A Preliminary Evaluation of Near-Transducer Velocities Collected with Low-Blank Acoustic Doppler Current Profiler

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ABSTRACT

Many streams and rivers for which the US Geological Survey must provide discharge measurements are too shallow to apply existing acoustic Doppler current profiler techniques for flow measurements of satisfactory quality. Because the same transducer is used for both transmitting and receiving acoustic signals in most Doppler current profilers, some small time delay is required for acoustic "ringing" to be damped out of transducers before meaningful measurements can be made. The result of that time delay is that velocity measurements cannot be made close to the transducer thus limiting the usefulness of these instruments in shallow regions. Manufacturers and users are constantly striving for improvements to acoustic instruments which would permit useful discharge measurements in shallow rivers and streams that are still often measured with techniques and instruments more than a century old. One promising area of advance appeared to be reduction of time delay (blank) required between transmitting and receiving signals during acoustic velocity measurements. Development of a low- or zero-blank transducer by RD Instruments[3] held promise that velocity measurements could be made much closer to the transducer and thus in much shallower water. Initial experience indicates that this is not the case; limitation of measurement quality appears to be related to the physical presence of the transducer itself within the flow field. The limitation may be the result of changes to water flow pattern close to the transducer rather than transducer ringing characteristics as a function of blanking distance. Results of field experiments are discussed that support this conclusion and some minimum measurement distances from transducer are suggested based on water current speed and ADCP sample modes.

INTRODUCTION

A tremendous number of shallow streams and rivers exist for which the US Geological Survey (USGS) is required to make discharge measurements. Many of these locations are too shallow for measurements using conventional acoustic Doppler current profilers (ADCPs) because a minimum water depth is required for ADCP applications. The limiting water depth is a result of the inability of the instrument to make velocity measurements close to the transducer because the same transducer is used to both transmit and receive acoustic signal. The limitation results because a short time delay is needed after transmitting signal to allow acoustic ringing to decline to the point that a received signal can be interpreted. The time delay (which can be thought of as a distance) is set by the ADCP user and is called blanking distance.

Recently, a great deal of interest has been expressed in the development of a low-blank ADCP manufactured by RD Instruments (RDI). This is a 1200 kHz ADCP (referred to as ZedHed) with modified transducer head to reduce acoustic ringing. Current recommended

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blanking distance for a conventional 1200 Work Horse (WH) ADCP is no less than 25 cm. Initially, the manufacturer suggested a minimum blanking distance of 0-5 cm was possible for ZedHed ADCPs although the minimum was later increased to12 cm. A large reduction in the required blanking distance significantly increases the number of possible sites where ADCP can be used for discharge measurements; however, an initial field test of a ZedHed revealed that velocity measurements close to the transducer were biased toward low speed when using a small blanking distance. Additional tests were carried out to examine the extent and cause of the low speed bias. Results of those tests are presented following an introductory description of ADCPs and their operational modes and two potential sources of measurement bias. Finally, a rough rule of thumb for minimum blanking distance is suggested for ZedHed ADCPs.

DESCRIPTION OF INSTRUMENT AND SOURCES OF BIAS NEAR TRANSDUCER

An ADCP measures water motion by transmitting sound at fixed frequency. The instrument measures the Doppler-shifted echoes backscattered from scatterers (plankton and sediment) in the water and converts the echoes to along (acoustic) beam velocity components. The ADCP then converts the along beam velocities to horizontal and vertical velocity components. Velocity profiles are determined by range gating echoes so that velocities are determined at preset intervals along the acoustic path (called bins). Velocity measurements using RDI ADCPs are made using one of several water measurement modes available that employ different time lags and acoustic pulse forms. There are two basic types of water measurement modes. These include pulse-to-pulse coherent modes such as Water Mode 5 (WM5), and WM11. Pulse to pulse coherent modes use two transmitted pulses that are independent but synchronized; the second pulse is not sent until the first dies out. The long time lag between pulses creates a velocity measurement of low standard deviation, high vertical resolution, but limited range. Pulse-to-pulse measurements utilizing long lags have a potential for signal de-correlation from high speed, turbulence, or shear. The primary general (non pulse-to-pulse coherent) water mode is WM1. This mode has higher standard deviation and thus, to attain similar accuracy, requires more averaging and bigger bin size than when using pulse-to-pulse coherent modes such as WM5 or WM11; however, it is far less susceptible to signal de-correlation and has longer range.

There are two potential sources of bias toward low velocity in ADCP measurements close to the transducer. The first is due to signal de-correlation when an ADCP is operated in one of the pulse-to-pulse coherent modes. De-correlation from turbulence near bed or transducer would not bias data. However, de-correlation from high water speed is not random; it causes loss of only high velocity data. A measurement of a mean velocity profile is the result of averaging many pings. If high velocity data were lost because of de-correlation, the resulting average velocity would be biased low. If an entire profile is lost then the resulting mean velocity profile would not have correct speed but its general shape would not be distorted. On the other hand, if only some bins in the profile are lost from de-correlation the resulting velocity profile would be distorted. For example, if water current speed gradually increases (as normally expected) approaching water surface, at some point de-correlation may occur in upper bins because of speed rather than turbulence. Loss of data in those bins would tend to bias average velocities to lower values and might result in average speeds in upper bins being lower than those in bins further below surface thus distorting shape of the velocity profile. This should be recognized by a lower value of percent good pings in the averaging interval for those bins closest to transducer.

The physical change of flow field near the transducer is a second potential source of bias. As previously mentioned, ADCPs calculate the radial velocity in each acoustic beam. If there is no velocity component along the acoustic beam (velocity is zero or perpendicular to the beam), the instrument calculates zero velocity in the beam. If one thinks of the ADCP head and transducer as being generally hemispherical with the acoustic beams oriented perpendicular to the head it is reasonable to assume that there will be a larger and larger component of velocity that is perpendicular to the beam (rather than horizontal) as the water flow is deformed more to parallel the head at positions close to the transducer. As the component of flow that is perpendicular (rather than horizontal) to the beam(s) grows larger, so does the bias toward low or zero speed that is calculated by the ADCP. Obviously, this effect is correlated with water speed and distance from transducer.

FIELD TESTS OF LOW-BLANK ADCP

A discharge measurement site on the San Joaquin River at Vernalis, California is an important location because of a number of issues including biological resources, managed flows, and water diversions. It is also a difficult site at which to measure discharge because for much of the year the river is shallow (< 2 m average over cross section) but wide (> 60 m). Natural and regulated variations in flow throughout the year produce changes in bathymetry which results in an unstable stage-discharge rating curve increasing the need for a suitable method of making reliable discharge measurements. Recently, the Vernalis site has also been the location of a series of tests of new and innovative methods to try to estimate discharge from surface velocity measurements using microwave radar and bathymetry measurements using ground-penetrating radar. As part of these tests, ground truth data were needed including near-surface velocity, mean velocity profile, and water depth. A 1200 kHz ZedHed ADCP appeared well suited to make some of these measurements because of its potential to use short blanking distance.

Initial Tests of ZedHed ADCP Using WM5 and 4 cm Blanking Distance

The first use of ZedHed ADCP to measure high-resolution velocity profiles and discharge on the San Joaquin River at Vernalis was on December 6, 2001. At that time the river was about 60 m wide and about 2.5 m deep. Measurements were made from a boat attached to a tag line in a manner similar to a discharge measurement with conventional current meter. The boat was positioned at each section in the river and a series of velocity profiles taken that were later averaged for a mean velocity profile at that location. Concurrent measurements were taken near surface with a SonTek acoustic Doppler velocimeter (ADV) mounted near the ADCP. The ADV was programmed to take 1024 samples at 10 Hz using 100 cm/s scale (single sample standard deviation: +/- 0.63 cm/s) or 250 cm/s scale (single sample standard deviation: +/- 1.6 cm/s).

Initial ADCP settings included WM11, Bottom Mode 7 (BM7), 5 cm bin size, and 4 cm blank. (See RDI, 2001 for a complete description of instrument setup commands.) The ADCP transducer was 15 cm below surface; the center of bin 1 of the ADCP measurement was at 24 cm below surface. The ADV sample location was at 25 cm below surface. Near-surface river velocities were in the range of 75-80 cm/s. Use of WM11 resulted in substantial loss of data because of de-correlation, probably resulting from near-bed turbulence or shear in spite of using a shortened ambiguity-resolving bin (ARB). Switching to WM5 improved the percent good data since this had the effect of moving the ARB away from the bottom. This suggests that the primary source of de-correlations was probably turbulence near bed and not high velocities thus the velocity data were probably not biased toward low speeds from de-correlations.

Speeds measured by ADCP in the upper three or four bins are well below those measured by ADV (not shown); bins closest to the transducer have the largest bias toward low velocity (10 to 15 percent). ADV data points generally fall on a line with those data in ADCP bins 5 and below when plotted using a semi-log scale. Peak magnitudes in velocity profiles measured by ADCP occur at about 40-45 cm below surface. Conditions on the river were generally calm with little wind; there is no reason to expect velocities near surface to be substantially less than those lower in the water column. These results indicate that very small blank distances might not be appropriate when using ZedHed ADCPs under these field conditions.

In order to clarify these findings, a series of additional tests was planned and carried out to examine results of velocity measurements with ZedHed using different blanking distances, different water track and bottom track modes, and different mountings. In addition velocity measurements made with other ZedHed and conventional ADCPs were planned. These tests were to be conducted in the San Joaquin River at Vernalis and in the Delta Mendota Canal at Byron, California.

Tests of ZedHed ADCP Utilizing WM5 with Various Blanking Distances 25 cm or Less

Initial tests of ZedHed using blanking distances between 5 and 25 cm were carried out at the Delta Mendota Canal. The Delta Mendota Canal is a man-made concrete (trapezoidal) channel for transporting water within the state of California. There is a bridge across the canal in the middle of a long and straight section making it an excellent site as an outdoor flume. The channel is approximately 30 m wide at surface and about 5 m deep. Flow is generally maintained at constant rate by pumping; however, the narrow aspect ratio (approximately 5:1) may result in secondary circulation patterns within the channel. During those tests water speed was near constant (+/- about 1.5 percent) through the range of depths (about 30-130 cm) sampled by the ADV. There is no evidence to suggest secondary circulation patterns generated flows with maximum velocities below surface (at least within 130 cm of surface).

In order to collect high-resolution velocity profiles, the ADCP was configured for WM5 in spite of channel depth and velocities that were more conducive to WM1. Setting lag length manually (4 m) and turning bottom track off resulted in no good data collection, probably because of de-correlation with long lag length (4 m) and water speeds of about 100 cm/s. With bottom track turned on, good data were collected, however, as expected, the profile length defaulted to about 50 percent of maximum lag length for WM5 because depth in the canal exceeded maximum lag length. The shortened lag length resulted in much improved correlations. Different blanking distances ranging from 5-25 cm were used in tests. For a few tests the ADCP was mounted in a small aluminum sled boat, as it would normally be used for "tethered boat" discharge measurements, however, for most tests, the ADCP was rigidly mounted, as it would be during a moving boat discharge measurement. The ADCP transducer was 21.5 cm below water surface except during tests using the sled boat for which the transducer was 10 cm below water surface. ADCP (single ping) measurements spanned at least 205 seconds to correspond with the ADV samples. For each set of measurements, the ADV was positioned on the bridge at about 1.5 m from the ADCP and at a depth corresponding to the center of bin 1 of the ADCP. The ADV was programmed to sample at 10Hz using 100 cm/s velocity scale for 2048 samples. There is no evidence of "moving bottom" during these tests.

Results of the tests (table 1) indicate a steady increase in difference between ADV and ADCP speeds as ADCP blanking distance decreases. One mean velocity profile measured using each ADCP blanking distance and its corresponding ADV velocity measurement are plotted in figure 1. Similar to previous results at Vernalis, portions of velocity profiles near surface are biased low. This effect is seen in as many as 10 bins with the extent lessening with increasing blanking distance. Even with 25 cm blank, there is a consistent, small difference between ADCP and ADV measured speeds at about 30 cm from transducer. A plot of one mean velocity profile with the ADCP mounted in sled boat (utilizing a 15 cm blanking distance) shows that the shape of velocity profiles is slightly different from those measured by ADCP mounted without the boat (fig. 1). Velocities are still biased low; the velocity profile shows lower than expected speeds extend further down into the water column than they do in the case of the ADCP without sled boat. Even at about 100 cm from the transducer some small effect may be present, however, some of that difference may be a function of water temperature values used by the ADV in speed calculations. Errors of about 2^o-3^o C can account for about 1 percent error in ADV calculated speeds. To try to minimize that effect, ADV speeds were adjusted by correcting assumed temperatures used in speed calculations to agree with ADCP measured temperatures whenever necessary using the equation described in SonTek, 1997. The source of low-speed bias near transducer does not appear to be the result of intermittent de-correlation from high velocity since the percent good pings in the averaging interval is similar for the entire profile (about 65 percent good when 10 cm blank used and about 68 percent good when 15 cm blank used).

Table 1. Comparison of speeds recorded by ADCP with speeds recorded by ADV at corresponding depth using different ADCP blank values (Delta Mendota Canal; 1/24/02).

ADCP BLANK	DISTANCE TO BIN 1 FROM TRANSDUCER	SAMPLE DEPTH	ADV SPEED	ADCP SPEED IN BIN 1	PERCENT DIFFERENCE
15 cm (sled)	120 cm	130 cm	110.9	109.5	-1.3
15 cm (sled)	120 cm	130 cm	110.9	110.0	-0.8
25 cm	30 cm	51 cm	110.8	108.1	-2.5
25 cm	30 cm	51 cm	110.9	107.2	-3.3
20 cm	25 cm	46 cm	110.3	106.7	-3.2
20 cm	25 cm	46 cm	107.8	103.2	-4.2
15 cm	21 cm	42 cm	111.2	102.9	-7.5
15 cm	21 cm	42 cm	109.2	103.4	-5.3
15 cm (sled)	20 cm	30 cm	N/A	103.7	N/A
15 cm (sled)	20 cm	30 cm	111.2	104.7	-5.8
10 cm	15 cm	36 cm	110.6	99.2	-10.3
10 cm	15 cm	36 cm	107.9	96.9	-10.2
5 cm	11 cm	32 cm	111.6	93.7	-16.0
5 cm	11 cm	32 cm	111.2	92.8	-16.5
5 cm	11 cm	32 cm	111.9	95.2	-14.9
5 cm	11 cm	32 cm	107.7	90.3	-16.2

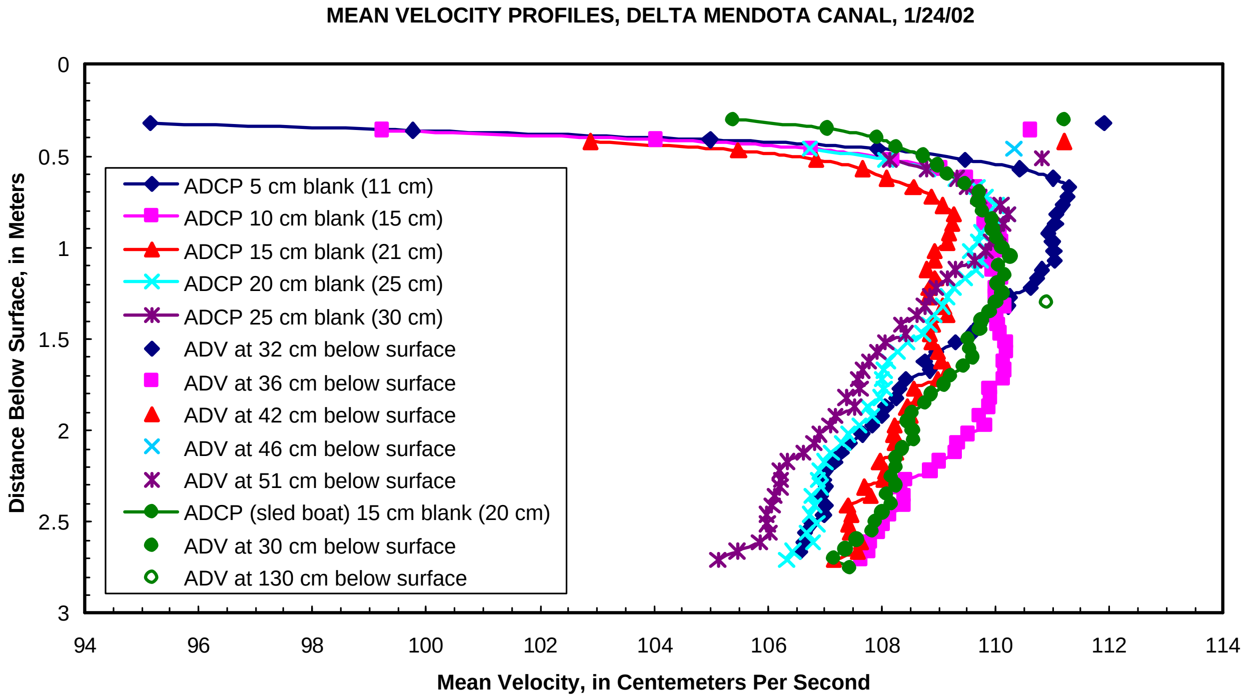

Figure 1. Examples of ADCP velocity profiles and ADV velocity point data at Delta Mendota Canal on January 24, 2002. The ADV data were collected at the same distance below surface as bin 1 of the ADCP; distance from transducer to ADCP bin 1 (value in parentheses) depends on blank distance. ADCP velocity profiles from ADCP moored in sled boat and ADV speeds recorded at 30 cm and 130 cm below surface are also shown. Depth of canal is about 5 m; velocity profiles do not extend to bottom. Horizontal scale is expanded for ease in viewing.

Tests of ZedHed and Conventional ADCP

A second series of tests was conducted at Delta Mendota Canal to compare velocity measurements made with ZedHed and conventional ADCPs in conjunction with the ADV (table 2). These tests employed several ADCP setups for data collection but limited blanking distances to 25-50 cm because of the limitations with conventional WH-ADCP. The ADCP transducers were located 20 cm below water surface. To address any question of potential spatial differences in flow, all measurements were made at the same location. The steady nature of flow in the canal suggested that simultaneous timing of measurements was less critical to results than using the same location. The ADV was programmed to make measurements in bursts of 2048 (205 seconds) and the ADCP WM5 measurements spanned about 205 seconds. ADCP WM1 measurements spanned about 360 seconds in order to produce mean velocity profiles of sufficient accuracy for comparison. Flow speeds as measured by ADV show a general increase in speed approaching water surface from about 96 cm/s at 1.4 m below surface to about 100 cm/s at 0.5 m below surface, an increase of about 4 (cm/s)/m. Measurements made utilizing BM7 experienced some moving bottom phenomena (less than 1.2 percent of current speed in bin 1), however, there was no evidence of moving bottom when using BM5. Mean speeds recorded using BM7 are little different from those recorded using BM5. Note that presence of moving bed would not change overall shape of the velocity profile but only the relative magnitude of speed for all bins.

Table 2. ADCP and ADV velocity measurements (Delta Mendota Canal 2/20/02). Negative values for percent difference indicate ADCP speed values are lower than ADV speeds values.

TIME	BLANK	DISTANCE TO BIN 1 FROM TRANSDUCER	SAMPLE AT	MAGNITUDE	BIN SIZE	WM	BM	MOVING BOTTOM	PERCENT DIFFERENCE
9:16	ADV	N/A	50 cm	98.7 cm/s	N/A	N/A	N/A	N/A	-6.2
9:25	ADV	N/A	50 cm	98.9 cm/s	N/A	N/A	N/A	N/A	
9:44	25 cm	30 cm	50 cm	92.9 cm/s	5 cm	5	7	No	
9:48	25 cm	30 cm	50 cm	93.1 cm/s	5 cm	5	7	No	
14:46	25 cm	30 cm	50 cm	92.6 cm/s	5 cm	5	5	No	
11:52	25 cm	30 cm	50 cm	95.8 cm	5 cm	5	5	No	
11:57	25 cm	30 cm	50 cm	94.0 cm/s	5 cm	5	5	No	
12:31	ADV	N/A	50 cm	102.3 cm/s	N/A	N/A	N/A	N/A	
12:39	ADV	N/A	50 cm	98.5 cm/s	N/A	N/A	N/A	N/A	
16:16	ADV	N/A	50 cm	101.0 cm/s	N/A	N/A	N/A	N/A	
13:03	ADV	N/A	75 cm	99.1 cm/s	N/A	N/A	N/A	N/A	-2.6
13:09	ADV	N/A	75 cm	99.1 cm/s	N/A	N/A	N/A	N/A	
11:33	25 cm	56 cm	76 cm	96.6 cm/s	20 cm	1	7	1.7 cm/s	
11:33	25 cm	56 cm	76 cm	95.2 cm/s	20 cm	1	7	1.5 cm/s	
12:10	25 cm	56 cm	76 cm	97.2 cm/s	20 cm	1	5	No	
12:10	25 cm	56 cm	76 cm	96.9 cm/c	20 cm	1	5	No	
12:46	ADV	N/A	55 cm	98.1 cm/s	N/A	N/A	N/A	N/A	-4.7
12:51	ADV	N/A	55 cm	98.1 cm/s	N/A	N/A	N/A	N/A	
13:43	30 cm	35 cm	55 cm	93.1 cm/s	5 cm	5	7	1.1 cm/s	
13:47	30 cm	35 cm	55 cm	92.5 cm/s	5 cm	5	7	1.0 cm/s	
14:41	30 cm	35 cm	55 cm	94.5 cm/s	5 cm	5	5	No	
14:07	30 cm	35 cm	55 cm	93.0 cm/s	5 cm	5	5	No	
14:13	30 cm	35 cm	55 cm	94.3 cm/s	5 cm	5	7	0.7 cm/s	
15:06	30 cm	35 cm	55 cm	92.3 cm/s	5 cm	5	5	No	
15:11	30 cm	35 cm	55 cm	94.7 cm/s	5 cm	5	5	No	
13:16	ADV	N/A	80 cm	99.3 cm/s	N/A	N/A	N/A	N/A	-3.6
13:21	ADV	N/A	80 cm	97.8 cm/s	N/A	N/A	N/A	N/A	
13:54	30 CM	61 cm	81 cm	96.1 cm/s	20 cm	1	5	No	
13:54	30 CM	61 cm	81 cm	95.1 cm/s	20 cm	1	5	No	
14:20	30 cm	61 cm	81 cm	94.9 cm/s	20 cm	1	5	No	
14:26	30 cm	61 cm	81 cm	94.1cm/s	20 cm	1	7	0.8 cm/s	
15:19	30 cm	60 cm	80 cm	95.3 cm/s	20 cm	1	5	No	
15:19	30 cm	60 cm	80 cm	94.7 cm/s	20 cm	1	5	No	
15:57	50 cm	55 cm	75 cm	94.9 cm/s	5 cm	5	5	No	-0.6
15:53	50 cm	55 cm	75 cm	93.9 cm/s	5 cm	5	5	No	
15:25	50 cm	55 cm	75 cm	96.3 cm/s	5 cm	5	5	No	
15:29	50 cm	55 cm	75 cm	94.7 cm/s	5 cm	5	5	No	
16:23	ADV	N/A	75 cm	95.5 cm/s	N/A	N/A	N/A	N/A	
16:05	50 cm	81 cm	101 cm	94.8 cm/s	20 cm	1	5	No	-3.3
16:05	50 cm	81 cm	101 cm	93.6 cm/s	20 cm	1	5	No	
15:38	50 cm	81 cm	101 cm	96.4 cm/s	20 cm	1	5	No	

TIME	BLANK	DISTANCE TO BIN 1 FROM TRANSDUCER	SAMPLE AT	MAGNITUDE	BIN SIZE	WM	BM	MOVING BOTTOM	PERCENT DIFFERENCE
15:38	50 cm	81 cm	101 cm	94.2 cm/s	20 cm	1	5	No	
16:28	ADV	N/A	100 cm	98.2 cm/s	N/A	N/A	N/A	N/A	
16:33	ADV	N/A	100 cm	97.7 cm/s	N/A	N/A	N/A	N/A	
15:57	50 cm	105 cm	125 cm bin 11	95.5 cm/s	5 cm	5	5	No	-0.6
15:25	50 cm	105 cm	125 cm bin 11	96.5 cm/s	5 cm	5	5	No	
16:38	ADV	N/A	125 cm	96.3 cm/s	N/A	N/A	N/A	N/A	
16:43	ADV	N/A	125 cm	96.8 cm/s	N/A	N/A	N/A	N/A	

Little difference is found between measurements made with the conventional and ZedHed versions of ADCPs (measured speeds compare within about 1 percent) (table 2 and fig. 2). All ADCP measured speeds are lower than ADV measurements. Differences decrease with distance from the ADCP transducer (increasing blank); they range from 0.6 to 6.2 percent with the largest differences occurring when using WM5 with 25 and 30 cm blanking distances.

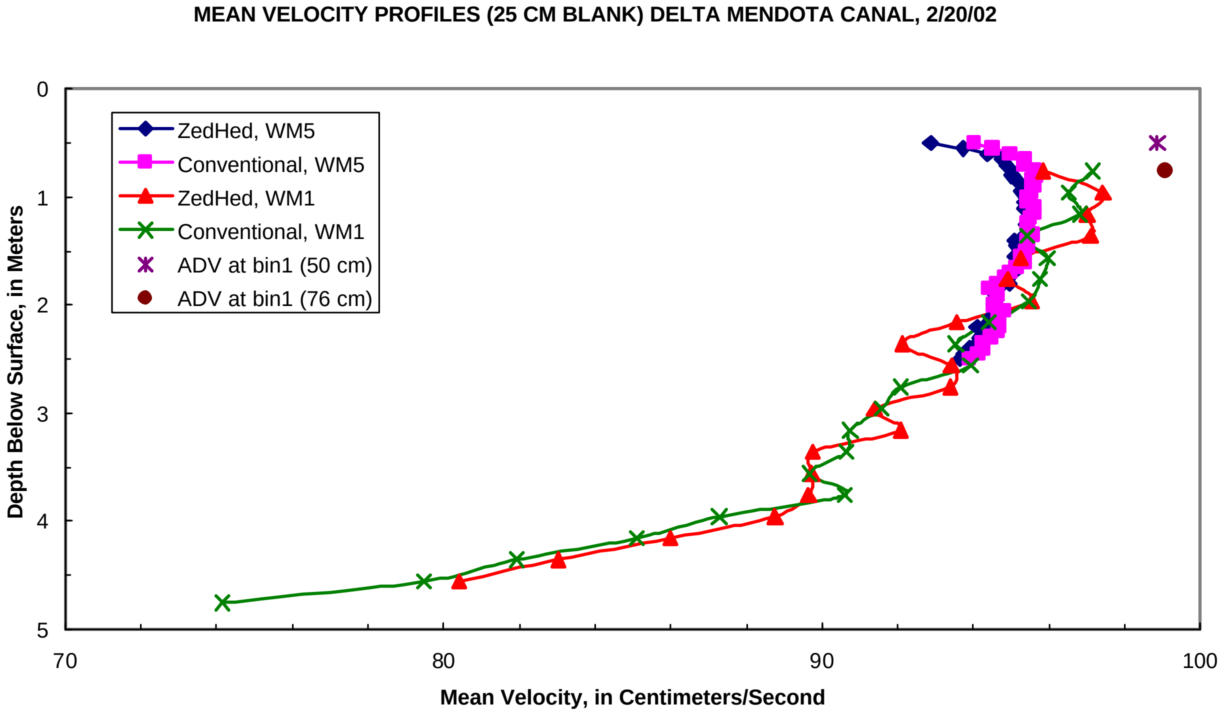

Figure 2. ADCP velocity profiles (25 cm blank) and current speed measured by ADV at Delta Mendota, February 20, 2002. Although ADV data appear slightly higher than WM1 ADCP measurements at corresponding level, there is little indication of velocity bias in WM1. WM5 speeds are biased low for both conventional and ZedHed ADCPs.

Comparison of measurements using WM5 and WM1 is somewhat more complex because of differences in bin size used for each mode and the distance to bin 1. ADCP measurements using WM5 compare more favorably to ADV measurements than do WM1 measurements at the same distance from transducer (for example: ADCP WM5 using 50 cm blank and 5 cm bin compared to WM1 using 25 cm blank and 20 cm bin). However, differences between ADV and ADCP WM1 measurements are less than those for WM5 when the same blanking distance is used. For example, results for WM1 with 25 cm blank show ADV and ADCP agree within about 2.6 percent (table 2 and fig. 2). That is better agreement than when using ADCP WM5 (with the same 25 cm blank). This is probably the result of greater distance from ADCP transducer to bin 1 when using WM1. In this case the distance also includes use of larger bin size (20 cm rather than 5 cm). Distance from transducer to bin 1 (center) when using WM1 is equal to blank plus one half of the sum of bin size plus transmit length plus lag. Distance to bin 1 (center) when using WM5 is equal to blank plus one half of the sum of bin size plus transmit length only. In WM1, lag is approximately equal to half the bin size thus, all else being equal, the distance from transducer to bin 1 is about one quarter bin further for WM1 than it is for WM5.

The shapes of the WM5 profiles shown in figure 2 appear somewhat distorted displaying speed bias in bins close to the transducer as well as some evidence that the bias may be transferred into adjacent bins that are in the region where little or no bias would be expected based on the WM1 profiles. Therefore, blanking distance, and thus the position of the first bin, must be chosen carefully to avoid contaminating what would otherwise be good data bins.

Similar to results of prior tests at Delta Mendota Canal, speeds measured by ADCP in bin 1 are slightly low (especially for WM5) even when using the minimum recommended blank for conventional ADCPs. There are several possible explanations for this in addition to potential small errors (probably < 1 percent) that might result from incorrect water temperature used for speed of sound calculations. The first possibility is that the ADV speeds may be a biased high as a result of errors in instrument beam geometry. That possibility will be discounted in a later discussion of test results at Vernalis, California. The second possibility is that de-correlation of signals (in WM5) at higher speeds near surface may cause a bias toward low velocities in upper portion of water column. Examination of WM5 measurements shows no increase in data loss in the first few bins compared to the rest of the velocity profile. However, velocity profiles (especially those collected using WM5) tend to look abnormal in the upper bins close to the transducer where they bend back toward low velocity. The ADV measurements of speed show no indication of this trend. In addition, both WM1 and WM5 tests show somewhat similar results although the majority of effect of the low speed bias is seen closer to the transducer in the region measured when using WM5 (nearly 19 cm additional). The third and most likely explanation is that flow deformation around the ADCP transducer extends further than originally believed (at least at these water speeds).

ZedHed Comparisons With BoogieDopp and Vector Instrument Inter-comparisons

As part of the tests evaluating use of microwave radar to estimate discharge from surface velocity measurements, flow and discharge measurements were made on the San Joaquin River at Vernalis with an entire suite of instruments. Instruments included ZedHed ADCP, ADV, a Nortek acoustic vector velocimeter, and a prototype Doppler unit manufactured by Nortek called BoogieDopp. This provided an opportunity to use a second acoustic vector instrument for comparison with the SonTek ADV to address the question of accuracy of the ADV. Comparisons of results of velocity measurements made at seventeen sample stations across the river using the SonTek ADV with those from a vector instrument manufactured by Nortek showed that the SonTek and Nortek vector instruments were reading essentially the same during the first set of measurements. The SonTek instrument was actually recording speeds that were somewhat lower than the Nortek instrument (about 3.8 percent) during a second set of measurements. This provides some confidence that the differences between ADCP and SonTek

ADV instrument seen throughout these tests are probably not a result of SonTek ADV speeds being biased high.

For measurements of mean velocity profiles during these tests the ZedHed ADCP was configured in WM5 and used a 25 cm blanking distance with 5 cm bin size. On the first day of measurements ADCP speeds recorded for bin 1 (at 38 cm below surface) were about 5 percent lower on average than the SonTek ADV values recorded at 25 cm below surface. On the second day the average difference between the ADCP and ADV was about -6 percent (ADV at 20 cm below surface). During these tests the ADV was positioned as near to water surface as possible thus water speeds recorded by the ADV were not at the same depth as ADCP (bin 1) data. Nevertheless, comparison of mean velocity profiles from ADCP with near-surface velocity from ADV indicates that the ADCP was probably recording velocities that were biased low relative to actual values (not shown). In addition, velocity measurements by ZedHed ADCP have been compared with speed measurements from a prototype Nortek Doppler instrument mounted horizontally on a boogie board (BoogieDopp). Velocity measurements by ZedHed in bin 1 (at 38 cm below surface) were, on average, about 6.0 percent less than speed measurements by BoogieDopp in bin 3 (at 40 cm below surface).

In a later test, velocity profiles were measured at a single point in the river using several different ADCP configurations. These measurements are compared to speed measurements from the BoogieDopp (fig. 3). Each ZedHed ADCP measurement of mean velocity profile (over 180-300 seconds) used a 25 cm blank but different WM, BM, and bin size settings to examine potential differences in the measured velocity profiles.

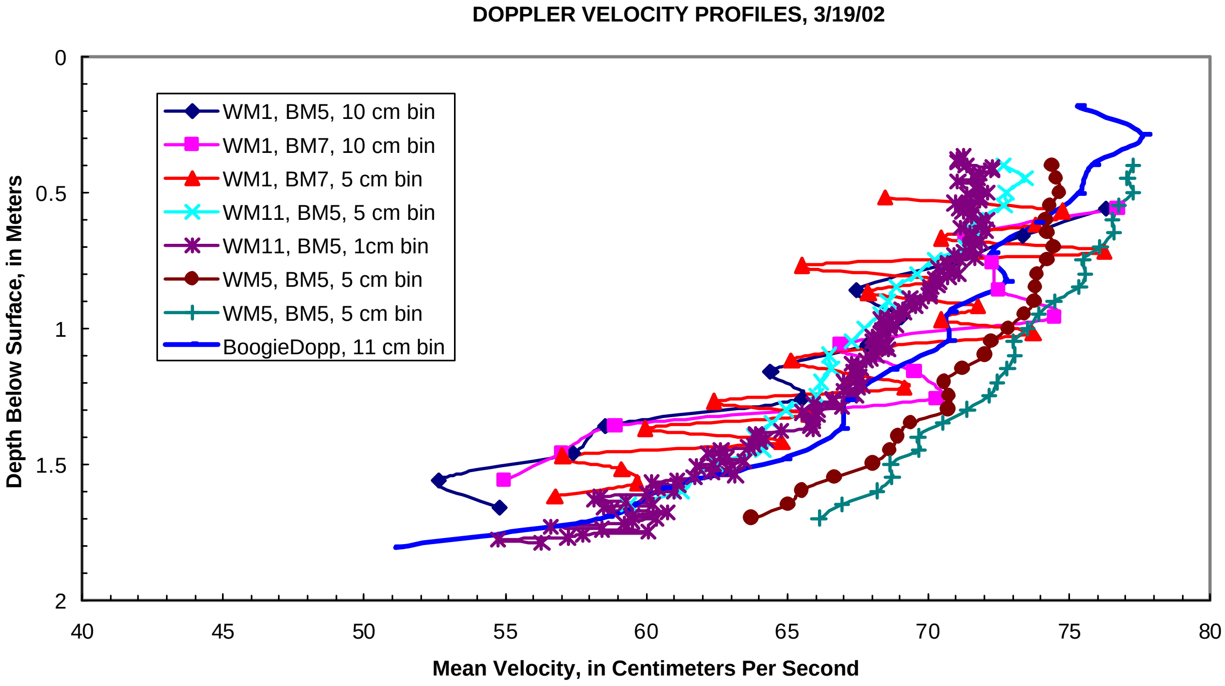

Figure 3. Comparison of ADCP velocity profiles collected with various Water Mode and Bottom Mode combinations and BoogieDopp velocity profile. BoogieDopp profile is average of seven data sets collected concurrently with data sets using seven different ADCP measurement setups. All ADCP samples collected using 25 cm blank. The second WM5 measurement (+ symbol) used a shortened ARB of 47 cm.

The advantages and disadvantages of the various configurations used under these shallow water conditions can be seen in figure 3. WM5 and WM11 provide well-defined current profiles but are sometimes biased low near transducer. The exception seems to be the measurement with WM5, BM5, a 5 cm bin and a shortened ARB. Velocity measurements with WM1 may not be biased near surface for reasons previously described, but profiles are noisy since bin sizes are much smaller than recommended unless substantial averaging is possible. The (highly smoothed) velocity profile determined from the average of all seven BoogieDopp data sets is shown for comparison. The shape of the BoogieDopp profile (fig. 3) suggests that flow is still increasing approaching surface at least to 29 cm below surface (bin 2). It is believed that near-surface velocity measured in the first bin (18 cm below surface) of the BoogieDopp may be biased low because of effects from the boogie board.

Comparisons of Velocity Measurements Utilizing Sled Boat and Tri-hull Riverboat

A set of velocity profile measurements by ZedHed ADCP in a tri-hull tethered boat (Riverboat, manufactured by Oceanscience Group) rather than the aluminum sled boat was made on April 24, 2002. The ZedHed was configured to use WM1, 5cm blank, and 10 and 25 cm bin sizes. Those measurements show little evidence of low speed bias (fig. 4) although no ADV or other instrument measurements are available for comparison. Shapes of the velocity profiles for both (bin size) measurements appear reasonably normal with no evidence of severe "bend-back" seen in earlier tests although low velocity bias of a few percent is possible. (Extensive averaging was performed to produce these smooth profiles using WM1.)

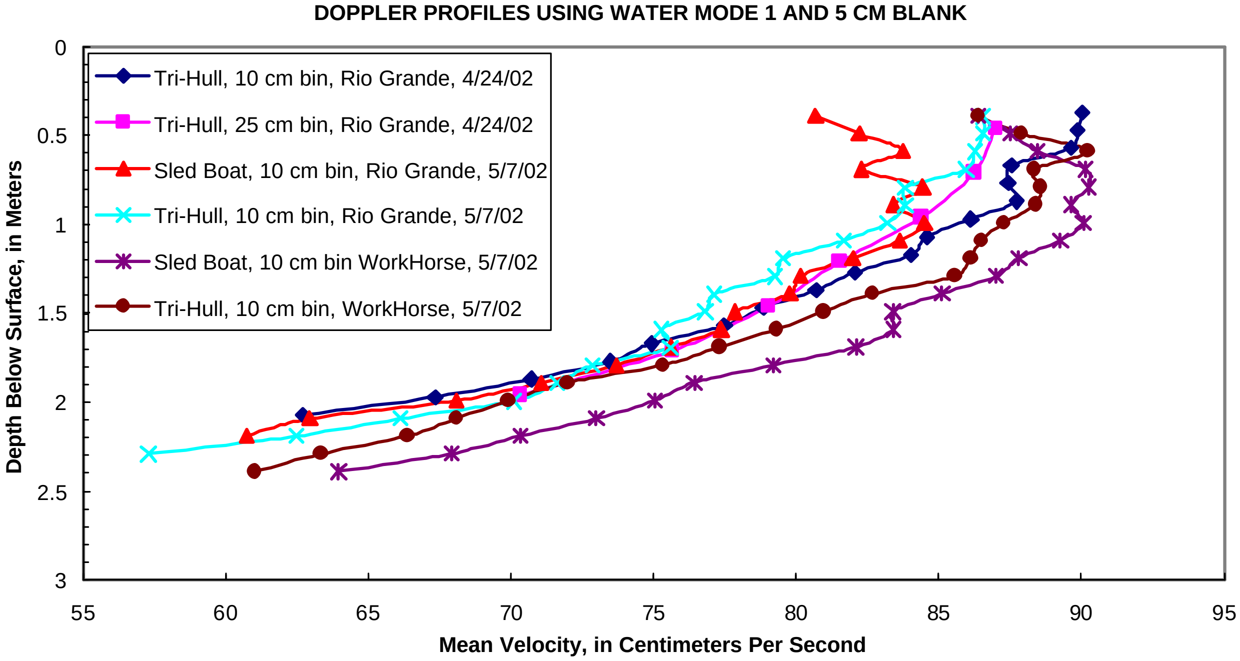

Figure 4. Velocity profiles collected using ADCP in OceanScience tethered Riverboat and aluminum sled boat with ADCP operating with Water Mode 1 and short blank. The ADCP transducer is located 11 cm below water surface.

These measurements suggested that use of the tethered Riverboat might mitigate some of the source of bias making low-blank speed measurements possible, at least beyond ranges (from transducer) as tested here with WM1. A subsequent test (5/7/02) to clarify this was conducted using Rio Grande and WH-ADCPs (both ZedHeds) configured for WM1 that were moored both in a Riverboat and an aluminum sled boat (fig. 4). Resulting velocity profiles indicate that while there is some improvement using the Riverboat rather than the aluminum sled boat, the problem of low speed bias is still present when using short blanking distances. Some of the improvement may be related to the fact that the Riverboat is more streamlined. In addition, the ADCP transducer head extends about 5 cm further below the hull of the aluminum sled boat than it does below the hull of the Riverboat.

A final test to quantify the possible improvement of measurements from a Riverboat over the aluminum sled boat was conducted using A Rio Grande operating in WM5 using several blanking distances. The ADCP was moored in both the aluminum sled boat and a Riverboat. Results shown in figure 5 show that the low-speed bias extends about one bin (5 cm) deeper in the water column when using the aluminum sled boat than when using the Riverboat. At near surface current speeds of about 75 cm/s, there is no evidence of the bias when using 25 cm blank with the Riverboat however, the velocity profile appears to be biased low in the first 1-2 bins when using the same 25 cm blank and the aluminum sled boat.

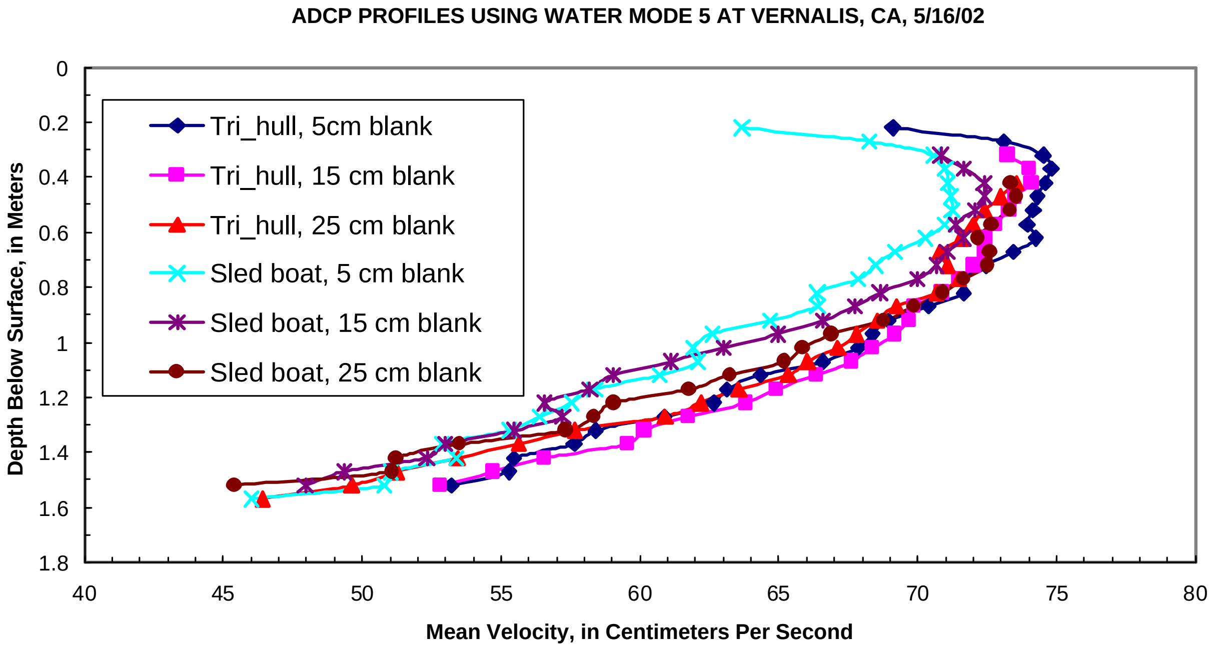

Figure 5. Velocity profiles collected using ADCP in OceanScience tethered Riverboat and aluminum sled boat with ADCP operating in Water Mode 5 using 5 cm bin size and various short blanks. The ADCP transducer is located 12 cm below water surface.

SUMMARY AND CONCLUSIONS

Analyses of velocity measurements collected with ZedHed ADCP at Delta Mendota Canal and the San Joaquin River at Vernalis, California indicate that there may be a finite limit to how close velocities can be measured to ADCP transducer without biasing measurements. That distance may be further than originally thought at high flow speeds. Although de-correlation from high current speed cannot be completely eliminated as a source of bias in these WM5 measurements, analyses of all results including measurements with WM1 tend to indicate that another source of bias results from changes in flow near the transducer. Larger bin size and instrument algorithms used with WM1 move the first data bin further away from the transducer than it is when using WM5 which reduces the bias in speed in the first few bins for a given blank value. Deploying the ADCP in the tri-hull Riverboat may allow use of smaller blank distance than using ADCP alone or ADCP mounted in aluminum sled boat. Analyses of measurements in Delta Mendota Canal where velocities were about 100 cm/s indicate that the limit is about 50 cm from the transducer for unbiased measurements. Analyses of measurements at Vernalis, where water speed was on the order of 75 cm/s, indicate that it might be possible to make accurate measurements slightly closer to transducer, perhaps on the order of 30 cm from transducer. Since distance to first bin is a function of blank length, bin size, and water track mode, those parameters must be taken into account, however a rough rule of thumb might be that blank should be adjusted such that the distance to the first bin in centimeters is equal to one half expected current speed in centimeters per second. For example, if maximum current speed is 80 cm/s, the blank should be adjusted such that the distance to bin 1 is about 40 cm from transducer. Because the first bin is located further from the transducer when using WM1 than it is when using WM5, it may be possible to use a smaller blank in WM1 than with WM5. Future testing should be conducted to see if smaller blanking distances can be used when flow speeds are less than those encountered during these tests to examine potential use of ZedHed in very shallow, low-flow regimes.

REFERENCES

RDI, 2001, WorkHorse Commands and Output Data Format, San Diego, Calif., RD Instruments, 157 p.

SonTek, 1997, SonTek ADV Acoustic Doppler Velocimeter (ADV), Principles of Operation, San Diego, Calif., SonTek/YSI, Inc, 14 p.