Pre-Mission and Mission Report

ADCP Measurement of the Blue Nile under High Sediment Conditions

2007

Jeff Woodward

Information Products for Nile Basin Water Resources Management
www.faonile.org

Table of Contents

Part I: Pre - Mission Report 4

1 Introduction 5

2 Measurement Issues 7

2.1 Moving Bed 8

2.2 Loss of Water Velocities 8

2.3 Loss of Bottom Tracking 8

2.4 Loss of Depth Determination 9

3 Flow Measurement Strategy 10

3.1 1200kHz ADCP Measurement Trial 10

3.2 600kHz ADCP Measurement Trial 10

3.3 500kHz Sontek ADP Measurement Trial 10

3.4 Non Accoustic Measurements 11

3.5 Methodology Overview 12

4 Equipment 13

5 Summary 14

6 References 14

Part II: Mission Report 15

1 Executive Summary 16

2 Introduction 17

3 Overview 18

4 Recommendations 20

5 Measurement 22

Pre-mission Report

August, 2007

Introduction

As a result of the needs identified under the project "Capacity Building for Nile Basin for Water Resources Management" several 1200kHz acoustic Doppler current profilers (ADCPs) were purchased and deployed throughout the region. This piece of equipment is used world wide to gather high quality and detailed discharge information and is a highly efficient and cost effective instrument for flow measurement. In most rivers, the portable ADCP is operated from a boat or other floating platform, thus eliminating the need to build an expensive cableway. As with any technology however, it has specific limitations.

Acoustic instruments rely on a few basic physical principles to function. A sound wave is introduced into the water column and the characteristics of its echo are measured to determine specific properties of the river environment. An ADCP uses sound waves in two ways when conducting a flow measurement; it measures the character of sound waves returned from particles in the water to determine flow velocity, and it uses sound waves returned from the bottom of the river to determine its position, velocity and orientation. The things that affect the measurement quality and ultimately the ability to conduct a measurement in this manner are:

- the characteristics of the sound wave including frequency, amplitude, and the amount of energy used to generate the sound wave,
- the characteristics of the reflective material including the sediment particle distribution, composition, and density (used to determine flow velocity) and the composition and density of the bottom material (used to determine depth and relative platform movement),
- the signaling and sampling strategy used to send and detect the sound waves, and
- the length of the path the wave must travel.

One of the most common problems related to conducting discharge measurements using ADCPs is high concentrations of sediment. While some sediment or suspended material must be present for an acoustic device to function, too much sediment can be a significant issue. As the amount of sediment increases, there is a tendency for the following to occur:

- bottom detection sound wave does not fully penetrate to the real bed material causing moving bed conditions to be detected,
- velocity detection sound wave does not penetrate deep enough into the water column or the return signal is attenuated to the point that water velocities cannot be measured at depth,
- bottom detection sound wave is attenuated to the point where the bottom position cannot be determined causing problems with determination of the position,
- bottom detection sound wave is attenuated so that the depth of flow cannot be accurately determined.

This report is intended to offer a strategy to deal with each of these conditions in a variety of ways so that measurements can be made under extreme conditions. Emphasis will be placed on keeping the solutions simple so that it can be easily integrated into the operational program.

With the methodology presented in this report, the probability of finding a measurement solution using acoustics is very high. Under the most extreme conditions a measurement using a moving boat and ADP or ADCP may not be possible. However this proposal includes utilizing a recent development using a Sontek ADP in stationary mode to determine discharge. Barring a complete equipment failure, this method can be used as long as the depth can be determined using any technology. In all probability, this will not be necessary and a moving boat solution will be possible.

While this investigation will focus on finding a solution for measurement using the equipment that is in operations, it is possible that a favorable result cannot be achieved. In this case, emphasis will be placed on finding an alternative measurement system that is appropriate for the conditions.

As a result of the needs identified under the project "Capacity Building for Nile Basin for Water Resources Management" several 1200kHz acoustic Doppler current profilers (ADCPs) were purchased and deployed throughout the region. This piece of equipment is used world wide to gather high quality and detailed discharge information and is a highly efficient and cost effective instrument for flow measurement. In most rivers, the portable ADCP is operated from a boat or other floating platform, thus eliminating the need to build an expensive cableway. As with any technology however, it has specific limitations.

Acoustic instruments rely on a few basic physical principles to function. A sound wave is introduced into the water column and the characteristics of its echo are measured to determine specific properties of the river environment. An ADCP uses sound waves in two ways when conducting a flow measurement; it measures the character of sound waves returned from particles in the water to determine flow velocity, and it uses sound waves returned from the bottom of the river to determine its position, velocity and orientation. The things that affect the measurement quality and ultimately the ability to conduct a measurement in this manner are:

- the characteristics of the sound wave including frequency, amplitude, and the amount of energy used to generate the sound wave,
- the characteristics of the reflective material including the sediment particle distribution, composition, and density (used to determine flow velocity) and the composition and density of the bottom material (used to determine depth and relative platform movement),
- the signaling and sampling strategy used to send and detect the sound waves, and
- the length of the path the wave must travel.

One of the most common problems related to conducting discharge measurements using ADCPs is high concentrations of sediment. While some sediment or suspended material must be present for an acoustic device to function, too much sediment can be a significant issue. As the amount of sediment increases, there is a tendency for the following to occur:

- bottom detection sound wave does not fully penetrate to the real bed material causing moving bed conditions to be detected,
- velocity detection sound wave does not penetrate deep enough into the water column or the return signal is attenuated to the point that water velocities cannot be measured at depth,
- bottom detection sound wave is attenuated to the point where the bottom position cannot be determined causing problems with determination of the position,
- bottom detection sound wave is attenuated so that the depth of flow cannot be accurately determined.

This report is intended to offer a strategy to deal with each of these conditions in a variety of ways so that measurements can be made under extreme conditions. Emphasis will be placed on keeping the solutions simple so that it can be easily integrated into the operational program.

With the methodology presented in this report, the probability of finding a measurement solution using acoustics is very high. Under the most extreme conditions a measurement using a moving boat and ADP or ADCP may not be possible. However this proposal includes utilizing a recent development using a Sontek ADP in stationary mode to determine discharge. Barring a complete equipment failure, this method can be used as long as the depth can be determined using any technology. In all probability, this will not be necessary and a moving boat solution will be possible.

While this investigation will focus on finding a solution for measurement using the equipment that is in operations, it is possible that a favorable result cannot be achieved. In this case, emphasis will be placed on finding an alternative measurement system that is appropriate for the conditions.

The overall result of this investigation will be to recommend a measurement system for the Blue Nile that considers available technology and expertise.

Measurement Issues

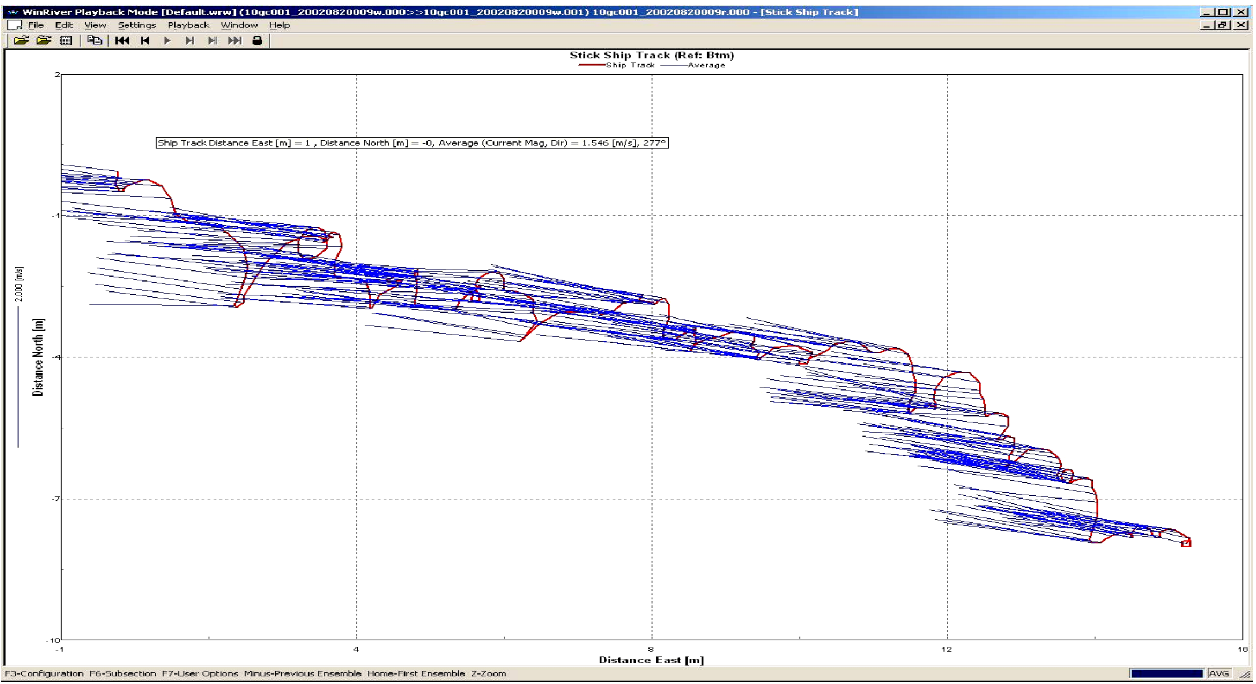
Traditional river discharge measurements require the integration of several different processes and procedures. In general, discharge is measured using the velocity area method. Acoustic technologies utilize the same velocity area approach but measure the velocity in the entire profile in hundreds or even thousands of panels. The resulting issues relate to the accurate determination of the boat position (boat velocity, direction, orientation etc) relative to the bottom or some other reference, and the determination of the water velocity profile.

2.1 Moving Bed

There is a tendency for acoustic devices, under specific conditions, to erroneously detect movement of the measurement platform. This is referred to as moving bed because the device is actually detecting movement of sediment along the bottom of the river but interpreting it as boat movement. While this phenomena is related to the bed load of the river, it is not a direct analog because it is dependent on the frequency of the sound wave in addition to the movement of sediment and other conditions. When moving bed is detected, there are several compensation strategies that can be used including:

- Conducting moving bed measurements and adjusting the measured flow accordingly,
- Modifying the measurement procedure to employ the "loop method" to correct for the moving bed,
- Employing a GPS in conjunction with the ADCP to determine platform position, and [The detection of the moving bed only affects the bottom tracking and thus the boat position. Using a GPS to compute position reduces the reliance on bottom tracking for position]
- Employing a lower frequency instrument. [lower frequencies mean more power in the water and more penetration through sediment]

A typical moving bed measurement is shown in Figure 1. A moving bed test is conducted by keeping the measurement platform stationary and allowing the system to measure the position relative to the bottom. A moving bed is present when the vessel seems to track downstream when in reality it does not.



2.2 Loss of Water Velocities

As the amount of sediment increases, the distance the sound wave travels decreases and can result in the loss of velocity measurements further away from the transducer. This can be problematic if there is a significant amount of the water column where velocities are not being measured. This strategy to deal with this problem is:

- Modify the measurement strategy. By introducing more sound pings into the water column, more data may be successfully returned,
- Employ a lower frequency ADCP. Lower frequency ADCPs mean more power in the water and thus more data will be returned.

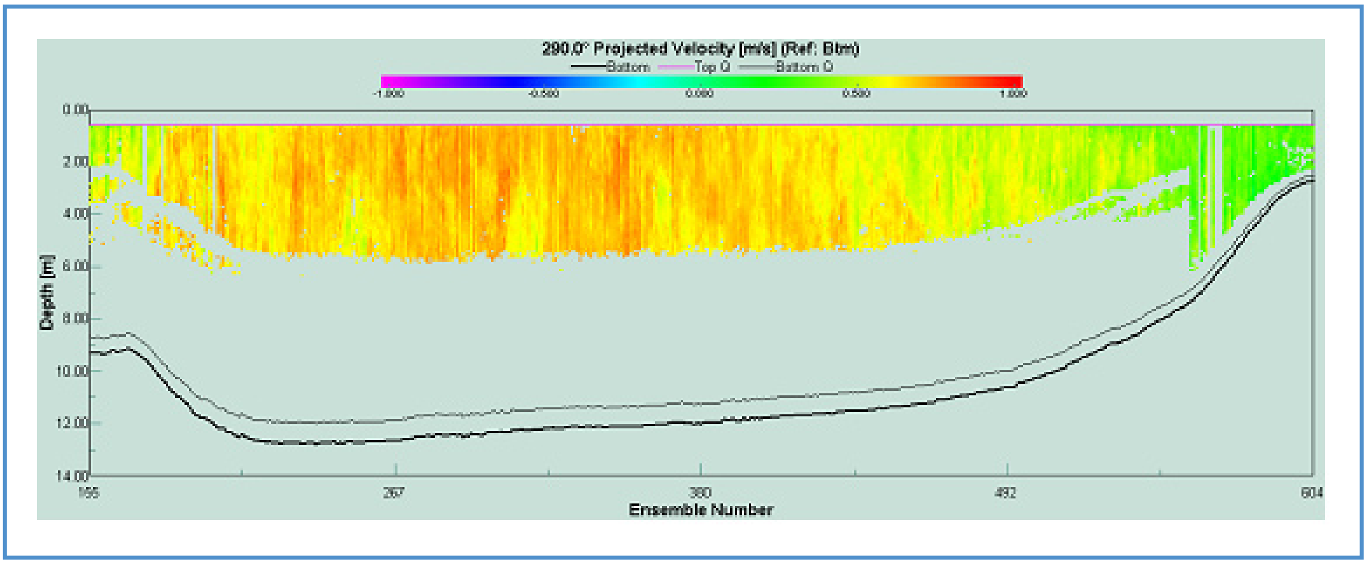


FIGURE 2. Example of Velocity Measurement in Only Top of Water Column

Figure 2 shows an example where the velocity measurements are only being made in the upper part of the water column. This condition may not be terminal to obtaining a suitable measurement as long as the velocities that are measured are representative of the entire column. This would need to be verified using an alternative measurement system.

2.3 Loss of Bottom Tracking

As the amount of sediment further increases, there may be tendency for the bottom tracking to fail intermittently or permanently. While a certain amount of lost velocity data is acceptable, loss of bottom tracking is fatal to the measurement. This severity pf the problem increases as the amount and duration of missing data increases. The strategy to deal with this is:

- Modify the measurement strategy. Changing the bottom tracking modes and tweaking the characteristics of the mode may improve the collection of data,
- Employing a GPS in conjunction with the ADCP. Using a GPS to compute position reduces the reliance on bottom tracking for position.
- Employing a lower frequency instrument. (lower frequencies mean more power in the water and more penetration through sediment.

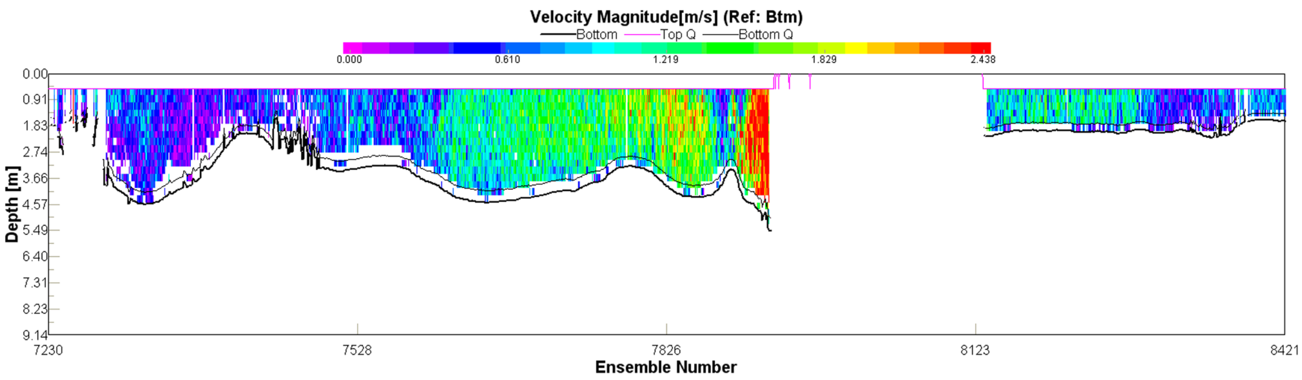


FIGURE 3. Example of Loss of Bottom Tracking.

Figure 3 shows an example where bottom tracking is lost. This condition is generally terminal to the measurement as the distance traveled during the period of the bottom tracking loss cannot be determined without the use of alternative positioning systems.

2.4 Loss of Depth Determination

As the sediment concentration increases further, one of the last things to fail with is the ability of the ADCP to determine the depth of the river. The strategy to deal with this is:

- Modify the measurement strategy. Changing the correlation and amplitude characteristics of the data may improve the data recovery however there can be significant issues related to this that need to be understood and avoided.
- Employing a Depth Sounder in conjunction with the ADCP (and usually GPS). Conditions where the depth cannot be determined generally would also include loss of bottom tracking requiring the use of a GPS and partial loss of velocity determination at lower depths. A depth sounder may however provide the depth data needed to yield good results.
- Employing a lower frequency instrument. Lower frequency units can operate at much greater depths than higher frequency units.

Flow Measurement Strategy

Based on the discussion presented, there are many options and combinations of options that can be used to deal with high sediment conditions. The intent of the consultancy is to be able to test all of the options presented in a comprehensive manner to arrive at the solution that best fits the existing program.

3.1 1200kHz ADCP Measurement Trial

Emphasis will first be placed on utilizing existing equipment to find the easiest and lowest cost solution for the program. The program has invested in 1200kHz ADCP and river boats as the main measurement system therefore this setup will provide the starting point for arriving at a measurement solution. The initial trial would focus on testing a 1200kHz ADCP in the following order:

- Tweaking measurement mode characteristics,
- Making moving bed measurements,
- Utilizing the loop method,
- Employing a GPS
- Employing a depth sounder.

Based on the description of measurement conditions, it is probable that this trial will not yield acceptable results or a viable measurement process meaning that the 1200kHz unit cannot be used for the discharge measurement using a moving boat. What will be learned from this trial that will be useful in the decision making process will be the degree of the acoustic-sediment interaction. This will be important in setting the course for future trials. For example, a partially successful measurement (some transects with successful bottom tracking or successful depth determination) will indicate that the use of a lower frequency ADCP will be advantageous whereas the failure of even the depth sounder to reach the bottom will indicate that conventional moving boat measurements will likely not be possible.

3.2 600kHz ADCP Measurement Trial

The second trial will use a 600kHz ADCP and will follow the same tests as the 1200kHz ADCP. The 600kHz ADCP operates in the same manner as the 1200kHz unit except it uses a lower frequency. Because it uses the same software, mount, boat etc, it could easily be used by any technologists already familiar with ADCP operations. No additional training, software or hardware would be required for implementation. As with the 1200KHz unit, the testing that is proposed would take place in the following order:

- Tweaking measurement mode characteristics,
- Making moving bed measurements,
- Utilizing the loop method,
- Employing a GPS
- Employing a depth sounder.

Based on the description of measurement conditions, it is probable that this trial will yield either partially or fully satisfactory results. The best case scenario is that the 600kHz unit will yield measurements alone or with peripheral equipment such as depth as GPS and depth sounder. If only partially favorable results are obtained using this type of unit, a third option using a different measurement technique will be attempted.

3.3 500kHz Sontek ADP Measurement Trial

The 500kHz Sontek ADP will be the focus of the third trial. This unit has two characteristics that offer some advantage over the RDI ADCPs. First, it is a lower frequency unit so the performance should be improved over the 600kHz ADCP.

Second, the Sontek unit has a specialized software function that eliminates the need for bottom tracking. The first part of the trial using the Sontek ADP will focus on using the unit in the conventional moving bed measurement mode and the second part will focus on a stationary mode.

Any failure in the positioning of the platform and any failure in the determination of the depth of flow is terminal to the moving boat measurement therefore reducing the reliance on these two factors can assist in determining flow. By modifying the measurement technique and using "stationary" software, discharge measurements can be obtained [usually high accuracy] when high sediment conditions compromise the continuity in the data. Using this mode, a measurement of some minimum quality is most probable as long as the depth can be measured (using any methodology), and a complete or partial profile is obtained. Stationary measurement mode uses the ADP to determine the depth and the velocity profile in a single vertical while maintaining position using other methods and technologies. The traditional velocity area technique is used to determine discharge. If this methodology is successful either partially or fully, there are several options available to the user.

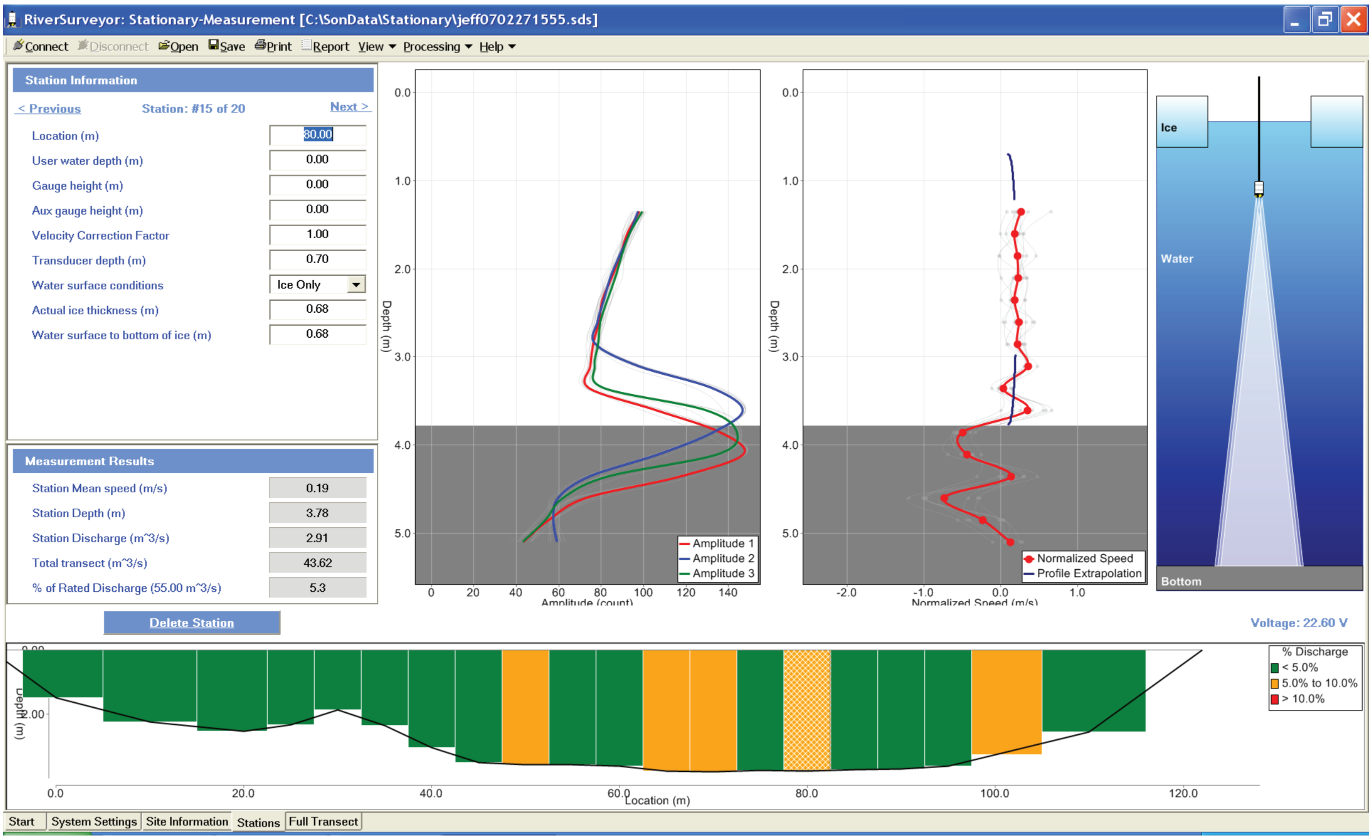


FIGURE 4. Example of Stationary Software

It should be noted that while the stationary software is only available using the Sontek ADP, a similar approach can be developed using the Teledyne RDI ADCP. Teledyne RDI will be releasing a comparable software package within the next few months. If the stationary measurement mode is found to be an acceptable option, it may be possible to employ this methodology using the 600kHz or 1200kHz ADCP in the near future. This option will be tested and evaluated.

3.4 Non Accoustic Measurements

It is possible that no acceptable solution can achieved or that the only solution is not the most practical or appropriate using the instrumentation and expertise available. In this case emphasis will be placed on developing procedures using conventional measurement techniques or a combination of conventional and other technologies and use the velocity area method in conjunction with readily available equipment. To this end, a price current meter will be provided to conduct the testing and develop the appropriate measurement practices.

3.5 Methodology Overview

The overall methodology that will be used in determining the best solution is contained in the following table 1.

Table 1: Wiring Schedule

Trial 1	1200 kHz ADCP	Moving Boat Measurement	Basic Setup
		with Mode Setting Refinement	Basic Setup
		with Assessment of Moving Bed	Basic Setup
		with Positioning	Basic Setup and GPS
		with Positioning and Depth Meas.	Basic Setup and GPS and Depth Sounder
Trial 2	600 kHz ADCP	Moving Boat Measurement	Basic Setup
		with Mode Setting Refinement	Basic Setup
		with Assessment of Moving Bed	Basic Setup
		with Positioning	Basic Setup and GPS
		with Positioning and Depth Meas.	Basic Setup and GPS and Depth Sounder
Trial 3	500kHz ADP	Moving Boat Measurement	Basic Setup
		with Positioning	Basic Setup and GPS
		with Positioning and Depth	Basic Setup and GPS and Depth Sounder
		Stationary Mode using Positioning	Basic Setup
		with Positioning and Depth Meas.	Basic Setup and GPS and Depth Sounder
Trial 4	Conventional	Conventional with tag line	Basic Setup
		with Positioning	Basic Setup and GPS
		with Positioning and Depth Meas.	Basic Setup and GPS and Depth Sounder

Equipment

The primary equipment that will be required and the responsibility for providing the equipment will be as follows:

- Manned Boat and ADCP mount FAO
- Ocean Science Tethered Boat FAO
- 1200kHz Teledyne/RDI ADCP FAO
- 600kHz Teledyne/Rdi ADCP Water Survey
- 500kHz Sontek ADP Water Survey
- Novotel RTK GPS Water Survey
- Lowrance GPS/Depth Sounder or equivalent Water Survey
- Ancillary provided by Water Survey will include:

1. Drag chute
2. Range finder
3. Marker buoys
4. Freewave modems
5. Communication Radios
6. Field Laptop
7. Price Current Meter
8. Beeper

It will be the responsibility of each individual to provide the necessary safety equipment for all operations. This includes life jackets, protective clothing, etc.

Summary

The measurement of river flow has always posed significant obstacles to overcome so that high quality data is the result. With new technologies come new obstacles that require new solutions. Solving these problems in a participatory and cooperative manner always yields the best long term gain. Measurement of the Nile River near Kharoum is no different.

It is expected that even though the solution to this particular measurement issue may not be straight forward, a solution does exist. The main focus will be in finding a solution that first uses existing equipment, second by minimizing the impact on the operational program and third by taking advantage of new developments in hydro-acoustic technology. Advancements of the software like the stationary software almost guarantee a solution of some quality if the appropriate methodology can be developed.

Some References

"ADCP's may not accurately measure depths in streams with high sediment concentrations and/or high bedload transport. In these instances it may be necessary to use a vertical depth sounder. The sediment concentration or bedload transport rate at which it becomes necessary to use a depth sounder is not presently known. As we learn more about his issue, further guidance will be provided. If you have a "moving bed condition" at your measurement site we recommend that you make several trial measurements using a vertical depth sounder to determine if the ADCP depths are representative under a variety of flow conditions."
OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM NO. 2002.02
SUBJECT: Policy and Technical Guidance on Discharge Measurements using Acoustic Doppler Current Profilers

Mission Report

October, 2007

Executive Summary

In an attempt to develop procedures for conducting ADCP measurements in high sediment conditions on the Nile River in Sudan, a special mission was completed. This mission tested different hydro-acoustic and peripheral devices. A measurement was obtained using a RDI 600kHz ADCP with depth sounder and GPS. As a result of these trials, the following recommendations are made:

- One or more 600 kHz ADCPs should be acquired for use in the region
- GPS units will be required for measurements under high sediment conditions. Some work will be required to find an appropriate GPS (GGA and VTG outputs) preferable with differential correction. GPS units should be available for each 600kHz ADCP and should also be used with 12MHz units under moving bed conditions.
- Depth sounders should be procured with each 600kHz ADCP.
- A GPS or gyrocompass will be required to obtain positioning if steel boats are used and the ADCP compass cannot be relied upon.
- ADCP Mounts will be required to mounting the ADCP on the measurement boats.
- If an alternative to the compass is not used, different measurement boats will be required. Consideration should be given to using inflatable zodiac type, or aluminum boats.
- Consideration should be given to updating and ensuring that laptops and tethered boats are upgraded and are in good condition.
- New software and firmware should be implemented across the region. This includes WinRiverII software and firmware 10.16
- Consideration should be given to providing advanced training for ADCP practitioners. There is already a high level of understanding among the users. Additional training would ensure measurement consistency and could be used to introduce new software and firmware.

Introduction

This mission was designed to evaluate and remediate sediment issues in obtaining discharge measurements using hydro-acoustics on the Nile River in Sudan. The FAO sponsored project "Capacity Building for Nile Basin for Water Resources Management" introduced several 1200kHz Acoustic Doppler Current Profilers (ADCPs) to the water resources agencies in the Nile Basin area to assist with the collection of hydrometric data. This piece of equipment is used world wide to gather high quality and detailed discharge information and is a highly efficient and effective instrument for flow measurement. All acoustic technology however, has operational limitations which can reduce its effectiveness under certain conditions. The Ministry of Irrigation and Water Resources of Sudan has been experiencing total equipment failure under high flow and high sediment conditions. This report summarizes the activities undertaken to resolve this problem and outlines recommendations to assist with obtaining future measurements.

As part of the project preparation, a pre-mission report was prepared and distributed, and attached as Appendix 1. The initial report outlined the approach or plan to solving the issue of acoustic discharge measurement in extreme conditions in the field.

This document represents the second part or implementation of the initial report and summarizes the results of implementing the basic plan.

Overview

As outlined in the pre-mission report, the operation of an acoustic sensor is a function of the frequency of the instrument and the river environment. When the acoustic signal starts to become degraded, there are a number of options that can be used to obtain a measurement. This includes using a lower frequency instrument, adding a depth sounder to accurately determine depths, adding a GPS to accurately determine position. To this end, the following equipment was brought to Sennar, Sudan, and deployed in an attempt to measure the flow on the Blue Nile at Sennar:

Teledyne RDI 600kHz ADCP,
Sontek/YSI 1000kHz ADCP,
Novatel Propak RTK GPS (base station and rover),
Lowrance Sporting GPS and Depth Sounder,
ADCP Mount,
Panasonic Toughbook field computer,
Miscellaneous troubleshooting equipment.

In addition, the following was provided by the mission participants:
2 1200kHz ADCPs
Ocean Science Tethered boat
12v batteries for power
240v generator
Miscellaneous supplies as required.

A more detailed description of the mission activities is contained in Appendix 2. To summarize, the approach that was taken was to first replicate the problems encountered and quantify the severity of the sediment and measurement issue. This was done by attempting to conduct a discharge measurement using the 1200KHz ADCP. Once completed, a trial and error process was used to determine the equipment that was necessary to conduct a flow measurement.

There were two main boats that were permanently tethered together during the trials to measure the flows (as shown on the cover) The powered measurement boat was a 10m (approximate) diesel powered working. It was manned by an engineer who controlled the throttle and a driver that steered the boat. The un-powered measurement boat was permanently attached to the side of the powered boat and consisted of a 6m (approximate) flat bottomed steel boat. This provided the working area for the trials to be completed. The trial results are summarized as follows:

• 1200KHz ADCP No measurement was obtainable. ADCP would not profile beyond 5m. Sediment was simply too concentrated.
Conclusion – it was verified that the 1200kHz ADCP could not be used to measure under these conditions.

• Ocean Science Tethered Boat The tethered boat could not be used in any fashion to obtain a measurement. Several attempts in a variety of configurations were made to obtain a measurement and they all failed. With the Ocean Science boat tethered to the side of the powered measurement boat, it would submerge. Attempts were made to move the tethered boat away from the powered measurement boat and out of the wake zone, and to mount the ADCP lower in the tethered boat to increase the contact with the water. These attempts failed.
Conclusion - the tethered boat could not be used as the measurement platform to conduct high flow discharge measurements. A different mount is required to conduct high flow measurements.

• 600 kHz ADCP The 600kHz ADCP was partially successful in obtaining a discharge measurement with the following issues: measurements were only successful in one transect direction, measurements showed excessive moving bed, and measurements were of low quality with unacceptable missing bins, skipped bottom tracking, and missing transects.

Conclusion – The 600KHz ADCP could not be used accurately measure the discharge under these flow conditions. A GPS would be required to provide positioning.

- 1000kHz ADP The 1MHz Sontek was partially successful in obtaining a measurement with similar results as the 600kHz ADCP.

Conclusion – The 1000KHz Sontek ADP could not be used accurately measure the discharge under these flow conditions. A GPS would be required to provide positioning.

- 600kHz with GPS A discharge measurement was obtained successfully when using the 600kHz ADCP and the Novatel RTK GPS. Because the boat position was not reliant on bottom tracking, data recovery was well within acceptable limits.

Conclusion – the addition of the GPS is necessary to accurately measure under high sediment conditions.

- 600kHz with Depth Sounder and GPS The best quality measurement was possible using the Depth Sounder in conjunction with the GPS. Using the depth sounder allowed for much more data to be recovered both with and without the GPS functioning.

Conclusion – the addition of the depth sounder is required to conduct flow measurements under high sediment conditions.

- Powered Measurement Boat The quality of the discharge measurement was significantly affected by the configuration of the boat and the skill of the boat driving team. Good boat control was an important factor in obtaining a good flow measurement. The configuration used was the un-powered measurement boat tethered to the side of the powered boat. This was the setup used to conduct standard measurements. While this provided significant working area for these tests, the configuration resulted in the boat being easier to control in one direction as compared to the other. This had an important affect on the measurement bias particularly when not using the GPS. In addition, the measurement boat was constructed from steel and therefore had significant affect on the compass of the ADCP. When conducting a measurement with the GPS, it is necessary to have the compass accurately calibrated and the magnetic declination appropriately set. Initial attempts at calibrating the compass while the ADCP was installed in the boat were not successful. However reasonable measurement results were obtained when the ADCP compass was calibrated away from the boat and later mounted. This is contrary to practice however provided the best results and may need further investigation.

The skill of the boat driving team was superior. After several days of measurements, the team understood the requirements for operation and performed very well. There were no limitations in the measurement that resulted from the boat drivers.

Recommendations

As a result of the mission activities, the following recommendations and further investigations should be considered.

1. Acquisition of 600kHz ADCP.

All flow measurements under high sediment will require the use of the 600kHz ADCP or similar hydro-acoustic device to maximize the depth of penetration of the acoustic signal and minimize the affect of measuring moving bed. It would be beneficial if this type of ADCP was available for all high sediment measurements in the region. A minimum of one unit is required in Sudan and consideration should be given to additional units in the Nile Basin region. The goal should be to have this type of ADCP available to all locations that need to conduct flow measurements under high sediment and high flow conditions.

2. Acquisition of GPS systems.

A GPS system should be acquired and made available for measurements using the 600kHz ADCP and the 1200kHz ADCPs. Unfortunately there is no clear recommendation that can be given on the type of system to acquire. The GPS that was used during this mission was a high accuracy Novatel G2 RTK system. RTK was used because it offers a high degree of accuracy without reliance on third party corrections or post processing. It will always provide acceptable results without depending on anything except the availability of satellites. There are some recent developments and recommendations that might be beneficial in deciding on the GPS to use. GPS positioning of the ADCP is usually done using the GGA string from the GPS. This approach requires the use of a correction to achieve accurate flow measurements. WinRiverII supports the use of VTG as well as GGA which is a velocity measurement instead of a positional measurement. The use of VTG may allow the use of the lower accuracy and uncorrected signals to achieve acceptable flow measurement results. Any GPS that is purchased should be configurable to use both of these outputs. An investigation needs to be conducted to determine what the most cost effective solution for Sudan and the Nile Basin countries may be as there are many options to consider. Consideration needs to be given to the following:

a. GPS must have NMEA output to be compatible with WinRiver software.
b. GPS must provide GGA string for positioning
c. GPS must provide VTG string for relative positioning. VTG is being tested as a replacement to GGA. This could ultimately reduce the requirement for high accuracy GGA data as accurate VTG data may be obtainable from much lower priced GPS units.
d. Need to investigate the availability of corrected GPS signals in Sudan. WASS and EGNOS or other.

3. Depth Sounder.

The presence of the depth sounder appeared to increase the amount of data significantly therefore it is recommended. The improved data recovery is probably because the 600KHz ADCP could not reliably provide depth and bottom detection and tracking. In the areas where the bottom detection was an issue, no water velocity data would be available without the use of the depth sounder. For this reason, a depth sounder is recommended for measurements under high flow sediment conditions. Depth sounders are available in a variety of different levels of quality and accuracy. This mission used a relatively inexpensive depth sounder and appeared to give good results however the accuracy of the unit was not checked. The depth sounder that is selected should output NMEA data strings to be used in conjunction with the ADCP.

4. Compass.

The integration of the compass and GPS are critical when conducting measurements using a GPS. Although the measurements received appeared to be of good quality, significant problems will arise using the fluxgate compass in the ADCP around steel structures and boats. Alternatives to the ADCP compass are the gyrocompass or a GPS compass. A GPS compass may in fact give the desired positional accuracy for the GPS as well as the directional information when the compass is affected. Some consideration should be given to products such as Simrad HS52 GPS Compass and DGPS Navigator or the Magellan 3011 GPS compass. These products have not been tested by Environment Canada at this point. Again, the data needs to be output in NMEA format.

5. Mounts – ADCP mounts will be required.

The use of the tethered boat as the measurement platform will not work for high discharge measurements. There are many ADCP mount designs available and can be made locally. Care should be taken to ensure that the materials of construction are not magnetic. I.e. they should be aluminum, stainless steel, fiberglass etc.

6. Boats

Existing measurement boats can be used for ADCP measurements if used in conjunction with a gyro or GPS compass. If however this equipment is not available, consideration should be given to using inflatable zodiac type, or aluminum boats. Care should be given to the selection of the appropriate motor size as the velocities that can be encountered are high. Personal experience suggests a horse power requirement of 60 to 100 hp depending on boat size.

7. Associated Equipment.

Consideration should be given to updating and ensuring that the supporting equipment for ADCP measurements are in good condition and updated appropriately. More specifically, consideration should be given to life cycle management of the computers that are used for the ADCP measurements and the tethered boats that are in use.

8. Software and Firmware.

There are new versions of software and firmware that should be implemented in the Nile basin area. WinRiver-II is the latest version of software that is available. In addition, the version of firmware is 10.16 which fixes some rather serious issues with mode 12 biases.

9. Procedures and Training.

Consistent and quality measurements are only possible if appropriate measurement procedures are used. Consideration should be given delivering refresher or advanced training to the ADCP users in the region. This would be used to ensure consistency in software, firware, measurement procedures and general data collection in the region.

Measurement

The measurement results are shown in table 1 and a sample ship track and velocity contour is shown below. This measurement was post processed with no significant errors. After conducting the first four transects, one exceeded the measurement criteria of 5% so four more transects were completed and the results averaged. This measurement would be rated as good by water survey standards. It is recommended that this measurement should be compared to a conventional measurement for accuracy. Since this site is directly downstream of a dam, flows and water levels may have fluctuated significantly over the course of the measurement. Measurement data is available on request.

Table 1: Measurement Results (Blue Nile at Sennar on 10 September 2007)

File Name	Start Time	Total Q [m³/s]	Total Area [m²]	Width [m]
100907_000r.000	3:05:02	6901.385	3288.03	323.57
100907_001r.000	3:14:36	6853.092	3046.49	305.46
100907_002r.000	3:24:51	7201.475	3271.46	321.53
100907_003r.000	3:31:27	6625.865	3040.21	300.65
100907_004r.000	3:42:53	6843.185	3027.3	291.12
100907_005r.000	3:48:56	6823.579	3053.66	301.21
100907_006r.000	3:56:30	7194.036	3189.49	301.89
100907_007r.000	4:03:16	6662.851	2965.16	304.27
Average		**6888.184**	**3110.23**	**306.21**
Std. Dev.		**213.437**	**121.88**	**10.97**
Std./| Avg.|		**0.03**	**0.04**	**0.04**

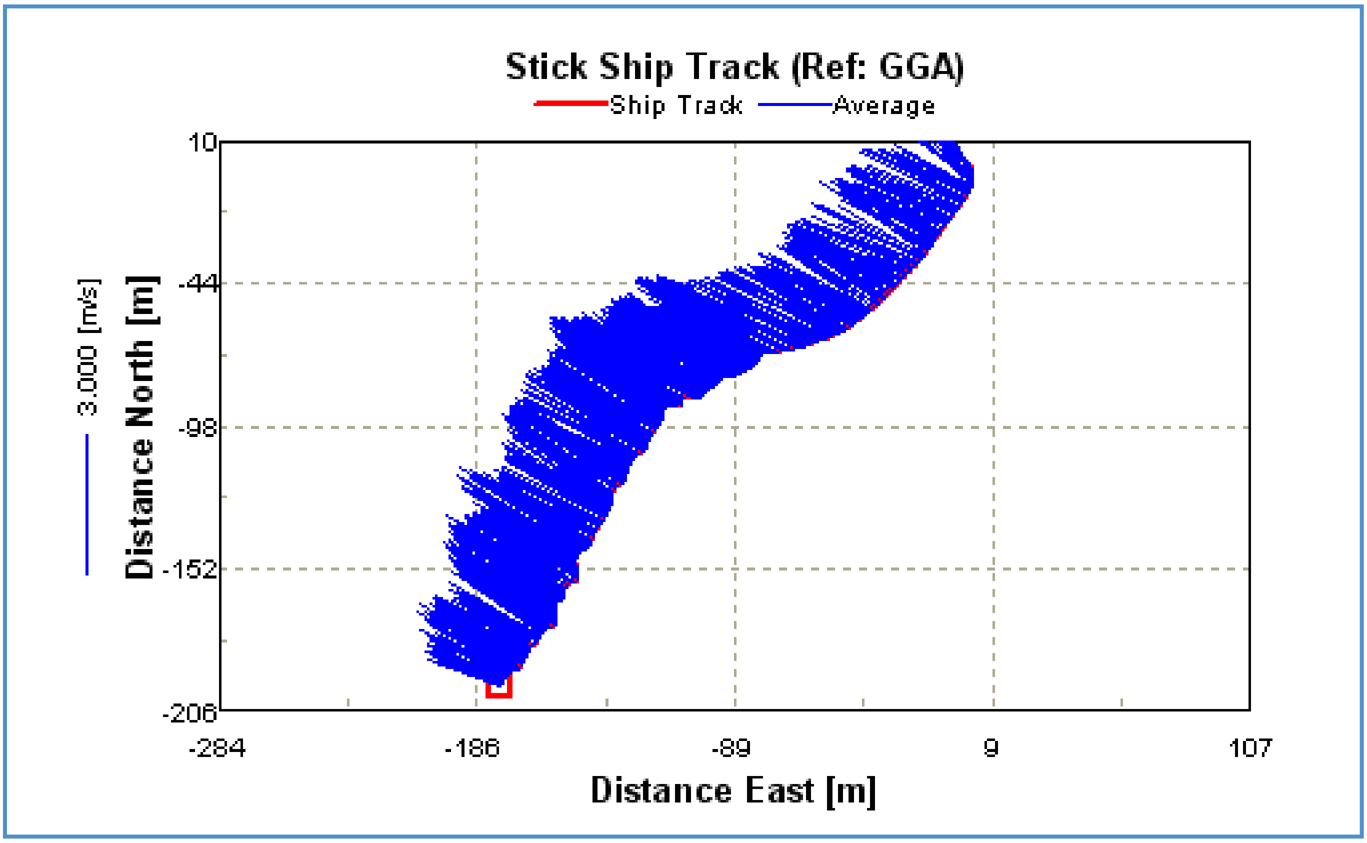


Figure 1: Ship Track

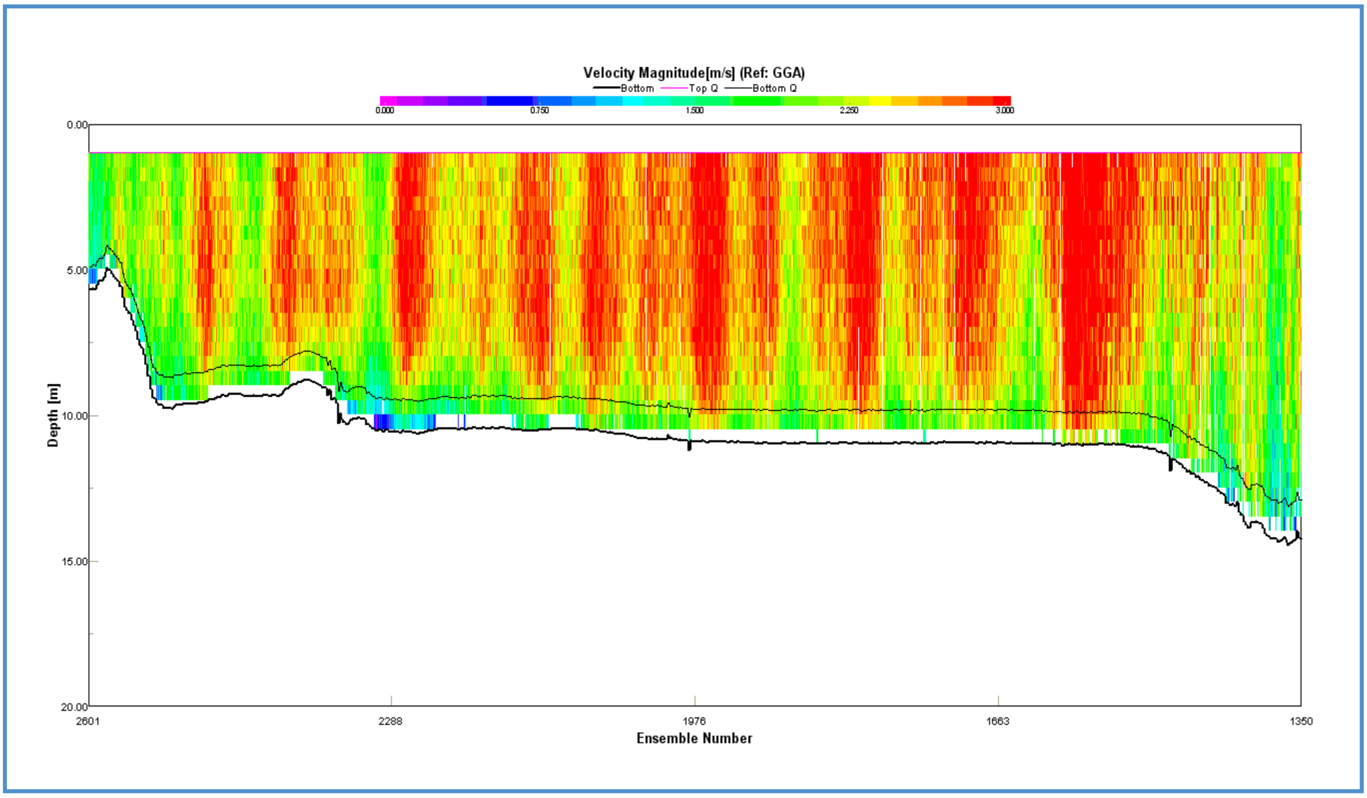


Figure 2: Velocity Contours