

Yangtze River ADCP Discharge Measurement Using Multiple External Sensor Inputs

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Abstract - During high flow season, the sediment load of the Yangtze River can reach 20 grams per liter. When the sediment load is high, acoustic absorption and scattering interfere with the bottom tracking of ADCPs used to measure discharge on the Yangtze River. In addition, the Changjiang Water Resources Commission (CWRC) uses 30 meter steel hulled vessels to perform discharge measurements on much of the Yangtze River. The steel hull of the vessel prevents using the ADCP's internal flux-gate compass as a heading reference. We performed tests to determine if accurate discharge measurements could be performed using an ADCP to measure water velocity, a depth sounder for water depth, DGPS to determine vessel speed over ground, and a gyrocompass to provide heading information. The tests were performed during normal flow conditions when the ADCP bottom tracking is reliable. Using four different ADCPs with the three other external devices, we measured discharge at the CWRC Three Gorges Huangling Temple Hydrology Station. Discharge computed using the external depth sounder, DGPS, and gyrocompass was found to be within 2% of the discharge computed using the ADCP alone. The results of those tests are presented in this paper.

I. INTRODUCTION:

Acoustic Doppler Current Profilers (ADCPs) have been used since the late 1980's to measure discharge in rivers [1-4]. Comprehensive studies of this technique have shown that the use of ADCPs from moving vessels produces reliable discharge measurements under most circumstances tested. However, certain combinations of high velocity and high sediment load can create an underestimation of discharge. This effect has come to be known as a 'moving bed' [5] because the effect is identical to the results one would obtain if the bottom were moving in the same direction as the bulk flow of the water. For a given location, the magnitude of the moving bed error has been observed to depend on the frequency of the ADCP, being a larger bias when the ADCP frequency is higher. One method of correcting this is to replace the ADCP's bottom tracking velocity data with differential GPS velocity as the reference with which to remove the vessel velocity from the total measured water velocity and to compute the vessel's path and from these, the river discharge. Under very high sediment load conditions, the acoustic energy transmitted by the ADCP is absorbed and

scattered sufficiently to prevent the ADCP from reliably measuring depth as well. Again, the effect is reduced by using a lower frequency ADCP but this has the consequence of requiring larger vertical profiling depth cells which leads to extrapolating more of the flow at the surface and at the bottom.

On Oceanographic vessels, GPS or DGPS is often used for the ADCP velocity reference because the water is frequently too deep for an ADCP to bottom track. DGPS is also used on some rivers for which a moving bed occurs. The software normally supplied with an ADCP includes the ability to receive information from a DGPS and combine it with the ADCP data stream. Oceanographic research vessels also often use a gyrocompass to determine the vessel heading. The ADCP and/or its software can be interfaced to the vessel's gyrocompass by using the proper interface. Some vessels also have low frequency echo sounders that can measure water depth in deeper water than can the ADCP. The ADCP software can receive the depth data over a RS-232 connection and include record this data with the ADCP data.

II. THE YANGTZE RIVER

During the summer Monsoon season, The Yangtze River in the People's Republic of China carries a sediment load of up to 20 grams/liter. This sediment is sufficient to cause bottom tracking biases and occasionally total lack of bottom detection for data taken with a 300 kHz ADCP, the lowest frequency normally used for moving-boat river discharge measurements. One solution is to use differential GPS for the over-ground velocity reference and a lower frequency depth sounder to provide bathymetric information for the computation of discharge. Because of the depths, velocities, and other conditions encountered on the Yangtze River during flood season, the CWRC, which is responsible for measuring the flow on the Yangtze River, employs 30 meter long, steel-hulled vessels (Figure 1). The steel hull interferes with obtaining accurate heading data from the internal compass of the ADCP. Since these vessels have a gyrocompass, that can be used to provide heading information to the ADCP and its software.



Figure 1 A steel-hulled survey vessel used in Yangtze River ADCP discharge measurements

In September of 2002, the CWRC and RD Instruments collaborated in a project to acquire ADCP discharge data and simultaneously acquire depth sounder, DGPS, and gyrocompass data. This was the first occasion on which all three external sensors were combined with an ADCP for the purpose of discharge measurement of a river. Discharge was then computed using the ADCP for water velocity data and the gyrocompass for heading information in conjunction with various combinations of ADCP bottom tracking for depth and/or vessel velocity over ground, a depth sounder for water depth, and GPS for vessel velocity. The goal was to determine the agreement between the various combinations of instruments for computing discharge. If the measurements were successful, then the CWRC would be able to use an ADCP for discharge measurement during the flood season as well as the rest of the year.



Figure 2 Yangtze River at Three Gorges Huangling Temple Hydrology Station

The Three Gorges Huangling Temple Hydrology Station (Figure 1) was chosen because it was an existing ADCP measurement station in a location that had experienced ‘moving bed’ problems during flood events as

well as acoustic absorption so high that a 300 kHz ADCP could not reliably measure depth in the deeper parts of the channel, which can be up to 65 meters deep during flood season. Since the summer flood season was completed and the sediment load had decreased below 1 g/l, it was hoped that no ‘moving bed’ effects would be observed. If the ADCP bottom tracking worked properly, then discharge acquired using ADCP bottom tracking for the vessel velocity and water depth would provide the reference against which to compare discharge computed using DGPS for the velocity reference and a separate depth sounder for depth information. The site is approximately 10 kilometers downstream of the Three Gorges Project Dam near Yichang in the central part of the People's Republic of China. During the measurements discussed here, the channel was about 500 meters wide with a maximum depth of 55 meters and mean velocity of 0.8 meters/second. The sediment load was 0.5 - 1.0 kg/m³.

III. EQUIPMENT

Four different ADCPs were used in the tests: a 150 kHz Workhorse ADCP, a 300 kHz Broadband ADCP, a 300 kHz Workhorse Monitor ADCP, and a 600 kHz Workhorse Rio Grande ADCP (Figure 3). This provided a range of frequencies, beam angles, beam widths, transmit powers, and electronic platforms with which to acquire ADCP data. Frequency was the most important criteria for reducing any moving bed effects that have affected the data. The Yangtze River is sufficiently deep to allow 2 meter depth cells to be used with the 150 kHz ADCP. Each ADCP was used individually to acquire data in conjunction with the other three sensors. The shipboard gyrocompass was connected to an RD Instruments deckbox which has a gyrocompass interface card and output heading in a proprietary RD Instruments format across an RS-232 connection. The heading output, the ADCP, a 100 kHz commercial depth sounder with RS-232 NEMA output, a DGPS with RS-232 NEMA output were then connected to a laptop computer by connecting three of the devices to a USB-to-RS-232 converter which broke out the USB into four RS-232 ports. All devices were operating at 9600 bps which was the highest speed at which the USB-to-RS-232 converter operated reliably. WinRiver, the software used to perform discharge measurements with ADCPs, acquired the data from the various sensors and stored the data on disk for later playback.

IV. TAKING THE DATA

On the first full day of operation, we began taking data using the 150 kHz ADCP. However we found that the depth sounder did not have reliable communication to the computer. We determined that it needed to have a separate power supply to eliminate a ground loop that it created. So, for the 150 kHz ADCP, no depth sounder data was acquired simultaneously with the other data. By the time a second power source was located and installed, the 300 kHz BroadBand ADCP had already been exchanged for the 150 kHz ADCP. On the second day, a 300 kHz Workhorse

Monitor and 600 kHz Workhorse Rio Grande ADCP were used. Each time that an ADCP was mounted, it was necessary to make calibration runs to determine the correct heading offset for the ADCP relative to the gyrocompass. The total time required for a typical discharge measurement was 8-10 minutes during which the vessel speed in the center of the channel was about 1.5 m/sec.



Figure 3 ADCPs used in the tests. Top left: 150 kHz WH ADCP; Top right: 300 kHz BB ADCP; Bottom left: 300 kHz WH Minitor ADCP; Bottom right: 600 kHz WH Rio Grande ADCP

An interesting side note is that during the tests, it was mentioned that in the past, data was often lost near the starting bank as the boat pulled away from shore. We stood by the ADCP during the beginning of a transect and noticed that when leaving the left shore, the boat pilot would put the port engine in reverse to help the boat turn. This caused heavily aerated water to be forced toward the bow of the boat on the port side, where the ADCP is usually mounted. The bubbles in this propwash are very strong scatters of acoustic energy, effectively blocking the acoustic beams from the ADCP until the port engine was returned to normal rearward thrust. The procedure for leaving the shore was changed so that the engines were never reversed while leaving shore. No more instances of bad data when pulling from shore have been observed.

Figures 4 and 5 show examples of transect screen shots of WinRiver.

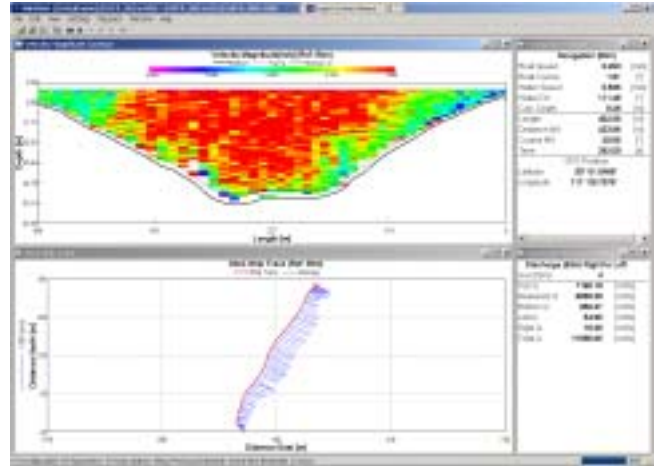


Figure 4 An example of transect screen shot of WinRiver. The water velocity, boat velocity, and depth were measured by the ADCP

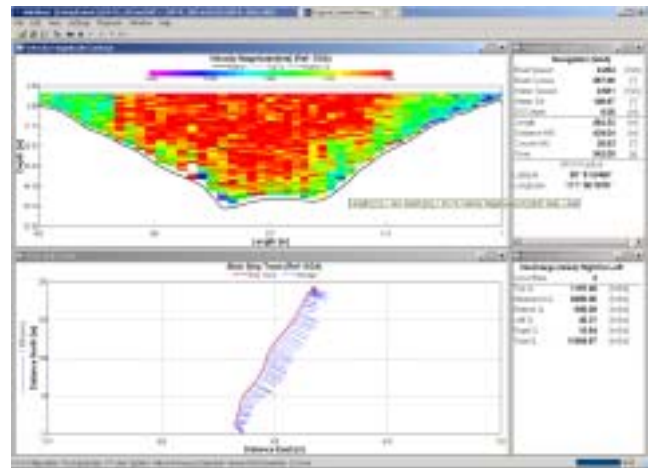


Figure 5 The same transect as in Figure 4. But the boat velocity was measured by the DGPS and the depth was measured by the depth sounder

V. DISCHARGE MEASUREMENT RESULTS

The results of the measurements are summarized in Table 1. For each ADCP Model, except for the 150 kHz Workhorse, the river discharge was computed using two vessel speed references, ADCP or DGPS, and two depth references, ADCP or depth sounder, giving a total of four different computations of discharge for each transect that was done. In Table 1, ΔQ shows the difference, in percent, of the discharge computed using the ADCP bottom tracking for depth and vessel velocity to discharge computed using one or both of the external depth and vessel speed references. The results show that there is less than a 2% difference overall between discharge measured using solely the ADCP and discharge measured using DGPS for vessel speed and/or an external depth sounder for channel depth. This implies that during high sediment conditions on the Yangtze River, accurate discharge measurements can be made using a 300 kHz ADCP if an external depth sounder is used to determine the water depth and DGPS is used to measure the vessel's velocity.

VI. SUMMARY

For the first time, river discharge measurements were made on the Yangtze River using ADCPs combined with differential GPS, an external low frequency depth sounder, and a gyrocompass. The results obtained were within 2% of the discharge measured using only the ADCP and gyrocompass. So, when high sediment loads cause moving bed bias or complete loss of bottom tracking depth, discharge measurements can still be made using DGPS and an external depth sounder to supplement the ADCP data.

VII. ACKNOWLEDGEMENTS

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Table 1:
Summary of Discharge Measurements with Different ADCPs, Vessel Speed, and Depth References

Date	ADCP Model	Number Transects	Vessel Velocity Reference	Depth Reference	Avg Q (m ³ /sec)	Q std (% Avg Q)	ΔQ (%)	Cell size (m)	# Cells
Sept. 19	150 kHz WH	5	ADCP	ADCP	11233	1.7%		2	30
			DGPS	ADCP	11316	2.2%	+0.7		
Sept. 19	300 kHz BB	5*	ADCP	ADCP	11067	1.9%		2	60
			ADCP	DS	10994	2.0%	+0.7		
			DGPS	ADCP	10799	2.0%	-2.4		
			DGPS	DS	10909	2.4%	-1.4		
Sept. 20	300 kHz WH	5	ADCP	ADCP	11746	1.0%		1	60
			ADCP	DS	11701	1.2%	-0.4		
			DGPS	ADCP	11787	2.1%	+0.3		
			DGPS	DS	11712	2.0%	-0.3		
Sept. 20	600 kHz WH	3	ADCP	ADCP	12238	2.5%		0.52	120
			ADCP	DS	12066	3.2%	-1.4		
			DGPS	ADCP	12451	2.7%	+1.7		
			DGPS	DS	12262	3.2%	+0.2		

* Seven transects were made but the ADCP rotated in its mount before the last two transects, changing the correct heading reference. Only the first five measurements were used to compute the standard deviation in Q.

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