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Selective Withdrawal Evaluation for Shasta Lake for 1995

by

Tracy Vermeyen, P.E.

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SELECTIVE WITHDRAWAL EVALUATION FOR SHASTA LAKE FOR 1995

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This hydraulic data and its interpretation are being submitted as a final product of a service agreement between Reclamation's Technical Service Center and Northern California Area Office.

Scope of Work: The Shasta TCD (Temperature Control Device) Study is being conducted by the NCAO (Northern California Area Office) to evaluate biological and limnological effects of TCD operation, and to develop operational refinements to maximize TCD benefits. The study is currently in the pre-TCD operation stage. The planned life of the study is five years, including both pre- and post-TCD periods.

Acoustic Doppler Current Profiling: The Water Resources Research Laboratory (WRRL) is working with the NCAO to determine the hydraulic characteristics of power and spillway withdrawals from Shasta Lake for both baseline conditions and for operation of the Shasta TCD. A boat-mounted ADCP (acoustic Doppler current profiler) was used to measure the velocity profiles in the near-field around the penstock intakes and spillway outlet structure. Far-field measurements were collected in the body of Shasta Lake. Measuring velocity profiles defines the withdrawal layer in the reservoir, as well as, documents velocity fields around the intakes. Velocity profile data are necessary to verify which reservoir elevations (layers) are affected by reservoir releases and can be used to determine the removal rate of biological or chemical constituents.

Sampling Program: WRRL and NCAO personnel collected ADCP data monthly for the months May through September. Velocity profiles were measured at locations near the power intakes (near-field) and at five water quality and biological monitoring sites (far-field). Lake sampling sites were located 1, 2, 3, 4, and 5 kilometers from Shasta Dam and were located in the thalweg of the inudated river channel. Monthly sampling provides an instantaneous sample of withdrawal characteristics for a variety of reservoir releases and temperature stratifications. However, selective withdrawal characteristics will change with modifications to reservoir operations, especially with changes in release flows or release elevations.

Data Summary: The monthly ADCP sampling program resulted in documenting the following selective withdrawal characteristics, some of which are also summarized in table 1:

- Reservoir water surface elevations
- Reservoir outflows and operations
- Temperature profiles

DATE	PEER REVIEWER(S)	CODE
4/16/96	Signature	D-8560
	BRENT MEFFORD Printed Name	
	Signature	
	Printed Name	
Author initials	PEER REVIEW NOT REQUIRED	

- Upper withdrawal limit
- Lower withdrawal limit
- Average release water temperature

For 1995 reservoir elevations ranged from elevation 1058 in June to elevation 1016 in September. 1995 represents a good water year, where the reservoir filled in the early summer and was drawn down throughout the irrigation season to meet downstream water demands.

Reservoir outflows and operations varied from a combination of spillway and power generation releases in the early summer to strictly power releases in mid-summer months to low level spillway releases to meet water temperature requirements in September. This year's wide range of reservoir operations were valuable in documenting selective withdrawal characteristics for several pre-TCD operational conditions.

Date	Reservoir Elev. (ft)	Reservoir Outflow (ft^3/s)	Operations (primary and secondary)	Elevation of Upper limit of Withdrawal (ft) (depth, ft)	Average release water temperature (°F)
5/16-17/95	1055.0	11,500	Power (el. 815) and Spill (el. 742)	891.0 (164)	47.0
6/12-13/95	1057.6	9,000	Power (el. 815)	926.4 (131.2)	49.6
7/17/95	1048.6	14,500	Power (el. 815)	901.0 (147.6)	51.0
8/18/95	1032.2	12,600	Spill (el. 742) and Power (el. 815)	835.3 (196.9)	52.4
9/20/95	1016.3	8,100	Spill (el. 742)	806.3 (210)	52.5

Table 1. 1995 selective withdrawal characteristics for Shasta Lake.

Monthly temperature profiles presented in figure 1 were collected by NCAO's hydrologic technicians. These profiles show the general warming of the reservoir throughout the summer months. In addition, the upper limits of withdrawal show that water is removed from the hypolimnion and lower limits of the metalimnion.

The upper limit of the withdrawal layer is a function of density stratification, flowrate, intake elevation and geometry, and physical boundaries. The depths to the upper limit of withdrawal was determined from ADCP data for the May through September and are presented in Table 1. In general, the upper limit of withdrawal was confined to the metalimnion and hypolimnion (see Figure 1) and did not vary significantly between the five lake stations for a given month. The velocity

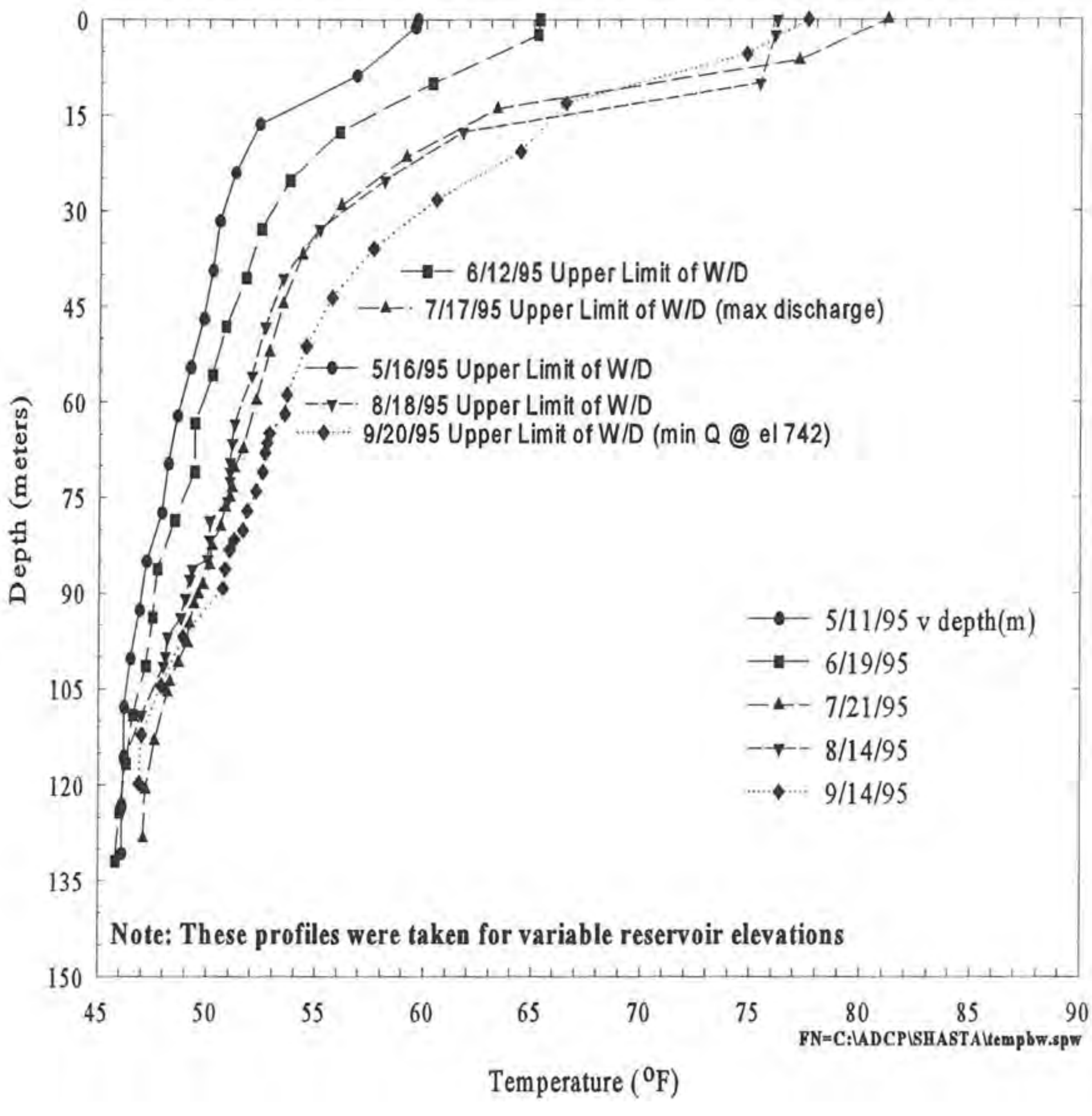


Figure 1. Monthly temperature profiles collected in the forebay with the corresponding upper limit of withdrawal (W/D). Note that the temperature profiles were collected on different dates from the ADCP velocity profiles.

distribution within the withdrawal layer was measured using an ADCP and are presented in the monthly data reports in the appendix. The quality of the velocity measurement varied depending on water quality, velocity magnitudes, and reservoir surface conditions. Lack of acoustic scatterers, low velocities, and windy/wavy conditions are some conditions we experienced which affected the ADCP data quality. However, for each month we were able to, at a minimum, document the upper limit of withdrawal. Another characteristic is that the upper limit of withdrawal is suppressed at temperature stratification is increased. This is illustrated in figure 1 as the increasing depth to the upper limit of withdrawal even though the reservoir level is dropping. Factors which affect the upper limit of withdrawal is the outflow, temperature stratification, and the elevation of withdrawal (elevation 815 ft for power releases and elevation 742 for low level spillway releases). For example, the drop in the upper limit of withdrawal in September is attributed to increased temperature stratification, low level releases, and a reduced flow (8,100 ft^3/sec).

The lower limit of withdrawal is a function of same variables which were described above. For the Shasta Dam penstock withdrawals, the lower limit of withdrawal is set by the physical boundary located below the intake invert (varies from el. 720 to el. 800). In general, the lower limit of withdrawal was difficult to determine because of acoustic interference from the bottom. Because of these difficulties lower limits of withdrawal are not reported. However, figure 1 indicates a lower limit of withdrawal of about 100 meters because of the relatively constant temperature of water stored below this depth.

Average release water temperature data were collected from the California Data Exchange Center (CDEC) Database. The release water temperatures provide an indication of the integrated effects of the selective withdrawal characteristics for the wide range of conditions tested.

The following is a brief description of the principle of ADCP operation.

Acoustic Doppler Current Profilers (ADCPs) are state of the art instruments which measure current velocity profiles in oceans, rivers, and lakes. ADCPs use the Doppler effect to determine the current velocity by measuring the velocity of sound reflectors (sediment or plankton) moving with the current. ADCPs use the Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from the sound scatterers in the water column. The echoes are referred to as back scattered signals. The amount of frequency shift in the back scattered signal is proportional to the relative velocity between the ADCP and scatterer. In addition, the ADCP can only measure the velocity component in the direction of a line between the scatterer and the acoustic transducer. As a result, ADCPs use multiple beams pointed in different directions to measure two or three orthogonal velocity components. Beams are positioned 90 degrees apart horizontally and at a angle of 20 or 30 degrees from vertical, figure 2.

One problem with this method is that the beams make their measurements in different locations. Therefore, the currents in a horizontal layer must be homogeneous, which for lakes and oceans is a reasonable assumption. The most important feature of ADCPs is their ability to measure current profiles, although bathymetric data is also generated. ADCPs break the acoustic beams into uniform volumes called depth cells or bins. Each depth cell is comparable to a single current meter measurement, while the ADCP velocity profile is equivalent to a string of evenly spaced current meters. The only difference being the ADCP measures average velocity over the depth range of each cell, whereas a current meter is a point measurement. Profiles are generated by range gating the acoustic pulse. This technique breaks the signal into successive segments and processes each segment independently of the others. Echoes from far ranges take longer to arrive than do echoes from nearby ranges. Thus, successive range gates correspond to echoes from increasingly distant depth cells.

ADCPs measure currents relative to the ADCP, which can be oriented arbitrarily and moving relative to the earth. Therefore, it is usually necessary to correct the data for ADCP attitude and motion. There are two kinds of motion that require correction: rotation (pitch, roll, and heading) and translation (for moving-boat applications). Heading is determined using a gyrocompass or a flux gate compass, pitch and roll are measured using a vertical gyro or pendulums, and translation is determined using a variety of navigation instruments (GPS, LORAN, Satnav, etc.) or a bottom tracking system.

The errors associated with ADCP measurements can be attributed to random and bias components. Random errors are a function of transducer frequency, depth cell size, the number of signals or pings averaged together, and beam geometry. Bias errors are a function of temperature, mean current speed, beam geometry error, etc. At this time this bias error can not be computed, but they are estimated to be on the order of 0.5 to 1.0 cm/sec. Random errors for a single ping is typically around 11 cm/sec. However, averaging of several hundred pings is used to reduce the random error to an acceptable level, approximately 2-3 cm/sec. Averaging can reduce the relatively large random error present in single ping data, but after a certain amount of averaging, the random error becomes less than the bias error. At this point, further averaging will not reduce the overall systematic error.

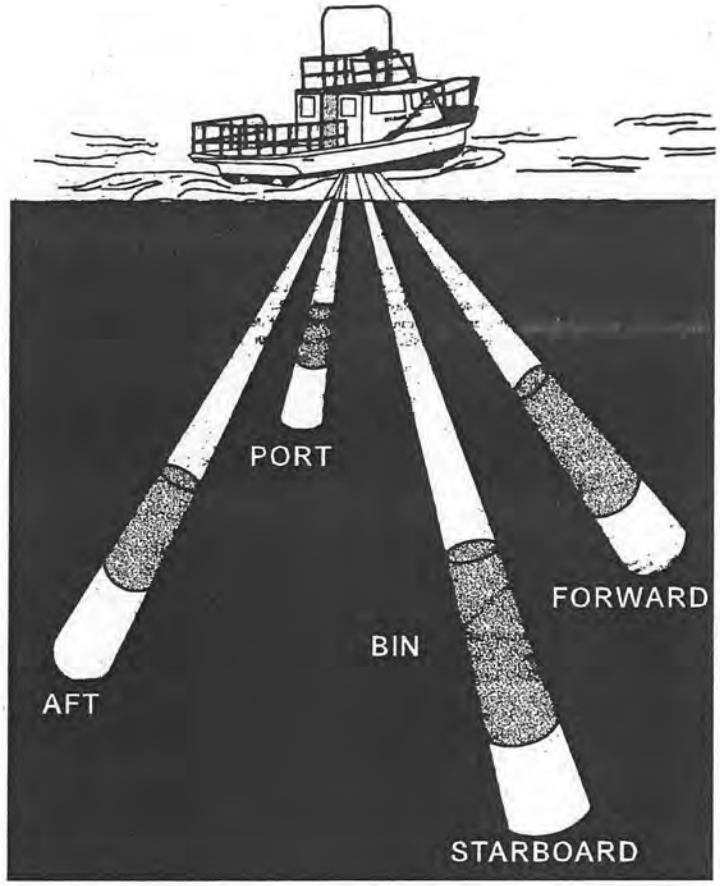


Figure 2 - Moving boat application of an acoustic Doppler current profiler.

Another ADCP limitation is the effect of the bottom (or surface) reflections of the acoustic signal. As a result, the ADCP cannot measure water velocities near the top and bottom of the water column. Water velocities near the surface cannot be measured for two reasons: 1) the ADCP must be submerged during a measurement, and 2) velocities can not be measured near the transducer face because there is a delay between the send and receive modes of operation. Water velocities near the bottom can not be measured because of side-lobe interference. Side-lobe interference causes a corruption of data from the last 10% of the profiling range. Consequently, the ADCP processing software automatically rejects velocity data collect from beyond 90 percent of the depth.

TO: Spencer Hovekamp, Fishery Biologist May 18, 1995

FROM: Tracy Vermeyen, P.E., Hydraulic Engineer

SUBJECT: Shasta Lake ADCP measurements - Data Report for May 16-17, 1995

ADCP measurements taken near the dam and at five lake stations were of mixed quality. The flow through Shasta Lake was about 11,500 ft^3/sec and the reservoir water surface elevation was 1055 ft. The release water temperature was reported by CDEC to be 47.0 °F. Several velocity profiles and transects were collected at several sampling locations (stations 1, 2, and 4). Analysis of the ADCP data showed there were some problems with poor data quality. I asked the instrumentation manufacturer, RD Instruments, to look at the data and identify any equipment or configuration problems. Randy Marsden from RD Instruments said the equipment and configuration were working properly, but that there may not be enough acoustic scatters in the water column to collect good velocity measurements at all depths. This may be attributed to limited number of organic scatters in the deeper portions of the water column. Data quality may improve as biologic activity increases in the summer months.

I was encouraged by our initial field tests and learned much about the instrument. With this months experience and suggestions from RD Instruments, I think that June's ADCP measurements will produce even better results than reported in this data report. Even though the velocity profiles have some poor or missing data they do provide an indication of the upper limit of the withdrawal layer. There was also enough information to get an estimate of the maximum velocities and at what depth they occur.

The ADCP data were post-processed to eliminate poor-quality data from the data files. This was done using programs developed by the author. Strict quality assurance guidelines were followed as suggested by the ADCP manufacturer in their operators manuals. Velocity data collected on May 16 and 17, 1995 are summarized as follows:

ADCP Transect Data

Figure 1 is a plot of velocity data from an ADCP transect taken along a parallel course 200 ft from the face of the dam. This color plot shows bad data as black rectangles. The upper limit of the withdrawal zone (where velocities are near zero) is visible at a depth of 37 meters (120 ft on the figure). Good velocity measurements in the withdrawal zone were limited, but some velocities in the 60-90 cm/sec (2 to 3 ft/sec on the figure) range were measured.

Figure 2 is a plot of velocity data from an ADCP transect taken along a parallel course 300 ft from the face of the dam. This data set was improved by making adjustments to the ADCP configuration; the profiling increment was changed from 1 meter to 2 meters. This plot shows the upper limit of the withdrawal zone (where velocities are near zero) is visible at a depth of 44 meters. This plot also shows the high velocity fields, 30 to 60 cm/sec, generated by the power outflows. Power releases are withdrawn from penstock intakes at a depth of 73 meters (elevation 815 ft).

ADCP Profile Data

The following figures are of velocity profiles taken at different stations in Shasta Lake. These velocity profiles consist of the three components (V_{north}, V_{east}, and V_{vert}) and a direction toward the intake which is in a southwesterly direction. On these plots, negative values represent the south, west, and downward velocity components. Please note that velocity magnitudes measured near the lower limit of the ADCP's velocity resolution (about 3 to 5 cm/sec) can make interpretation difficult.

Figure 3 is a plot of velocity profiles from an ADCP profile taken while moored to the buoyline surrounding the intake structures. The ADCP was positioned at the centerline of penstock intake no. 3. This plot shows a 10 cm/sec southwesterly current at a depth of 30 meters. This may be explained by operation of the upper (el. 942) spillway outlets. The upper limit of withdrawal is at a depth of about 60 m. The lower limit of withdrawal is controlled by the lake bottom, or elevation 800 ft.

Figure 4 is a plot of velocity profiles from an ADCP profile taken while moored at lake station no. 1. This plot shows a weak velocity in the westerly direction at a depth of 40 to 60 meters. This velocity direction is consistent with the direction toward the penstock intakes. The overall magnitude of the velocities (5 cm/sec) is about as low as the ADCP can measure. As a result, it is difficult to determine the extent of the withdrawal zone from this profile.

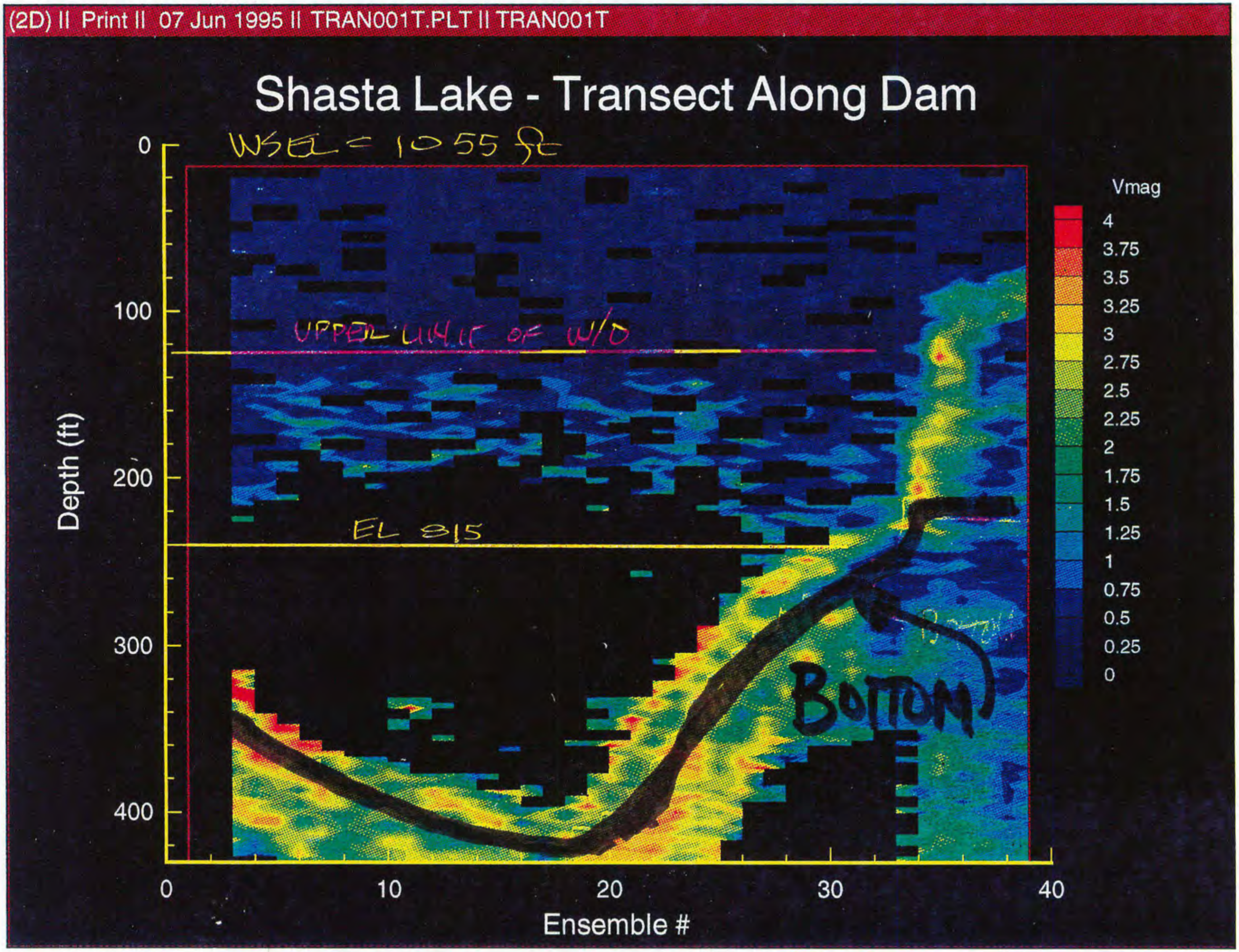
Figure 5 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 2. This plot shows a near-surface current in the southeasterly direction at a depth of 10 to 30 m. The overall magnitude of the withdrawal layer velocities are below 5 cm/sec, but there is a higher velocity region at the penstock intake, el. 815 ft. Velocities measured below el. 815 are in the wrong direction and are probably [illegible]erence (noise) from bottom reflections.

? depth? in meters

Figure 6 is a plot of velocity profiles from an ADCP pro[illegible]r lake station no. 4. This plot indicates a 5 cm/sec near-surface cur[illegible]ction. It is strange that the velocities are very low or zero for dep[illegible]gain, the higher velocities are measured around the penstock int[illegible]nit of withdrawal is at 55 m deep, the lower limit is at about 90 m deep.

In conclusion, I feel this field trip was a good learning experience and the ADCP performed well. I believe the data quality will improve in the summer months as biological activity increases. If you have any questions on this data or comments please contact me at (303) 236-2000 extension 451.

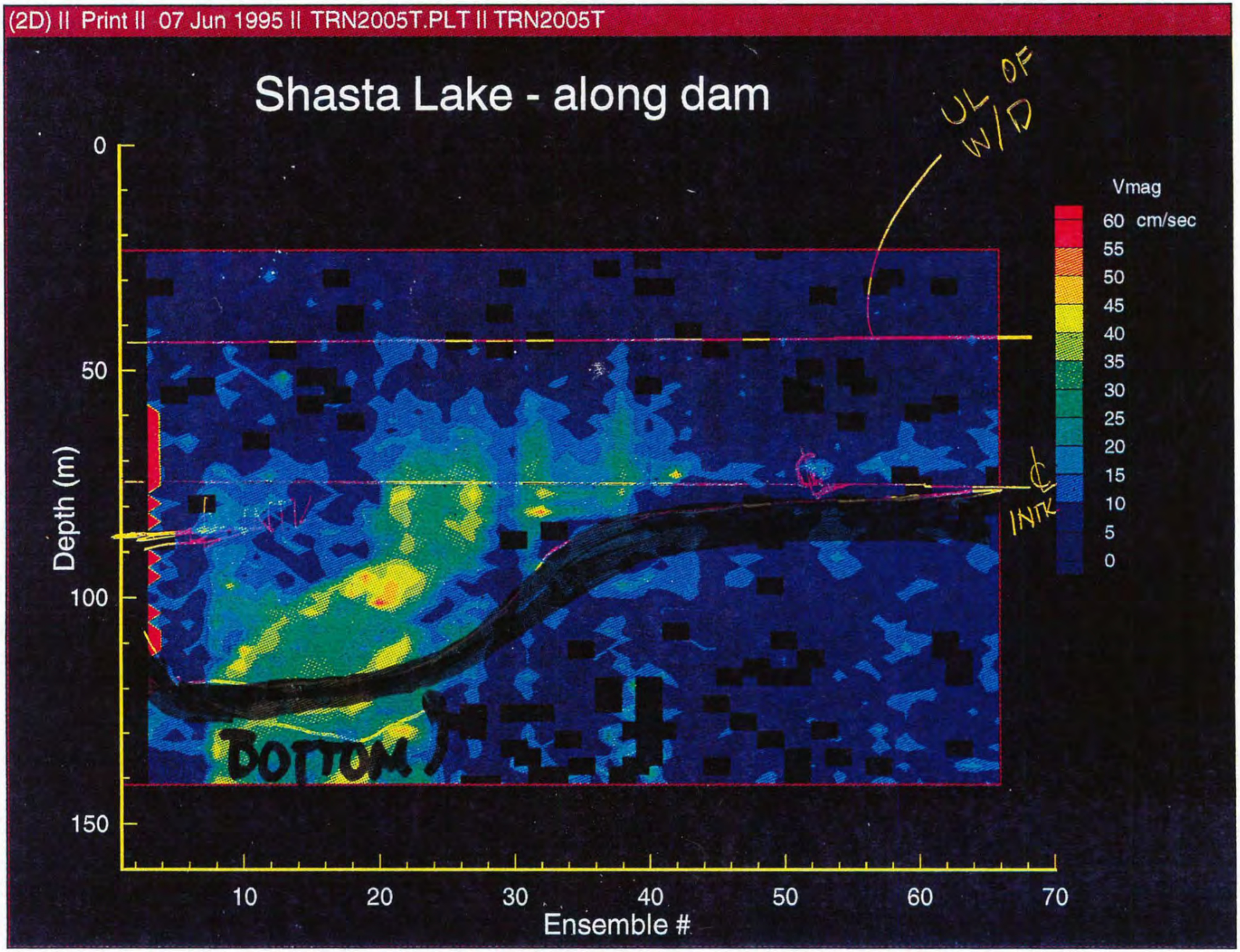
FIG. 1



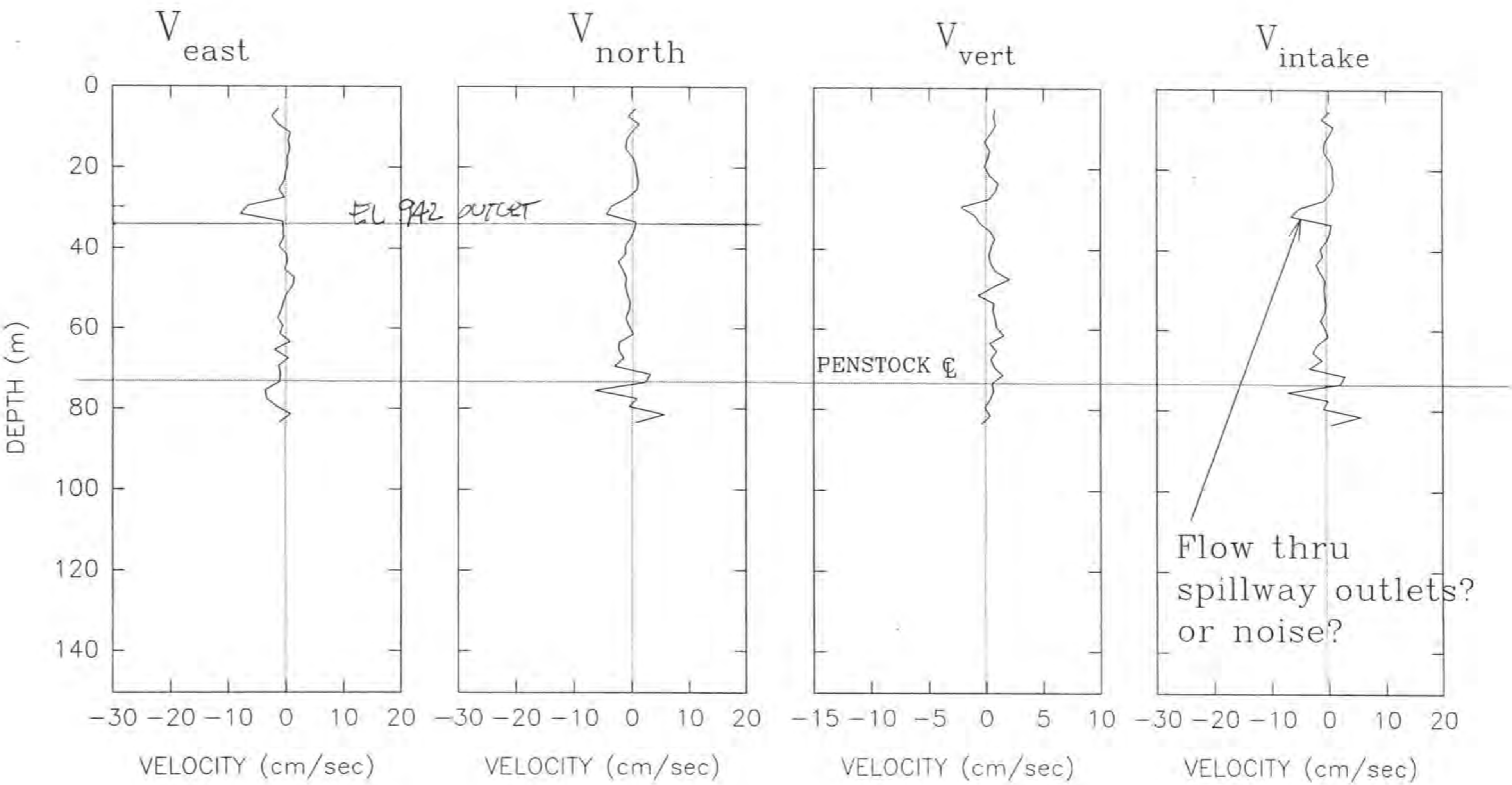
(2D) II Print II 07 Jun 1995 II TRAN001T.PLT II TRAN001T
Shasta Lake - Transect Along Dam
WSEL = 1055 ft
UPPER LIMIT OF W/O
EL 815
BOTTOM
Depth (ft)
0
100
200
300
400
Ensemble #
0
10
20
30
40
Vmag
4
3.75
3.5
3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0

ft/sec

FIG. 2


(2D) II Print II 07 Jun 1995 II TRN2005T.PLT II TRN2005T
Shasta Lake - along dam
Depth (m)
0
50
100
150
10
20
30
40
50
60
70
Ensemble #
Vmag
60 cm/sec
55
50
45
40
35
30
25
20
15
10
5
0
UL OF W/D
℄ INTK
BOTTOM

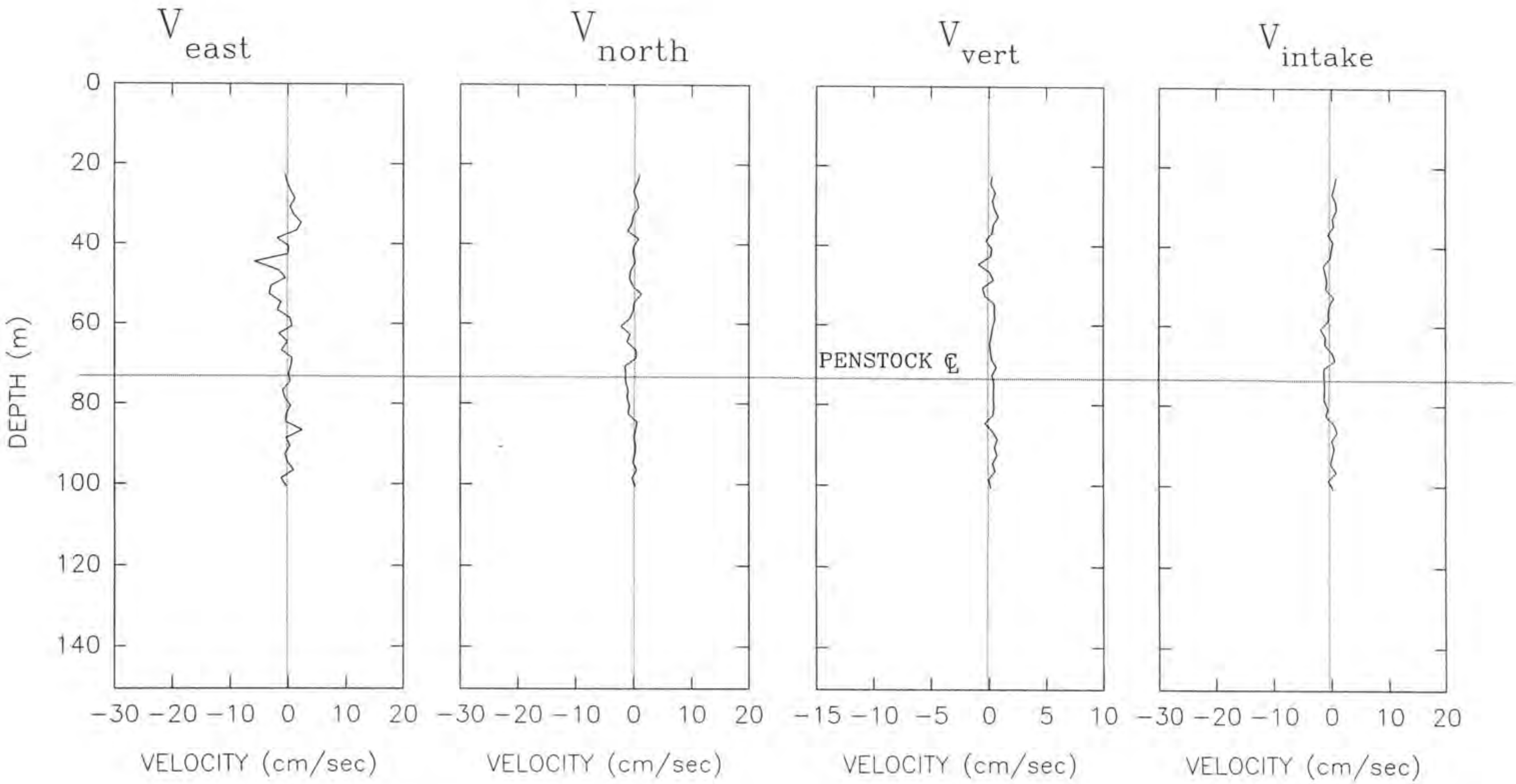
Shasta Lake
5/17/95
PRF2005T.000
VELOCITY PLOTS – INTAKE BUOYLINE



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 3

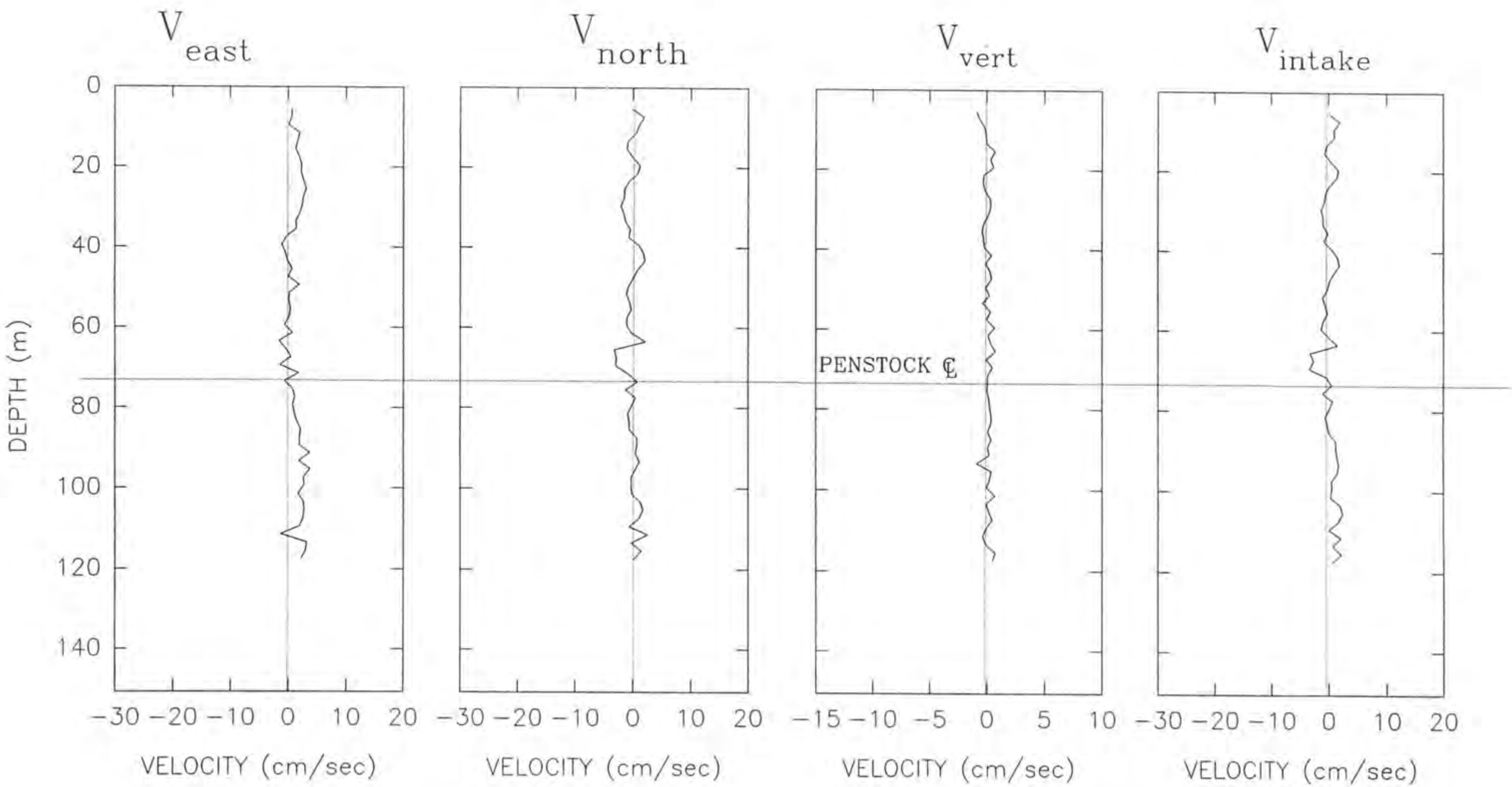
Shasta Lake
5/17/95
PRF2003T.000
VELOCITY PLOTS – LAKE STATION NO. 1



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 4

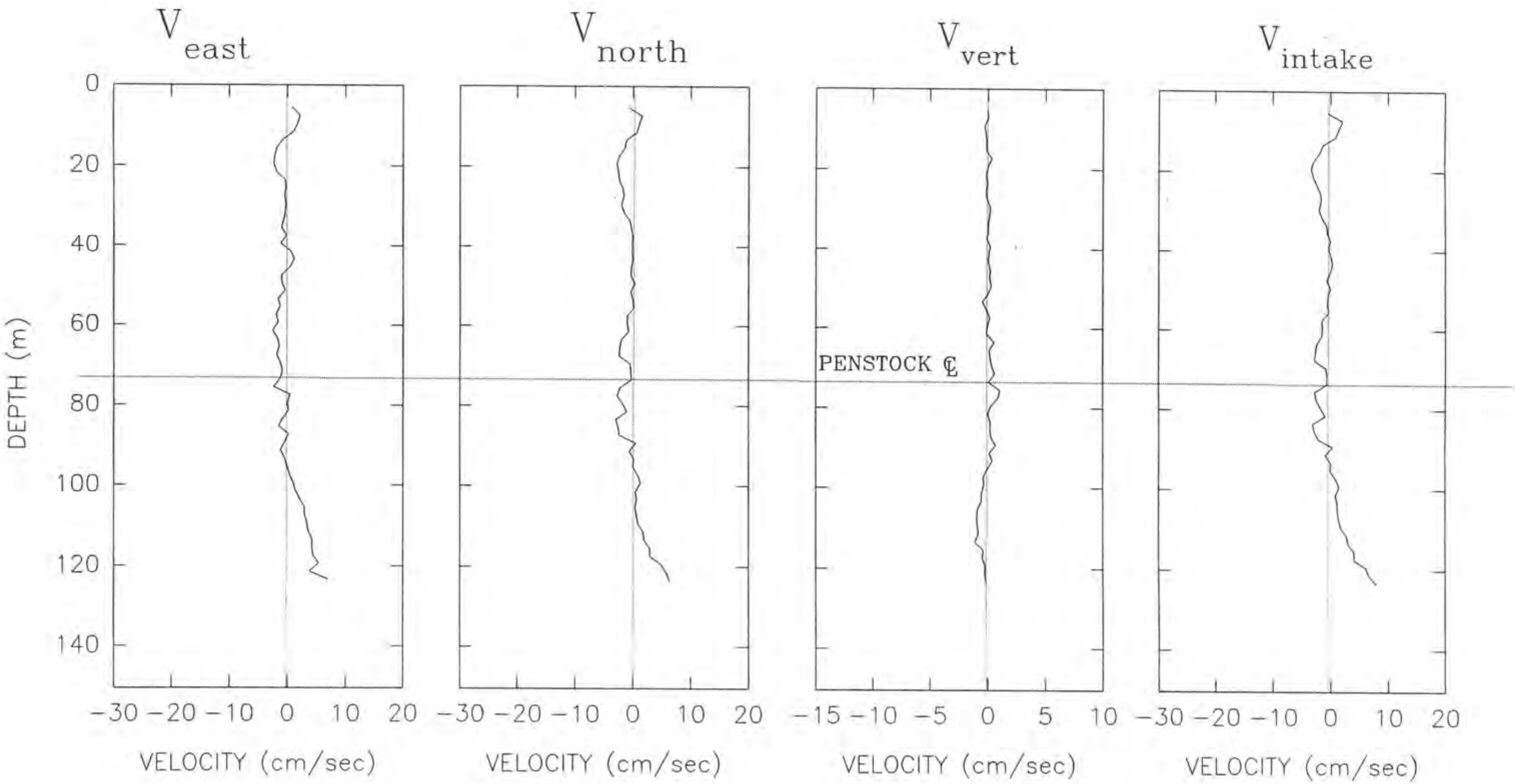
Shasta Lake
5/17/95
PRF2002T.000
VELOCITY PLOTS – LAKE STATION NO. 2



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 5

Shasta Lake
5/17/95
TRN2001R.000
VELOCITY PLOTS – LAKE STATION NO. 4



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

0.79 0.96

FIG. 6

TO: Spencer Hovekamp, Fishery Biologist June 15, 1995

FROM: Tracy Vermeyen, Hydraulic Engineer

SUBJECT: Shasta Lake ADCP measurements - Data Report for June 12 -13, 1995

ADCP measurements taken in June were of good quality. The flow through Shasta Lake was about 11,500 ft^3/sec in the morning and was reduced to 9,000 ft^3/s in the afternoon. The reservoir water surface elevation was 1057.6 ft. The release water temperature was reported by CDEC to be 49.6 °F. We were able to collect several velocity profiles and transects at the dam and at all five lake stations. We also collected ADCP measurements in the Sacramento River Arm.

The problems with poor data quality reported in the May data report were resolved by making some configuration changes suggested by Randy Marsden from RD Instruments.

Another improvement was that ADCP data were post-processed to eliminate poor-quality data from the data files. Strict quality assurance guidelines were followed as suggested by the ADCP manufacturer. Velocity data collected on June 12 and 13, 1995 are summarized as follows:

ADCP Transect Data

Figure 1 is a plot of velocity data from an ADCP transect taken along a parallel course about 200 ft from the face of the dam. This plot illustrates velocities of 10 to 40 cm/sec for depths greater than 40 meters. These velocities were generated by the hydropower releases. For the reservoir water surface elevation of 1057 ft the intake centerlines are at a depth of 74 meters. The upper limit of the withdrawal zone near the dam face is at a depth of 40 meters. The lower limit of the withdrawal zone extends to the reservoir bottom.

Figure 2 is a plot of velocity data from an ADCP transect perpendicular to the dam face heading towards the buoyline. This data set shows how rapidly the water speed decreases with distance from the intakes. This plot shows the upper limit of the withdrawal zone decrease from a depth of 40 to 55 meters near the buoyline. The lower limit of withdrawal is controlled by the reservoir bottom.

Figure 3 is a plot of an ADCP transect collected in the Sacramento River arm of Shasta Lake. The ADCP computed the discharge to be 44 m^3/s. Using the CDEC database to get inflow data for the McCloud and Pit Rivers I was able to estimate the Sacramento River's flow to be about 55 m^3/s. I do not have much confidence in the CDEC flowrates because they were constant over several days which is not normal for this time of year. The maximum velocity measured was in the center of the channel and was 40 cm/sec. This plot is a good example of how an ADCP measures velocity and discharge in large rivers.

ADCP Profile Data

The following figures are of velocity profiles taken at sampling stations in Shasta Lake. These velocity profiles consist of the three components (V_{north}, V_{east}, and V_{vert}) and a direction toward the intake which is in a southwesterly direction. On these plots, negative values are the south, west, and downward velocity components. Please note that the velocity magnitudes measured near the lower limits of the ADCP's velocity resolution (3-5 cm/sec) make data interpretation difficult.

Figure 4 is a plot of velocity profiles from an ADCP profile taken while moored to the buoyline surrounding the intake structures. The ADCP was positioned in alignment with the centerline of penstock intake no. 3. This plot shows that the flow is toward the intake and is confined to a withdrawal layer from 40 to 75 meters deep. The maximum approach velocity is about 5-6 cm/sec. At this location no surface currents were measured.

Figure 5 is a plot of velocity profiles from an ADCP profile taken while moored at lake station no. 1. This plot was collected using the ADCP's water mode 1 which is able to measure low velocities. It is also has a higher uncertainty with each measurement so more averaging is necessary to lower the standard deviation of the mean (aka standard error). This plot shows the current is in the southwesterly direction at a depth of 40 to 80 meters. Data below 80 m is very noisy because of acoustic interference from the reservoir bottom. Note that this data is less consistent than water mode 4 data. As a result, further tests with water mode 1 will not be done.

Figure 6 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 2. This data set is a very good profile because it has a very small V_{vert} component and the data is very consistent. The V_{intake} plot shows that the current is toward the intake and is confined to a withdrawal layer from 40 to 80 meters deep. The approach velocity is about 5 cm/sec.

Figure 7 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 3. This plot is inconsistent with respect to current direction and the V_{vert} component indicates some resolution errors. The data quality for this profile is suspect and should not be used in this investigation. The reason for this poor data quality is probably caused by boat motion which is faster than the current speed. When this occurs the ADCP cannot accurately subtract the boat speed from the current speed.

Figure 8 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 4. This plot, like figure 7, is inconsistent with respect to current direction and the V_{vert} component indicates some resolution errors, the velocity bias appears to be 1 to 2 cm/sec. The noise in the data is greater than the velocity being measured. As a result, this profile data set is suspect and should not be used in this investigation.

Figure 9 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 5. The V_{intake} plot shows a similar withdrawal zone as figure 6, except that it extends to the bottom at a depth of 100 meters. The velocity in the withdrawal layer is about 2 to 3 cm/sec. A second current was measured and the profile plots show a relatively strong northeasterly current over depths of 20 to 40 meters. This current may be caused by a change in Pit River inflows. On June 9, the Pit River flows were increased from 2,500 to 8,100 ft^3/s. CDEC data show that during the flow change the temperature of Pit River inflows dropped from 61 to 58 °F. This inflow increase coupled with the density change may have generated a current necessary to stabilize the localized disturbance to the reservoir density stratification.

In conclusion, I feel this field trip was a good learning experience and the ADCP performed well. The data quality was much improved over the May data set. I suspect it will continue to improve over the course of the summer. If you have any questions on this data or comments please contact me at (303) 236-2000 extension 451.

Tracy Vermeyen, P.E.
Hydraulic Engineer
Technical Service Center

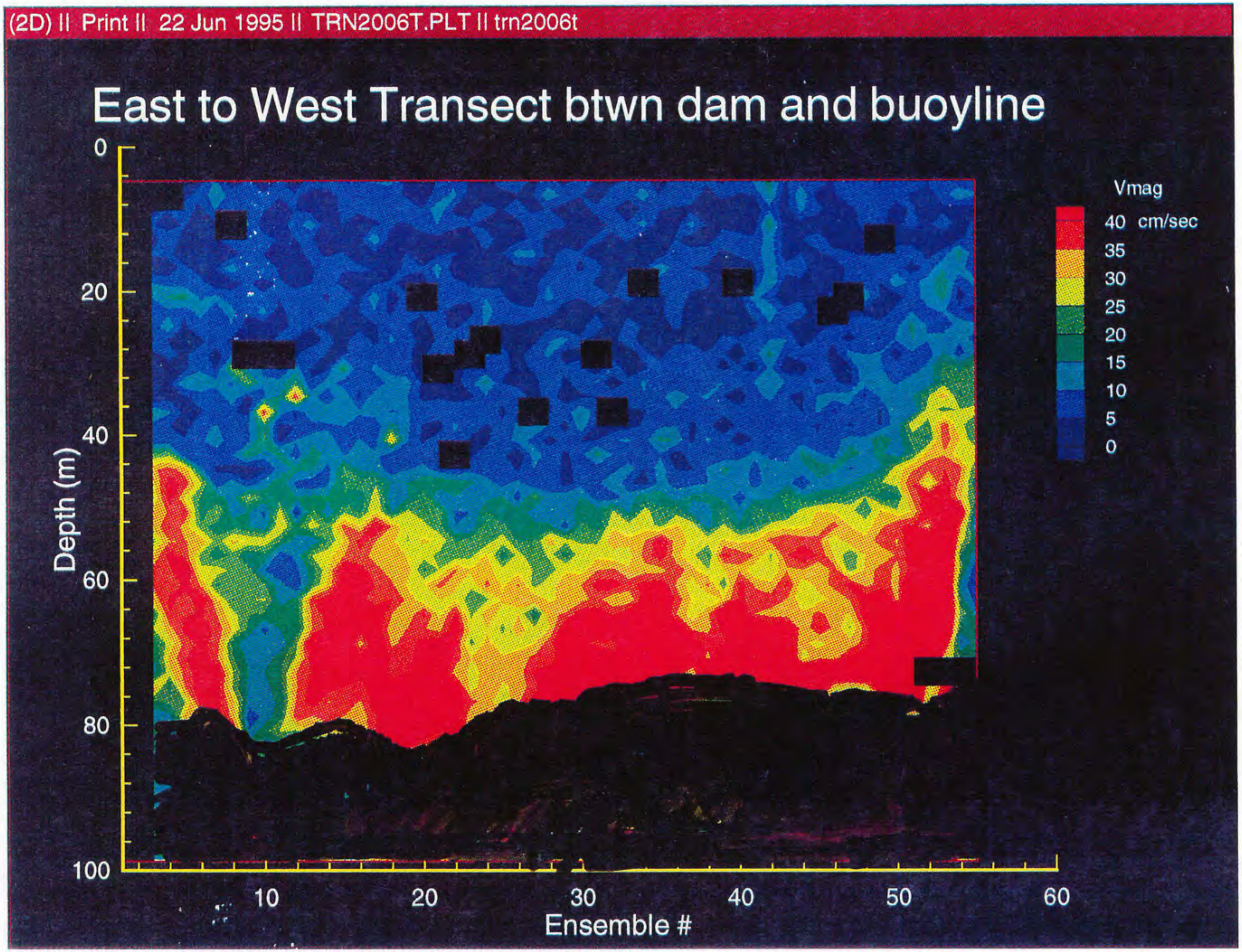

(2D) II Print II 22 Jun 1995 II TRN2006T.PLT II trn2006t
East to West Transect btwn dam and buoyline
Depth (m)
0
20
40
60
80
100
Ensemble #
10
20
30
40
50
60
Vmag
40 cm/sec
35
30
25
20
15
10
5
0

Fig 1

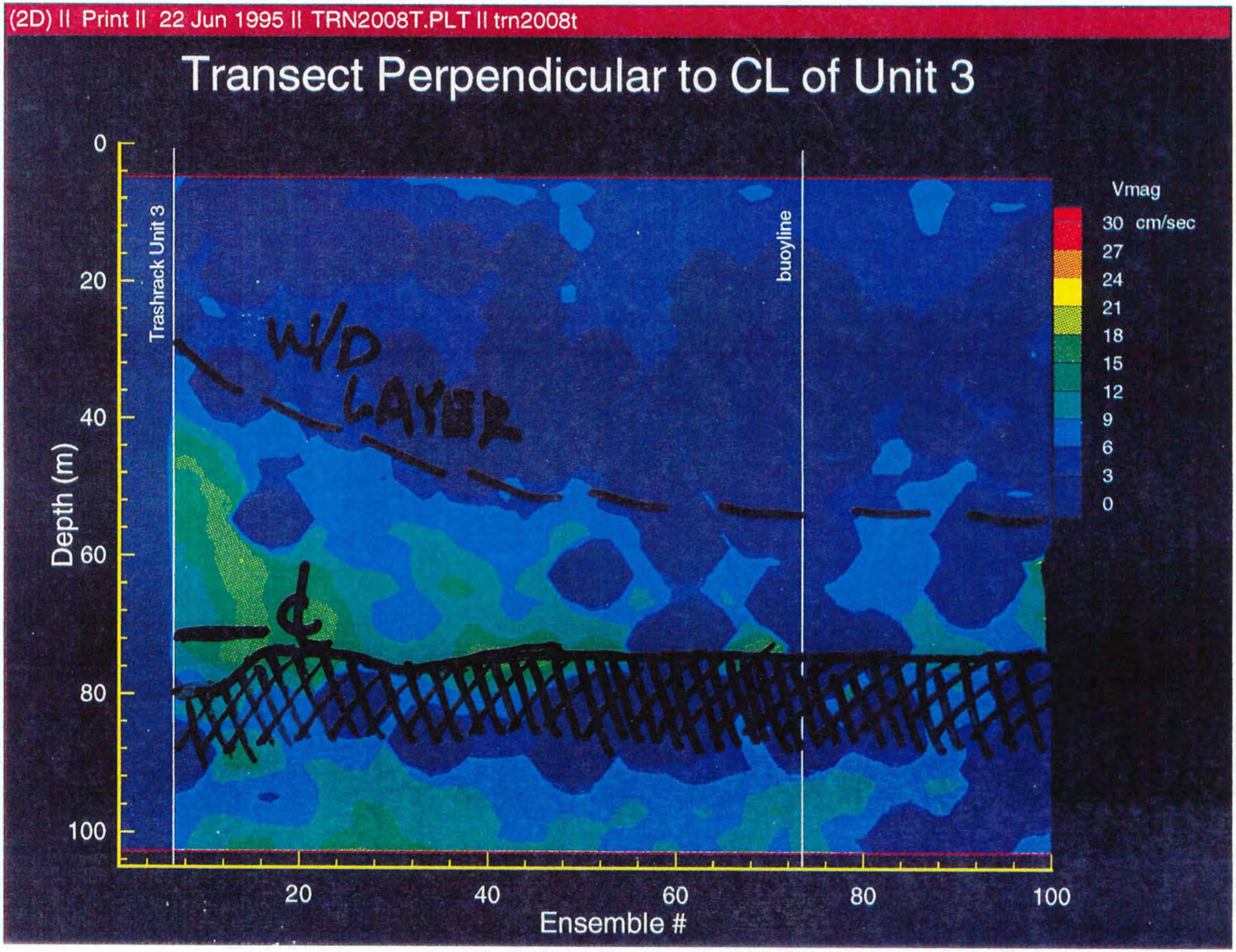
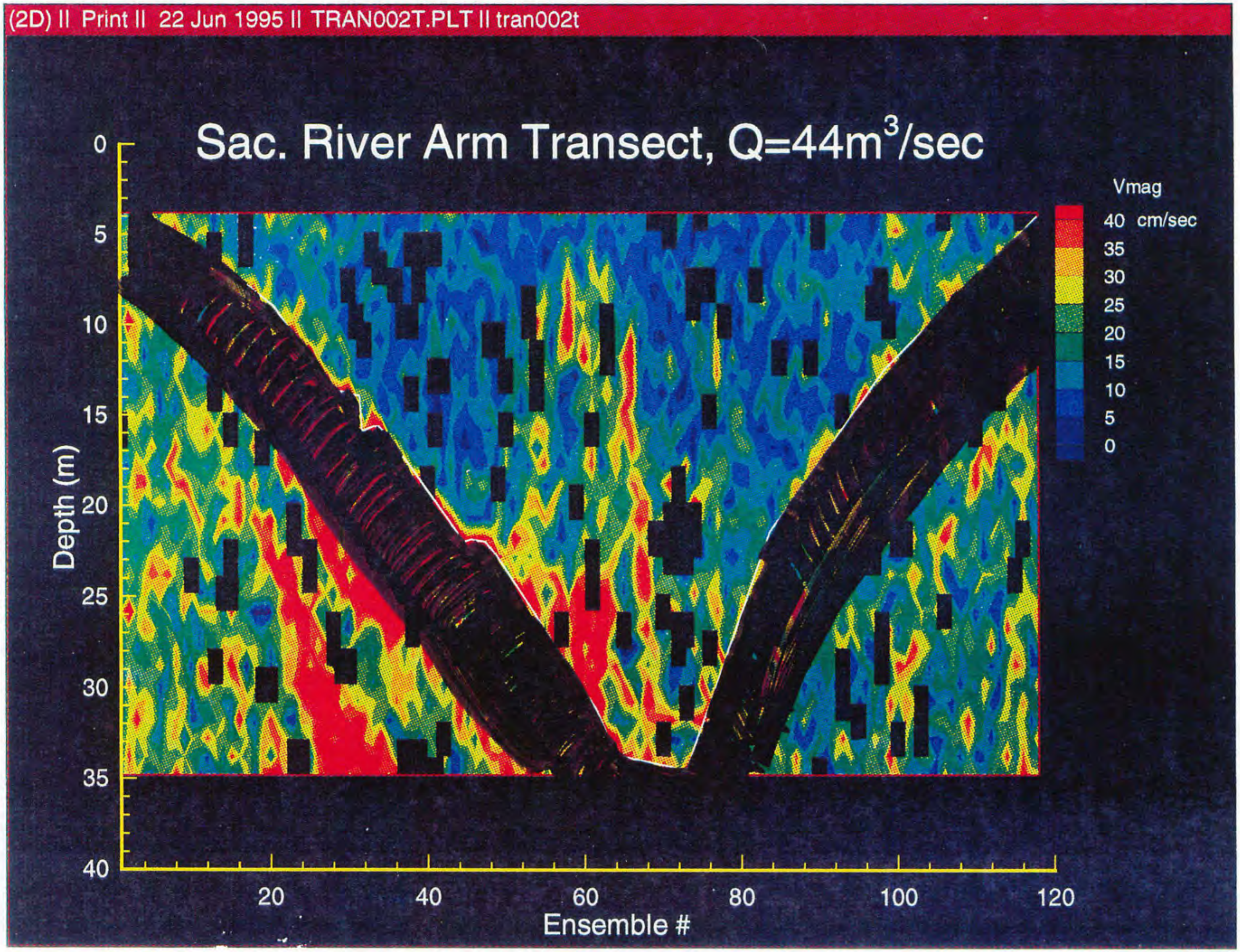

(2D) II Print II 22 Jun 1995 II TRN2008T.PLT II trn2008t
Transect Perpendicular to CL of Unit 3
Depth (m)
0
20
40
60
80
100
Trashrack Unit 3
buoyline
W/D
LAYER
℄
Vmag
30 cm/sec
27
24
21
18
15
12
9
6
3
0
20
40
60
80
100
Ensemble #

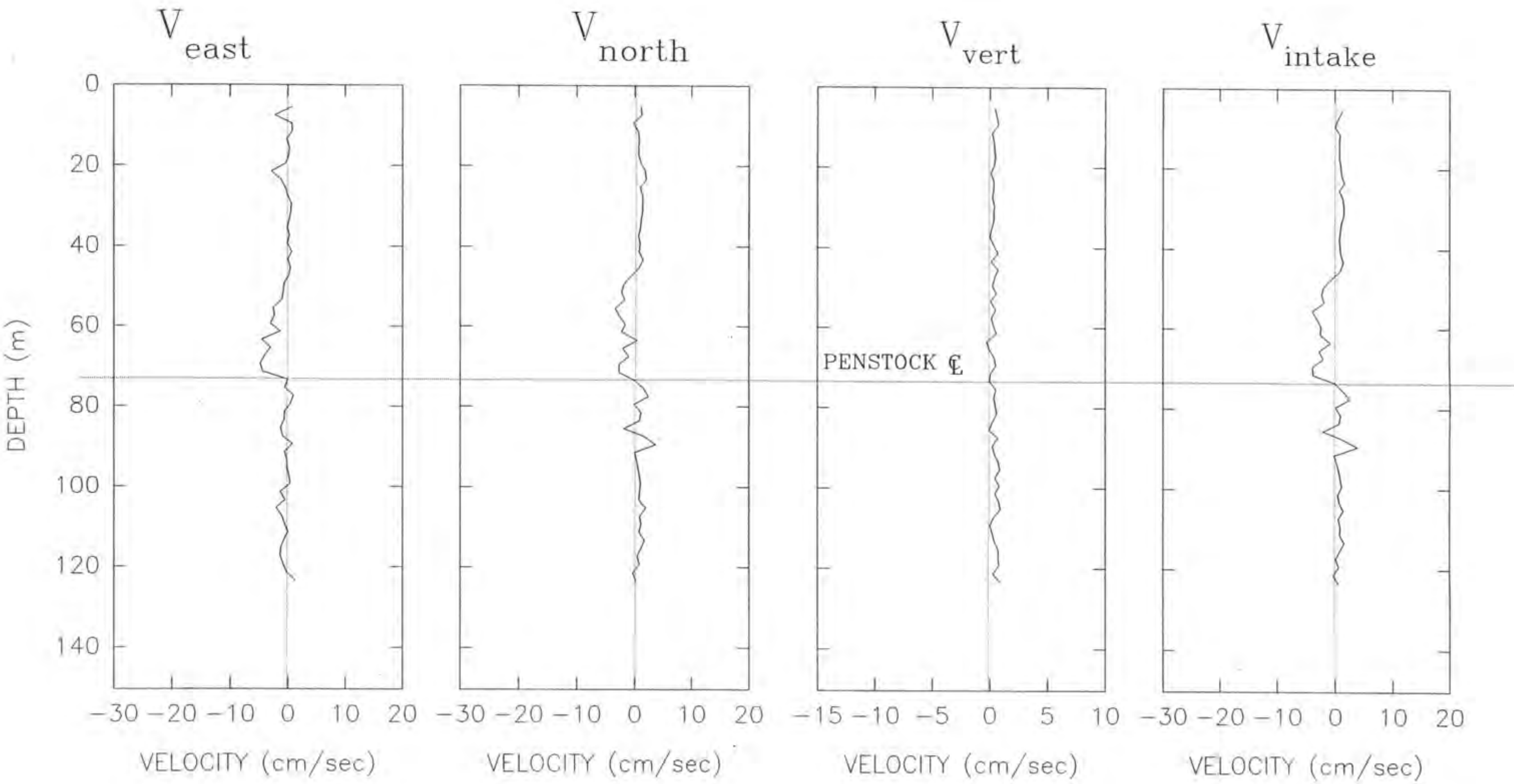
FIG. 2



(2D) II Print II 22 Jun 1995 II TRAN002T.PLT II tran002t
Sac. River Arm Transect, Q=44m³/sec
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
Depth (m)
0
5
10
15
20
25
30
35
40
Ensemble #
20
40
60
80
100
120

FIG. 3

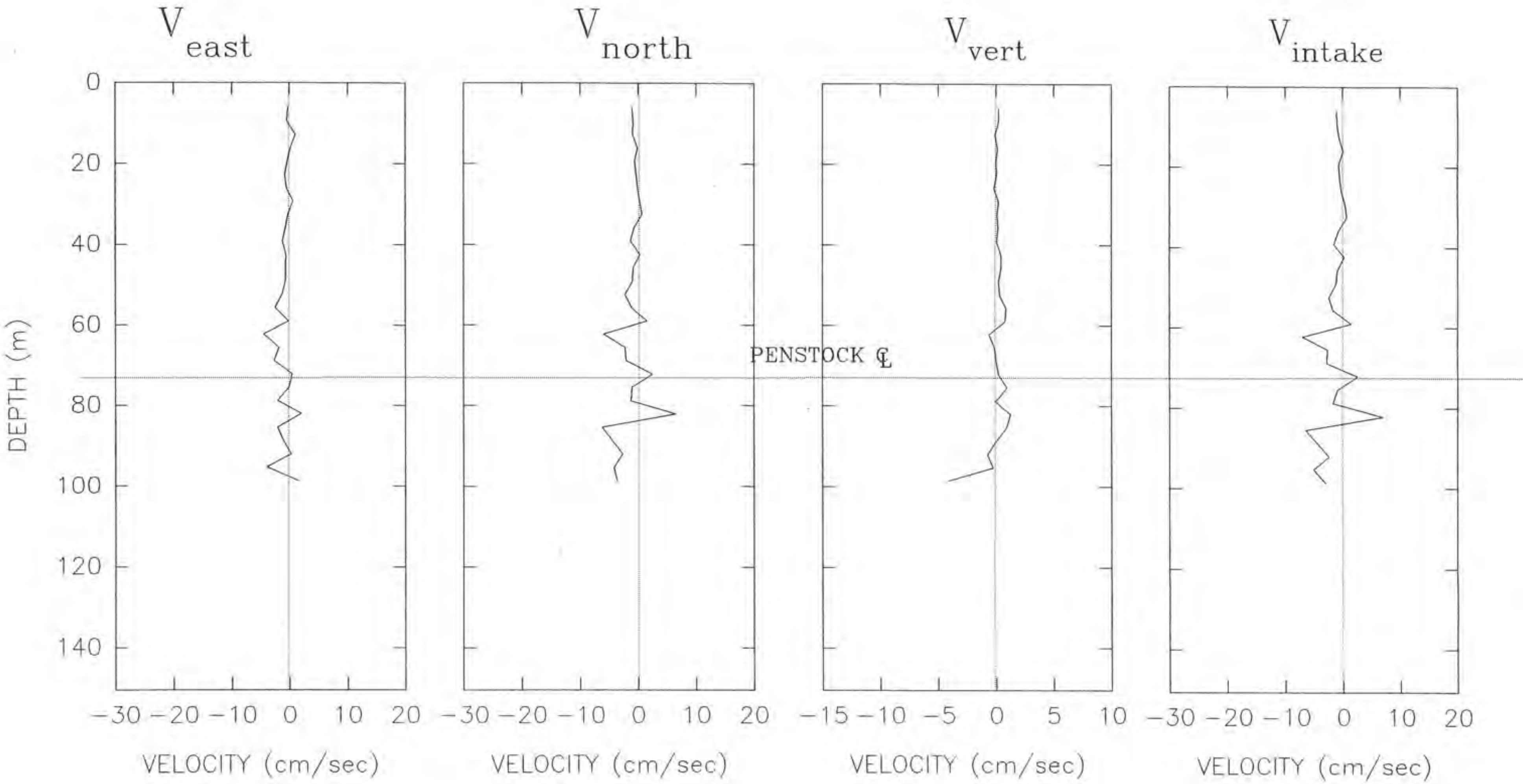
Shasta Lake – Profile data @ buoyline @ ℄ of intake #5
6/12/95
PRF2004T.000
VELOCITY PLOTS



$V_{INTAKE} = (V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3))$

FIG 4.

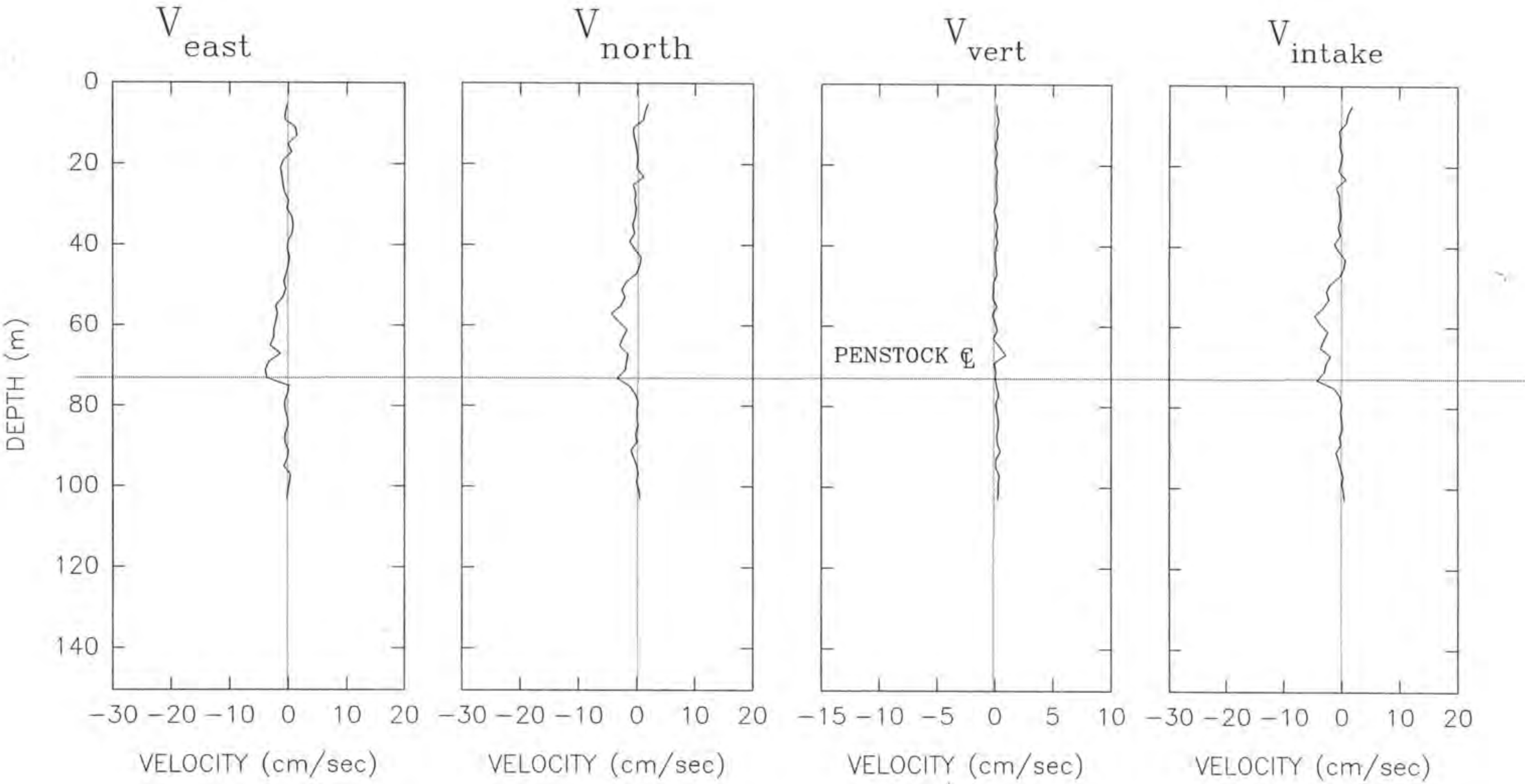
Shasta Lake – Profile data
6/13/95
STA1003T.000 Water Mode 1
VELOCITY PLOTS



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 5

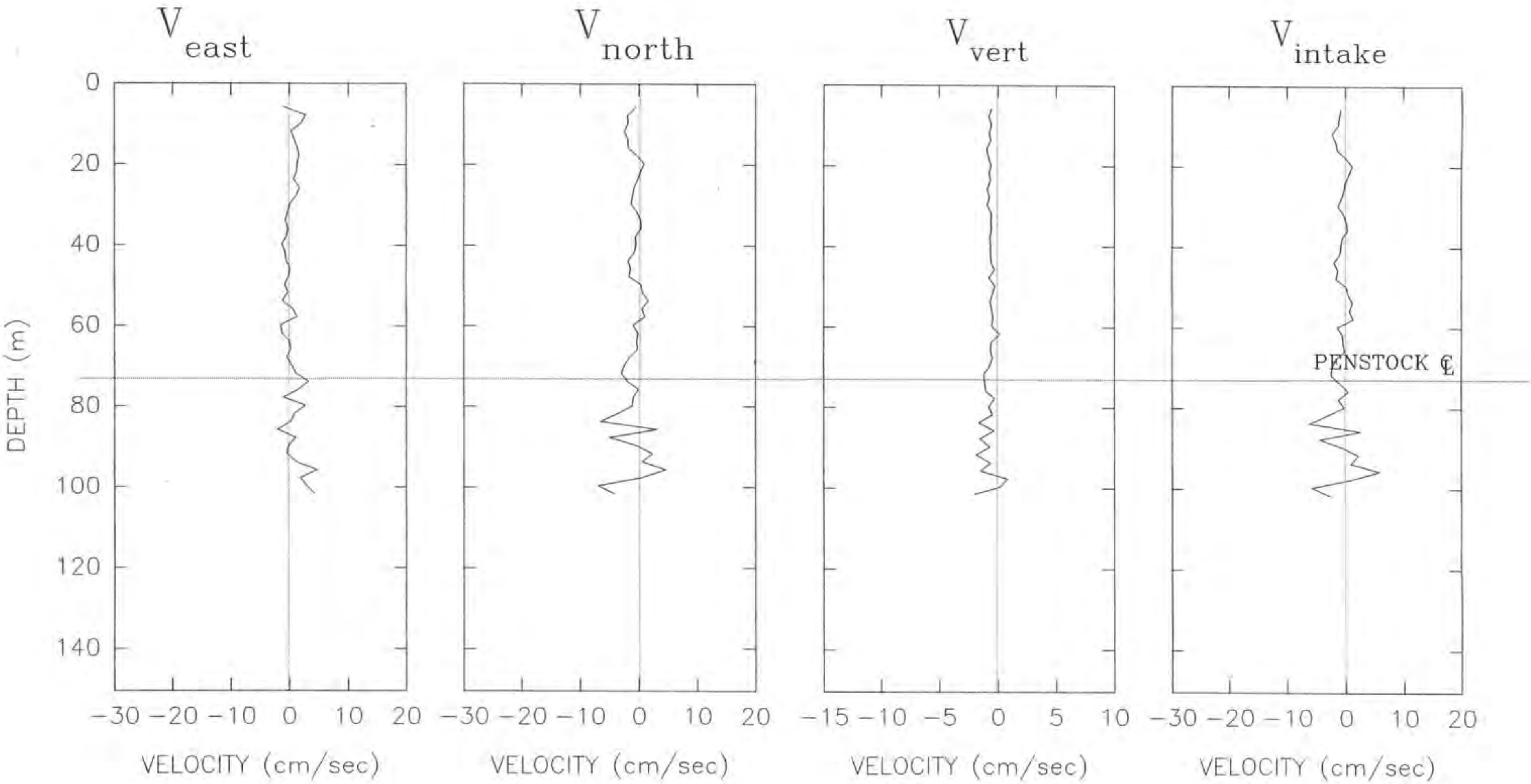
Shasta Lake – Profile data
6/13/95
STA2002T.000
VELOCITY PLOTS



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 6

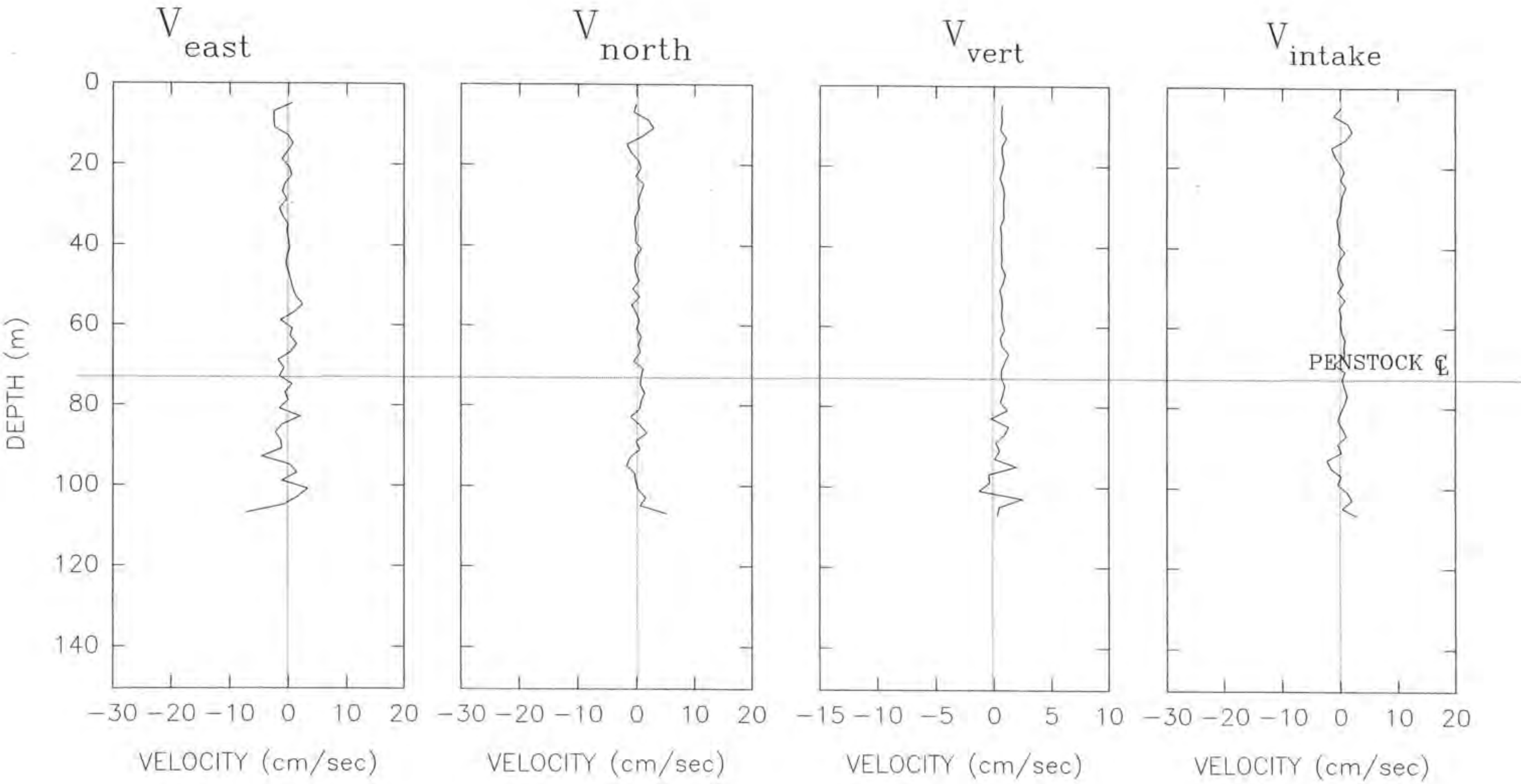
Shasta Lake – Profile data
6/13/95
STA3003T.000
VELOCITY PLOTS



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 7

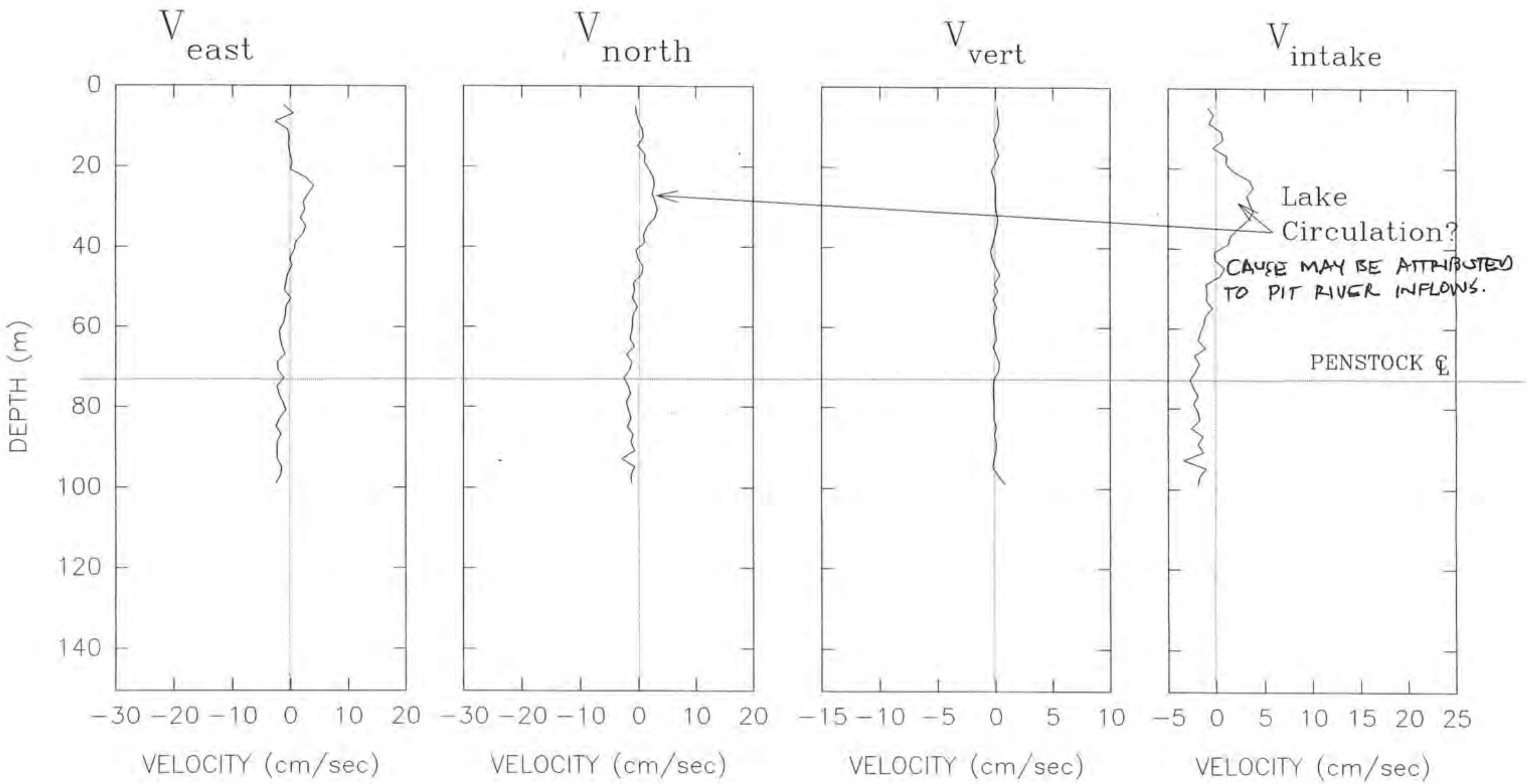
Shasta Lake - Profile data
6/12/95
STA4002T.000
VELOCITY PLOTS



$V_{INTAKE} = (V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3))$

FIG. 8

Shasta Lake – Profile data
6/12/95
STA5002T.000
VELOCITY PLOTS



$V_{INTAKE}=(V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3))$

FIG. 9

TO: Spencer Hovekamp, Fishery Biologist July 17, 1995

FROM: Tracy Vermeyen, Hydraulic Engineer

SUBJECT: Shasta Lake ADCP measurements - Data Report for July 17, 1995

ADCP measurements taken in July were of good quality. The flow through Shasta was about 14,500 ft^3/sec, the reservoir water surface elevation was 1048.6 ft, down from 1057.6 ft in June, and the release water temperature was 51 °F. John Martin and I were able to collect several velocity profiles at all five sampling locations (stations 1, 2, 3, 4, and 5) in Shasta Lake. Likewise, we collected four transects near the face of the dam.

The ADCP data files were post-processed to exclude poor-quality data from the data analysis. Strict quality assurance guidelines were followed as suggested by the ADCP manufacturer. Velocity data collected on July 17, 1995 are summarized as follows:

ADCP Transect Data

Figure 1 shows a transect collected from the buoyline's west anchorage to the first drum gate. This transect shows a high velocity area which indicates flow through penstock intakes no. 1 and no. 2. High velocities at made good distances of 0m to 20m are caused by acoustic reflections from the dam face and should be ignored. The withdrawal zone extends from a depth of about 40 meters to the bottom. The maximum velocity was about 40 cm/sec.

Figure 2 is an ADCP transect over the same course as shown in figure 1, but in the opposite direction. This figures illustrates the upper limit of withdrawal which occurs at a depth of 40 meters or elevation 917.3 ft which is about 100 ft above the penstock intake elevation of 815 ft.

Figure 3 is a plot of velocity data from an ADCP transect perpendicular to the face of the dam heading towards the buoyline. This data set shows how rapidly the water speed decreases with distance from the intakes. This plot shows the upper limit of the withdrawal zone to be at a depth of abut 45 meters. This plot is very similar to the same transect collected in June.

ADCP Profile Data

The following figures are of velocity profiles taken at different stations in Shasta Lake. These velocity profiles consist of the three components (V_{north}, V_{east}, and V_{vert}) and a direction toward the intake which is in a southwesterly direction. On these plots, negative values are the south, west, and downward velocity components. Please note that the velocity magnitudes measured near the lower limits of the ADCP's velocity resolution (3-5 cm/sec) make data appear noisy and interpretation difficult.

Figure 4 is a plot of velocity profiles from an ADCP profile taken while moored at lake station no. 1. This plot shows the current is in the southwesterly direction at a depth of 45 to 80 meters. Data below 80 m was not plotted because of acoustic interference from the reservoir bottom. Velocities of 20 to 30 cm/sec were measures at the level of penstock intakes.

Figure 5 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 2. This data set has a noisy V_{vert} component from top to bottom which indicates poor acoustic measurement conditions. However, with extensive averaging the V_{intake} profile shows that the current is toward the intake and is confined to a withdrawal layer from 45 to the reservoir bottom at 80 meters deep. The approach velocity is about 10 cm/sec. This plot shows how averaging a large sample of profile measurements can provide reliable velocity measurements.

Figure 6 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 3. This plot is inconsistent with respect to current direction and the V_{vert} component indicates a velocity bias error in the upward direction. As a result, the data quality for this profile is suspect and should not be used in this investigation.

Figure 7 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 4. This plot is more consistent with respect to current direction and the V_{vert} component indicates improve resolution when compared to figure 6. The only current of any meaningful magnitude was a northwesterly current measured at a depth of 10 meters. The normal withdrawal current (V_{intake}) toward the intake structure was not detectable at this station. However, an westerly current of about 5 cm/sec was measured in the normal withdrawal zone of 45 to 90 meters deep.

Figure 8 is a plot of velocity profiles from an ADCP profile taken while drifting near lake station no. 5. The V_{intake} plot shows a very little current toward the intake structure. The small current measured was in the northwesterly direction at 3-5 cm/sec. The withdrawal layer extends from 45 meters to about 100 meters deep on the V_{east} profile. A near-surface current was measured and the north and east profiles show a northwesterly current over depths of 10 to 20 meters. This near-surface current could be caused by wind or tributary inflows.

For profiles collected at lake stations 4 and 5 (figures 7 and 8) it is not unexpected that the withdrawal currents are not in a southwesterly direction, like at lake stations 1 through 3, because the lake basin forces water to move in a westerly direction. Likewise, the old river channel may also influence the withdrawal currents which move through it.

In conclusion, I feel this field trip was successful well and we collected several good ADCP data sets. The data quality was similar to the June data set. If you have any questions on this data or comments please contact me at (303) 236-2000 extension 451.

Tracy Vermeyen, P.E.
Hydraulic Engineer
Technical Service Center

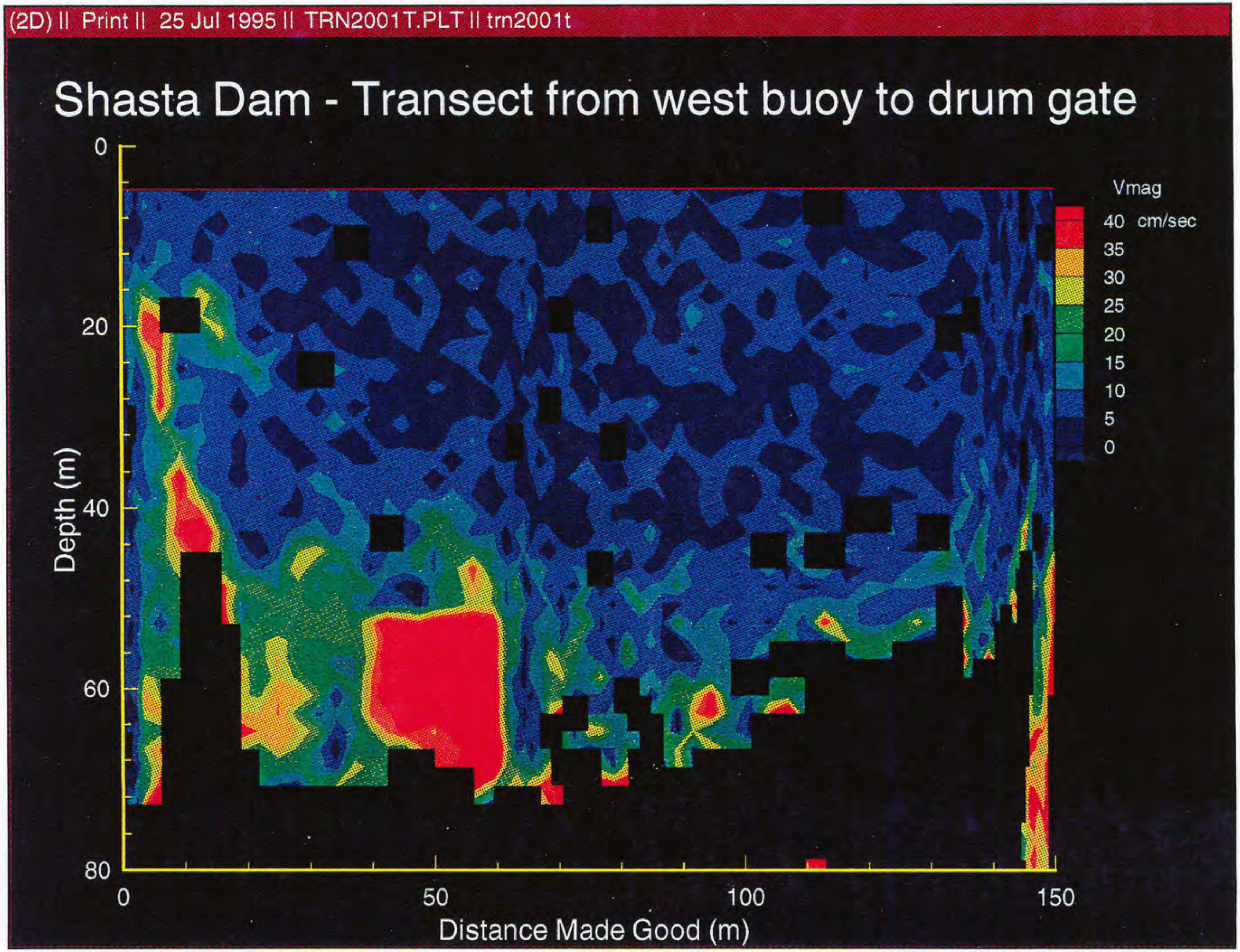
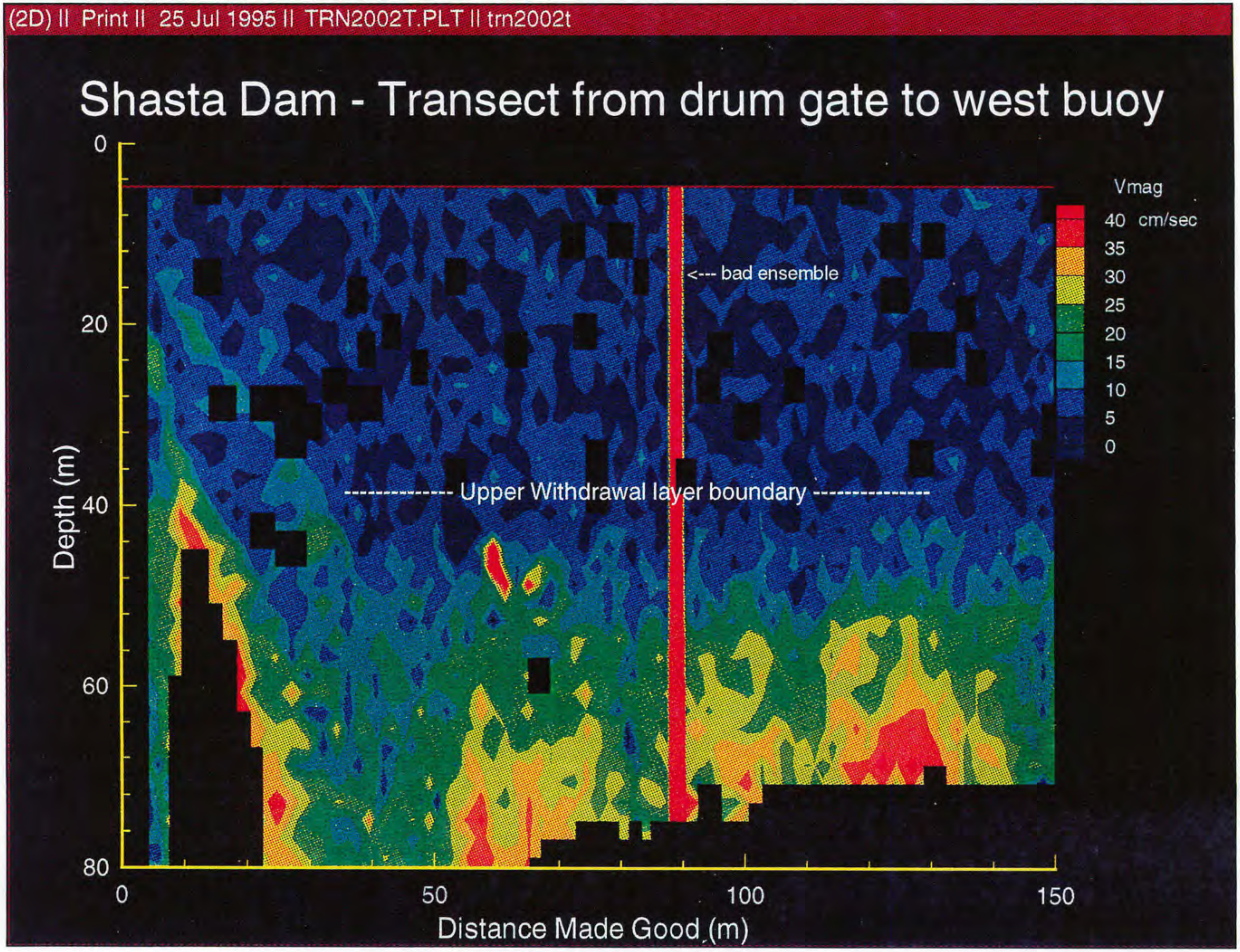

(2D) II Print II 25 Jul 1995 II TRN2001T.PLT II trn2001t
Shasta Dam - Transect from west buoy to drum gate
Depth (m)
0
20
40
60
80
Distance Made Good (m)
0
50
100
150
Vmag
40 cm/sec
35
30
25
20
15
10
5
0

FIG. 1



(2D) II Print II 25 Jul 1995 II TRN2002T.PLT II trn2002t
Shasta Dam - Transect from drum gate to west buoy
Depth (m)
0
20
40
60
80
Distance Made Good (m)
0
50
100
150
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
<--- bad ensemble
-------------- Upper Withdrawal layer boundary ---------------

FIG. 2

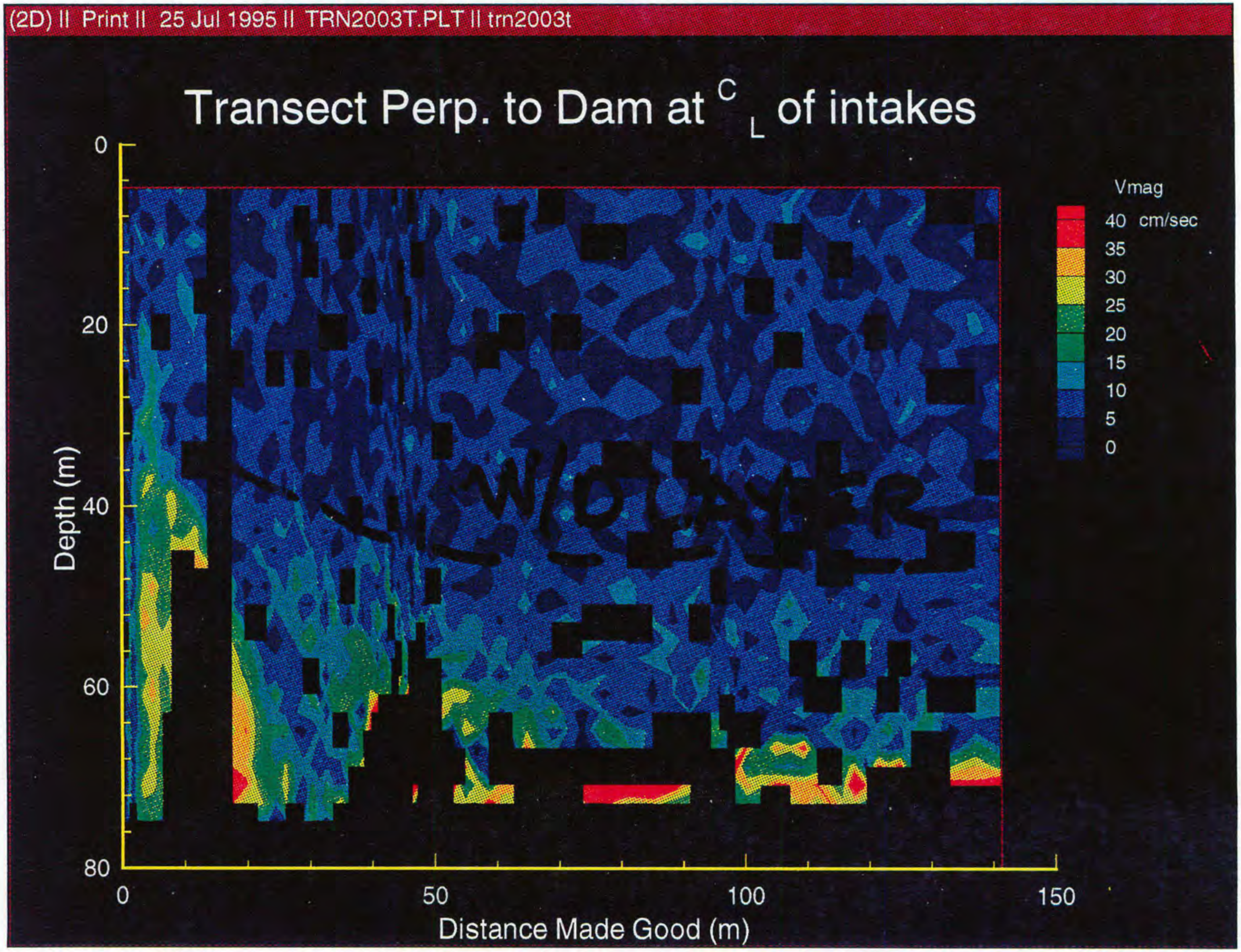
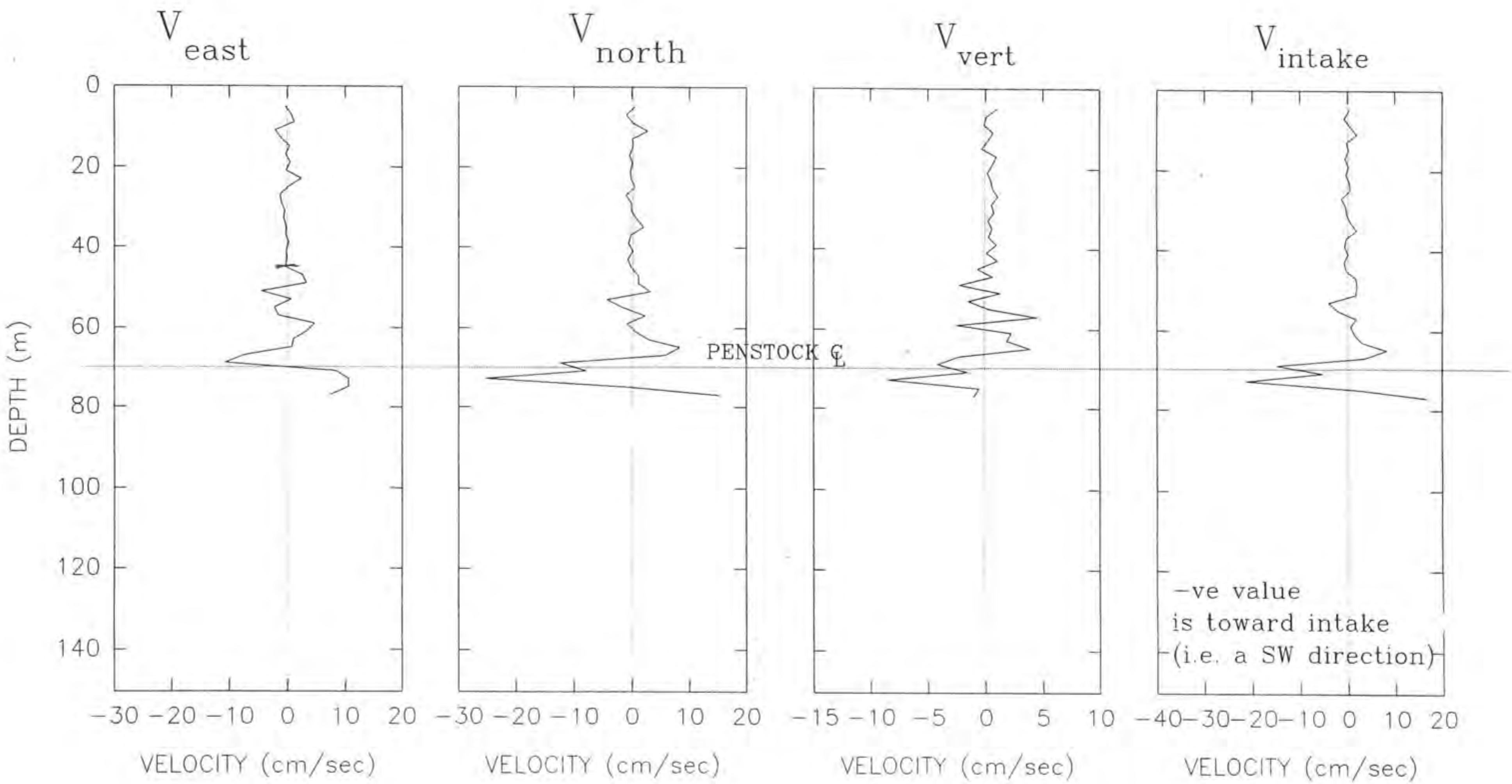

(2D) II Print II 25 Jul 1995 II TRN2003T.PLT II trn2003t
Transect Perp. to Dam at C L of intakes
Depth (m)
0
20
40
60
80
Distance Made Good (m)
0
50
100
150
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
W/O LAYER

FIG. 3

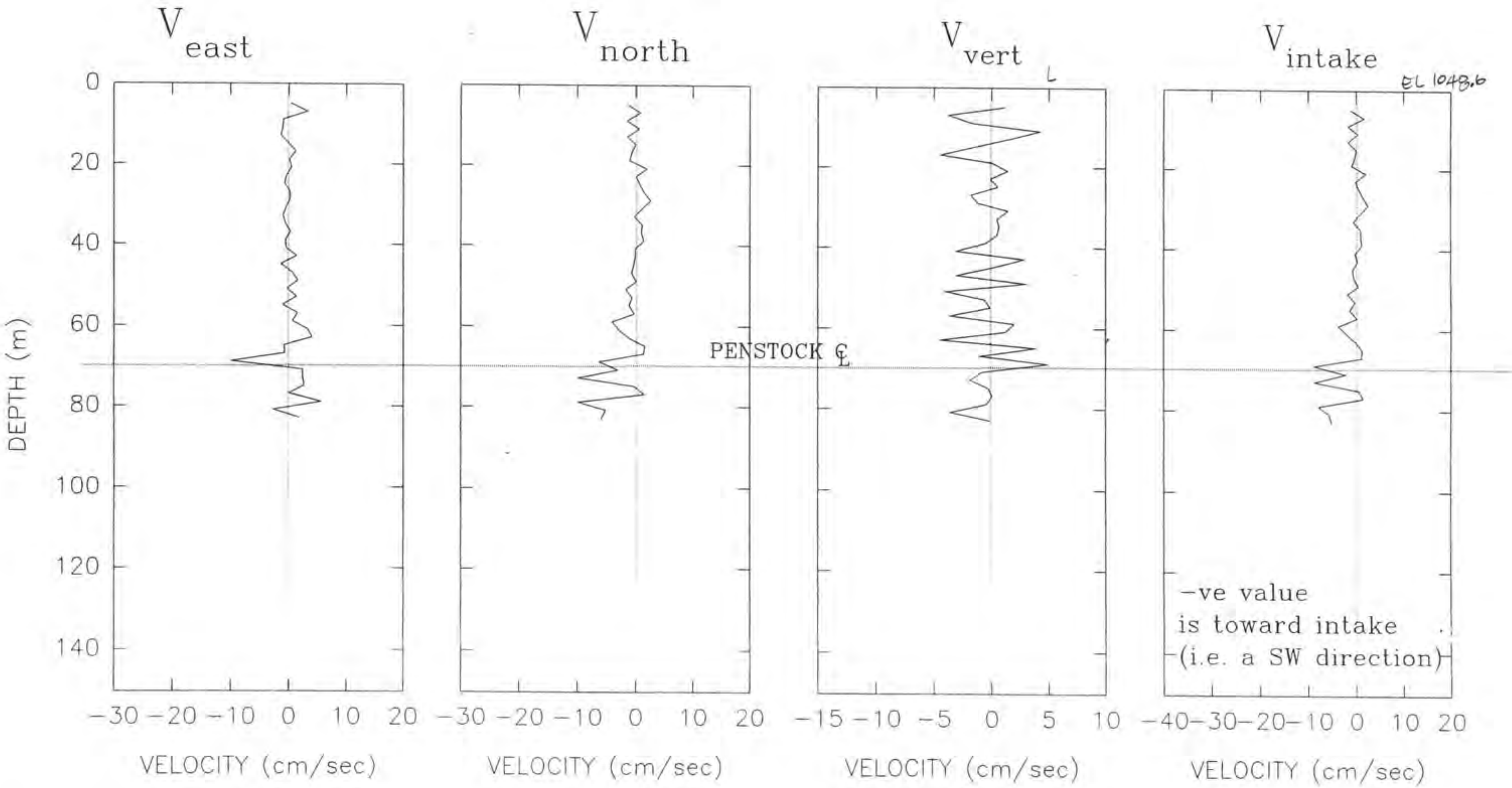
Shasta Lake – Profile data
7/17/95
STA1001T.000
VELOCITY PLOTS



$V_{INTAKE} = V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3)$

FIG. 4

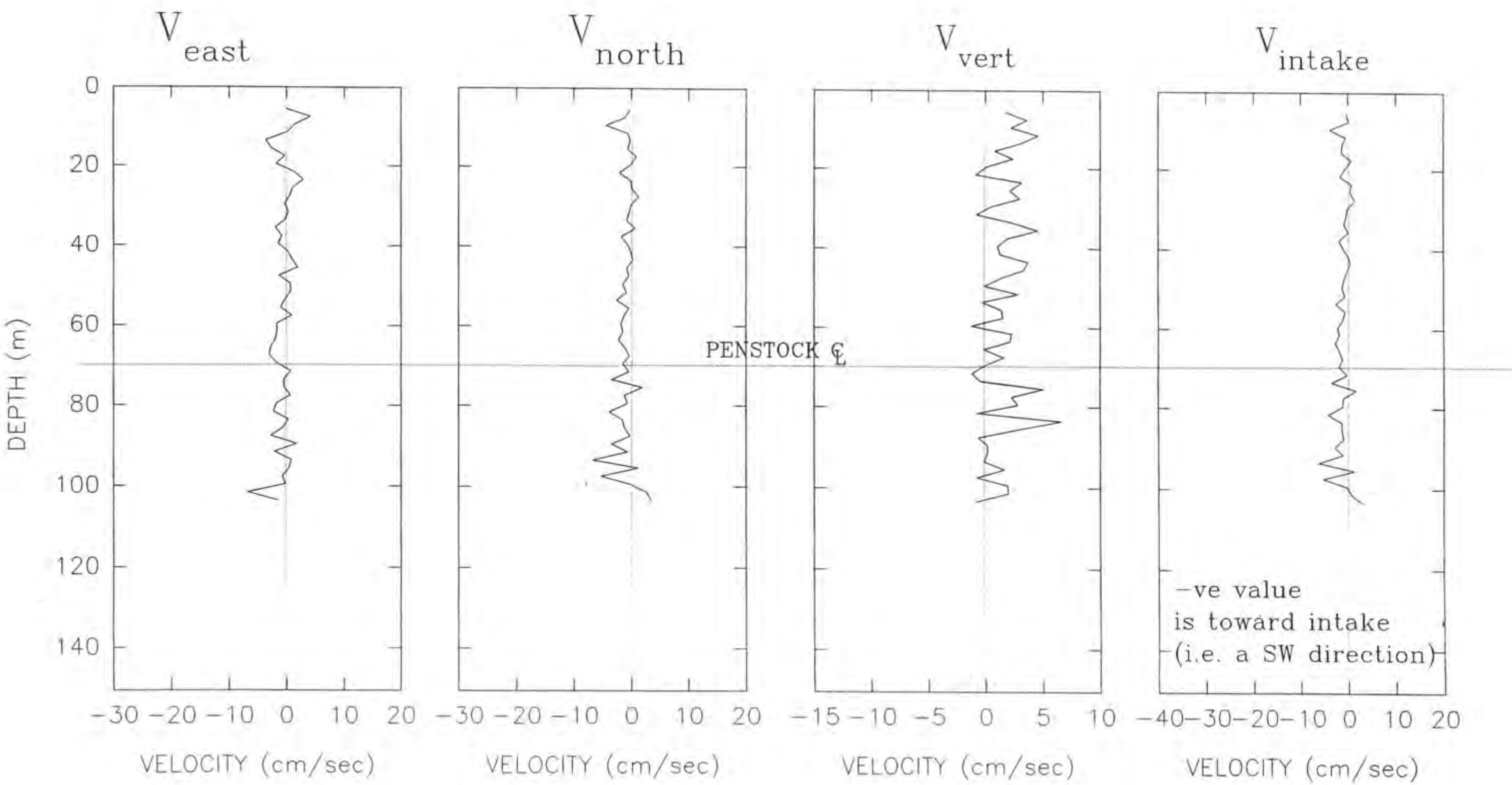
Shasta Lake - Profile data
7/17/95
STA2001T.000
VELOCITY PLOTS



$V_{INTAKE}=V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3)$

FIG. 5

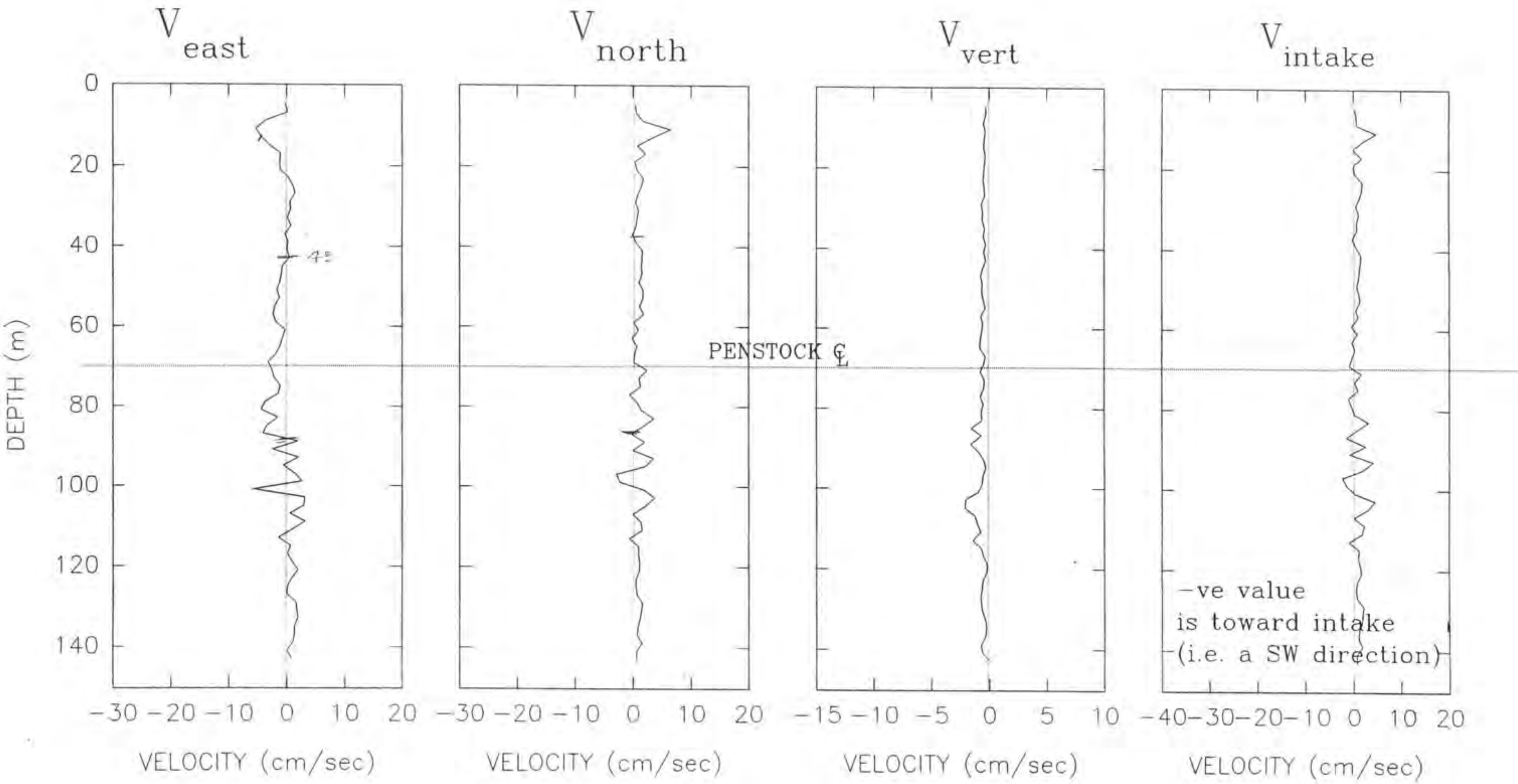
Shasta Lake - Profile data
7/17/95
STA3002T.000
VELOCITY PLOTS



$V_{INTAKE} = V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3)$

FIG. 6

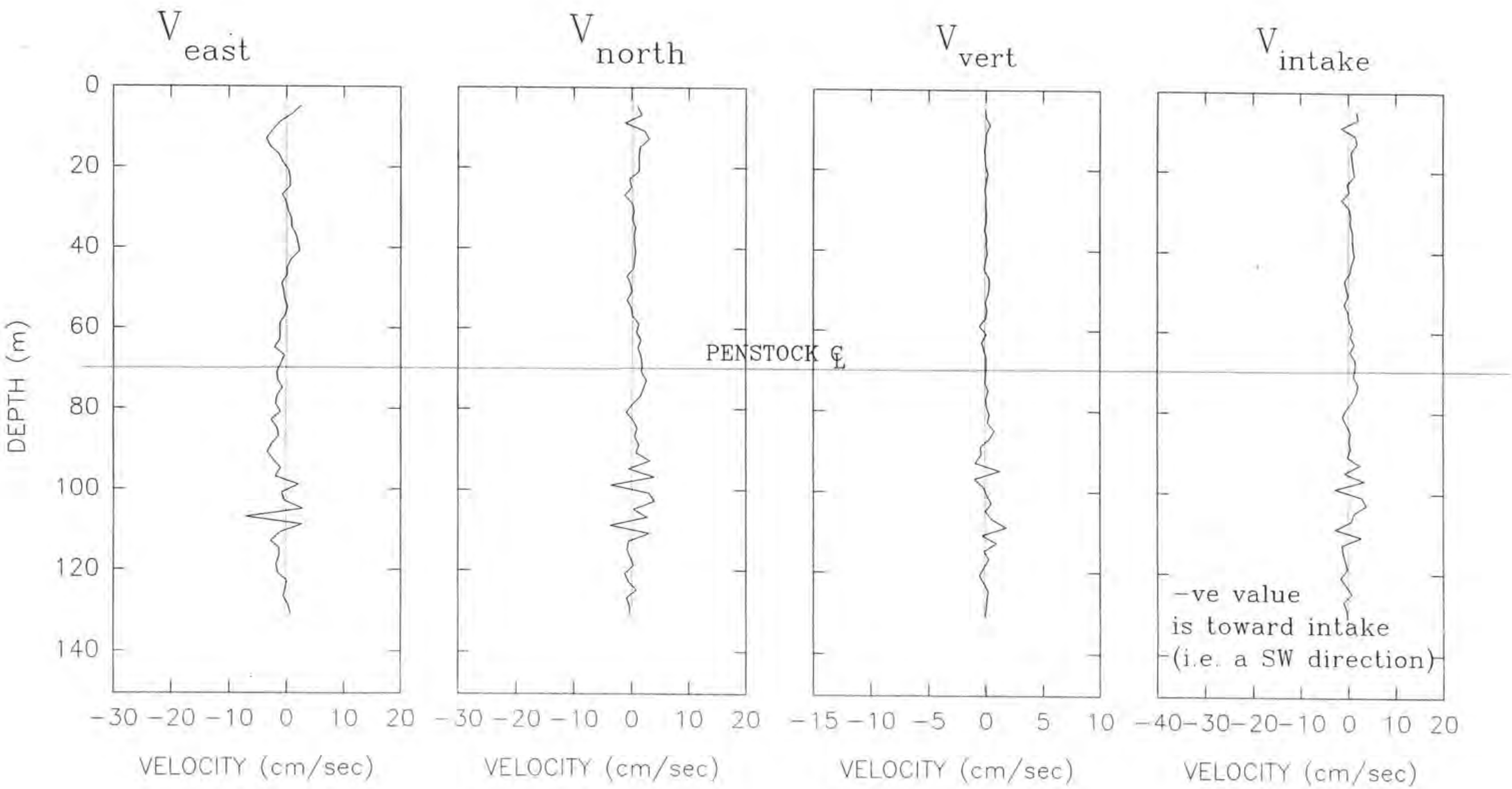
Shasta Lake - Profile data
7/17/95
STA4002T.000
VELOCITY PLOTS



$V_{INTAKE}=V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3)$

FIG. 7

Shasta Lake – Profile data
7/17/95
STA5002T.000
VELOCITY PLOTS



$V_{INTAKE} = V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3)$

FIG. 8

TO: Spencer Hovekamp, Fishery Biologist August 20, 1995

FROM: Tracy Vermeyen, Hydraulic Engineer

SUBJECT: Shasta Lake ADCP measurements - Data Report for August 18, 1995

August ADCP measurements were of poor quality because winds caused wavy water surface conditions. The total flow out of Shasta Lake was about 12,600 ft^3/sec, with 8,000 ft^3/s passing through the el. 742 spillway outlets and 2,300 ft^3/s through penstocks no. 1 and 2. The reservoir water surface elevation was 1032.2 ft, down from 1048.6 ft in July. The release water temperature was 52.4 °F. John Martin and I were able to collect velocity profiles at Shasta Lake stations 1, 2, and 3. Stations 4 and 5 were not sampled because of the poor conditions. Likewise, we collected one transect near the face of the dam.

The ADCP data were post-processed to eliminate poor-quality data from the data files. Strict quality assurance guidelines were followed as suggested by the ADCP manufacturer. Velocity data collected on August 18, 1995 are summarized as follows:

ADCP Transect Data

Figure 1 is a plot of **vertical** velocity data from an ADCP transect collected from the buoyline's east anchorage to the west anchorage which covers releases from the outlets (el. 742) and the penstocks. This transect shows that very little valid velocity data were collected below 40 meters deep because the current measurements were affected by pitching and rolling of the boat. The ADCP cannot measure small velocities under wavy conditions because the relative motion between the boat and the moving water is greater than the water velocity. Therefore, the ADCP cannot accurately resolve the boat motion from the water velocity.

ADCP Profile Data

Figures 2 through 5 are plots of average velocity profiles collected at the lake sampling stations no. 1 through no. 3. The figures show the east, north, and vertical velocity components (negative values are in the opposite direction). They also show the resultant velocity (V_{intake}) in the direction normal to the intake structure. Poor velocity measuring conditions are often indicated by high vertical velocity components which is visible in figures 2 and 4.

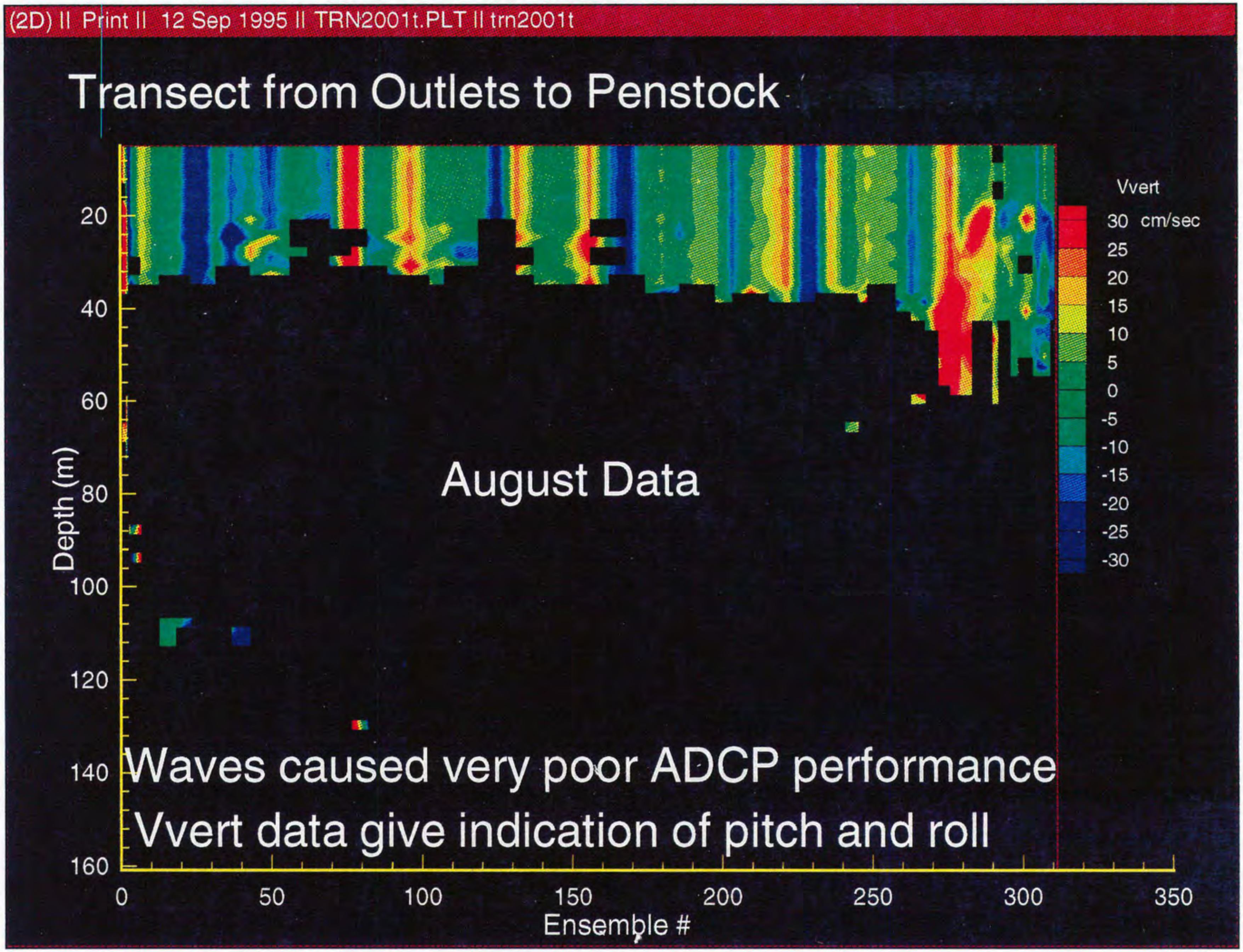
Figure 2 is a plot of a profile collected at lake station no. 1 and shows only velocities measured to about 40 meters, below which the ADCP could not measure velocity profiles. The velocities below the *no data* zone are effected by bottom interference and should be ignored.

Figure 3 has a vertical velocity component which indicates reasonably good measurements, but it also gets noisy below a depth of 70 meters. This plot indicates the upper limit of the withdrawal zone is at a depth of 60 meters.

Figures 4 and 5 show large vertical velocity components which indicate a large bias error. These profiles do not contain any useful information for this study.

In conclusion, I found out how important calm water surface conditions are to making ADCP measurements on Shasta Lake. In the future, ADCP measurements will have to be taken weather permitting. Perhaps sampling should be carried out in the early morning hours when the reservoir is normally calm? If you have any questions on this data or comments please contact me at (303) 236-2000 extension 451.

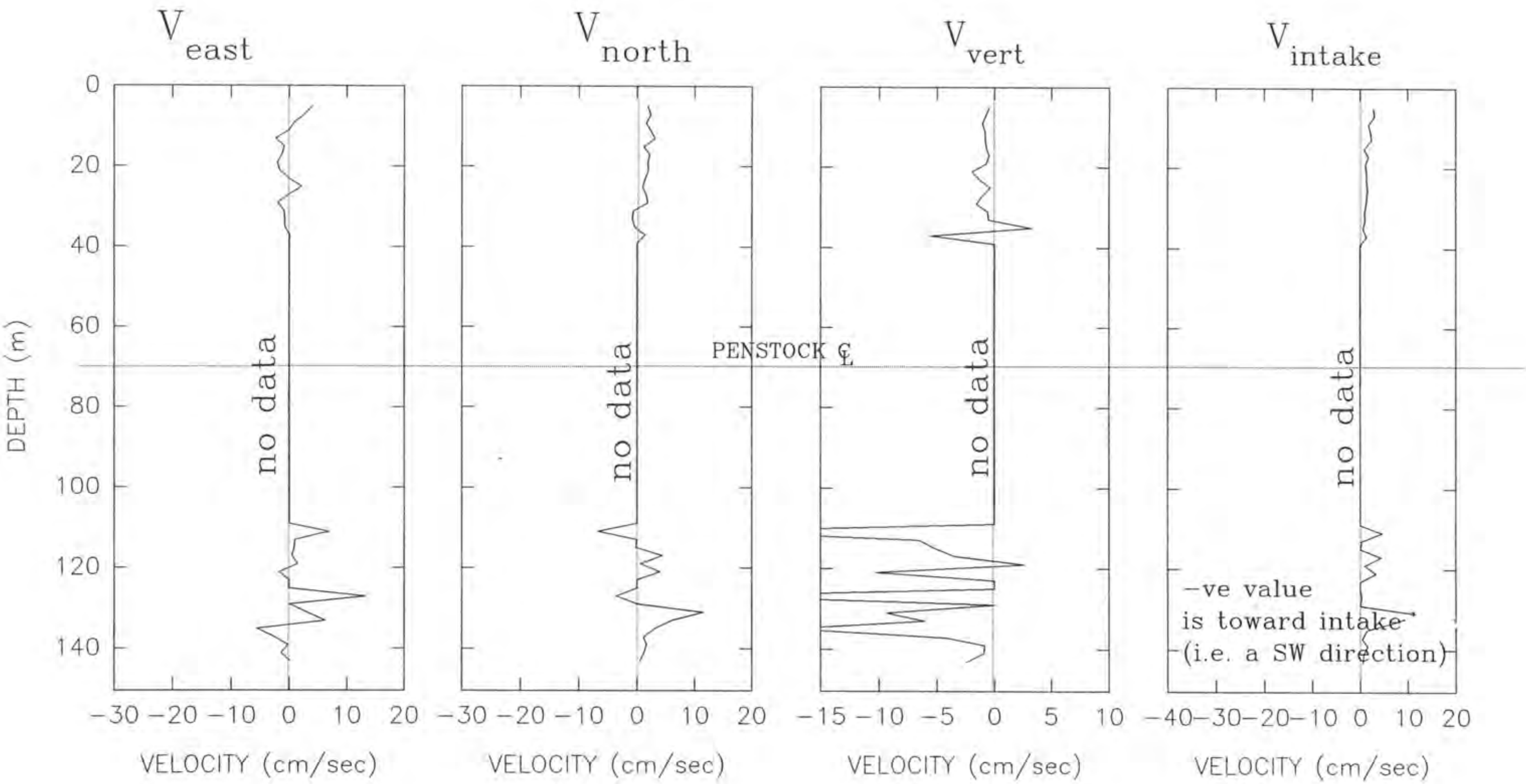
Tracy Vermeyen, P.E.
Hydraulic Engineer
Technical Service Center



(2D) ‖ Print ‖ 12 Sep 1995 ‖ TRN2001t.PLT ‖ trn2001t
Transect from Outlets to Penstock
Vvert
30 cm/sec
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Depth (m)
20
40
60
80
100
120
140
160
August Data
Waves caused very poor ADCP performance
Vvert data give indication of pitch and roll
0
50
100
150
200
250
300
350
Ensemble #

FIG 1.

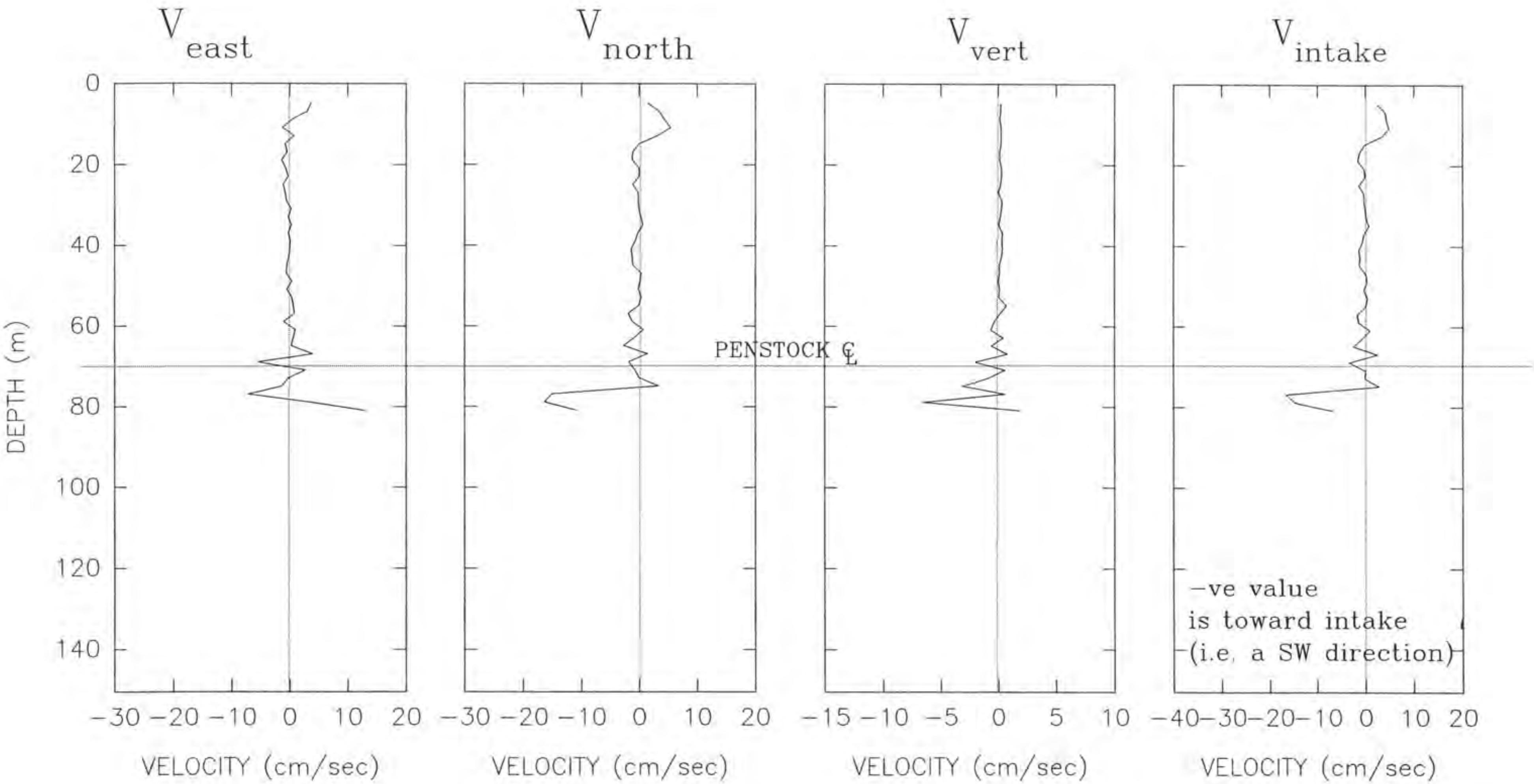
Shasta Lake – Profile data
8/18/95
STA1002T.000
VELOCITY PLOTS



$V_{INTAKE} = V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3)$

FIG. 2

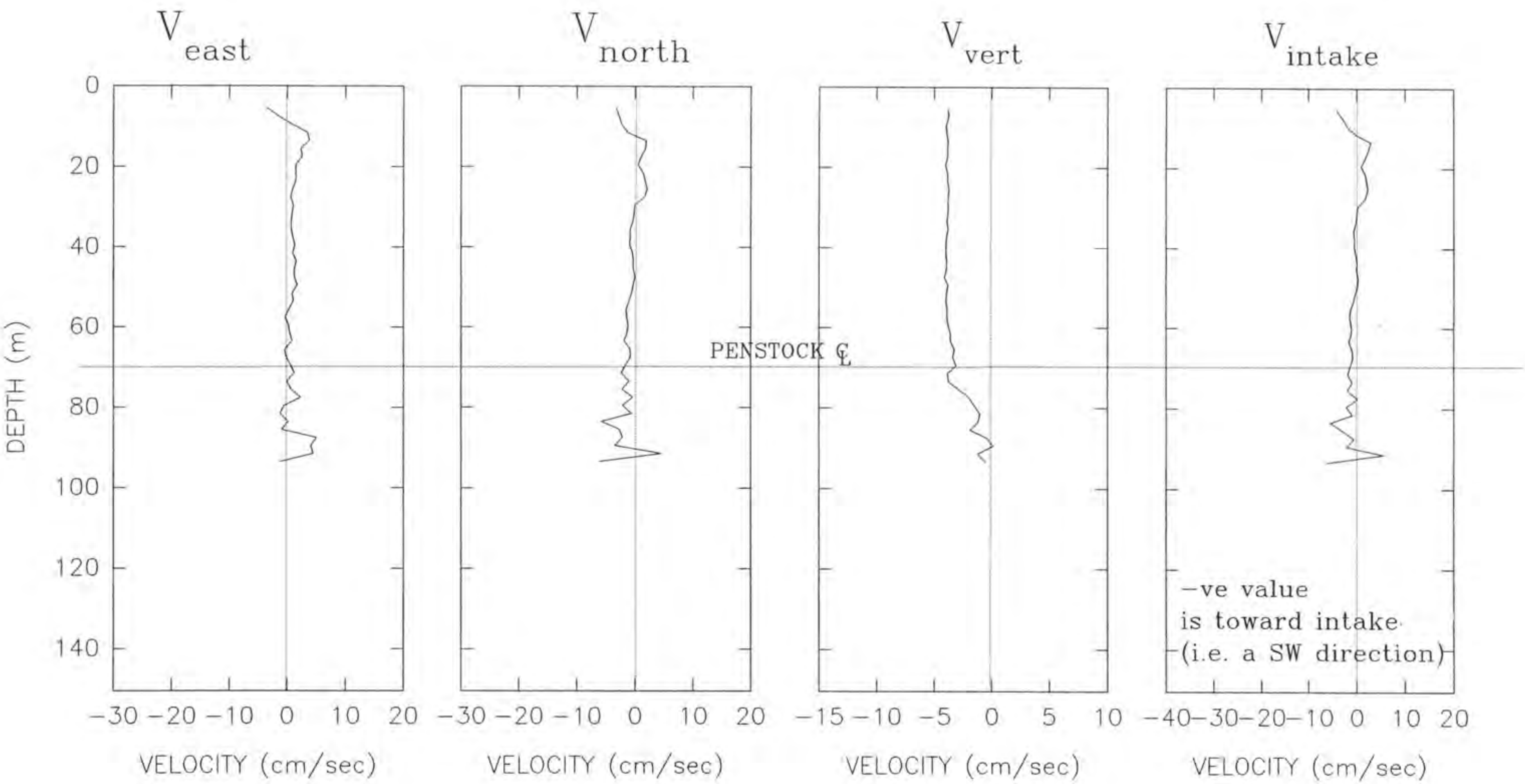
Shasta Lake - Profile data
8/18/95
STA2002T.000
VELOCITY PLOTS



$V_{INTAKE}=V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3)$

FIG. 3

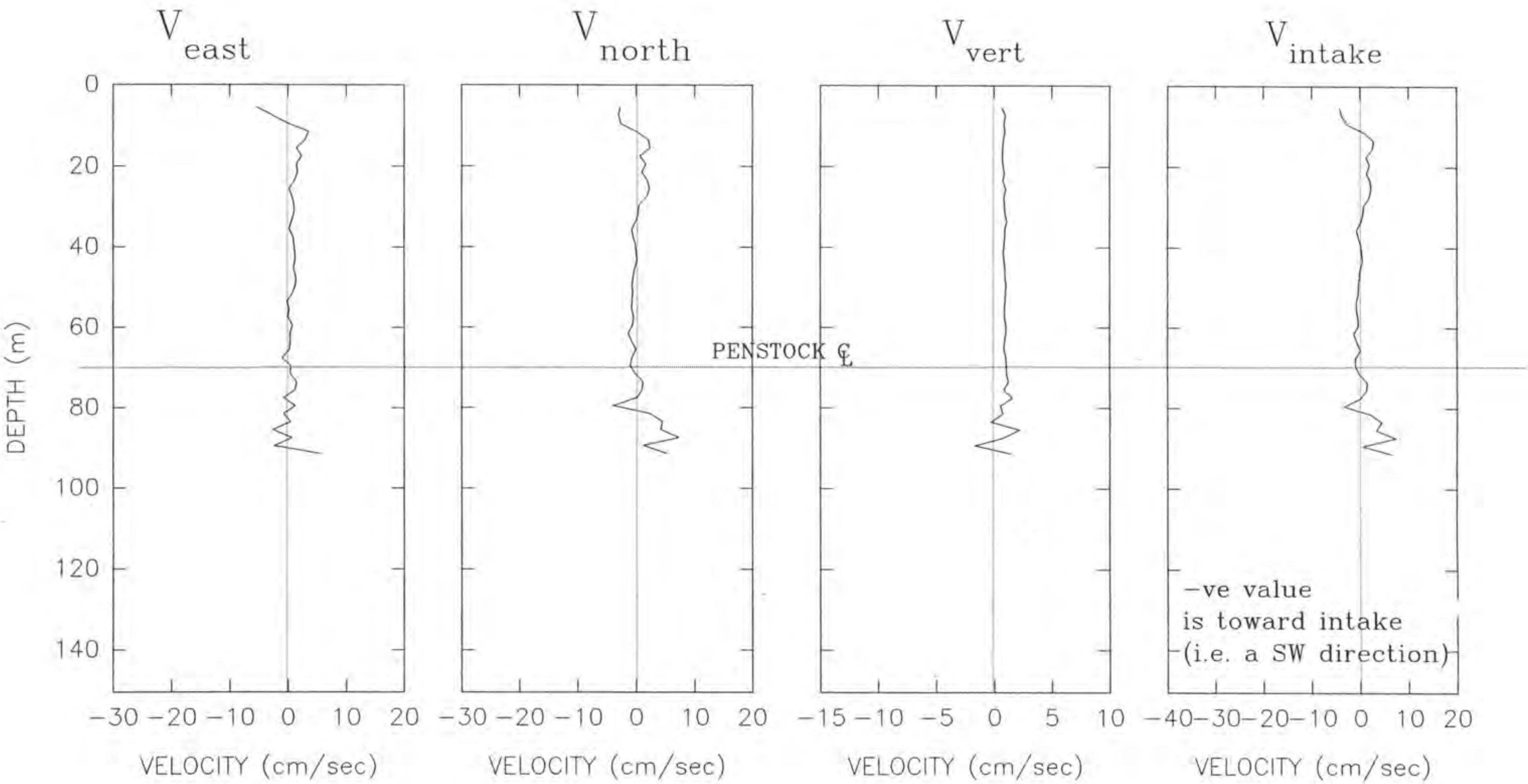
Shasta Lake - Profile data
8/18/95
STA3001T.000
VELOCITY PLOTS



$V_{INTAKE}=V_{EAST}*COS(73.7)+V_{NORTH}*COS(16.3)$

FIG. 4

Shasta Lake - Profile data
8/18/95
STA3002T.000
VELOCITY PLOTS



$V_{INTAKE} = V_{EAST} * COS(73.7) + V_{NORTH} * COS(16.3)$

FIG. 5

TO: Spencer Hovekamp, Fishery Biologist September 27, 1995

FROM: Tracy Vermeyen, Hydraulic Engineer

SUBJECT: Shasta Lake ADCP measurements - Data Report for September 20, 1995

September ADCP measurements were of mixed quality because winds caused wavy water surface conditions. However, the winds subsided by late morning and data quality improved and several of the early morning measurements were repeated under calm conditions. The total flow out of Shasta Lake was about 8,100 ft^3/s passing through the low level (el. 742) spillway outlets. The releases from the low-level spillway outlets gave us the opportunity to document a operational condition not sampled previously, that is strictly bypass releases from Shasta Dam. The reservoir water surface elevation was 1016.3 ft, down from el. 1032 in August. The release water temperature was 52.5 °F. Barry Brownson and I were able to collect velocity profiles at all five Shasta Lake stations. We also collected transects along the face of the dam to document near-field velocity profiles.

The ADCP data were post-processed to eliminate poor-quality data from the data files. Velocity data collected on September 20, 1995 are summarized as follows:

ADCP Transect Data

Figure 1 is a plot of an ADCP transect encompassing the width of the drum-gated spillway. This transect was collected during calm water surface conditions. The purpose of this ADCP transect was to measure the velocity profiles created by releases from the low-level spillway outlets (el. 742 ft). The transect data shows that little valid velocity data were collected below a depth of 50 meters. This result is very similar to data collected in August. The reason for the lost data is a low signal correlation for depths greater than 50 meters. This is likely caused by two factors: 1) a small number of acoustic scatterers in the water column below 50 meters and 2) the relatively high velocities generated by reservoir releases from the spillway outlets. The low correlation occurs when one group of scatters moves out of the sample volume and are replaced by a new group. The correlation of the doppler shift between the two groups have a low correlation because the new set of scatterers are in a unique distribution. The deeper you go into the reservoir the longer the lag time between the send and receive signals. As a result, the scatters have more time to move through the sampling volume. It is difficult to establish a upper limit of withdrawal, but I estimated it to be around 60 meters deep.

Figure 2 is a plot of velocity data from an ADCP transect collected along a course perpendicular to the center of the middle spillway gate. This transect was also collected during calm water surface conditions. The purpose of this transect was to measure the formation of the withdrawal zone in the vicinity of the dam. This transect data shows that little valid velocity data were collected below a depth of 50 meters. However, this data shows the upper limit of the withdrawal zone at about 55 to 60 meters depth when we passed the buoyline. Velocities of 20 to 30 cm/sec were measured.

ADCP Profile Data

Figures 3 through 7 are plots of velocity profiles collected at the five lake sampling stations. The figures show a time-series of velocity profiles collected at each of the lake stations. The plots show the velocity magnitude (resultant of the east and north velocity components).

Figure 3 is a plot of profiles collected at lake station no. 1 and shows only velocities measured to about 56 meters, below which the ADCP could not measure water velocities. There is only a slight indication of any significant velocities at a depth of 55 meters. The high velocities measured after 160 seconds had elapsed is probably an irregularity caused by pitch or roll of the boat. This data indicates the upper limit of the withdrawal zone is at about 55 meters deep.

Figure 4 is a plot of profiles collected at lake station no. 2 and shows only velocities measured to about 65 meters, below which the ADCP could not measure water velocities. There is a strong indication of withdrawal velocities at a depth of 60 meters and below. The high velocities measured at four different times are poor data caused by pitch or roll of the boat. This data set gives a good indication of the upper limit of the withdrawal zone at 60 meters deep.

Figure 5 is a plot of profiles collected at lake station no. 3 and shows only velocities measured to about 80 meters, below which the ADCP could not measure water velocities. There is a strong indication of withdrawal velocities at a depth of 68 meters and below.

Figure 6 is a plot of profiles collected at lake station no. 4 and shows velocities measured to about 76 meters. There is a strong indication of withdrawal velocities at a depth of 64 meters and below.

Figure 7 is a plot of profiles collected at lake station no. 5 and shows velocities measured to about 100 meters. There appears to be a upper limit of withdrawal at a depth of 72 meters.

In conclusion, I think the best estimate of the upper limit of the withdrawal zone is at a depth of 64 meters. This is substantially different from the upper limit (40 meters deep) which develops when powerplant releases are the dominant percentage of reservoir releases. The velocity magnitudes are also greater because the cross sectional area in the withdrawal zone is smaller than when power withdrawals are made. Another interesting observation is that the ADCP was able to sample to greater depths as we moved further away from the dam. At this time I am pursuing an explanation for this observation.

If you have any questions on this data or comments please contact me at (303) 236-2000 extension 451.

Tracy Vermeyen, P.E.
Hydraulic Engineer
Technical Service Center

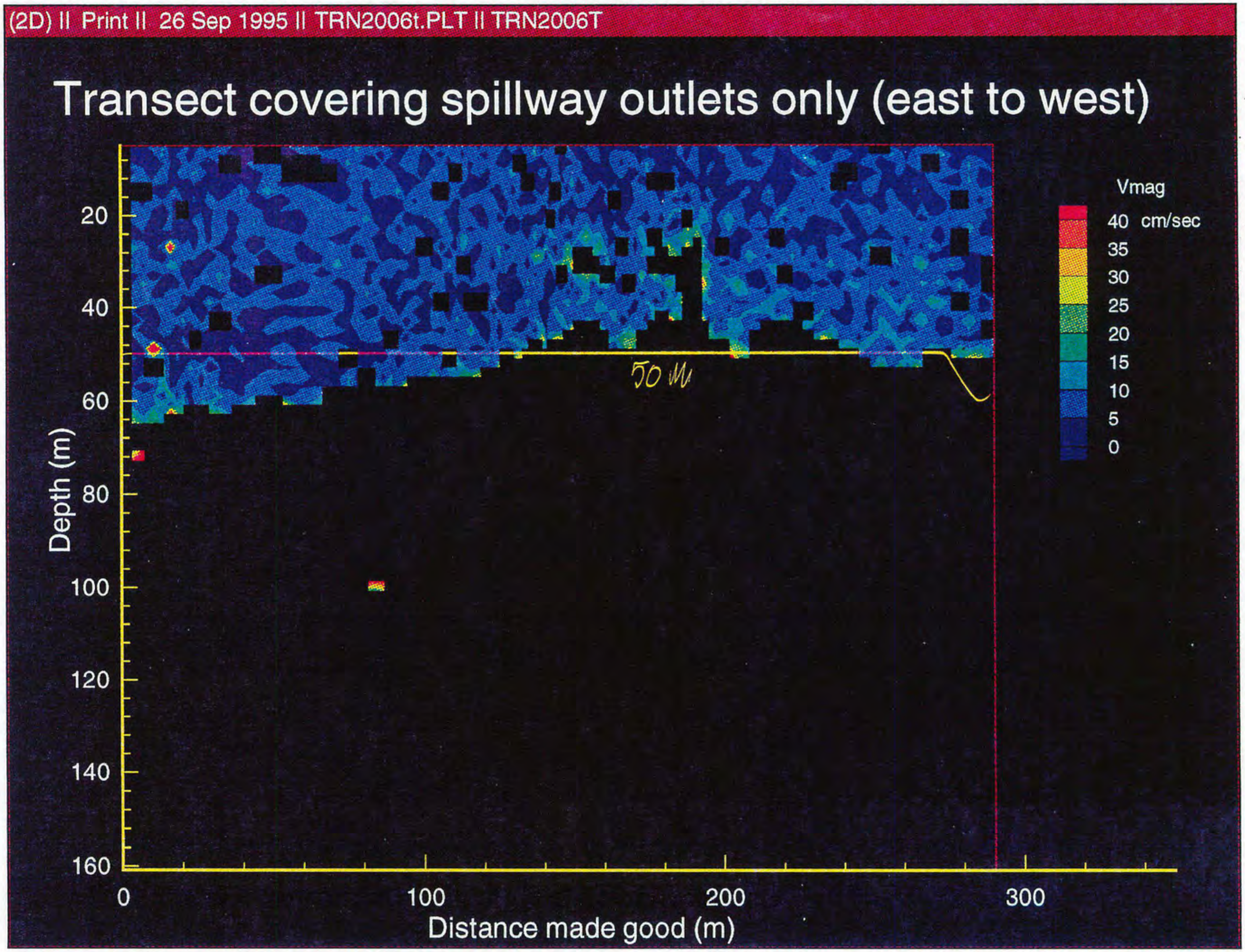

(2D) II Print II 26 Sep 1995 II TRN2006t.PLT II TRN2006T
Transect covering spillway outlets only (east to west)
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
50 m
Depth (m)
20
40
60
80
100
120
140
160
0
100
200
300
Distance made good (m)

FIGURE 1.

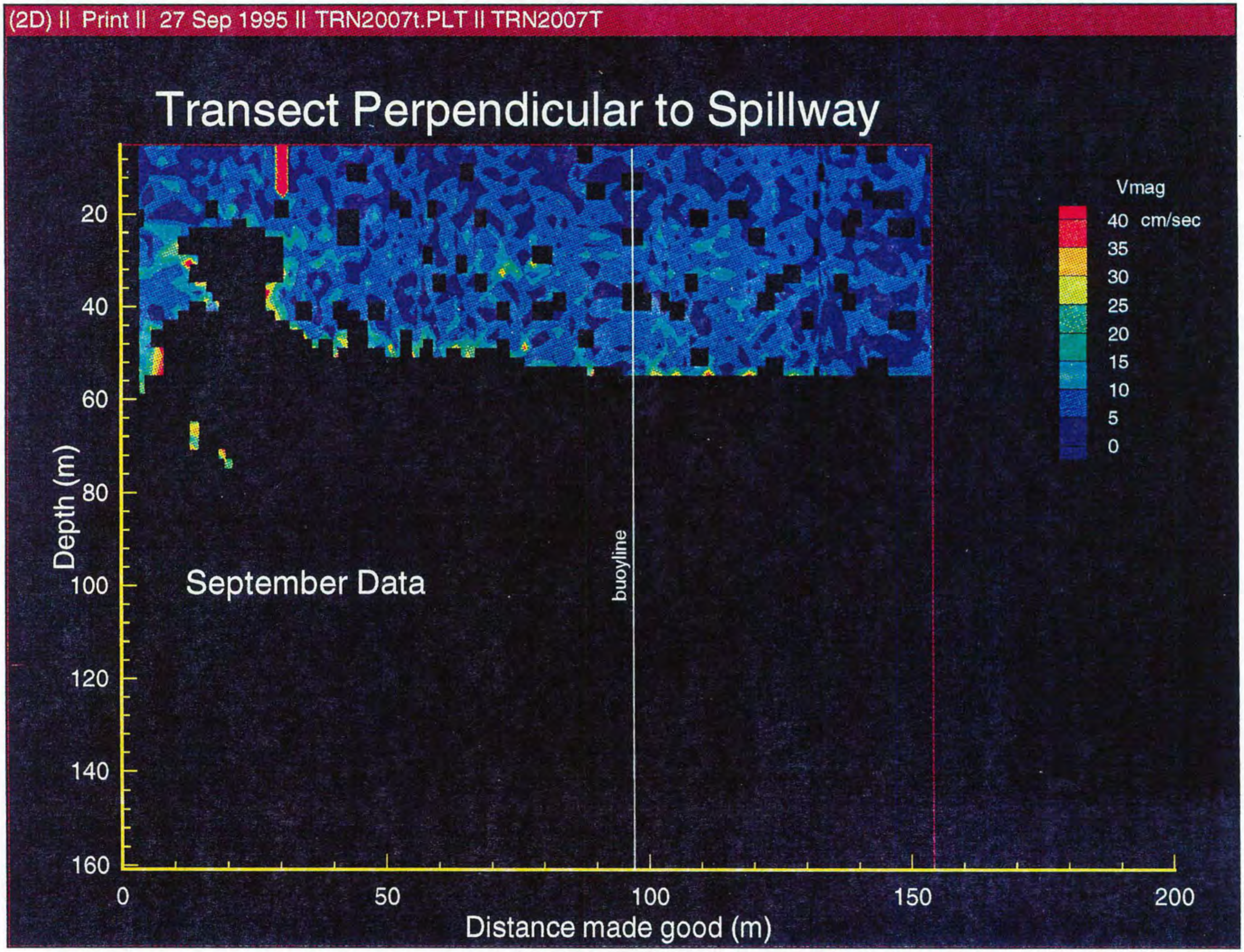

(2D) II Print II 27 Sep 1995 II TRN2007t.PLT II TRN2007T
Transect Perpendicular to Spillway
Depth (m)
20
40
60
80
100
120
140
160
September Data
buoyline
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
0
50
100
150
200
Distance made good (m)

FIGURE 2.

FIGURE 3

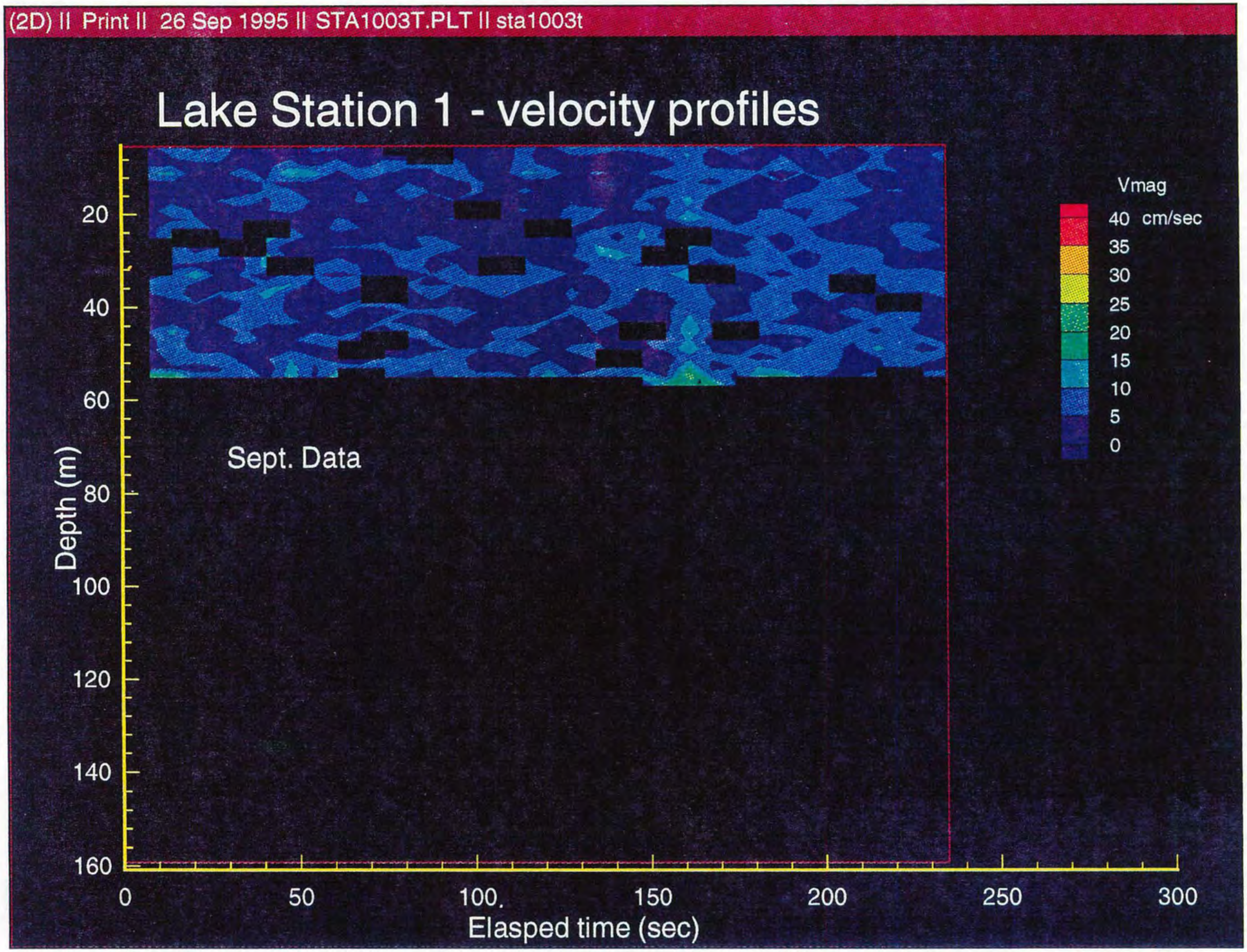
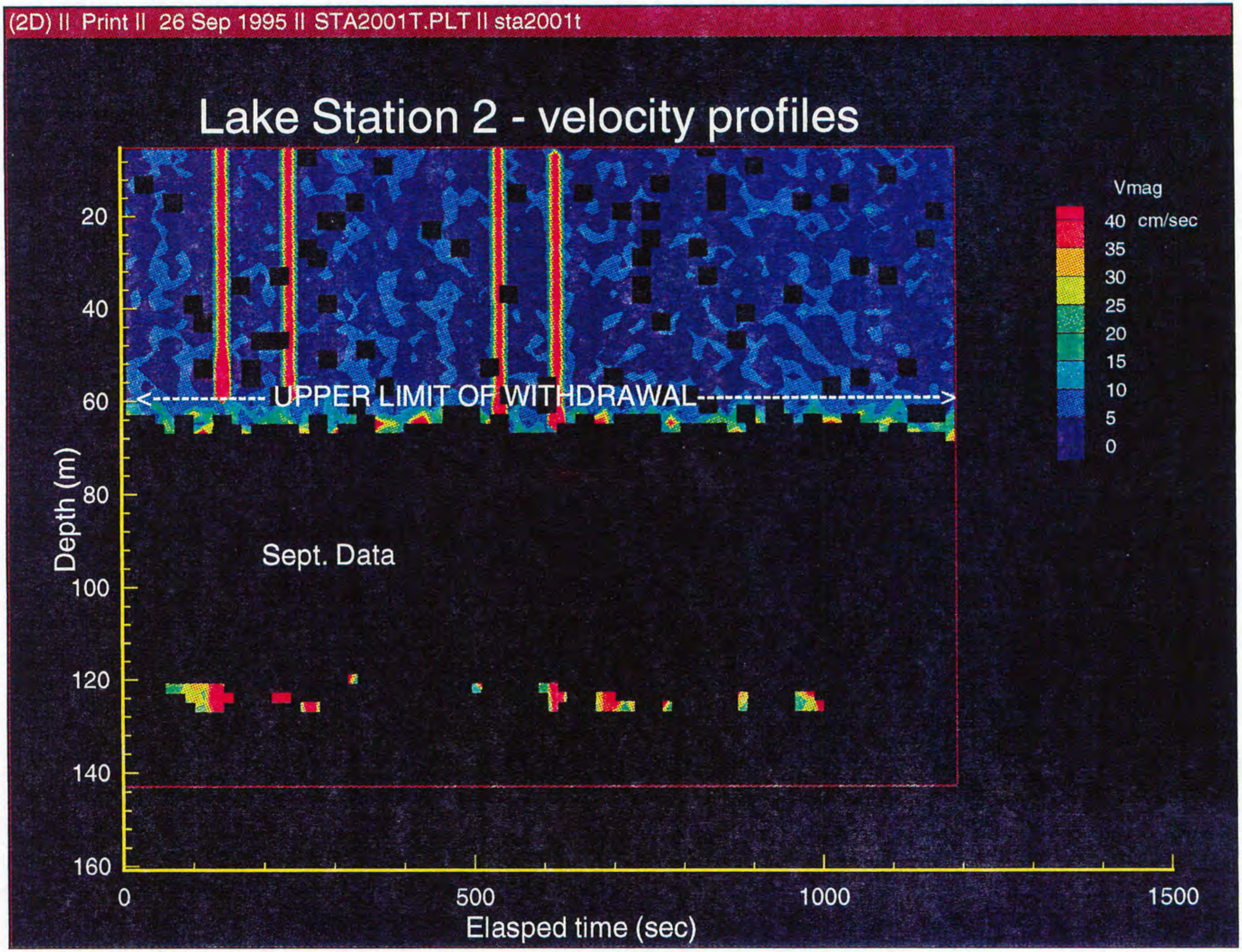

(2D) II Print II 26 Sep 1995 II STA1003T.PLT II sta1003t
Lake Station 1 - velocity profiles
Depth (m)
20
40
60
80
100
120
140
160
Sept. Data
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
0
50
100.
150
200
250
300
Elasped time (sec)

FIGURE 4



(2D) II Print II 26 Sep 1995 II STA2001T.PLT II sta2001t
Lake Station 2 - velocity profiles
<------------ UPPER LIMIT OF WITHDRAWAL------------------------->
Sept. Data
Depth (m)
20
40
60
80
100
120
140
160
0
500
1000
1500
Elasped time (sec)
Vmag
40 cm/sec
35
30
25
20
15
10
5
0

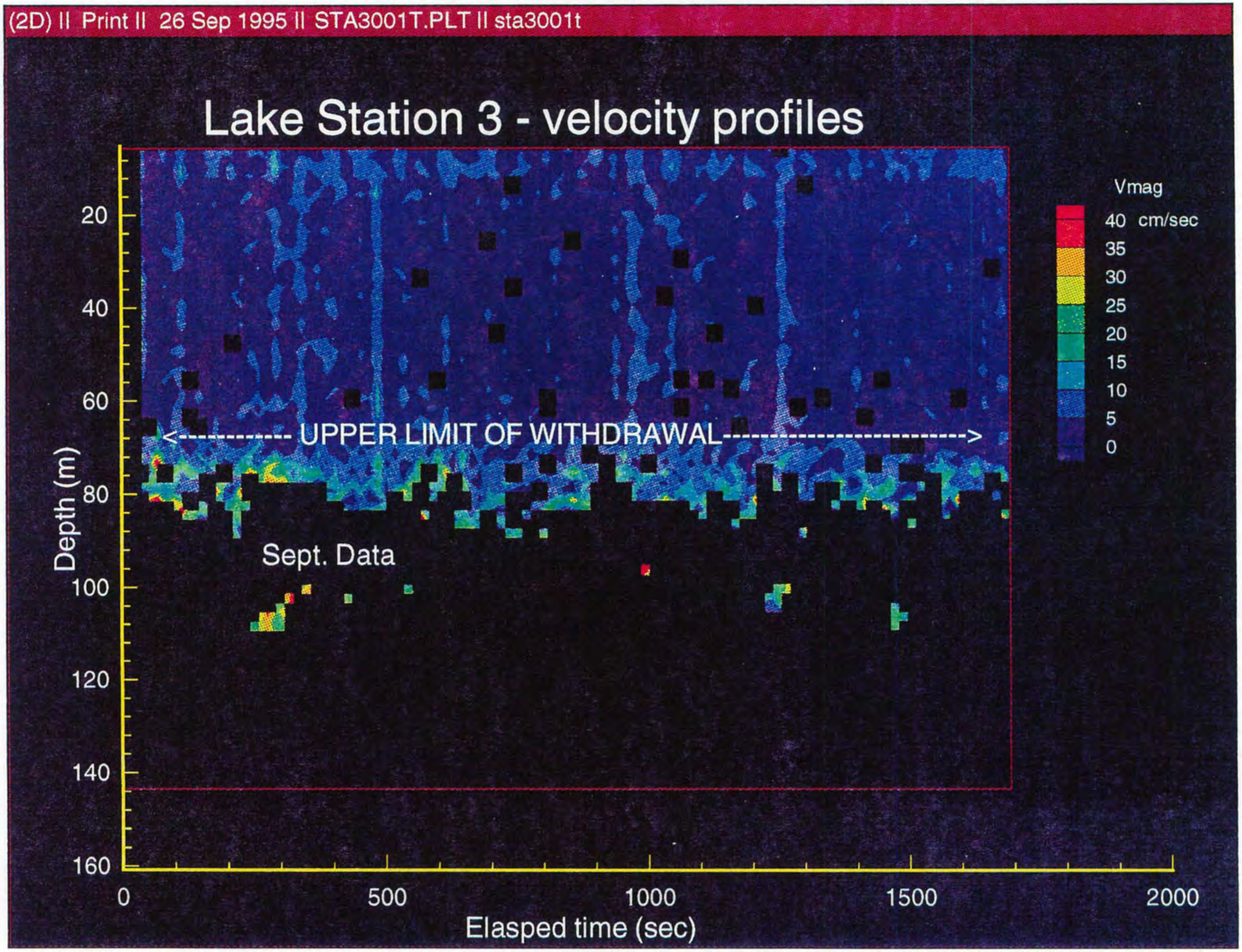

(2D) II Print II 26 Sep 1995 II STA3001T.PLT II sta3001t
Lake Station 3 - velocity profiles
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
<------------- UPPER LIMIT OF WITHDRAWAL------------------------------>
Sept. Data
Depth (m)
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
Elasped time (sec)

FIGURE 5

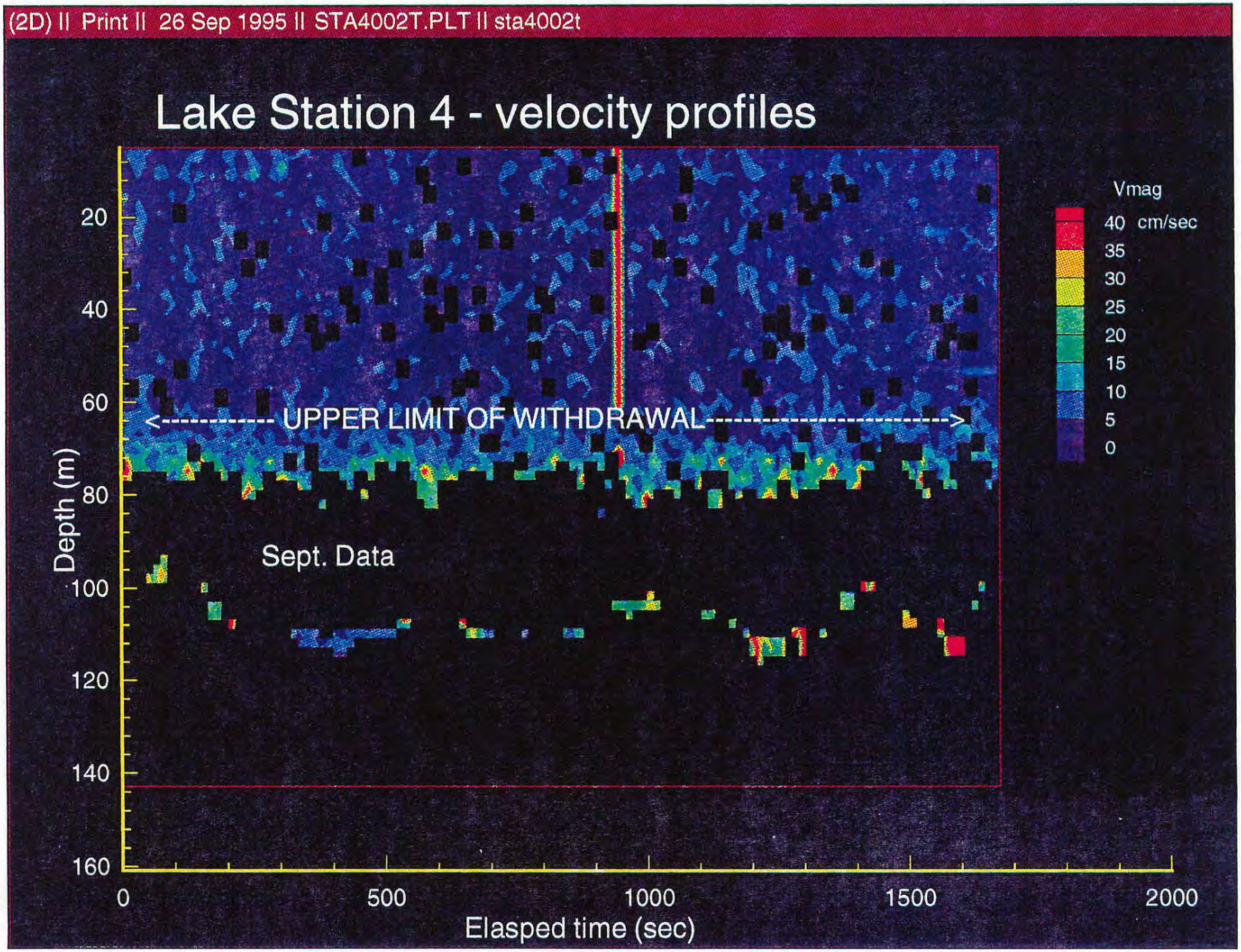
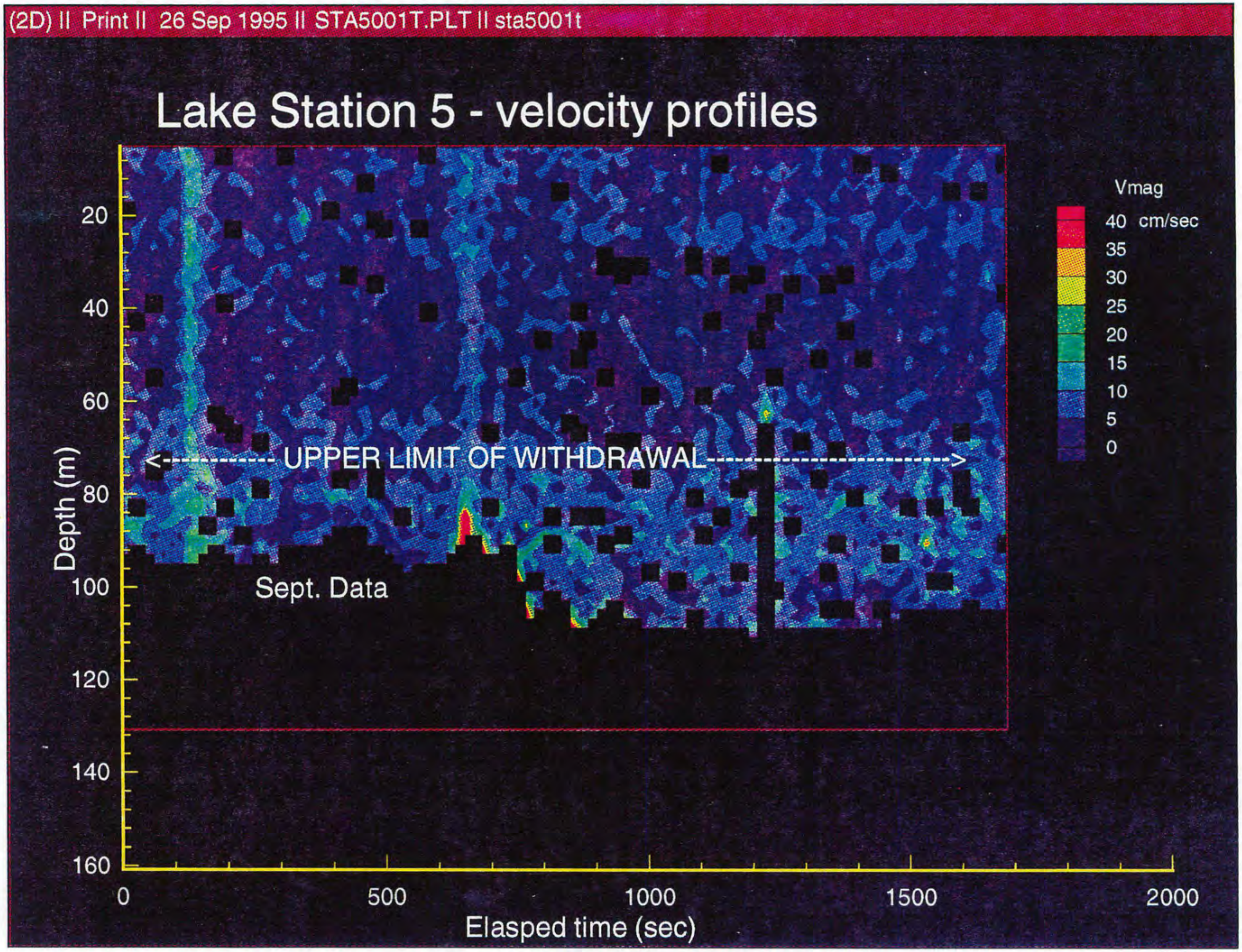

(2D) || Print || 26 Sep 1995 || STA4002T.PLT || sta4002t
Lake Station 4 - velocity profiles
<------------ UPPER LIMIT OF WITHDRAWAL------------------------->
Sept. Data
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
Depth (m)
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
Elasped time (sec)

Figure 6



(2D) II Print II 26 Sep 1995 II STA5001T.PLT II sta5001t
Lake Station 5 - velocity profiles
Vmag
40 cm/sec
35
30
25
20
15
10
5
0
<------------ UPPER LIMIT OF WITHDRAWAL-------------------------->
Sept. Data
Depth (m)
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
Elasped time (sec)

Figure 7