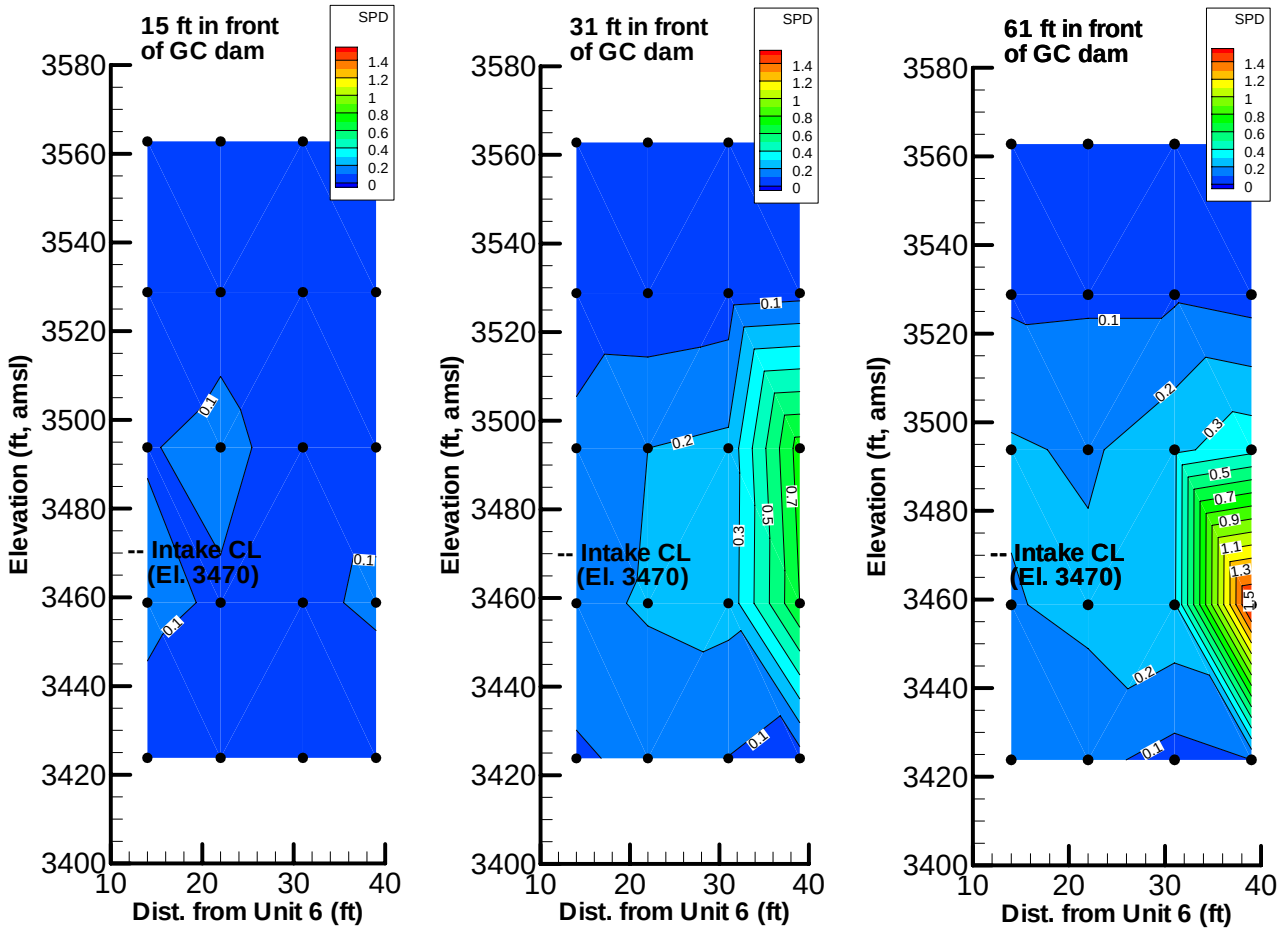

Figure 5. Data set no. 1 intake currents measured between unit nos. 6 and 7 and with unit no. 7 running at 2600 ft^3/sec. Panels from left to right are incrementally offset further from the dam face.

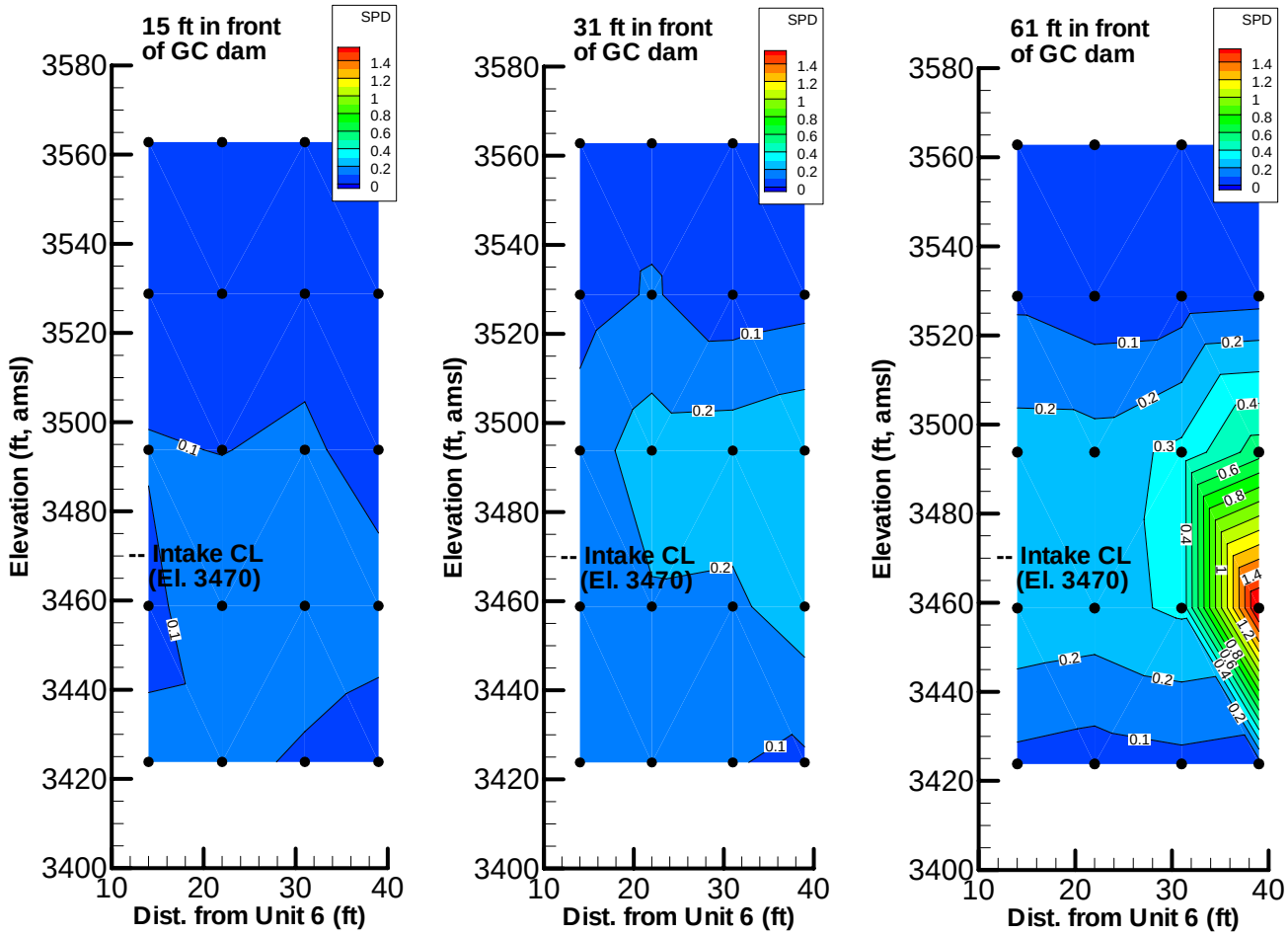

Figure 6. Data set no. 2 intake currents measured between unit nos. 6 and 7 and with unit no. 7 running at 3600 ft^3/sec. Panels from left to right are incrementally offset further from the dam face.

In general, water currents measured between unit no. 6 and no. 7 indicate that currents increase with distance uplake from the dam face and with proximity to operating unit no. 7. However, these data indicate that water currents below 0.4 ft/sec can be expected for clear distances from 0 to 31 ft away from the unit no. 6 trashrack structure for unit no. 7 flows up to 3600 ft^3/sec.

Data Set No. 3

The currents for data set no. 3 are presented in figure 7. The first plot is for data collected 15 ft from the dam which shows that water speeds at all elevations were less than 0.2 ft/sec. At a distance 31 ft from the dam face, a maximum water speed of 1.50 ft/sec was measured at El. 3458.8 ft for the location nearest to unit no. 5 (x=65 ft). However, current speed decreased to below 0.3 ft/sec at a distance of 48 ft from unit no. 6. The reason for the high velocities at this location was that the probe was in contact with unit no. 5 trashracks. This assertion was confirmed when we attempted to lower the probe to El. 3423.8 ft and the probe was hung-up on the trashracks. The third contour plot shows the current speeds were lower than those measured 31 ft from the dam face. The maximum speed measured was 0.34 ft/sec at El. 3458.8 ft.

For all plots, the water currents decreased to around 0.2 ft/sec at a clear distance of 38 ft from unit no. 6.

Data Set No. 4

The currents for data set no. 4 are presented in figure 8. The first plot of current speeds, measured 15 ft from the dam face, shows that water speeds at all locations were less than 0.2 ft/sec. At a distance 31 ft from the dam face, the water speed increased to 0.24 ft/sec at El. 3458.8 ft for the point nearest to unit no. 5. Currents quickly decreased to below 0.2 ft/sec at a clear distance of 31 ft from unit no. 6. The third contour plot shows the currents measured 61 ft from the dam face were somewhat faster than those measured 31 ft away. The maximum speed measured was 0.53 ft/sec at El. 3458.8 ft.

In general, the water current measurements between unit no. 5 and no. 6 indicate that currents increase with distance uplake from the dam face and proximity to operating unit no. 5. However, these data indicate that water currents below 0.4 ft/sec can be expected for clear distances from 0 to 48 ft away from the unit no. 6 trashrack structure.

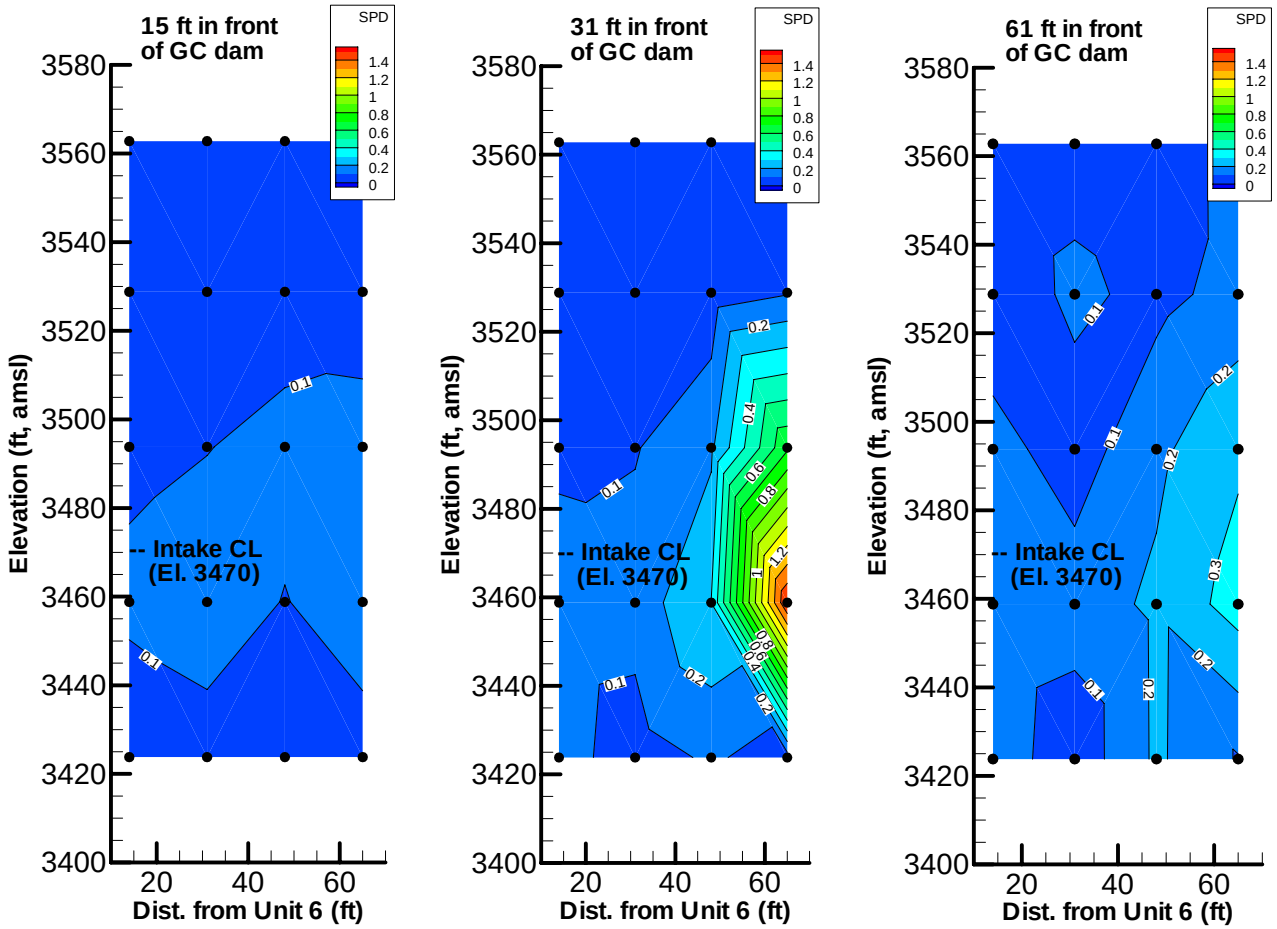

Figure 7. Data set no. 3 intake velocity fields measured between unit nos. 5 and 6 and with unit no. 5 running at 2600 ft^3/sec. Panels from left to right are incrementally offset further from the dam face.

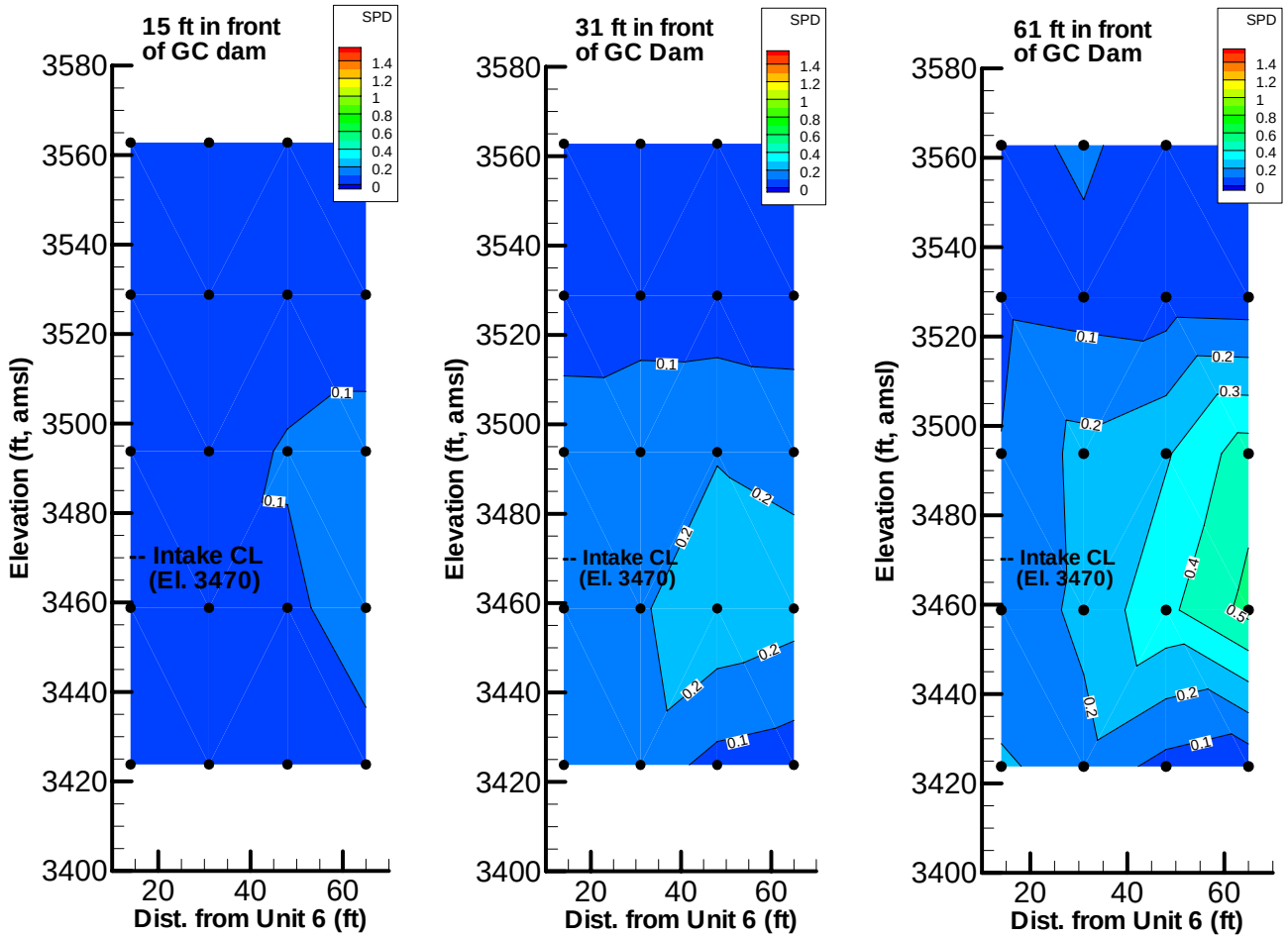

Figure 8. Data set no. 4intake velocity fields measured between unit nos. 5 and 6 and with unit no. 5 running at 3600 ft^3/sec. Panels from left to right are incrementally offset further from the dam face.

Water Current Uncertainties

An analysis of the uncertainties in the Argonaut ADV velocity data revealed that horizontal current speeds have an average standard error of ±0.04 ft/sec and the average standard error in current direction is ±50 degrees. The low value of the standard error of the current speeds is an indicator of acceptable data quality. The large value of standard error of current direction is related to the radial velocity field around the intake structure and with potential compass errors associated with close proximity to the steel trashracks. For example, current data collected 61 ft from the dam face can vary in direction from parallel to nearly perpendicular to the dam face depending on ADV position with respect to the operating unit. However, a review of current direction data in appendix tables A1 to A4 shows that the individual standard error of current direction were reasonable (less than 10°) for current measurements collected in the withdrawal zone.

Vertical Velocities

Vertical velocities were analyzed, but not plotted because they were relatively small when compared to the horizontal water speed. The average magnitude of all vertical currents was 0.05 ft/sec. No vertical currents greater than 0.20 ft/sec were measured. At the three lowest elevations, the vertical currents were stronger but were, on average, less than 0.1 ft/sec. As expected, the vertical currents in the withdrawal zone were directed downward for El. 3493.8 ft and were upward for elevations 3458.8 and 3423.8 ft because of their location with respect to the penstock intake centerline elevation (El. 3470 ft).

Forebay Temperature Profile

As shown in figure 5, Lake Powell was thermally stratified during velocity data collection. The epilimnion (mixed surface layer) extended from the water surface down to El. 3540 ft and was about 70 °F. The thermocline extended from El. 3540 to El. 3430 ft which encompasses the penstock intake centerline (El. 3470 ft). The hypolimnion (cold water layer) extends from the bottom of the thermocline to the reservoir floor and was about 46 °F. The observed thermal stratification was weaker than a mid-summer profile. The weaker stratification may have had a small impact on the water currents measured. For example, a stronger thermocline could restrict the withdrawal zone limits and result in somewhat stronger horizontal currents.

Forebay Velocity Profile

A velocity profile collected in the forebay to Glen Canyon Dam was collected to document the far-field currents generated by penstock withdrawals of 11,000 ft^3/sec. The profile was collected about 1000 ft uplake (at the safety boom) from

Glen Canyon Dam (see cover photograph or figure A1 in the appendix). Forebay velocity data were post-processed to obtain average velocity values at each sample elevation. In general, the average horizontal currents were less than 0.3 ft/sec and were characterized by relatively high standard errors. The high standard errors indicate a high degree of uncertainty in the average velocity data. The reason for this uncertainty is likely attributed to boat motion during data collection. The wind was increasing during the forebay measurements and was starting to generate some waves. Boat motion was minimized by mooring to the safety boom, but motion could not be eliminated.

The forebay velocity profile data did show that currents above El. 3531 ft, in the epilimnion (mixed surface layer), were directed away from the dam (northwesterly) and had an average speed and standard error equal to 0.02 and ±0.11 ft/sec, respectively. Similarly, currents below El. 3531 ft were predominantly directed toward the dam (southeasterly) and had an average speed and standard error equal to 0.20 and ±0.47 ft/sec, respectively. Table A5 in the appendix A contains the forebay current profile data.

Conclusions

The strongest horizontal currents were measured on the trashracks of the operational units (no. 5 and no. 7). Under steady flows, the maximum current measured was 1.64 ft/sec at El. 3458.8 ft near unit no. 7 which was withdrawing 3600 ft^3/sec.

Current magnitudes quickly dropped with distance from the operating unit's trashrack. Currents decreased to less than 0.4 ft/sec at a distance of 20 ft from the operating intake for high flows (3600 ft^3/sec). Similarly, currents decreased to less than 0.4 ft/sec at a distance of 15 ft from the operating intake for normal flows (2600 ft^3/sec).

For all 4 test conditions, there was at least a 48 ft envelope on either side of the non-operating unit no. 6 centerline where velocities are less than 0.4 ft/sec. Because of similarity in the spacing between penstock intake structures, this same 48 ft envelope can be expected around the unit no. 4 centerline for similar flow conditions.

It is important to note that current magnitudes are a function of reservoir water surface elevation, discharge, proximity to an operating intake, and reservoir stratification. As a result, currents in the vicinity of unit nos. 4 and 6 could be somewhat higher than those measured during this 3-day survey.

Current directions varied with distance from the dam face. For offset distances less than or equal to 31 ft, currents were primarily parallel to the dam face. For

offset distances greater than 31 ft, the currents were directed radially toward the operating intake structure.

Horizontal currents were typically greater than vertical current components, except when waves affected the readings. Wave action was minimal during the data collection, except for occasional boat wakes.

References

Deepsea Development Services, *Water Current Velocity Measurements at the Shasta Dam Penstocks, May 1994.* Prepared for Harza Engineering Company, Chicago, IL 60606, and July, 1994.

Bureau of Reclamation, *Constructability Review Report, Glen Canyon Dam Temperature Control Device. Final Report*. August 22, 2006

Appendix – Tables of Current Data and Supplemental Figures

Table A1. Velocity data collected between unit nos. 6 and 7 for a flow of 2600 ft^3/sec entering unit no. 7. Coordinates x, y, and z represent distance from unit no. 6, distance offset from the dam, and depth, respectively.

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	15	39	3562.8	1	0.05	100.3	-0.19	0.04	82.5
14	15	73	3528.8	2	0.04	54.4	-0.11	0.01	21.7
14	15	108	3493.8	3	0.10	259.0	-0.06	0.07	36.7
14	15	143	3458.8	4	0.12	204.2	-0.05	0.01	41.6
14	15	178	3423.8	5	0.07	150.5	-0.06	0.04	102.2
22	15	178	3423.8	6	0.02	182.2	-0.02	0.00	32.8
22	15	143	3458.8	7	0.09	142.1	-0.02	0.06	140.6
22	15	108	3493.8	8	0.12	168.9	-0.10	0.09	27.8
22	15	73	3528.8	9	0.07	168.5	-0.15	0.05	137.3
22	15	39	3562.8	10	0.08	86.1	-0.08	0.07	80.0
31	15	39	3562.8	11	0.03	72.7	-0.08	0.01	22.4
31	15	73	3528.8	12	0.03	212.0	-0.17	0.02	157.2
31	15	108	3493.8	13	0.06	91.6	-0.10	0.06	10.9
31	15	143	3458.8	14	0.08	37.8	-0.04	0.03	24.1
31	15	178	3423.8	15	0.03	131.2	-0.03	0.01	36.0
39	15	178	3423.8	16	0.03	88.3	-0.04	0.02	26.6
39	15	143	3458.8	17	0.12	48.6	0.01	0.03	12.0
39	15	108	3493.8	18	0.06	342.8	0.01	0.03	20.4
39	15	73	3528.8	19	0.02	170.2	-0.09	0.01	142.8
39	15	39	3562.8	20	0.02	155.3	-0.09	0.01	104.5
14	31	39	3562.8	21	0.05	273.1	-0.06	0.02	43.2
14	31	73	3528.8	22	0.04	114.0	-0.14	0.02	39.6
14	31	108	3493.8	23	0.13	79.1	-0.04	0.02	60.7
14	31	143	3458.8	24	0.17	74.8	0.01	0.10	28.7
14	31	178	3423.8	25	0.08	159.1	-0.10	0.05	60.1
22	31	178	3423.8	26	0.13	145.1	-0.06	0.11	40.3
22	31	143	3458.8	27	0.21	81.3	0.01	0.04	16.1
22	31	108	3493.8	28	0.20	81.0	0.02	0.02	3.5
22	31	73	3528.8	29	0.03	143.6	-0.08	0.01	53.4
22	31	39	3562.8	30	0.03	264.4	-0.09	0.01	27.4
31	31	39	3562.8	31	0.08	190.1	-0.08	0.06	106.6
31	31	73	3528.8	32	0.05	274.9	-0.10	0.03	48.9
31	31	108	3493.8	33	0.22	70.3	0.06	0.06	9.8
31	31	143	3458.8	34	0.23	67.4	0.03	0.07	37.9
31	31	178	3423.8	35	0.10	138.5	-0.08	0.04	49.6
39	31	178	3423.8	36	n/a	n/a	n/a	n/a	n/a
39	31	143	3458.8	37	n/a	n/a	n/a	n/a	n/a
39	31	108	3493.8	38	0.75	88.5	-0.09	0.02	1.6
39	31	73	3528.8	39	0.07	209.4	-0.11	0.05	96.7
39	31	39	3562.8	40	0.09	147.3	-0.14	0.07	93.2

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	61	39	3562.8	41	0.08	173.3	-0.03	0.06	83.0
14	61	73	3528.8	42	0.08	201.6	-0.08	0.06	127.7
14	61	108	3493.8	43	0.22	153.0	0.01	0.05	14.2
14	61	143	3458.8	44	0.19	94.2	-0.02	0.06	20.3
14	61	178	3423.8	45	0.15	107.7	-0.09	0.06	23.6
22	61	178	3423.8	46	0.13	185.3	-0.15	0.06	65.3
22	61	143	3458.8	47	0.23	94.6	0.05	0.05	8.0
22	61	108	3493.8	48	0.18	129.6	0.03	0.04	7.3
22	61	73	3528.8	49	0.09	74.1	-0.07	0.02	47.6
22	61	39	3562.8	50	0.08	219.7	-0.14	0.03	74.8
31	61	39	3562.8	51	0.05	251.6	0.01	0.02	23.3
31	61	73	3528.8	52	0.09	118.2	-0.06	0.08	55.1
31	61	108	3493.8	53	0.27	129.0	0.01	0.05	4.4
31	61	143	3458.8	54	0.28	122.5	0.02	0.05	4.3
31	61	178	3423.8	55	0.06	173.2	-0.13	0.03	112.1
39	61	178	3423.8	56	n/a	n/a	n/a	n/a	n/a
39	61	143	3458.8	57	1.56	129.2	0.11	0.02	6.7
39	61	108	3493.8	58	0.37	126.8	-0.09	0.02	13.9
39	61	73	3528.8	59	0.05	219.2	-0.11	0.04	94.5
39	61	39	3562.8	60	0.04	268.2	-0.09	0.03	25.8

Table A2. Velocity data collected between unit nos. 6 and 7 for a flow of 3600 ft^3/sec entering unit no. 7. Coordinates x, y, and z represent distance from unit no. 6, distance offset from the dam, and depth, respectively.

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	15	39	3562.8	1	0.06	90.47	0.00	0.03	87.86
14	15	73	3528.8	2	0.03	136.60	-0.12	0.02	79.23
14	15	108	3493.8	3	0.11	302.75	-0.10	0.04	4.88
14	15	143	3458.8	4	0.07	189.43	-0.06	0.02	148.77
14	15	178	3423.8	5	0.13	111.37	-0.10	0.08	96.42
22	15	178	3423.8	6	0.13	60.93	-0.14	0.06	10.79
22	15	143	3458.8	7	0.19	202.80	-0.10	0.03	117.73
22	15	108	3493.8	8	0.10	245.60	-0.01	0.04	30.55
22	15	73	3528.8	9	0.05	91.23	-0.09	0.04	70.10
22	15	39	3562.8	10	n/a	n/a	n/a	n/a	n/a
31	15	39	3562.8	11	n/a	n/a	n/a	n/a	n/a
31	15	73	3528.8	12	0.05	165.35	-0.05	0.04	134.59
31	15	108	3493.8	13	0.12	278.20	-0.06	0.10	27.97
31	15	143	3458.8	14	0.17	175.93	-0.10	0.01	174.88
31	15	178	3423.8	15	0.08	66.73	-0.10	0.04	42.99
39	15	178	3423.8	16	0.04	96.47	-0.06	0.06	73.90
39	15	143	3458.8	17	0.15	79.06	-0.10	0.04	25.34
39	15	108	3493.8	18	0.05	114.63	-0.08	0.02	96.65
39	15	73	3528.8	19	n/a	n/a	n/a	n/a	n/a
39	15	39	3562.8	20	n/a	n/a	n/a	n/a	n/a

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	31	39	3562.8	21	0.05	155.70	-0.05	0.03	26.33
14	31	73	3528.8	22	0.06	312.30	-0.09	0.04	0.00
14	31	108	3493.8	23	0.15	67.20	-0.01	0.03	9.55
14	31	143	3458.8	24	0.18	91.93	0.05	0.09	19.40
14	31	178	3423.8	25	0.19	111.75	-0.07	0.01	53.39
22	31	178	3423.8	26	0.13	11.75	-0.10	0.01	7.71
22	31	143	3458.8	27	0.19	128.93	0.03	0.05	26.45
22	31	108	3493.8	28	0.25	83.03	0.04	0.06	20.02
22	31	73	3528.8	29	0.11	70.03	-0.11	0.08	49.64
22	31	39	3562.8	30	0.06	182.97	-0.08	0.03	37.99
31	31	39	3562.8	31	0.03	167.97	-0.06	0.02	26.85
31	31	73	3528.8	32	0.04	222.35	-0.09	0.04	91.43
31	31	108	3493.8	33	0.26	76.88	0.04	0.07	12.30
31	31	143	3458.8	34	0.18	68.08	0.05	0.03	8.54
31	31	178	3423.8	35	0.11	125.58	-0.10	0.05	87.17
39	31	178	3423.8	36	0.08	232.65	-0.13	0.05	41.70
39	31	143	3458.8	37	0.26	62.27	0.04	0.03	7.52
39	31	108	3493.8	38	0.29	53.75	-0.01	0.05	5.11
39	31	73	3528.8	39	0.06	106.50	-0.10	0.06	14.25
39	31	39	3562.8	40	n/a	n/a	n/a	n/a	n/a
14	61	39	3562.8	41	0.07	78.00	-0.08	0.04	0.57
14	61	73	3528.8	42	0.08	90.00	-0.05	0.03	9.33
14	61	108	3493.8	43	0.25	111.23	0.01	0.14	11.18
14	61	143	3458.8	44	0.28	116.33	0.03	0.07	4.99
14	61	178	3423.8	45	0.07	207.33	-0.06	0.02	125.71
22	61	178	3423.8	46	0.05	97.97	-0.07	0.03	3.56
22	61	143	3458.8	47	0.27	130.20	0.01	0.02	2.20
22	61	108	3493.8	48	0.25	121.08	0.03	0.04	4.46
22	61	73	3528.8	49	0.04	95.75	-0.07	0.01	14.50
22	61	39	3562.8	50	0.05	140.00	-0.07	0.03	56.45
31	61	39	3562.8	51	0.04	121.67	0.00	0.04	10.77
31	61	73	3528.8	52	0.04	100.53	-0.06	0.02	41.68
31	61	108	3493.8	53	0.33	121.33	-0.02	0.03	2.61
31	61	143	3458.8	54	0.32	130.43	0.01	0.05	13.59
31	61	178	3423.8	55	0.07	102.63	-0.05	0.06	25.11
39	61	178	3423.8	56	n/a	n/a	n/a	n/a	n/a
39	61	143	3458.8	57	1.64	94.45	0.01	0.21	2.91
39	61	108	3493.8	58	0.56	133.98	-0.09	0.08	3.79
39	61	73	3528.8	59	0.06	78.73	0.02	0.02	17.78
39	61	39	3562.8	60	0.02	144.95	-0.07	0.01	31.75

Table A3. Velocity data collected between unit nos. 5 and 6 for a flow of 2600 ft^3/sec entering unit no. 5. Coordinates x, y, and z represent distance from unit no. 6, distance offset from the dam, and depth, respectively.

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	15	39	3562.8	1	0.03	178.6	-0.05	0.02	8.0
14	15	73	3528.8	2	0.02	37.1	-0.14	0.02	48.9
14	15	108	3493.8	3	0.07	208.0	-0.10	0.08	19.6
14	15	143	3458.8	4	0.13	238.2	-0.07	0.12	24.8
14	15	178	3423.8	5	0.02	189.0	-0.08	0.01	20.4
31	15	178	3423.8	6	0.06	76.4	-0.03	0.04	15.8
31	15	143	3458.8	7	0.15	214.3	0.02	0.03	26.3
31	15	108	3493.8	8	0.10	195.9	-0.03	0.04	43.6
31	15	73	3528.8	9	0.03	105.9	-0.06	0.01	10.4
31	15	39	3562.8	10	0.03	67.1	-0.05	0.00	58.3
48	15	39	3562.8	11	0.01	109.7	-0.06	0.01	170.8
48	15	73	3528.8	12	0.05	314.5	-0.10	0.06	48.8
48	15	108	3493.8	13	0.13	236.6	-0.03	0.06	1.9
48	15	143	3458.8	14	0.10	243.4	0.04	0.01	10.0
48	15	178	3423.8	15	0.02	184.5	-0.09	0.01	172.8
65	15	178	3423.8	16	0.06	125.6	-0.05	0.03	196.5
65	15	143	3458.8	17	0.15	235.1	0.03	0.07	43.8
65	15	108	3493.8	18	0.15	207.7	0.02	0.03	26.3
65	15	73	3528.8	19	0.04	215.1	-0.05	0.03	172.1
65	15	39	3562.8	20	0.05	271.5	-0.05	8.91	60.3
14	31	39	3562.8	21	0.02	119.7	-0.10	0.01	130.0
14	31	73	3528.8	22	0.03	152.4	-0.07	0.02	61.8
14	31	108	3493.8	23	0.08	126.6	-0.02	0.01	23.8
14	31	143	3458.8	24	0.15	184.8	-0.07	0.10	51.7
14	31	178	3423.8	25	0.14	155.3	-0.12	0.09	43.2
31	31	178	3423.8	26	0.05	239.9	-0.15	0.03	70.1
31	31	143	3458.8	27	0.14	206.3	-0.05	0.07	37.0
31	31	108	3493.8	28	0.09	140.3	-0.06	0.06	107.3
31	31	73	3528.8	29	0.09	112.5	-0.09	0.03	86.7
31	31	39	3562.8	30	0.02	255.2	-0.07	0.02	28.1
48	31	39	3562.8	31	0.03	218.6	-0.02	0.01	54.7
48	31	73	3528.8	32	0.04	195.5	-0.08	0.05	70.8
48	31	108	3493.8	33	0.18	214.2	-0.01	0.04	4.4
48	31	143	3458.8	34	0.30	191.3	0.05	0.02	4.8
48	31	178	3423.8	35	0.11	19.1	-0.11	0.06	6.2
65	31	178	3423.8	36	n/a	n/a	n/a	n/a	n/a
65	31	143	3458.8	37	1.50	266.9	-0.11	0.02	13.7
65	31	108	3493.8	38	0.68	201.1	-0.16	0.05	5.0
65	31	73	3528.8	39	0.09	165.7	-0.10	0.06	119.9
65	31	39	3562.8	40	0.04	28.8	-0.08	0.02	18.2
14	61	39	3562.8	41	0.04	99.3	-0.07	0.04	18.0
14	61	73	3528.8	42	0.03	233.7	0.00	0.02	141.7
14	61	108	3493.8	43	0.14	162.8	-0.03	0.11	60.1

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	61	143	3458.8	44	0.18	158.1	0.03	0.05	14.7
14	61	178	3423.8	45	0.16	226.7	-0.12	0.07	98.7
31	61	178	3423.8	46	0.03	168.6	-0.17	0.02	86.2
31	61	143	3458.8	47	0.15	181.5	0.02	0.01	10.9
31	61	108	3493.8	48	0.05	239.0	-0.06	0.01	10.4
31	61	73	3528.8	49	0.12	116.0	0.00	0.06	98.1
31	61	39	3562.8	50	0.06	102.2	-0.06	0.03	17.9
48	61	39	3562.8	51	0.04	56.6	-0.04	0.04	48.7
48	61	73	3528.8	52	0.07	22.5	-0.01	0.04	10.9
48	61	108	3493.8	53	0.18	181.5	0.01	0.04	23.5
48	61	143	3458.8	54	0.22	178.6	0.07	0.09	23.8
48	61	178	3423.8	55	0.22	146.6	-0.12	0.02	4.5
65	61	178	3423.8	56	0.09	137.8	-0.13	0.03	68.1
65	61	143	3458.8	57	0.34	169.9	0.11	0.09	15.8
65	61	108	3493.8	58	0.28	197.4	0.03	0.05	17.9
65	61	73	3528.8	59	0.14	131.6	-0.02	0.04	97.4
65	61	39	3562.8	60	0.14	307.0	-0.06	0.14	18.9

Table A4. Velocity data collected between unit nos. 5 and 6 for a flow of 3600 ft^3/sec entering unit no. 5. Coordinates x, y, and z represent distance from unit no. 6, distance offset from the dam, and depth, respectively.

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	15	39	3562.8	1	0.02	246.0	-0.05	0.01	84.2
14	15	73	3528.8	2	0.02	145.6	-0.08	0.00	183.5
14	15	108	3493.8	3	0.03	51.3	-0.07	0.01	47.8
14	15	143	3458.8	4	0.04	65.1	-0.09	0.04	11.9
14	15	178	3423.8	5	0.04	263.0	-0.04	0.02	3.4
31	15	178	3423.8	6	0.02	196.9	-0.01	0.02	106.2
31	15	143	3458.8	7	0.07	218.8	-0.05	0.02	86.7
31	15	108	3493.8	8	0.04	142.5	-0.03	0.01	39.2
31	15	73	3528.8	9	0.02	256.8	-0.06	0.00	104.8
31	15	39	3562.8	10	0.01	305.0	-0.06	0.01	51.8
48	15	39	3562.8	11	0.04	207.4	-0.02	0.03	103.1
48	15	73	3528.8	12	0.02	141.3	-0.06	0.01	37.2
48	15	108	3493.8	13	0.11	220.2	0.02	0.01	8.2
48	15	143	3458.8	14	0.07	194.2	0.01	0.02	52.7
48	15	178	3423.8	15	0.06	214.6	-0.04	0.03	57.1
65	15	178	3423.8	16	0.07	165.0	0.07	0.07	165.0
65	15	143	3458.8	17	0.16	230.6	0.00	0.02	2.1
65	15	108	3493.8	18	0.15	226.9	-0.02	0.02	2.2
65	15	73	3528.8	19	0.02	151.4	-0.11	0.00	40.0
65	15	39	3562.8	20	0.02	194.3	-0.04	0.01	46.0
14	31	39	3562.8	21	0.02	250.5	-0.09	0.01	158.2
14	31	73	3528.8	22	0.01	63.3	-0.09	0.00	26.4
14	31	108	3493.8	23	0.19	181.1	0.11	0.03	8.7

X (ft)	Y (ft)	Z (ft)	Elevation (ft)	pt	Current Speed (ft/s)	Current Direction (deg)	Vertical Current (ft/s)	SE Speed (ft/s)	SE Direction (deg)
14	31	143	3458.8	24	0.15	239.0	-0.10	0.02	38.8
14	31	178	3423.8	25	0.17	305.7	0.02	0.07	40.0
31	31	178	3423.8	26	0.16	213.7	-0.23	0.04	116.7
31	31	143	3458.8	27	0.19	208.4	0.04	0.04	15.9
31	31	108	3493.8	28	0.18	194.4	0.00	0.01	8.9
31	31	73	3528.8	29	0.04	219.8	-0.11	0.03	103.0
31	31	39	3562.8	30	0.02	35.5	-0.07	0.01	21.0
48	31	39	3562.8	31	0.02	113.8	-0.04	0.01	10.3
48	31	73	3528.8	32	0.04	82.4	-0.08	0.02	30.6
48	31	108	3493.8	33	0.19	219.6	-0.01	0.01	3.9
48	31	143	3458.8	34	0.28	213.7	0.01	0.06	21.9
48	31	178	3423.8	35	0.07	155.7	-0.08	0.04	71.9
65	31	178	3423.8	36	0.04	152.1	-0.10	0.03	62.6
65	31	143	3458.8	37	0.24	217.5	0.01	0.01	1.4
65	31	108	3493.8	38	0.17	222.1	0.00	0.06	10.6
65	31	73	3528.8	39	0.03	237.6	-0.07	0.04	92.1
65	31	39	3562.8	40	0.04	58.3	-0.07	0.02	24.6
14	61	39	3562.8	41	0.06	272.0	-0.02	0.02	46.2
14	61	73	3528.8	42	0.08	165.9	-0.01	0.02	134.3
14	61	108	3493.8	43	0.10	165.8	-0.02	0.05	44.7
14	61	143	3458.8	44	0.13	204.6	0.02	0.02	6.0
14	61	178	3423.8	45	0.21	240.1	-0.10	0.12	21.3
31	61	178	3423.8	46	0.16	149.6	0.03	0.03	93.1
31	61	143	3458.8	47	0.22	194.4	0.07	0.07	18.4
31	61	108	3493.8	48	0.23	182.0	0.02	0.08	18.1
31	61	73	3528.8	49	0.06	61.3	-0.07	0.02	61.5
31	61	39	3562.8	50	0.12	203.9	-0.08	0.08	100.9
48	61	39	3562.8	51	0.03	109.4	-0.03	0.01	66.8
48	61	73	3528.8	52	0.05	69.1	-0.06	0.05	8.7
48	61	108	3493.8	53	0.29	186.9	0.03	0.05	3.3
48	61	143	3458.8	54	0.38	188.6	0.03	0.10	6.2
48	61	178	3423.8	55	0.07	221.0	0.03	0.01	32.4
65	61	178	3423.8	56	0.03	271.6	0.02	0.01	35.0
65	61	143	3458.8	57	0.53	188.3	0.14	0.02	0.9
65	61	108	3493.8	58	0.45	172.4	-0.09	0.01	2.3
65	61	73	3528.8	59	0.04	72.8	-0.06	0.01	49.9
65	61	39	3562.8	60	0.08	103.5	-0.01	0.02	25.9

Table A5. Glen Canyon forebay velocity and temperature profiles collected on September 27, 2006 at 4:00 p.m. This profile was collected 1000 ft uplake from Glen Canyon Dam.

Elevation (ft)	Current Speed (ft/s)	Current Direction (°)	Vertical Velocity (ft/s)	SE Speed (ft/s)	SE Direction (°)	Temperature (°F)
3594.7	0.16	133.7	0.03	0.17	18.3	70.5
3583.5	0.10	308.5	-0.01	0.13	7.2	70.2
3578.5	0.12	175.2	0.01	0.08	20.4	70.2
3572.2	0.09	336.6	-0.04	0.12	4.0	70.1
3566.7	0.10	330.5	-0.02	0.12	29.3	70.0
3562.1	0.09	349.4	0.00	0.00	4.2	70.0
3551.6	0.07	309.5	-0.04	0.09	24.0	69.9
3548.1	0.08	239.7	-0.06	0.12	15.0	69.8
3541.9	0.16	304.4	-0.01	0.11	7.0	69.2
3531.3	0.06	18.1	-0.03	0.14	11.7	68.6
3524.0	0.20	228.7	-0.22	0.57	185.1	67.2
3517.3	0.15	354.4	-0.03	0.27	3.3	65.1
3510.9	0.28	309.0	-0.03	0.51	12.5	64.2
3504.4	0.07	289.9	0.00	0.21	9.4	62.4
3494.1	0.23	297.9	0.00	0.49	11.3	59.0
3486.5	0.19	300.8	0.03	0.11	24.2	57.0
3478.4	0.24	119.6	0.04	0.19	15.5	53.3
3471.5	0.17	126.8	-0.02	0.35	5.5	51.0
3462.7	0.13	98.1	0.01	0.39	16.7	49.7
3454.8	0.23	102.5	0.13	0.34	10.8	48.7
3447.4	0.27	144.0	0.05	0.41	16.2	47.6
3439.5	0.24	168.7	0.01	0.64	21.7	47.3
3428.5	0.32	127.8	-0.01	0.66	16.4	46.4
3422.2	0.31	122.6	-0.03	0.78	67.4	46.3
3414.3	0.15	136.8	0.06	0.54	66.7	46.3
3407.0	0.24	88.1	0.04	0.66	60.0	46.2
3400.7	0.15	115.6	-0.16	0.56	137.5	46.1
3395.2	0.06	271.2	-0.13	0.20	53.0	46.0
3389.0	0.31	177.0	-0.40	1.03	74.7	46.0
3381.2	0.16	94.5	-0.21	0.54	97.4	46.0

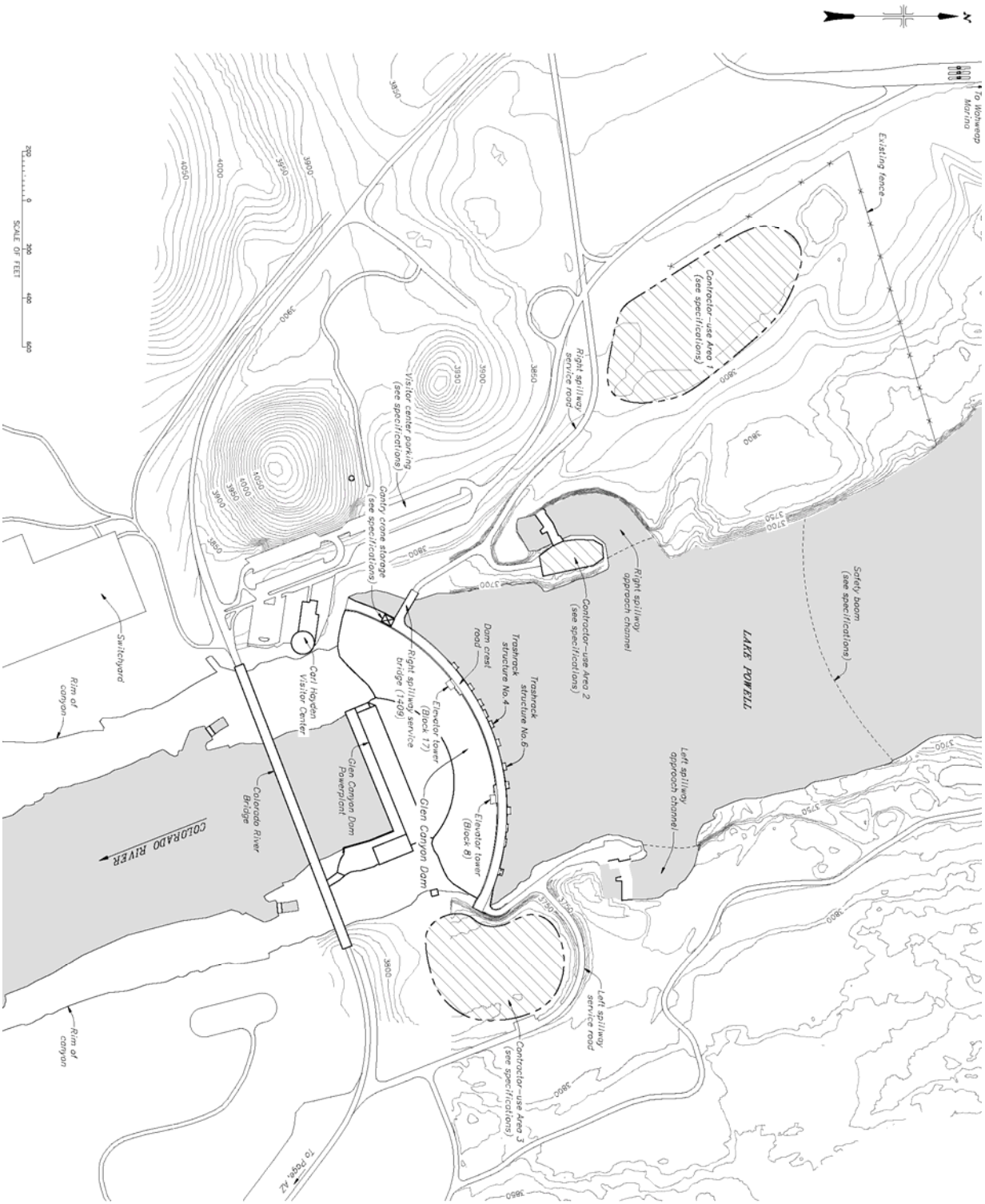

Figure A1. General plan view of Glen Canyon Dam that shows the proposed TCD locations at trashrack structures No. 4 and No. 6 and other major features.

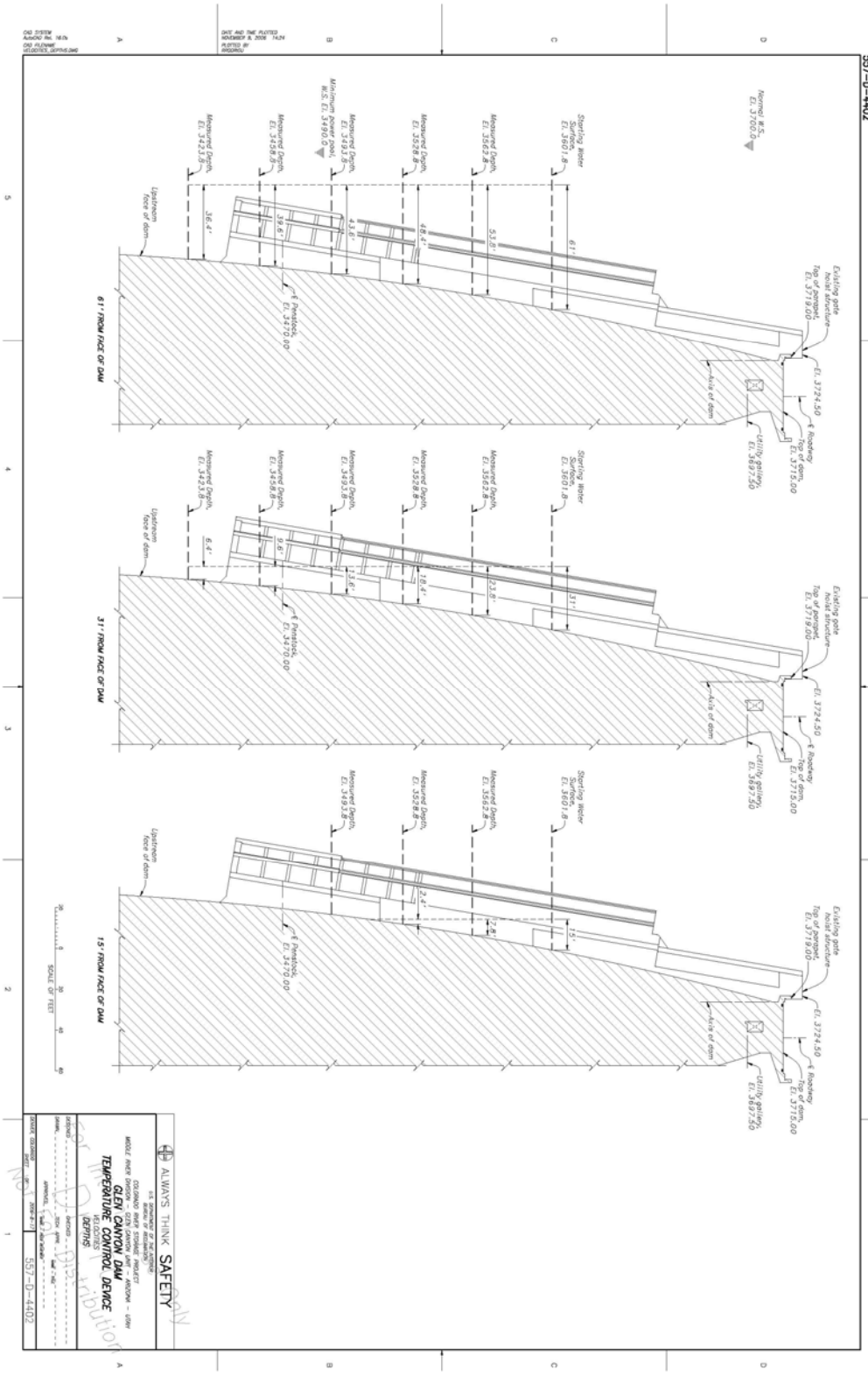

Figure A2. Working drawing that contains the locations of water current measurements with respect to the dam face. Cross sections through the trashrack structures show the locations for the three measurement planes.