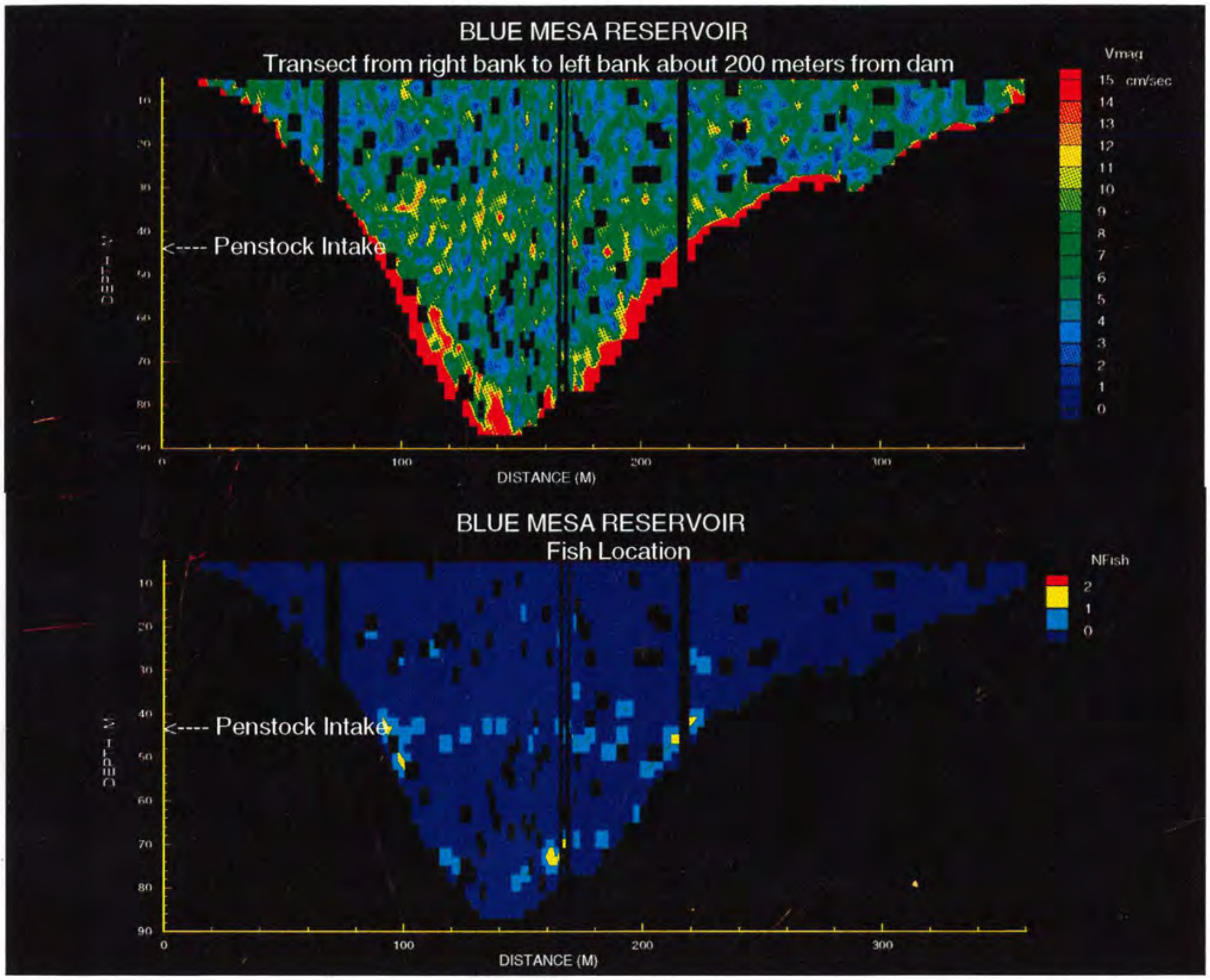
Acoustic Doppler Current Profiler Data Collected in Blue Mesa Reservoir, Colorado

July 8 and 9, 1996



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DATA REPORT

Code : D-8560 Date: November 1, 1996

To : Manager, Water Resources Research Laboratory

From : Tracy Vermeyen and Tony Wahl (D-8560)

Subject: Results of acoustic Doppler current profiling in Blue Mesa Reservoir, near Gunnison, Colorado.

The purpose of this field trip was to collect ADCP (acoustic Doppler current profiler) measurements to document Blue Mesa reservoir hydraulics near the penstock intake structure. This information was needed to support fish (juvenile Kokanee Salmon) entrainment studies being conducted by Steve Hiebert (D-8220).

Tony Wahl and I left Denver and drove to Gunnison, Colorado the evening of July 7. On July 8 and 9, we collected ADCP data in the forebay to the penstock intake structure. Blue Mesa reservoir was near maximum water surface (el. 7516) during the tests and the reservoir release flow was held constant at 93 m^3/s (3,300 ft^3/s) for the entire two-day test. Wahl and Vermeyen collected ADCP data concurrently with hydroacoustic (fish density) transects being collected in a separate boat by Hiebert and Gordon Mueller (NBS). We collected several ADCP transects parallel to the dam face to document the horizontal and vertical extents of the withdrawal layer.

On July 9 stationary ADCP profiles were collected over the thalweg of the old river channel to measure vertical velocity profiles at several locations in the reservoir. GPS (global positioning system) data were collected to document the position of each ADCP profile. A list of ADCP transects, profiles, and associated GPS coordinates are included in this report. In addition, Wahl and I assisted Hiebert with collecting and counting fish that passed through the turbines and were collected in a net placed below the turbine outlet. On average, we collected approximately 20 juvenile Kokanee during the daytime samples and no fish during the evening and night samples.

On Wednesday, July 10 we packed up our equipment and drove back to Denver.

Results

23 ADCP data files were collected over the two day tests. Ten of those files are used to document the hydraulics near the penstock intake structure. Two methods of ADCP data collection were employed during this field test. Transect data were collected by very slowly motoring across the

reservoir. Transects were collected over a range of 50 to 750 meters from the intake. ADCP transect data were collected to determine the horizontal and vertical extents of the withdrawal layer generated by hydropower releases. Ideally, the ADCP should be able to calculate the discharge from the reservoir. However, ADCP computed discharges were very inconsistent. The problem with the discharge calculations was caused by the large "apparent" velocities measured near the reservoir bottom. These "apparent" velocities were usually equal to the boat speed. This was verified when we slowed the boat and the velocities near the bottom would decrease. As a result, transect velocity data could not be validated using discharge comparisons, as is usually the case.

Velocity profiles were collected over a range of 50 to 1,200 meters from the intake. Velocity profiles were collect while holding position over the thalweg of the old river channel. Profile data were collected to eliminate boat motion from the velocity measurements.

Figure 1 shows a color contour plot of the velocity magnitudes in cm/sec for a depth cell interval of 2 meters and a transect length of 360 meters. This transect was collected 75 meters upstream from the dam while moving from the left to right abutment and parallel to the dam axis. In general, the velocity direction was towards the intake structure centerline which is about 240° from north. ADCP data show a stronger withdrawal velocity beginning at a distance 200 meters from the left abutment. The increase in velocity is a function of the proximity to the intake structure. The lower plot in figure 1 shows the distribution of fish along the transect, and that fish are concentrated at depths of 20 to 25 meters and 40 to 50 meters. Fish detection was based on when the echo intensity for an acoustic beam would increase above the normal echo intensity for a given depth. An increase in echo intensity results from a greater density of acoustic reflectors or a large reflector (in this case a fish). Indications of fish near the reservoir bottom are likely caused by increases in echo intensity associated with bottom reflections.

Figure 2 shows a contour plot of the velocity magnitudes in cm/sec for a depth interval of 2 meters and a transect length of 400 meters. This transect was collected from right bank to left bank (looking downstream), 200 meters upstream from the dam, and parallel to the dam axis. ADCP data indicate a withdrawal zone that extends from a depth of 25 to 50 meters. The lower limit of the withdrawal zone is limited to 50 meters because the bench the intake was constructed upon restricts withdrawal layer expansion. The velocity range varied from about 6 to 16 ± 4 cm/sec. The high velocities (greater than 20 cm/sec) measured near the bottom are false readings generated by the boat motion and corrupt the discharge measurements for this transect.

Figure 3 contains two plots, the upper plot is the same as figure 2 except for a finer velocity scale. While the lower plot shows the number and location of fish detected by the four acoustic beams.

In figure 4, the upper plot shows the velocity magnitudes in cm/sec and the lower plot shows the number of fish detected, for a depth interval of 2 meters and a transect length of 360 meters. This transect was collected 400 meters upstream from the dam and parallel to the dam axis. ADCP data do not clearly indicate a withdrawal layer. However, some of the higher velocities were measured in the withdrawal layer (as identified in figure 1). Again, high velocities measured near the bottom are false readings generated by the boat motion. The lower plot shows the majority of fish detected are on the same plane as the penstock intake.

In figure 5, the upper plot shows velocity magnitudes measured along a transect 500 meters upstream from the dam and parallel to the dam axis. In general, this transect had several bad ensembles of data illustrated by high velocities or blacked out areas. This data set had little useful velocity information. The poor data quality can be attributed to the velocities being very small and our inability to maintain a slow boat speed. As a result, the ADCP could not resolve the water velocity from the overall velocity which includes the boat velocity. This transect and several other ADCP data sets collected far from the intake contain little useful information. The lower plot shows the fish detected were distributed below a depth of 30 meters.

In figure 6, the upper plot shows velocity magnitudes measured 750 meters upstream from the dam and parallel to the dam axis. In general, this ADCP transect contained little useful velocity data because the velocities were too small to accurately measure. The poor data quality can be attributed to same factors described above. The lower plot shows the fish detected were concentrated in the same plane as the penstock intake. The fish indicated near the bed are false readings caused by increased echo intensities associated with reflections off the reservoir bottom.

Figure 7 is a plot of 100 individual ADCP profiles collected 300 meters upstream of the penstock intake structure. The x-axis for the following profile plots represent a sequence of 100 profile measurements or ensembles. In other words, these plots are a time-series representation of 100 vertical velocity profiles. ADCP data showed that the velocity direction was towards the intake structure centerline which is about 240° from north. ADCP data indicate a withdrawal zone extends from a depth of 25 to 50 meters. The velocity range is from about 6 to 15 $\pm$4 cm/sec. The high velocities (greater than 15 cm/sec) measured near the bottom are false readings generated by the boat motion and reflections from the reservoir bottom.

Figure 8 is a plot of 100 ADCP profiles collected 100 meters upstream of the penstock intake structure. This ADCP profile is very similar to figure 7 and shows that even though data were collected 200 meters closer to the intake the velocities do not significantly increase. The velocities do not increase because the cross sectional area is similar between the two profile locations.

Figure 9 is a plot of an ADCP profile collected 50 meters upstream of the penstock intake structure. This ADCP profile was collected above the intake bench so the maximum depth is limited to 50 meters. The ADCP data show higher velocity magnitudes (greater than 15 cm/sec) because data were collected close to the intake. This plot shows the upper limit of withdrawal extends to a depth of about 25 meters and the lower limit of withdrawal is fixed at about 50 meters. A high velocity anomaly measured at a depth of 21 meters in ensemble 75 appears to be a measurement of a fish or school of fish moving through the acoustic beams. The ADCP data showed the fish were moving at 48 $\pm$4 cm/sec in a northwest direction.

When 100 ensembles of ADCP data were averaged together the "noise" or random variations in the velocity measurements were averaged out. This results in a smoother velocity profile as is shown in figure 10. V_{east} and V_{north} are the velocity components measured referenced to earth coordinates. V_{intake} is the average velocity resolved about the longitudinal axis of the penstocks. The maximum velocity was 9 $\pm$5 cm/sec at the penstock intake elevation. These velocity profiles contain a $\pm$4 to 5 cm/sec bias error which is nearly equal to the standard deviation of a single velocity measurement. This bias error explains why the velocities do not decrease to zero above the upper limit of withdrawal, as would be expected. The source of the bias error can be attributed to many of the ADCP components, including smaller errors in transducer angles or with the internal compass, and pitch and roll sensors. In this case, we identified a malfunctioning pitch sensor. The direction of flow (V_{dir}) in the withdrawal zone was towards the intake structure centerline which is about 240° from north.

Figure 11 shows data from an ADCP transect collected while moving upstream from the intake structure while attempting to follow the old river channel. This transect shows how the near-field withdrawal velocities decrease with distance from the intake. After 40 to 60 meters the velocities decrease to a uniform far-field value. The transect data indicates a withdrawal layer between depths of 25 to 50 meters. Velocities greater than 15 cm/sec measured near the bottom and at the beginning of the transect caused by reflections off the reservoir bottom and intake structure, respectively. The lower plot shows fish distribution along this transect and that fish were concentrated at depths of about 25 meters and 40 meters.

Figure 12 shows a temperature profile collected in Blue Mesa Reservoir on July 9, 1996. The profile was collected over the inundated river channel upstream of the dam. The profile was collected using a HydroLab multi-parameter surveyor system. The nearly constant temperature below elevation 7340 is an indication of the the lower limit of withdrawal. The upper limit of withdrawal extended to aproximately elevation 7440. Often times the upper limit of withdrawal appears as a change in slope on the temperature profile.

Conclusions

The WRRL's 300 kHz ADCP worked very well for this reservoir application. We successfully measured the withdrawal hydraulics upstream of Blue Mesa Dam. This field trip was beneficial as a training opportunity for Tony Wahl to gain experience operating the ADCP. Analysis indicated that the power releases of 93 m^3/sec (3,300 ft^3/sec) were being selectively withdrawn from a layer bounded by depths of 25 and 50 meters. The maximum intake approach velocity was measured to be about 20 $\pm$5 cm/sec. In addition to the hydroacoustic fish density data collected by Mueller and Hiebert, the echo intensity of the ADCP beams also provided some indication of fish location. For ADCP data collected during the day, an analysis of ADCP echo intensity data indicated that fish were concentrated near depth of 20 meters and 45 meters. Consequently, those juvenile fish holding in waters 45 meters deep are within the selective withdrawal layer and are vulnerable to entrainment into the penstock intake. The intake is located at a depth of 44 meters.

The ADCP computed discharges were very inconsistent. The problems with the discharge calculations were caused by the large "apparent" velocities measured near the reservoir bottom. These "apparent" velocities were of the same magnitude as the boat velocity. This problem has not been observed in previous work on other reservoirs. However, the 300 kHz transducer did have some problems with the pitch and roll sensors that will be repaired in the near future. I plan on discussing the "apparent" velocity problem with the manufacturer, RD Instruments. As a result of these problems, stationary velocity profiles were collected to eliminate boat motion from the velocity measurements.

cc: D-8560, Tony Wahl (D-8560), Steve Hiebert (D-8220), Gordon Mueller (D-8220)

Figures, GPS Information, and Project Data

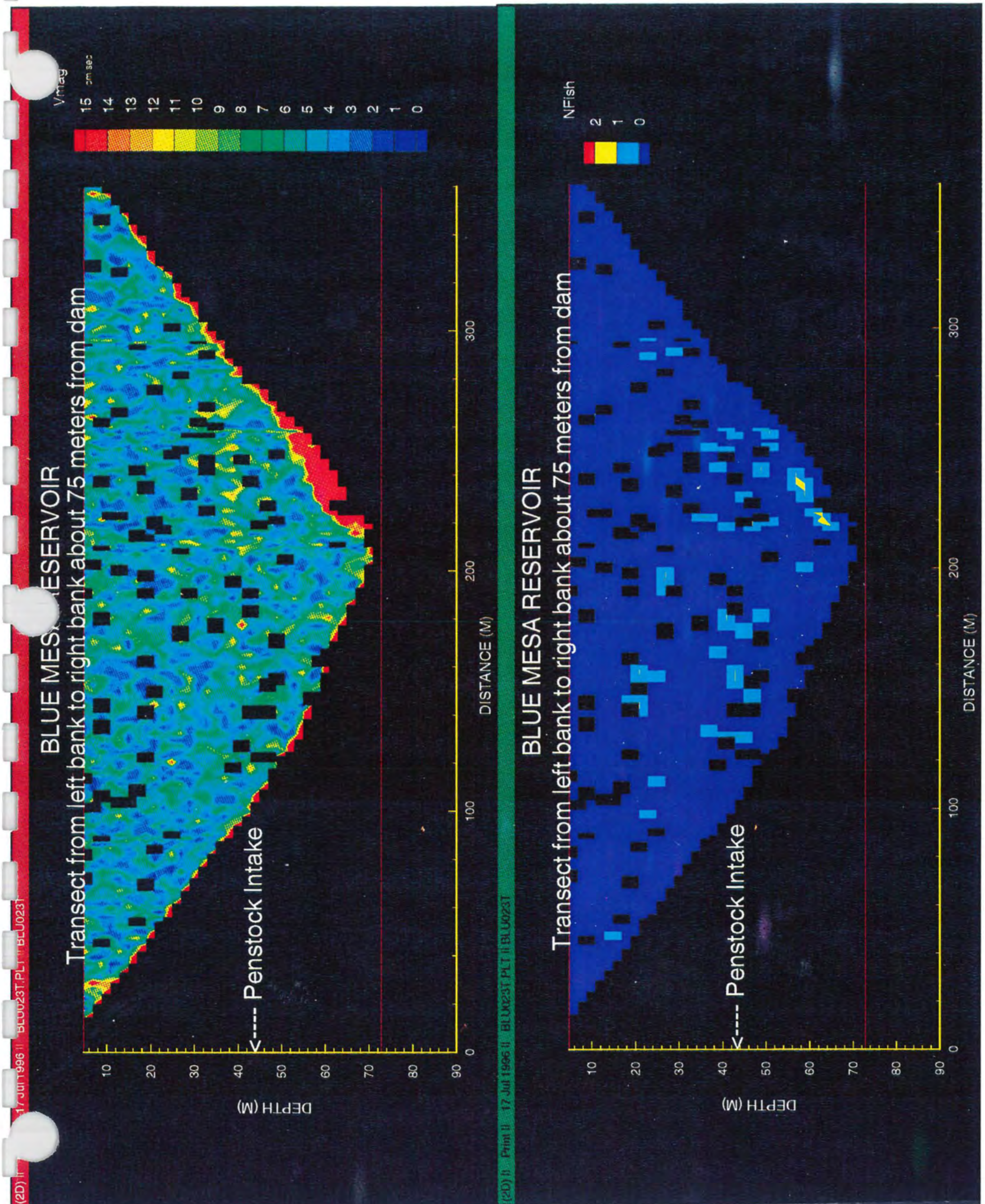


Figure 1. ADCP transect collected 75 meters upstream of the dam while moving from the left to right abutment and parallel to the dam axis.

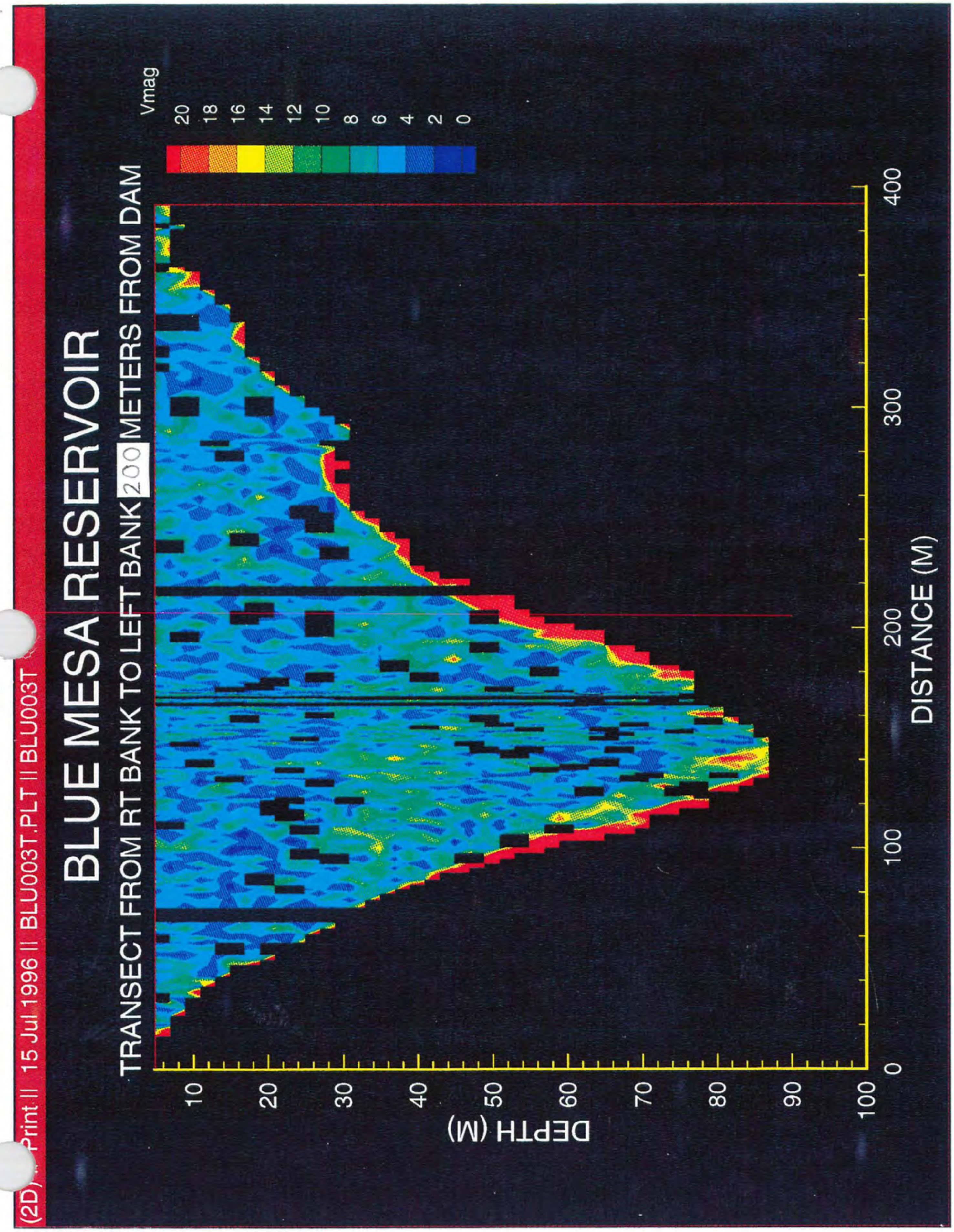


Figure 2. ADCP transect collected 200 meters upstream of the dam while moving from right to left bank and parallel to the dam axis.

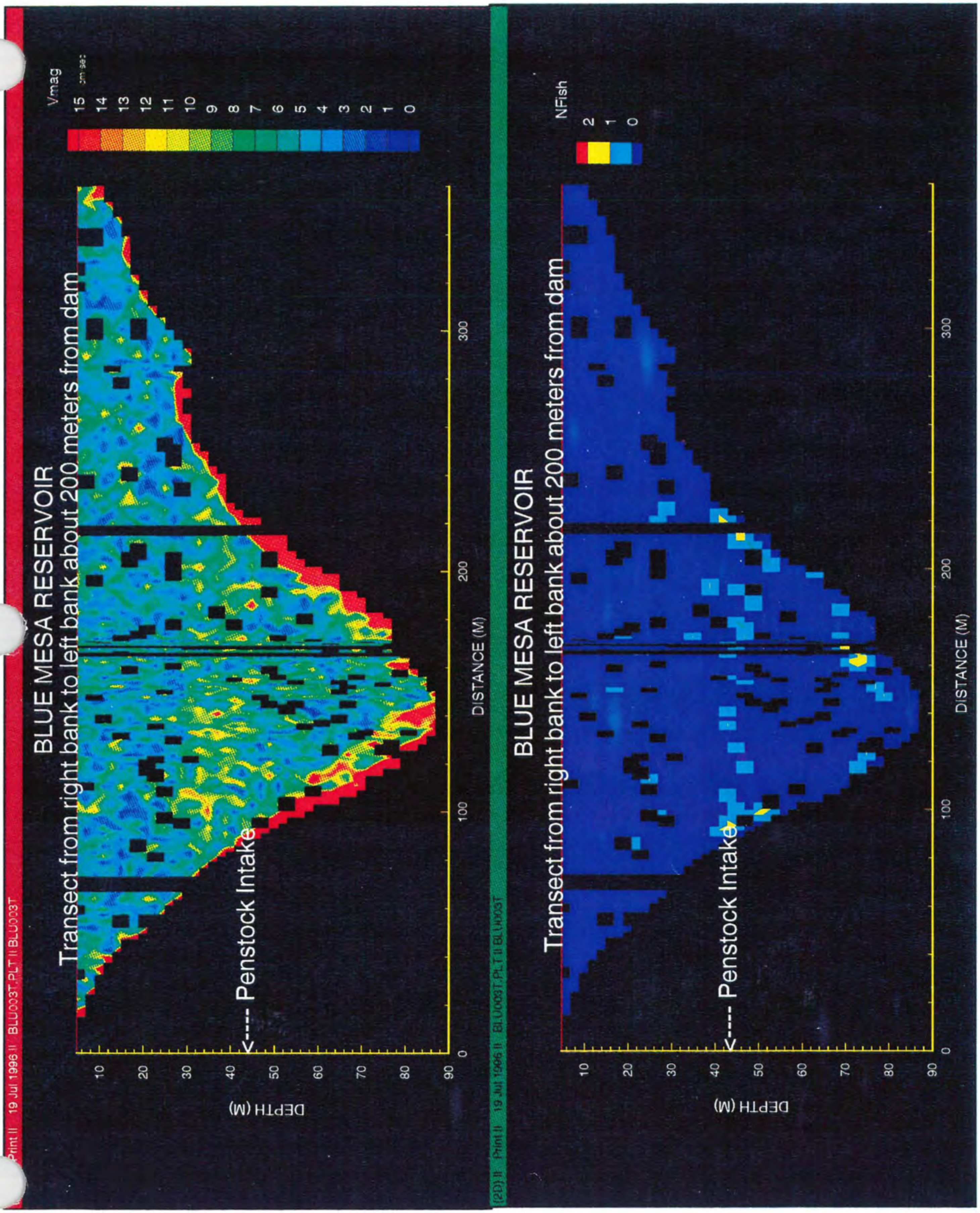


Figure 3. ADCP transect and fish density data collected 200 meters upstream of intake structure.

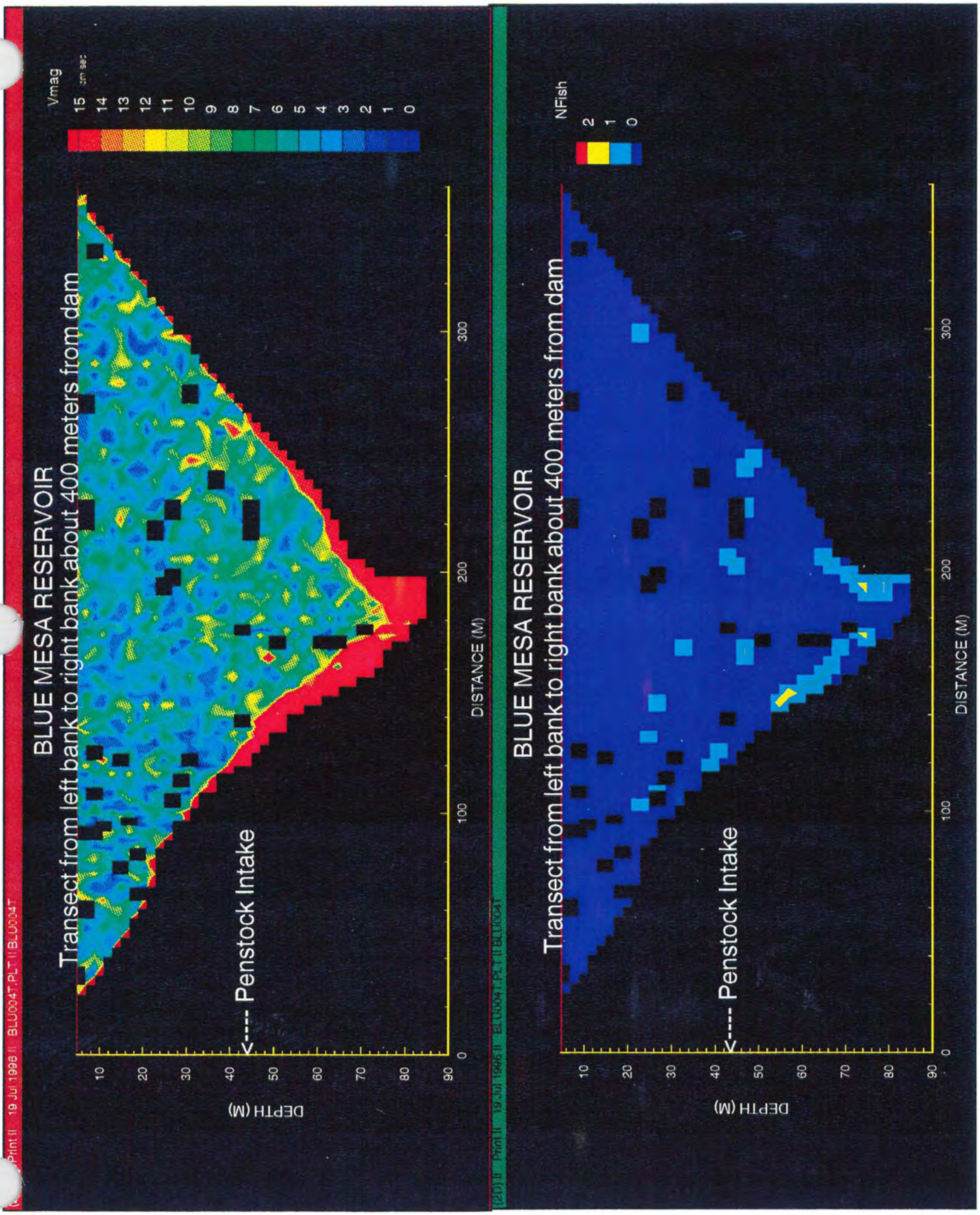


Figure 4. ADCP transect and fish density data collected 400 meters upstream of the dam while moving from left to right bank and parallel to the dam axis.

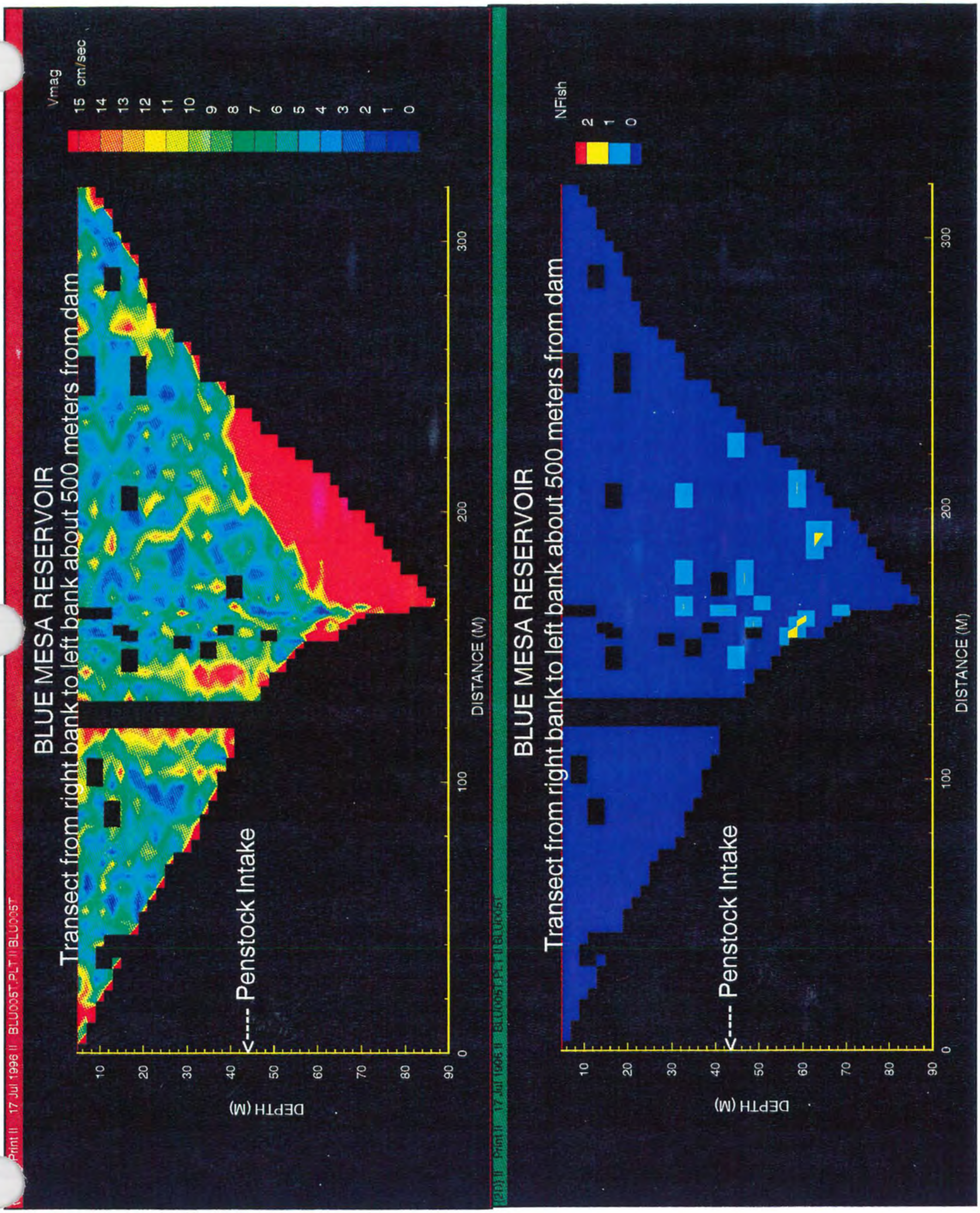


Figure 5. ADCP transect and fish density data collected 500 meters upstream of the dam while moving from right to left bank and parallel to the dam axis.

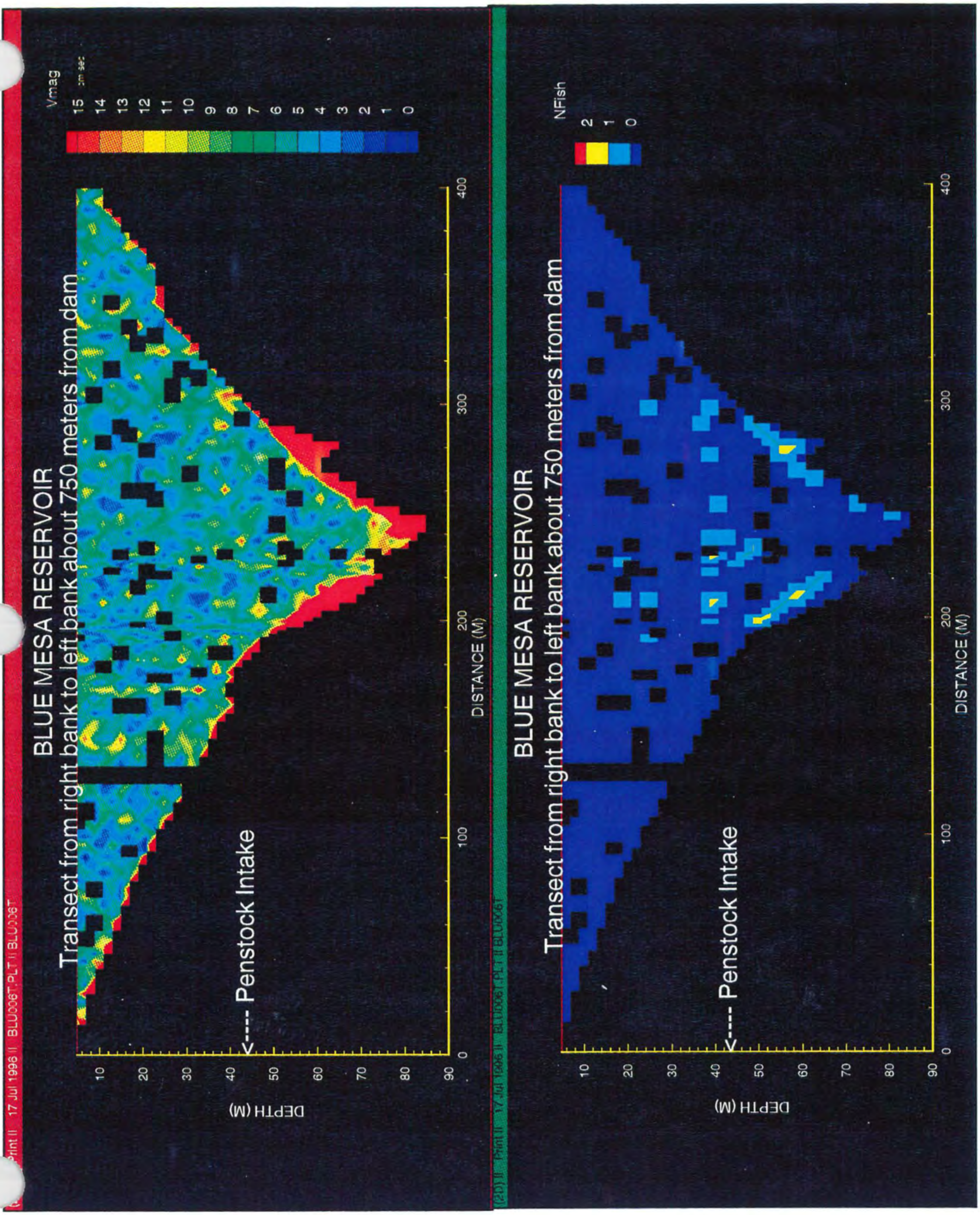


Figure 6. ADCP transect and fish density data collected 750 meters upstream of the dam while moving from right to left bank and parallel to the dam axis.

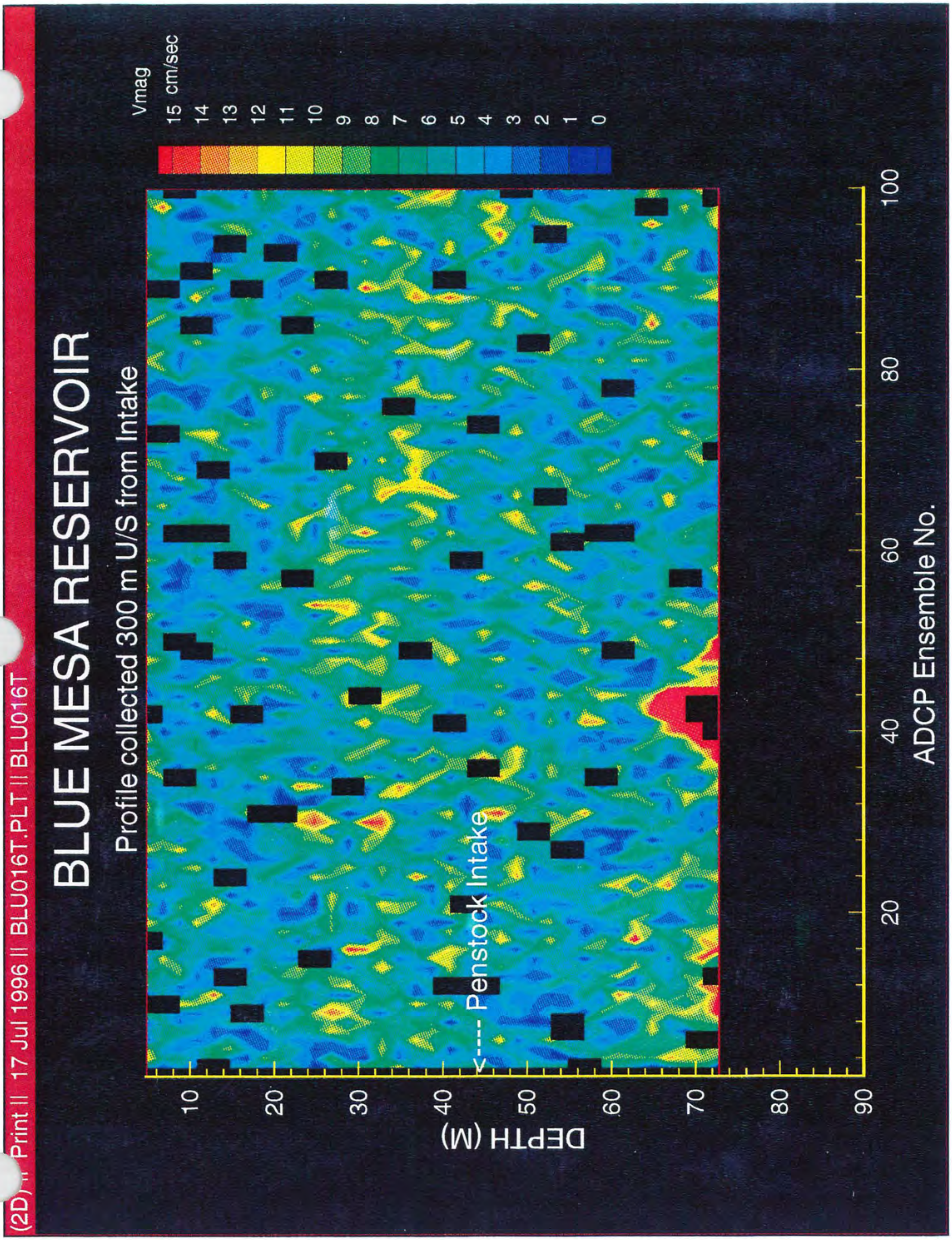


Figure 7. ADCP profile collected 300 meters upstream of the intake structure.

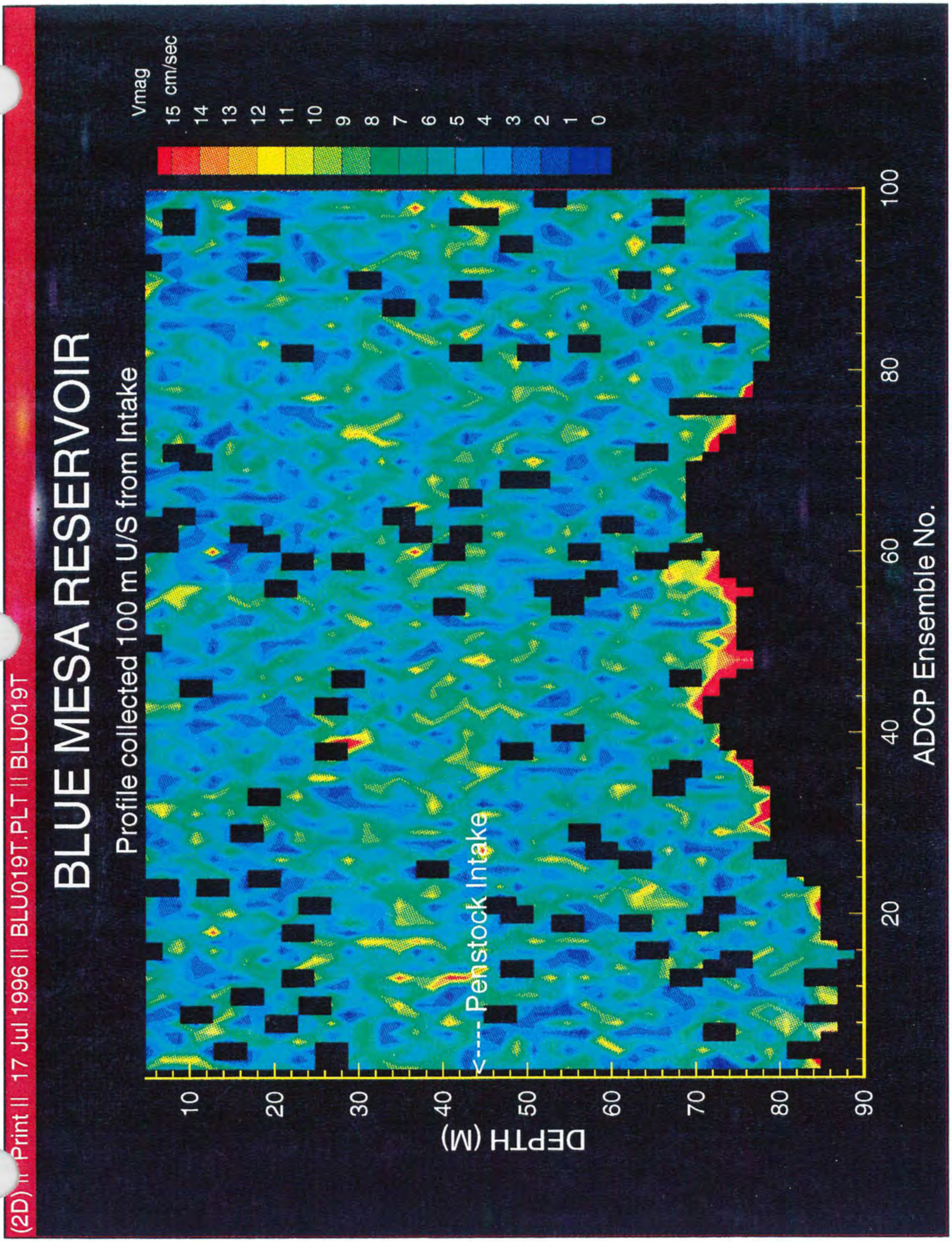


Figure 8. ADCP profile collected 100 meters upstream of the intake structure.

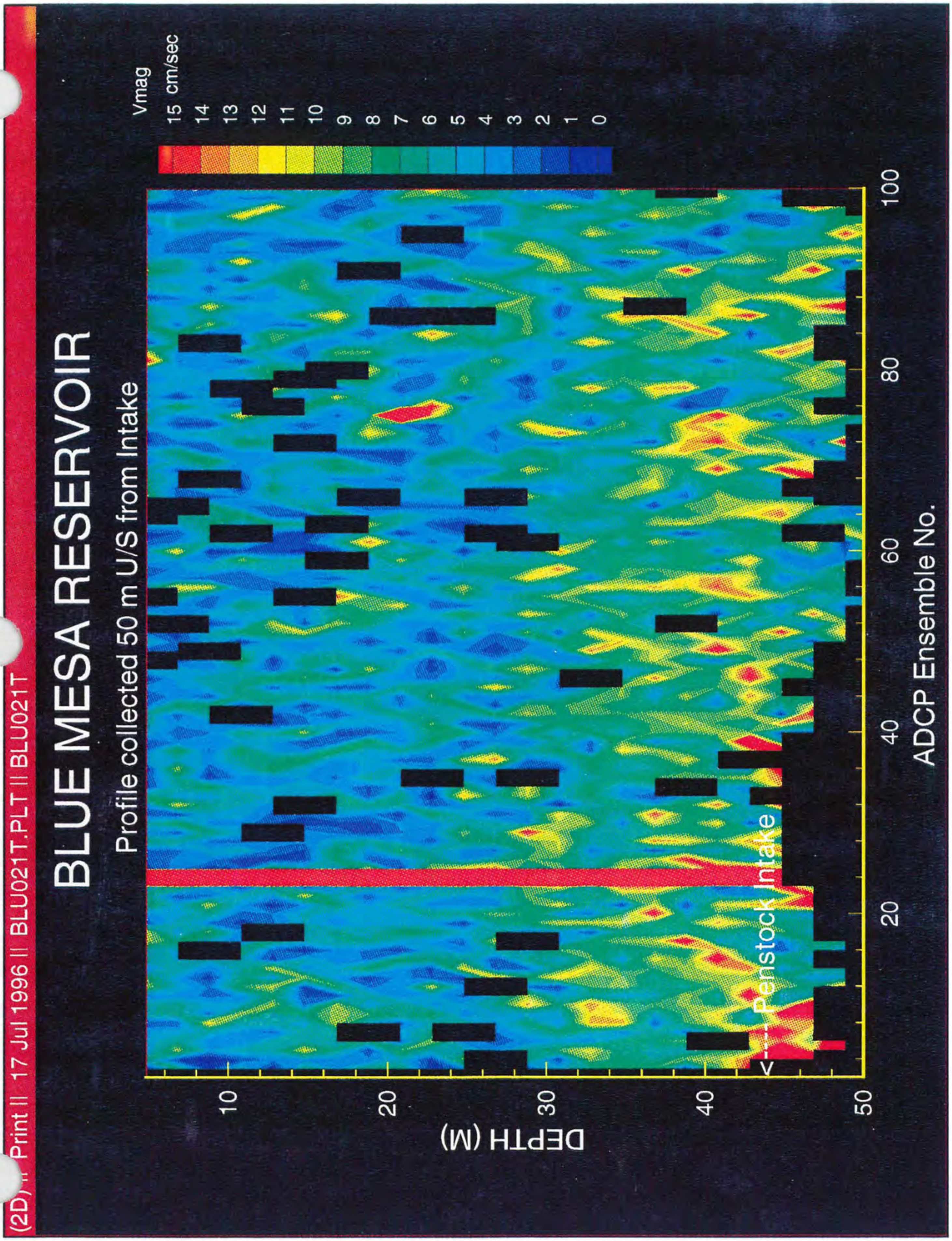


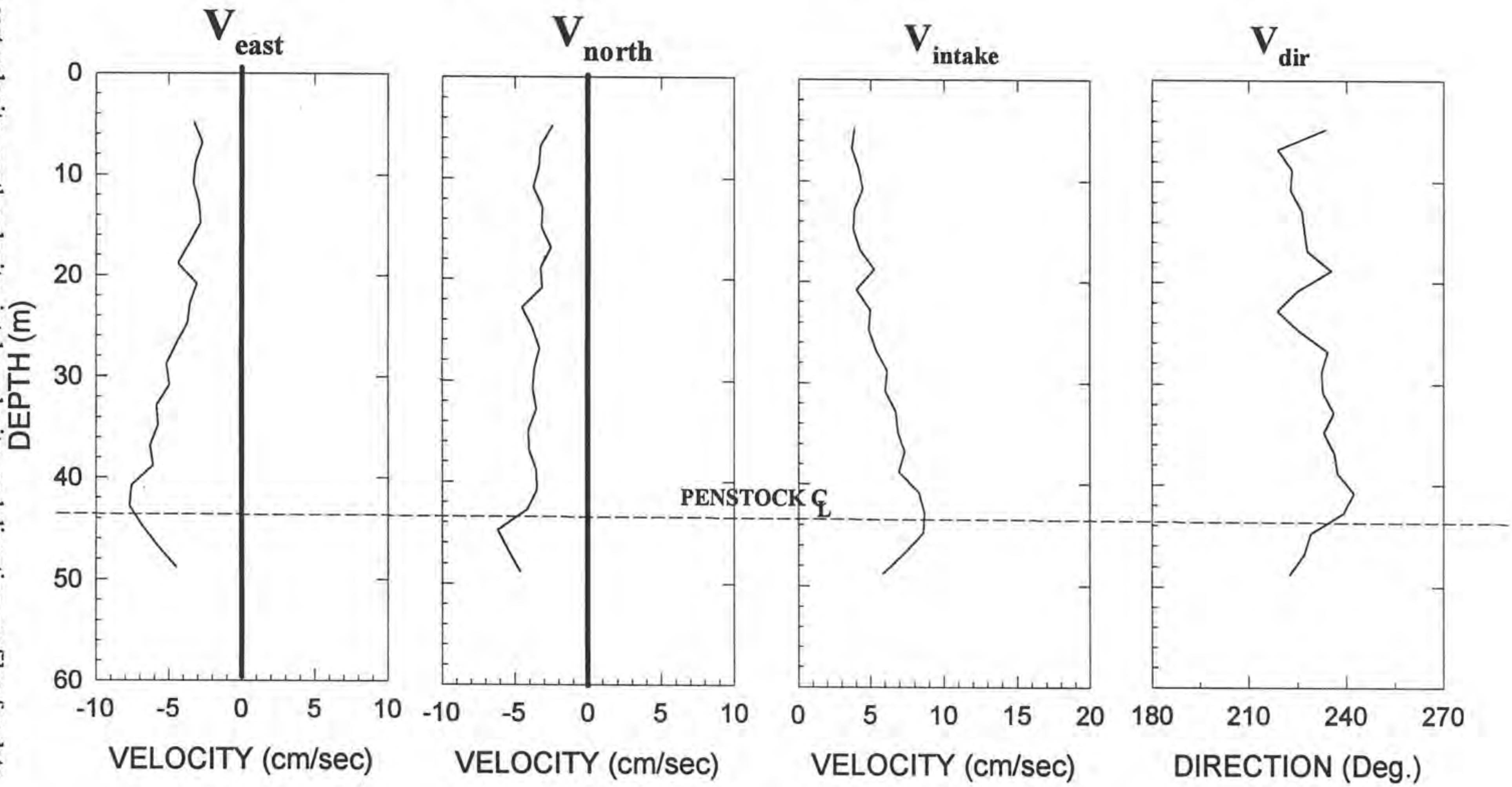
Figure 9. ADCP profile collected 50 meters upstream of the intake structure.

Blue Mesa Reservoir - ADCP Data

Profiles collected 50 m U/S of Intake (fn=blu021t.000)

Average Velocity Plots (100 Ensembles)

7/9/96



$V_{INTAKE} = V_{EAST} * SIN(240^{o}) + V_{NORTH} * COS(240^{o})$

Figure 10. Average east velocity, north velocity, intake velocity, and direction profiles for data collected 50 meters upstream of the intake structure.

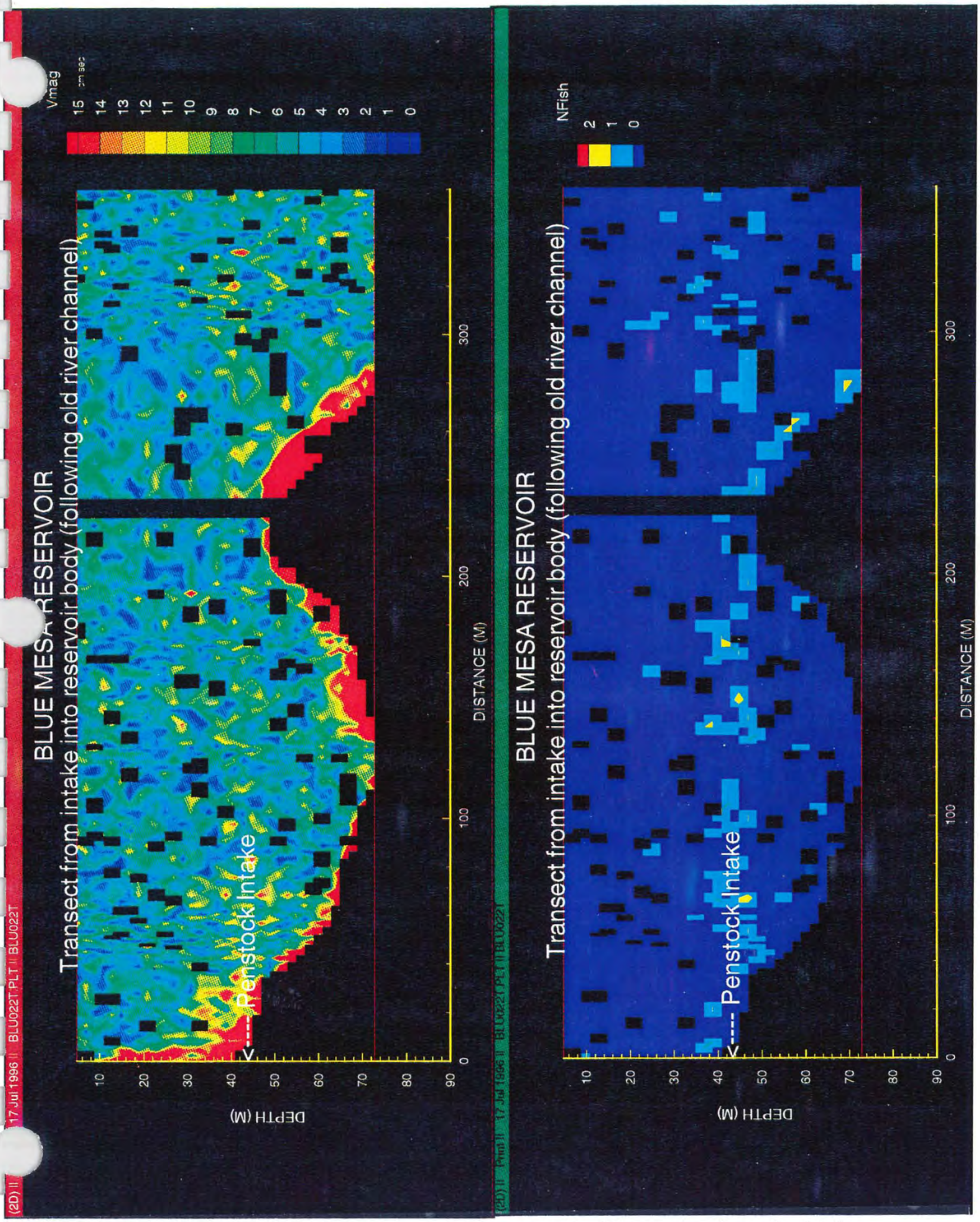


Figure 11. ADCP transect and fish density data collected while moving from the intake structure into the reservoir body. The transect length was about 360 meters.

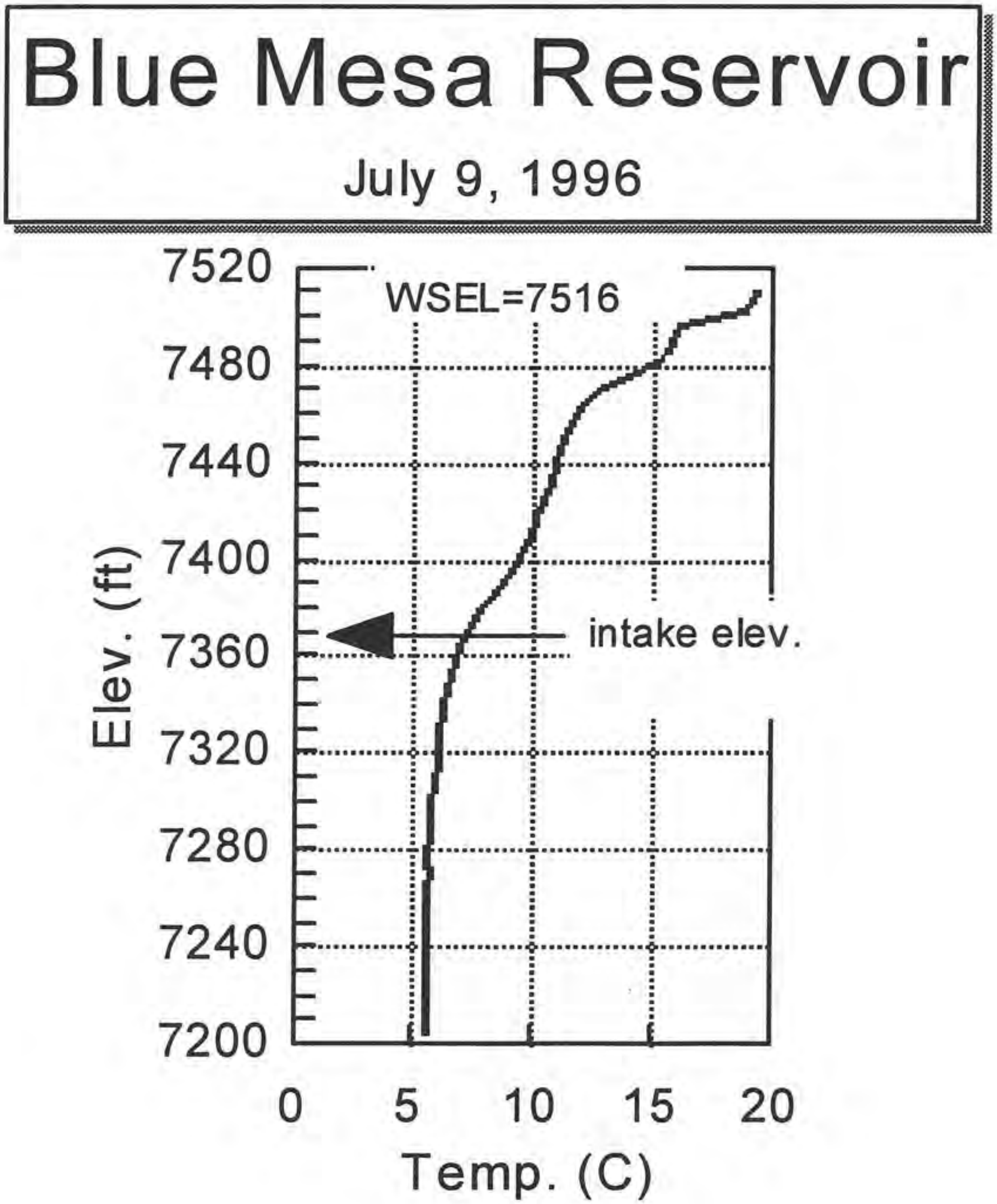


Figure 12. HydroLab temperature profile collected in Blue Mesa Reservoir. The nearly constant temperature below elevation 7340 is an indication of the the lower limit of withdrawal. The upper limit of withdrawal extended to elevation 7440.

led by one 16- by 18-foot fixed-wheel gate in the intake structure and by two 84-inch ring-follower gates and two 84-inch hollow-jet valves in a gate house at the terminus of the outlet conduits. Maximum discharge from the outlet works is 5,000 cubic feet per second at maximum water surface elevation, with two 84-inch hollow-jet valves 62 percent open.

Blue Mesa Reservoir has a total capacity of 940,800 acre-feet and an active capacity of 748,500 acre-feet. At maximum water surface elevation, the reservoir occupies 9,180 acres.

The Blue Mesa Powerplant consists of two 30,000-kilowatt generators, driven by two 41,500-horsepower turbines. Each turbine is designed to operate at a maximum head of about 360 feet.

One 16-foot-diameter penstock conveys water to the two turbines and also carries water for the outlet works. After branching from the main penstock, each of the penstock laterals is controlled by 156-inch butterfly valves. The main penstock is reduced by a wye branch to the outlet works control valves.

Morrow Point Dam, Reservoir, and Powerplant

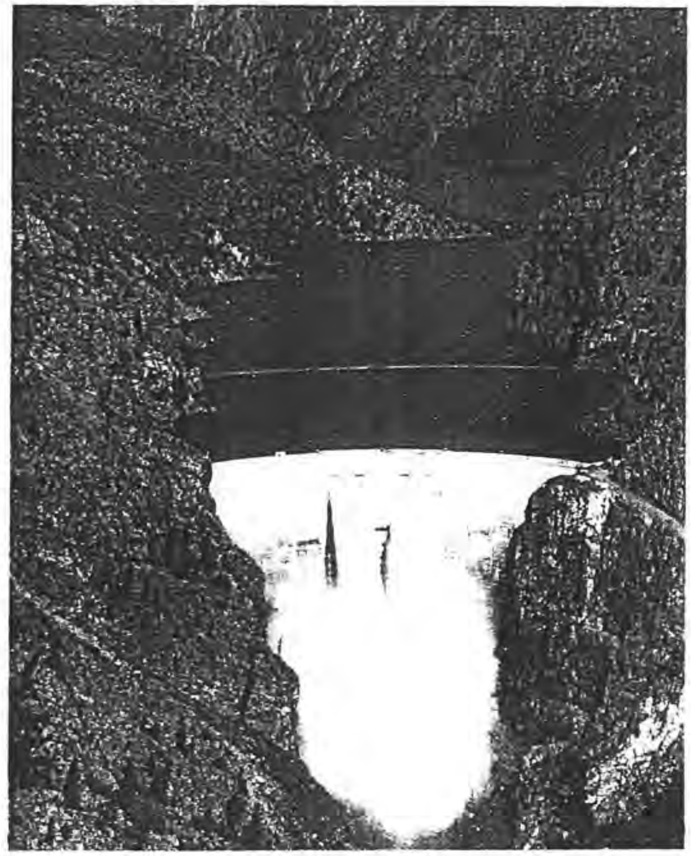
Morrow Point Dam, 12 miles downstream from Blue Mesa Dam, is Reclamation's first thin-arch, double-curvature dam. It is 468 feet high, 52 feet thick at the base, and 12 feet thick at the crest. The dam has a crest length of 724 feet and a volume of 365,180 cubic yards of concrete.

The spillway consists of four orifice-type openings in the top central part of the dam, providing a free-fall discharge higher than 350 feet to the concrete stilling basin at the toe of the dam. Each of the four spillway openings is controlled by a 15- by 16.83-foot fixed-wheel gate. Maximum capacity of the spillway is 41,000 cubic feet per second.

The outlet works consists of one stainless-steel lined 4-foot-square conduit through the dam. Control is by two 3.5-foot-square slide gates. Discharge capacity of the outlet works is 1,500 cubic feet per second.

Reservoir capacity behind Morrow Point Dam is 117,190 acre-feet at maximum water surface. The active capacity is 42,120 acre-feet. Surface area for Morrow Point Reservoir is 817 acres at elevation 7160.

The powerplant chamber is tunnelled into the canyon wall in the left abutment about 400 feet below the ground surface. The powerplant chamber is 231 feet long and 57 feet wide with a height ranging from 65 to 134 feet. There are two 60,000-kilowatt generators driven by two [illegible],000-horsepower turbines. The power penstocks consist of 13.5-foot-diameter steel liners in 18-foot-diameter tunnels.



Morrow Point Dam and Reservoir

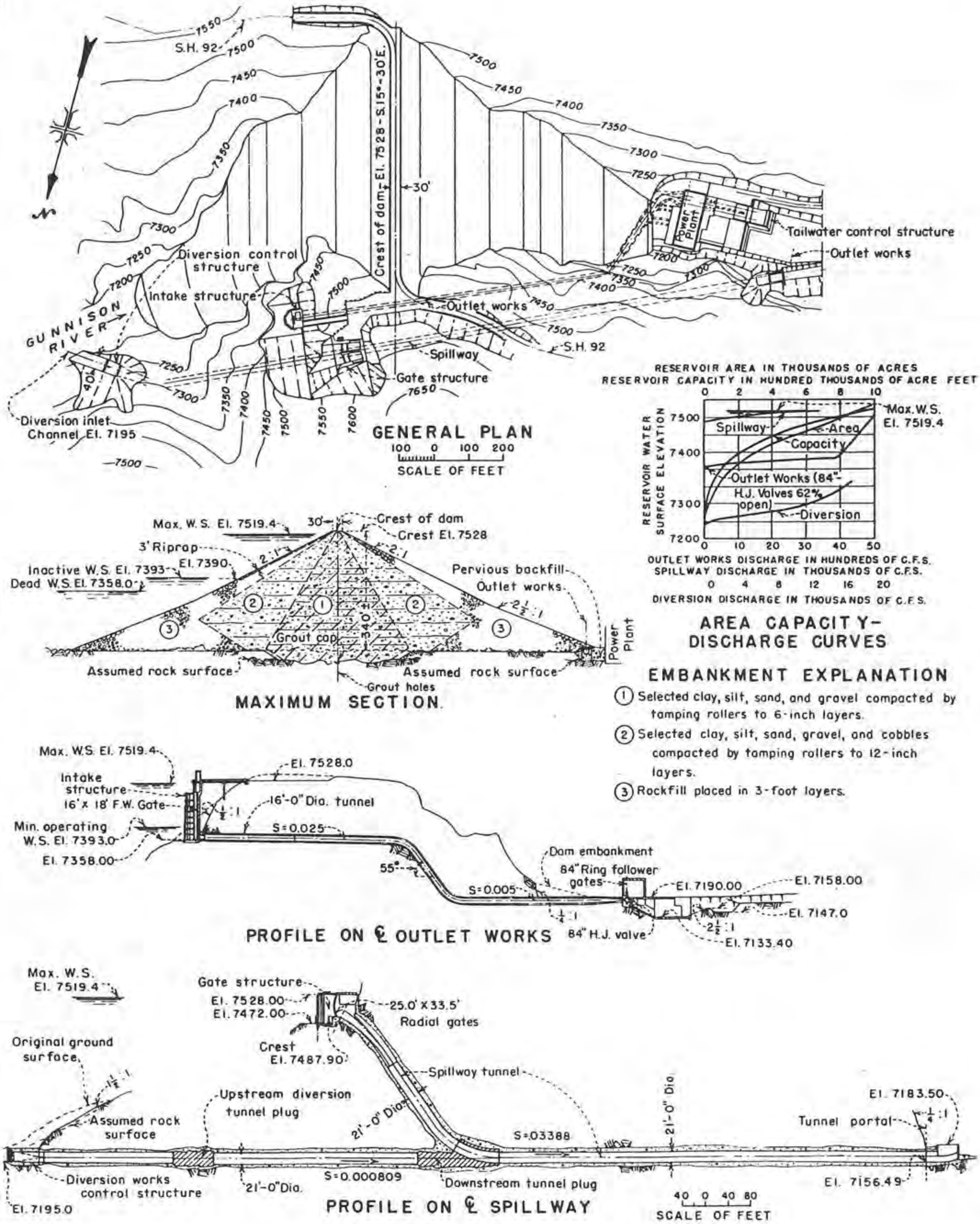
Crystal Dam, Reservoir, and Powerplant

Crystal Dam is located 6 miles downstream from Morrow Point Dam and approximately 20 miles east of Montrose, Colo. The dam is a double-curvature thin-arch type, 323 feet high, with a crest length of 635 feet, and a volume of 147,000 cubic yards of materials.

The spillway consists of an ungated ogee crest on the right side of the dam and a plunge pool at the toe of the dam. The crest is at elevation 6756.0 feet, 1 foot above normal water surface. The plunge pool is unlined except for a downstream retaining wall to contain the river fill material.

Water is conveyed from the reservoir to the hydraulic turbine by an 11.5-foot-diameter concrete penstock, the lower portion of which is steel lined. The intake structure consists of a metal trashrack, a 10.58- by 17.27-foot bulkhead gate, an 8.33- by 13.58-foot fixed-wheel gate, and a transition. The fixed-wheel gate is provided for emergency closure and for inspection and maintenance of the penstock. Water from the turbine exits through the draft tube to the tailrace.

The river outlets consist of an intake structure on the upstream face of the dam and two 54-inch pipes through the dam and powerplant. The 54-inch ring-follower



Blue Mesa Dam, Plan and Sections

BLUE MESA RESERVOIR - ADCP DATA COLLECTED IN JULY 8,9 1996
RESERVOIR ELEVATION = 7516 FT, MAX WSEL=7519.4
FLOW RATE WAS ABOUT 3,300 FT^3/SEC THRU POWERPLANT

7/8/96
SPILLWAY BOUYLINE
NP,WP100,MARK100,L/L-dms,,-107.3334638,38.4544106,NAR,,7504,WGD,,0.0,,ft,Mils

TRANSECT FROM RIGHT BANK TO LEFT BANK, 50 METERS FROM DAM, FN=BLU001R.000
NP,WP101,MARK101,L/L-dms,,-107.3343345,38.4559702,NAR,,7532,WGD,,0.0,,ft,Mils
NP,WP102,MARK102,L/L-dms,,-107.3362531,38.4563805,NAR,,7490,WGD,,0.0,,ft,Mils

TRANSECT FROM LEFT BANK TO RIGHT BANK, 150 TO 250 METERS FROM DAM, FN=BLU002R.000
NP,WP103,MARK103,L/L-dms,,-107.3318593,38.4528524,NAR,,7374,WGD,,0.0,,ft,Mils
NP,WP104,MARK104,L/L-dms,,-107.3324679,38.4558287,NAR,,7410,WGD,,0.0,,ft,Mils

TRANSECT FROM RIGHT BANK TO LEFT BANK, 200 METERS FROM DAM, FN=BLU003R.000
NP,WP105,MARK105,L/L-dms,,-107.3315701,38.4558372,NAR,,7389,WGD,,0.0,,ft,Mils
PROFILE LOCATIONNP,WP106,MARK106,L/L-dms,,-107.3315400,38.4552876
NP,WP107,MARK107,L/L-dms,,-107.3309813,38.4538285,NAR,,7260,WGD,,0.0,,ft,Mils

TRANSECT FROM LEFT BANK TO RIGHT BANK, 400 METERS FROM DAM, FN=BLU004R.000
NP,WP108,MARK108,L/L-dms,,-107.3286534,38.4542666,NAR,,7409,WGD,,0.0,,ft,Mils
NP,WP109,MARK109,L/L-dms,,-107.3308555,38.4576160,NAR,,7901,WGD,,0.0,,ft,Mils

TRANSECT FROM RIGHT BANK TO LEFT BANK, 450 METERS FROM DAM (MOTORING ACROSS THE INLET) FN=BLU005R.000
NP,WP110,MARK110,L/L-dms,,-107.3289319,38.4576179,NAR,,7333,WGD,,0.0,,ft,Mils
NP,WP111,MARK111,L/L-dms,,-107.3300690,38.4564643,NAR,,7181,WGD,,0.0,,ft,Mils

TRANSECT FROM RIGHT BANK TO LEFT BANK, 750 METERS FROM DAM, FN=BLU006R.000
NP,WP112,MARK112,L/L-dms,,-107.3288202,38.4606595,NAR,,7349,WGD,,0.0,,ft,Mils
NP,WP113,MARK113,L/L-dms,,-107.3266002,38.4522712,NAR,,7716,WGD,,0.0,,ft,Mils

PROFILE COLLECTED IN THALWEG OF OLD RIVER CHANNEL 600 METERS FROM DAM. FN=BLU007R.000
NP,WP114,MARK114,L/L-dms,,-107.3275820,38.4575759,NAR,,7456,WGD,,0.0,,ft,Mils

PROFILE COLLECTED IN THALWEG OF OLD RIVER CHANNEL 610 METERS U/S OF INTAKE. FN=BLU008R.000
NP,WP115,MARK115,L/L-dms,,-107.3278704,38.4579991,NAR,,7063,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 200 METERS U/S OF INTAKE, FN=BLU009R.000
REPEAT PROFILE COLLECTED WITH 3M BINS, FN=BLU010R.000
NP,WP116,MARK116,L/L-dms,,-107.3315298,38.4553130,NAR,,7899,WGD,,0.0,,ft,Mils

TRANSECT FROM RIGHT BANK TO LEFT BANK 80 METERS FROM DAM FACE. FN=BLU011R.000
NP,WP117,MARK117,L/L-dms,,-107.3341572,38.4555331,NAR,,7409,WGD,,0.0,,ft,Mils
NP,WP118,MARK118,L/L-dms,,-107.3617459,38.4725551,NAR,,7389,WGD,,0.0,,ft,Mils

TRANSECT FROM DAM FACE TO RIGHT BANK (NEAR BUOY), ABOUT 40 M U/S FROM INTAKE. FN=BLU012R.000
NP,WP119,MARK119,L/L-dms,,-107.3663673,38.4754324,NAR,,7390,WGD,,0.0,,ft,Mils
NP,WP120,MARK120,L/L-dms,,-107.3349098,38.4550984,NAR,,7328,WGD,,0.0,,ft,Mils

7/9/96
PROFILE COLLECTED 1.2KM U/S OF INTAKE, FN=BLU013R.000
NP,WP121,MARK121,L/L-dms,,-107.3222126,38.4606664,NAR,,7231,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 850M U/S OF INTAKE, FN=BLU014R.000
NP,WP122,MARK122,L/L-dms,,-107.3250978,38.4584332,NAR,,7410,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 720M U/S OF INTAKE, FN=BLU015R.000
NP,WP123,MARK123,L/L-dms,,-107.3261705,38.4576341,NAR,,7461,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 305M U/S OF INTAKE, FN=BLU016R.000
NP,WP124,MARK124,L/L-dms,,-107.3303214,38.4556829,NAR,,7517,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 167M U/S OF INTAKE, FN=BLU017R.000
NP,WP125,MARK125,L/L-dms,,-107.3324793,38.4560857,NAR,,6987,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 115M U/S OF INTAKE, FN=BLU018R.000
NP,WP126,MARK126,L/L-dms,,-107.3330608,38.4558126,NAR,,7624,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 100M U/S OF INTAKE, FN=BLU019R.000
NP,WP127,MARK127,L/L-dms,,-107.3338587,38.4560225,NAR,,7326,WGD,,0.0,,ft,Mils

PROFILE COLLECTED 50M U/S OF INTAKE, FN=BLU020R.000
NP,WP128,MARK128,L/L-dms,,-107.3349436,38.4559035,NAR,,7249,WGD,,0.0,,ft,Mils

PROFILE COLLECTED WHILE ANCHORED 50M U/S OF INTAKE, FN=BLU021R.000
NP,WP129,MARK129,L/L-dms,,-107.3359799,38.4564382,NAR,,7254,WGD,,0.0,,ft,Mils

TRANSECT FROM INTAKE TOWER TO WP 131 (TRAVELED 344 M U/S) FN=BLU022R.000

NP,WP130,MARK130,L/L-dms,,-107.3336729,38.4548958,NAR,,7650,WGD,,0.0,,ft,Mils
NP,WP131,MARK131,L/L-dms,,-107.3300463,38.4559217,NAR,,7513,WGD,,0.0,,ft,Mils

TRANSECT FROM DAM, 130 M LEFT OF INTAKE TOWER TO RT. BANK (TRAVELED 365 M U/S). FN=BLU023R.000

NP,WP132,MARK132,L/L-dms,,-107.3340693,38.4537356,NAR,,7571,WGD,,0.0,,ft,Mils
STRAIGHT OFF INTAKE TOWER (ABOUT 75m U/S OF INTAKE)
NP,WP133,MARK133,L/L-dms,,-107.3327812,38.4550494,NAR,,7279,WGD,,0.0,,ft,Mils
NP,WP134,MARK134,L/L-dms,,-107.3342853,38.4555103,NAR,,7817,WGD,,0.0,,ft,Mils