APPENDIX B

ADCP GUIDELINES

WorkHorse Read This First Guide

WorkHorse
Read This First

RD Instruments
Acoustic Doppler Solutions

P/N 957-6151-00 (January 2001)

Table of Contents

List of Figures

List of Tables

NOTES

RD Instruments
Acoustic Doppler Solutions

WorkHorse Read This First

1 Introduction

Thank you for purchasing a RD Instruments (RDI) WorkHorse Broadband Acoustic Doppler Current Profiler (ADCP). This guide is designed to help first time ADCP users to get familiar with their system.

2 Getting Started

You are probably eager to get started, but take a moment to read a few words of guidance. We have tried to make the WorkHorse and its manual/s easy to use. However, the WorkHorse *is* a complex instrument. You must take time to read the manuals.

The Reference Guides includes:

- **Read This First**. This guide is an introduction to the WorkHorse ADCP.
- **Installation Guide**. Use this guide to plan your installation requirements. This guide includes specifications and dimensions for the WorkHorse (including outline installation drawings).
- **Maintenance Guide**. This guide covers WorkHorse maintenance. Use this guide to make sure the WorkHorse is ready for a deployment.
- **Test Guide**. Use this guide to test the ADCP.
- **Troubleshooting Guide**. This guide includes a system overview and how to troubleshoot the WorkHorse. If the WorkHorse fails a built-in test or you cannot communicate with the system, use this guide to help locate the problem.

The WorkHorse User's Guide includes:

- These guides (one for Mariner, Monitor, Rio Grande, and Sentinel models) contain an overview of the WorkHorse hardware and software.

The Commands and Output Data Format Guide includes:

- This guide contains a reference for all commands and output data formats used by the WorkHorse. Use the *Command Quick Reference Card* to help remember the direct commands used by the WorkHorse.

The Documentation CD includes:

- The Documentation CD has Adobe Acrobat® Portable Document File (pdf) versions of all the user documentation. Use the electronic documentation to quickly search for information. See "Using the Documentation CD," page 12 for details on how to use Adobe's Acrobat Reader®.

The Reference Cards include:

- **Setup Cards**. The *Setup Cards* are designed for *first time users* to connect the ADCP and establish communications.
- **Command Quick Reference Card**. The *Command Quick Reference Card* is designed for *experienced* users to help remember the direct commands used by the WorkHorse.
- **Software Quick Reference Card(s)**. The *Software Quick Reference Cards* are designed to help *experienced* users remember the proper steps needed to deploy the WorkHorse for a deployment. First time users should read the appropriate ADCP and Software User's Guides before deploying the WorkHorse.

NOTE. Each software program has it's own user's guide.

3 What's New

New systems began shipping with firmware version 16.xx installed in April 2000. Firmware version 16.xx makes new features such as Waves available.

3.1 Upgrading Firmware from 8.xx to 16.xx

The 8.xx series firmware has been frozen. Thus, new features will only be available to users with the 16.xx firmware. If you have a Workhorse ADCP with version 8.xx firmware and wish to upgrade to version 16.xx firmware, please check the following items.

Who should upgrade?

- Users planning to take advantage of new features (i.e. Waves).

What do you need to upgrade?

- The CPU board must have EEPROM Parts installed. The firmware upgrade program *WH16FW.exe* checks if the ADCP is capable of upgrading to version 16.xx firmware.

How do I upgrade?

a. Connect your ADCP to the computer.

b. Start the program *WH16FW.exe*. Click **Setup**. Click the **View README.TXT** button to view the Readme.txt file for details on what is new in version 16.xx firmware.

c. Click **Next** and follow the on-screen prompts.

d. If you are not able to install the version 16.xx firmware, contact Customer Service and arrange for a CPU board replacement.

e. After successfully upgrading the firmware, use *DumbTerm* to test the ADCP.

3.2 New or Changed Software

RD Instruments is pleased to announce that new Windows software has been released. The Windows software is now included with your system. These programs will give you all of the capabilities of our older DOS software plus additional data analysis capabilities. Each program includes a help file that documents the software.

WinSC uses Wizards® to do the following:

- Helps you to create a command file (DOS equivalent program PLAN).
- Communicate directly with the ADCP (DOS equivalent programs BBTALK, CONNECT, and RESET).
- Helps you to verify the ADCP's compass alignment (DOS equivalent programs BBTALK and TESTADCP).
- Tests the ADCP (DOS equivalent programs BBTALK and TESTADCP).
- Sends the commands from your command file to the ADCP and sets up the ADCP's recorder (DOS equivalent programs INITADCP and DEPLOY).
- Creates a deployment log file (DOS equivalent program DEPLOY).
- Starts the Workhorse pinging (DOS equivalent program DEPLOY).
- Recovers data and erases the recorder (DOS equivalent programs RECOVER, MEM-INFO, ERASEMEM).

WinADCP gives the user a visual sense of the entire set of data. It also allows the user to zoom in on a portion of the data for closer analysis. *WinADCP* replaces CHECKDAT, QUIKLOOK, and WATCH (playback of data portion).

The **RDI Tools** CD includes *DumbTerm* and several DOS utility programs. This program is used for testing and "talking" to the ADCP. *DumbTerm* replaces BBTALK and TESTADCP.

4 Conventions Used in Manuals

Conventions used in the WorkHorse manuals have been established to help you learn how to use the WorkHorse quickly and easily.

Windows menu items are printed in bold: **File** menu, **Collect Data**. Items that need to be typed by the user or keys to press will be shown as **<F1>**. If a key combination were joined with a plus sign (**<ALT+F>**), you would press and hold the first key while you press the second key. Words printed in italics or uppercase include program names (*WinADCP*), DOS commands (TIME) and file names (DEFAULT.VMO).

Code or sample files are printed using a fixed font. Here is an example:

```
WorkHorse Broadband ADCP
RD INSTRUMENTS (c) 1997-2000
ALL RIGHTS RESERVED
Firmware Version 16.xx
>
```

You will find two other visual aids that help you: Notes and Cautions.

NOTE. This paragraph format indicates additional information that may help you avoid problems or that should be considered in using the described features.

CAUTION. This paragraph format warns the reader of hazardous procedures (for example, activities that may cause loss of data or damage to the ADCP).

5 WorkHorse Models and Options

The following section explains the different models and options available for WorkHorse ADCPs.

WorkHorse Monitor – The WorkHorse Monitor is designed to measure real-time current profiles from temporary or permanent mounting in the ocean, near-shore, harbors, and lakes. The Monitor ADCP system consists of an ADCP, cables, RS-232-to-RS-422 converter, and software. The Monitor system requires the addition of a Windows® compatible computer to collect data.

WorkHorse Sentinel – The WorkHorse Sentinel is designed for several-month autonomous current profile deployment from temporary or permanent mounting in the ocean, near-shore, harbors, and lakes. The Sentinel ADCP system consists of an ADCP, cables, battery pack, flash memory card, and software. Both battery capacity and memory can be increased with upgrades for longer deployments. The Sentinel can also be used for direct-reading current profile operation. The Sentinel system requires the addition of a Windows® compatible computer to configure the ADCP and replay collected data.

WorkHorse Rio Grande – The WorkHorse Rio Grande is designed to measure real-time current profiles from temporary or permanent mounting in a vessel. The Rio Grande ADCP system consists of an ADCP with Bottom Track mode, High Resolution Water Profiling modes, cables, and software. The input power requirements for the Rio Grande are +12 VDC. The Rio Grande system requires the addition of a Windows® compatible computer to collect data.

NOTE. Do not attempt to attach a Workhorse Monitor/Sentinel I/O cable or power supply to the Workhorse Rio Grande ADCP. The Workhorse Monitor and Sentinel ADCPs are 24 VDC systems. **The Workhorse Rio Grande uses 12 VDC only.**

NOTE. The Rio Grande End-Cap is red to differentiate it from the Monitor and Sentinel ADCPs. Do not swap end-caps between a Rio Grande and a Monitor/Sentinel. The pin-outs are different on both the I/O cable connector and the internal I/O cable.

WorkHorse Mariner – The WorkHorse Mariner is designed to measure real-time current profiles from temporary or permanent mounting in a vessel. The Mariner ADCP system consists of an Monitor ADCP with Bottom Track mode, cables, Deck Box, Mounting Plate, and software. The Mariner system requires the addition of a Windows® compatible computer to collect data.

WorkHorse Options

- **Bottom Track** – You can use your WorkHorse ADCP from moving boats and ships with the Bottom Track Upgrade. Once the Bottom Track Upgrade is added, a WorkHorse ADCP can measure both water depth and boat velocity over the ground.
- **High-Resolution Water Profiling Modes** - This upgrade allows you to collect water profiles using Water Modes 1, 5, and 8.
- **Waves** – This upgrade allows you to use the ADCP as a wave gauge.
- **External Batteries** – Adding external batteries can increase the deployment length for Sentinel ADCPs. Use an External Battery with a Monitor ADCP to provide backup power or for self-contained deployments.
- **AC Power Adapter (48 VDC Output)** – Converts AC power into 48 VDC output for the WorkHorse input power. The higher input voltage is sufficient to override the internal battery voltage (i.e. the ADCP will draw all power from the AC adapter even if the battery is installed and connected). Increasing the input volt-

age to the ADCP from 24 VDC (standard AC adapter) to 48 VDC will increase the transmitted power.

NOTE. Transmitted power increases or decreases depending on the input voltage. Higher voltage to the ADCP (within the voltage range of 20 to 60 VDC) will increase the transmitted power. The transmitted power is increased 6 DB if you double the input voltage from 24 VDC to 48 VDC. For a 300kHz WorkHorse ADCP, each additional DB will result in an increase in range of one default depth cell.

- **High-Pressure Housing** – The standard WorkHorse housing allows deployment depths to 200 meters. High-pressure housings are available in depth rating of 500, 1000, 3000, and 6000 meters. See the Installation Guide outline installation drawings for dimensions and weights.
- **Spare boards kit** – Contains a complete set of spare printed circuit boards for a WorkHorse ADCP. The set does not include boards purchased as options such as the gyro/synchro board or the receiver board (not field replaceable).
- ***VmDas* Software** – Controls the ADCP and displays profile data through a personal computer.
- ***WinRiver* Software** – Controls the ADCP and displays discharge data and profile data through a personal computer.
- ***Waves* Software** – Controls the ADCP and displays waves data through a personal computer.

Mariner Options

- **Deck Box** – Converts AC power input or 12 VDC input into 48 VDC output for the Mariner input power. Converts computer RS232 to RS422. Option: converts gyro analog input to a serial NMEA output (requires an optional gyro interface; must be purchased at time of order).
- **Gyrocompass (Gyro) Interface** – Connects the ship's gyro to the Deck Box (must be purchased at time of order).
- **Mounting Plate** – A bronze plate that helps mount the transducer head to a vessel. See the Installation Guide outline installation drawings for dimensions.

6 WorkHorse Care

This section contains a list of items you should be aware of every time you handle, use, or deploy your WorkHorse. *Please refer to this list often*.

6.1 General Handling Guidelines

- Never set the transducer on a hard or rough surface. **The urethane faces may be damaged.**
- Always remove the retaining strap on the end-cap underwater-connect cable and dummy plug when disconnecting them. **Failure to do so will break the retainer strap.**
- Do not apply any upward force on the end-cap connector as the I/O cable is being disconnected. **Stressing the end-cap connector may cause the ADCP to flood.** Read the Maintenance guide for details on disconnecting the I/O cable.
- Do not expose the transducer faces to prolonged sunlight. **The urethane faces may develop cracks.** Cover the transducer faces on the Workhorse if it will be exposed to sunlight.
- Do not expose the I/O connector to prolonged sunlight. **The plastic may become brittle.** Cover the connector on the Workhorse if it will be exposed to sunlight.
- Do not store the ADCP in temperatures over 75 degrees C. **The urethane faces may be damaged.** Check the temperature indicator inside the shipping case. It changes color if the temperature limit is exceeded.
- Do not scratch or damage the O-ring surfaces or grooves. **If scratches or damage exists, they may provide a leakage path and cause the ADCP to flood.** Do not risk a deployment with damaged O-ring surfaces.
- Do not lift or support a WorkHorse by the external I/O cable. **The connector or cable will break.**

6.2 Assembly Guidelines

- Read the Maintenance guide for details on WorkHorse re-assembly. Make sure the housing assembly O-rings stay in their groove when you re-assemble the WorkHorse. Tighten the hardware as specified. **Loose, missing, stripped hardware, or damaged O-rings can cause the WorkHorse transducer to flood.**

- Place a light amount of DC-111 lubricant on the end-cap connector pins (rubber portion only). **This will make it easier to connect or remove the I/O cable and dummy plug.**
- Do not connect or disconnect the I/O cable with power applied. An exception to this is the external battery case. The external battery case connector is always "hot" when batteries are installed. When you connect the cable with power applied, you may see a small spark. **The connector pins may become pitted and worn.**
- Do not attach a Workhorse Monitor or Sentinel I/O cable or power supply to the Workhorse Rio Grande ADCP. The Workhorse Mariner, Monitor and Sentinel ADCPs are 24 VDC systems. **The Workhorse Rio Grande uses 12VDC only.**
- The WorkHorse I/O cable is *wet* mate-able, not *under water* mate-able.

6.3 Deployment Guidelines

- Read the appropriate WorkHorse User's Guide and the Software User's Guides. **These guides have tutorials to help you learn how to use the ADCP.**
- Align the compass whenever the battery pack or recorder module is replaced, or when any ferrous metals are relocated inside or around the WorkHorse housing. **Ferro-magnetic materials affect the compass.**
- The AC power adapter is not designed to withstand water. **Use caution when using on decks in wet conditions.**
- Avoid using ferro-magnetic materials in the mounting fixtures or near the Workhorse. **Ferro-magnetic materials affect the compass.**

7 Unpacking

When unpacking, use care to prevent physical damage to the transducer face and connector. Use a soft pad to protect the transducer. When handling any electronics modules, follow electrostatic discharge (ESD) prevention measures.

7.1 Inventory

You should have the following items.

- ADCP transducer
- I/O cable
- Power adapter (Monitor and Sentinel only)
- Deck Box and mounting plate (Mariner only)
- Ship Kit (includes manuals, software (*WinSC* (Sentinel only), *WinADCP*, *RDI Tools*, and Documentation CD), and power cords)
- Shipping crate (please save all foam for reshipping use)

7.2 Visual Inspection of the WorkHorse

Inspect the WorkHorse using the following table and Figure 1, page 11 and Figure 2, page 11. If you find any discrepancies, call RDI for instructions.

Table 1: Visual Inspection Criteria

Item	Inspection Criteria
Transducer	Check the urethane face. There should be no gouges, dents, scrapes, or peeling (see Figure 1, page 11).
I/O connector	Check the I/O connector for cracks or bent pins (see Figure 2, page 11).
I/O Cable	Check the cable connectors for cracks or bent pins.
Deck Box (Mariner only)	Check the connectors on the rear panel for cracks or bent pins.

Figure 1. WorkHorse Transducer Face View

Figure 2. WorkHorse End-Cap Connector View

	NOTE. The Rio Grande End-Cap is Red to differentiate it from the Monitor and Sentinel End-Cap. The I/O cable pin-out arrangement is different between a Rio Grande and a Monitor/Sentinel.

	CAUTION. Do not attach a Workhorse Monitor or Sentinel I/O cable or power supply to the Workhorse Rio Grande ADCP. The Workhorse Monitor and Sentinel ADCPs are 24 VDC systems. **The Workhorse Rio Grande uses 12 VDC only.**

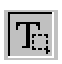
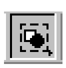
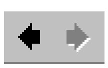
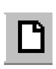
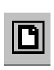
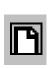
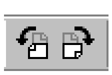
	NOTE. Refer to the appropriate ADCP User's Guide for instructions on how to connect and use the ADCP.

8 Using the Documentation CD

The documentation CD contains an electronic version of the WorkHorse Technical Manual. All of the files are in Adobe® Portable Document Format (*.pdf). To use these files, you must install the Acrobat version 4.0 Reader. This program is included on the documentation CD.

NOTE. If you have an earlier version of Acrobat Reader installed on your computer, please uninstall it prior to installing the version 4.0 Reader.

Table 2: Acrobat Reader Toolbar

Tool	Description
	Use these tools to visit Adobe's website.
	Use these tools to open or print a pdf file.
	Use the navigation pane button to turn on or off the table of contents or thumbnail pane.
	Use the hand tool to move the page around so that you can view all the areas on it.
	Zoom In/Out tool
	Text select tool. Use this button to highlight text to be copied into another document.
	Select the Graphics Select tool by holding down the mouse button on the text select tool and dragging to the graphics select tool. Use this button to select a graphic to be copied into another document.
	Use these buttons to page through a document.
	Use these buttons to return to a previous or next view.
	Actual size tool.
	Fit in window tool.
	Fit width tool.
	Rotates page 90 degrees.
	Find tool. Find will search only the current open document.
	Search tools. Use search to find information located in the WorkHorse Technical Manual.

8.1 Opening PDF Documents

Do one of the following:

- Start Acrobat Reader. Choose **File**, **Open**. In the Open dialog box, select the filename, and click **Open**. Acrobat Reader documents have the extension *.pdf.
- Double-click the file icon in your file system.

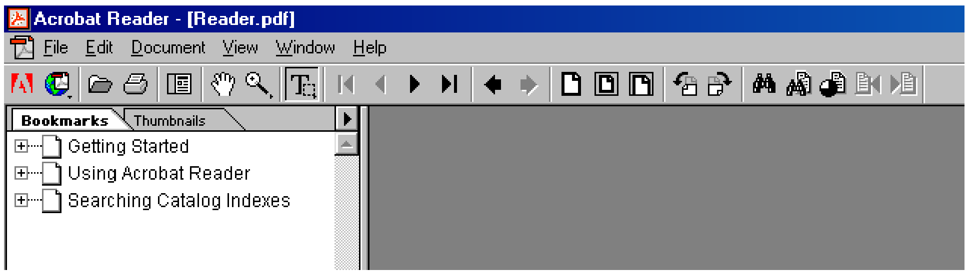


Figure 3. Adobe Acrobat Reader Screen

8.2 Viewing Documents

The minimum and maximum zoom levels available depend on the current page size. If you magnify a page to a size larger than the window, use the hand tool to move the page around so that you can view all the areas on it. Moving a PDF page with the hand tool is like moving a piece of paper on a desk with your hand.

To Resize a Page to Fit the Window:

Do one of the following:

- To resize the page to fit entirely in the window, click the **Fit in Window** button, or choose **View**, **Fit in Window**.
- To resize the page to fit the width of the window, click the **Fit Width** button, or choose **View**, **Fit Width**. Part of the page may be out of view.
- To resize the page so that its text and graphics fit the width of the window, choose **View**, **Fit Visible**. Part of the page may be out of view.

To Increase Magnification:

Do one of the following:

- Select the **Zoom-In** tool, and click the page.
- Select the **Zoom-In** tool, and drag to draw a rectangle, called a marquee, around the area to magnify.

- Click the **Magnification** button in the status bar, and choose a magnification level.

To Decrease Magnification:

Do one of the following:

- Select the **Zoom-Out** tool, and click the page.
- Select the **Zoom-Out** tool, and drag to draw a marquee the size you want the reduced page to be.
- Click the **Magnification** button in the status bar, and choose a magnification level.

NOTE. When the **Zoom-In** tool is selected, you can press **Ctrl** while clicking or dragging to **Zoom Out** instead of in. When the **Zoom-Out** tool is selected, press **Ctrl** to zoom in.

To Return a Page to Its Actual Size:

Click the **Actual Size** button, or choose **View**, **Actual Size**.

8.3 Paging Through a Document

Acrobat Reader provides buttons, keyboard shortcuts, and menu commands for paging through PDF documents.

To Go to Another Page:

Do one of the following:

- To go to the next page, click the **Next Page** button in the command bar or status bar, press the **Right Arrow key**, press **Ctrl + Down Arrow** key, or choose **Document**, **Next Page**.
- To go to the previous page, click the **Previous Page** button in the command bar or status bar, press the **Left Arrow** key, press **Ctrl + Up Arrow** key, or choose **Document**, **Previous Page**.
- To move down one line, press the **Down** Arrow key.
- To move up one line, press the **Up** Arrow key.

NOTE. The **Down** and **Up** Arrow keys move you one line at a time when you are not in Fit in Window view. In Single Page mode, these keys move you one page at a time if the page fills the entire screen.

- To move down one screen, press **Page Down** or **Return**.
- To move up one screen, press **Page Up** or **Shift + Return**.
- To go to the first page, click the **First Page** button in the command bar or status bar, press the **Home** key, or choose **Document**, **First Page**.

- To go to the last page, click the **Last Page** button in the command bar or the status bar, press the **End** key, or choose **Document**, **Last Page**.

To Retrace Your Viewing Path:

Do one or more of the following:

- To retrace your path within a PDF document, click the **Go to Previous View** button in the command bar, or choose **Document**, **Go Back** for each step back. Alternatively, click the **Go to Next View** button, or choose **Document**, **Go Forward** for each step forward.
- To retrace your viewing path through other PDF documents, choose **Document**, **Go Back Doc** for each step back or **Document**, **Go Forward Doc** for each step forward. Alternatively, hold down **Shift**, and click the **Go Back** or **Go Forward** button. This command opens the other PDF documents if the documents are closed.

8.4 Using Find

You can use the Find command to find a complete word or part of a word in the *current* PDF document. Acrobat Reader looks for the word by reading every word on every page in the file, including text in graphics.

To Find a Word Using the Find Command:

a. Click the **Find** button, or choose **Edit**, **Find**.

b. Enter the text to find in the text box.

c. Select search options if necessary:

- **Match Whole Word** Only finds only occurrences of the complete word you enter in the text box. For example, if you search for the word stick, the words tick and sticky will not be highlighted.
- **Match Case** finds only words that contain exactly the same capitalization you enter in the text box.
- **Find Backwards** starts the search from the current page and goes backwards through the document.

d. Click **Find**. Acrobat Reader finds the next occurrence of the word.

To Find the Next Occurrence of the Word:

Do one of the following:

- Choose Edit, Find Again.

- Reopen the **Find** dialog box, and click **Find Again** (the word must already be in the **Find** text box).

8.5 Using Search

The Acrobat **Search** command allows you to perform full-text searches of PDF document collections (i.e. the WorkHorse Technical Manual), whereas the Acrobat **Find** command allows you to search only a single document. The **Search** command also provides powerful tools for limiting and expanding a search. Opening a PDF document associated with an index automatically makes the index searchable.

> **NOTE.** The documentation CD version of the Adobe® Acrobat Reader has the Search plug-in included.

To Select an Index:

Choose **Edit**, **Search**, **Select Indexes** to list the currently available indexes and to add or delete indexes, and then do one of the following in the **Index Selection** dialog box:

- To add an index to the available indexes list, click **Add**, navigate to the index, and double-click on the index file.

> **NOTE.** The documentation CD has an index file in the same directory as the pdf files.

- To remove an index, select the index name, click **Remove**, and then click **OK**.
- To select or deselect an index, select the box for the index, and then click **OK**. Indexes that are grayed out are currently unavailable for searching.

Using the Search Command

The **Search** command allows you to perform a search on PDF documents. You can search for a simple word or phrase, or you can expand your search query by using wild-card characters and operators. You can use the search options to further refine your search.

To Perform a Full-Text Search:

a. Choose **Edit**, **Search**, **Query**.

b. Type the text you want to search for in the **Find Results Containing Text** box: The text that you type in can be a single word, a number, a term, or a phrase.

c. To clear the search dialog box and redefine the search, click **Clear**.

To View a Document Returned From a Search:

a. Double-click the document name to open the document.

b. Use the **Search** buttons on the tool bar to view all the matches for your query.

c. Review the search results that automatically appear in the text box: To highlight the next occurrence of a match in the document, click **Next Highlight**. To highlight the previous occurrence of a match in a document, click **Previous Highlight**.

d. To highlight the first occurrence of a match in the next document listed or previous document listed, **Shift-click Next Highlight** or **Previous Highlight**.

e. To view any other document listed, select **Search Results** to redisplay the list, and then double-click the document name.

8.6 Copying Text and Graphics

You can select text or a graphic in a PDF document, copy it to the Clipboard, and paste it into a document in another application such as a word processor.

NOTE. If a font copied from a PDF document is not available on the system displaying the copied text, the font cannot be preserved. A default font is substituted.

To Select Text and Copy It to the Clipboard:

Select the **Text Select** tool, and do one of the following:

- To select a line of text, select the first letter of the sentence or phrase and drag to the last letter.
- To select all the text on the page, choose **Edit**, **Select All**. To deselect the text and start over, click anywhere outside the selected text.

Choose **Edit**, **Copy** to copy the selected text to the Clipboard.

To Copy Graphics to the Clipboard:

Select the **Graphics Select** tool by holding down the mouse button on the text select tool and dragging to the graphics select tool, or press **Shift-V** as necessary to cycle through the group of tools. The cursor changes to the cross-hair icon.

Drag a rectangle around the graphic you want to copy. To deselect the graphic and start over, click anywhere outside the selected graphic.

Choose **Edit**, **Copy** to copy the graphic to the Clipboard.

NOTE. The graphic is copied using the *.wmf file format.

9 How to Contact RD Instruments

If you have technical problems with your instrument, contact our field service group in any of the following ways:

RD Instruments

9855 Businesspark Ave.

San Diego, California 92131

(858) 693-1178

FAX (858) 695-1459

Sales - rdi@rdinstruments.com

Field Service - rdifs@rdinstruments.com

RD Instruments Europe

5 Avenue Hector Pintus

06610 La Gaude, France

+33(0) 492-110-930

+33(0) 492-110-931

rdi@rdieurope.com

rdifs@rdieurope.com

Web: www.rdinstruments.com

10 Warranty

Solely for the benefit of the original buyer, RD Instruments (RDI) warrants all new products of its manufacture to be free from defects in material and workmanship. RDI will replace or repair free of charge, F.O.B. at its factory in San Diego, California or other location designated by RDI, any part or parts returned to it within one year of original delivery, which RDI's examination shall show to have failed under normal use and service.

For those parts or components of a product which RDI does not manufacture itself but which are acquired from other vendors, the duration on times of this warranty given above shall not exceed those of the vendor's warranties for such parts or components.

This warranty applies to all goods manufactured by RDI and is included in the Terms and Conditions contained in sales documents of RDI which Terms and Conditions set forth the provisions that govern all sales made by RDI. This warranty also applies to all other activities performed by research, design, design and development, joint development, field engineering, field testing and operation training and is the ONLY WARRANTY GIVEN FOR THE SALE OF PRODUCTS OR SERVICES. NO WARRANTIES IMPLIED IN LAW, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PARTICULAR PURPOSE SHALL APPLY. IN NO EVENT WILL RDI BE LIABLE FOR CONSEQUENTIAL DAMAGES RESULTING FROM THE PURCHASE OR USE OF RDI PRODUCTS, OR RESULTING FROM ANY DELAYS OR FAILURE OF PERFORMANCE OR RDI UNDER ANY AGREEMENT, OR RESULTING FROM ANY SERVICES FURNISHED BY RDI.

This warranty may not be modified, amended, or otherwise changed except in writing and properly executed by an officer of RDI.

NOTES

WorkHorse Rio Grande ADCP User’s Guide

WorkHorse Rio Grande ADCP User's Guide

RD Instruments
Acoustic Doppler Solutions

P/N 957-6167-00 (January 2001)

Table of Contents

List of Figures

List of Tables

RD Instruments
Acoustic Doppler Solutions

WorkHorse Rio Grande ADCP User's Guide

1 Introduction

Thank you for purchasing the RD Instruments (RDI) Rio Grande WorkHorse. This guide is designed to help first time WorkHorse users to set up, test, and deploy their ADCP.

This guide is designed for use *with* the other WorkHorse Technical Manual guides. Where needed, there are references to detailed information and figures contained in the WorkHorse Technical Manual.

WorkHorse Rio Grande deployments are most often Real-Time. Real-Time use refers to the fact you are viewing the data as the ADCP collects it via a personal computer. This data is also stored on the computer to allow for data playback and processing at a later time.

NOTE. When you receive your WorkHorse, look for a set up card that shows all of the pieces you should have in your box. If anything is missing or damaged, contact RDI immediately.

2 WorkHorse Rio Grande ADCP Applications

The Workhorse Rio Grande ADCP provides customers with reliable and repeatable river discharge measurements, and displays the results through its exceptional, user-friendly *WinRiver* software. For detailed information on how to use *WinRiver*, see the *WinRiver* User's Guide.

The WorkHorse Rio Grande ADCP can also be used in other moving vessel real time applications that take advantage of the Rio Grande's bottom tracking abilities. *WinRiver* is the most often used software package for Rio Grande ADCP setup, real-time data collection, and data review. RDI also offers the *VmDas* program for ADCP setup, real-time data collection, and data review. For detailed information on how to use *VmDas*, see the *VmDas* User's Guide.

Table 1: WorkHorse Rio Grande Application Guide

Estuaries/River	**Costal and Continental Shelf**
Rio Grande using WinRiver	**Rio Grande using VmDas**
• River, stream and channel discharge	• Plume tracking
• Suspended sediment load estimation	• Environmental surveys
• Plume tracking	• Planning new ports
• Bridge scouring	• Current mapping
• Simultaneous bathymetry discharge, flow structure	• Costal engineering
	• Cable and pipe laying
	• Circulation/model studies

3 System Overview

The WorkHorse Rio Grande is designed to measure real-time current profiles from temporary or permanent mounting in a vessel. The Rio Grande ADCP system consists of an ADCP with Bottom Track mode, High Resolution Water Profiling modes, cables, and software. The input power requirements for the Rio Grande are +12 VDC. The Rio Grande system requires the addition of a Windows® compatible computer to collect data.

NOTE. Do not attempt to attach a Workhorse Monitor/Sentinel I/O cable or power supply to the Workhorse Rio Grande ADCP. The Workhorse Monitor and Sentinel ADCPs are 24 VDC systems. **The Workhorse Rio Grande uses 12 VDC only.**

NOTE. The Rio Grande End-Cap is red to differentiate it from the Monitor and Sentinel ADCPs. Do not swap end-caps between a Rio Grande and a Monitor/Sentinel. The pin-outs are different on both the I/O cable connector and the internal I/O cable.

3.1 Rio Grande ADCP Overview

The transducer assembly contains the transducer ceramics and electronics. Standard acoustic frequencies are 600, and 1200kHz. See the outline drawings in the Installation Guide for dimensions and weights.

I/O Cable Connector – Input/Output (I/O) cable connects the WorkHorse ADCP to the computer.

Beam-3 Mark – The Beam-3 mark shows the location of Beam-3 (Forward).

Urethane Face – The urethane face covers the transducer ceramics. Never set the transducer on a hard surface. The urethane face may be damaged.

Housing – The standard WorkHorse housing allows deployment depths to 200 meters.

Thermistor – The Thermistor measures the water temperature.

Pressure Sensor – The Optional pressure sensor measures water pressure (depth).

Transducer Head – The WorkHorse electronics and transducer ceramics are mounted to the transducer head. The numbers embossed on the edge of the transducer indicates the beam number. When assembling the unit, match the transducer beam number with the Beam 3 mark on the end-cap.

End-Cap – The end-cap holds the I/O cable connector. When assembling the unit, match the Beam 3 mark on the end-cap with beam 3 number on the transducer.

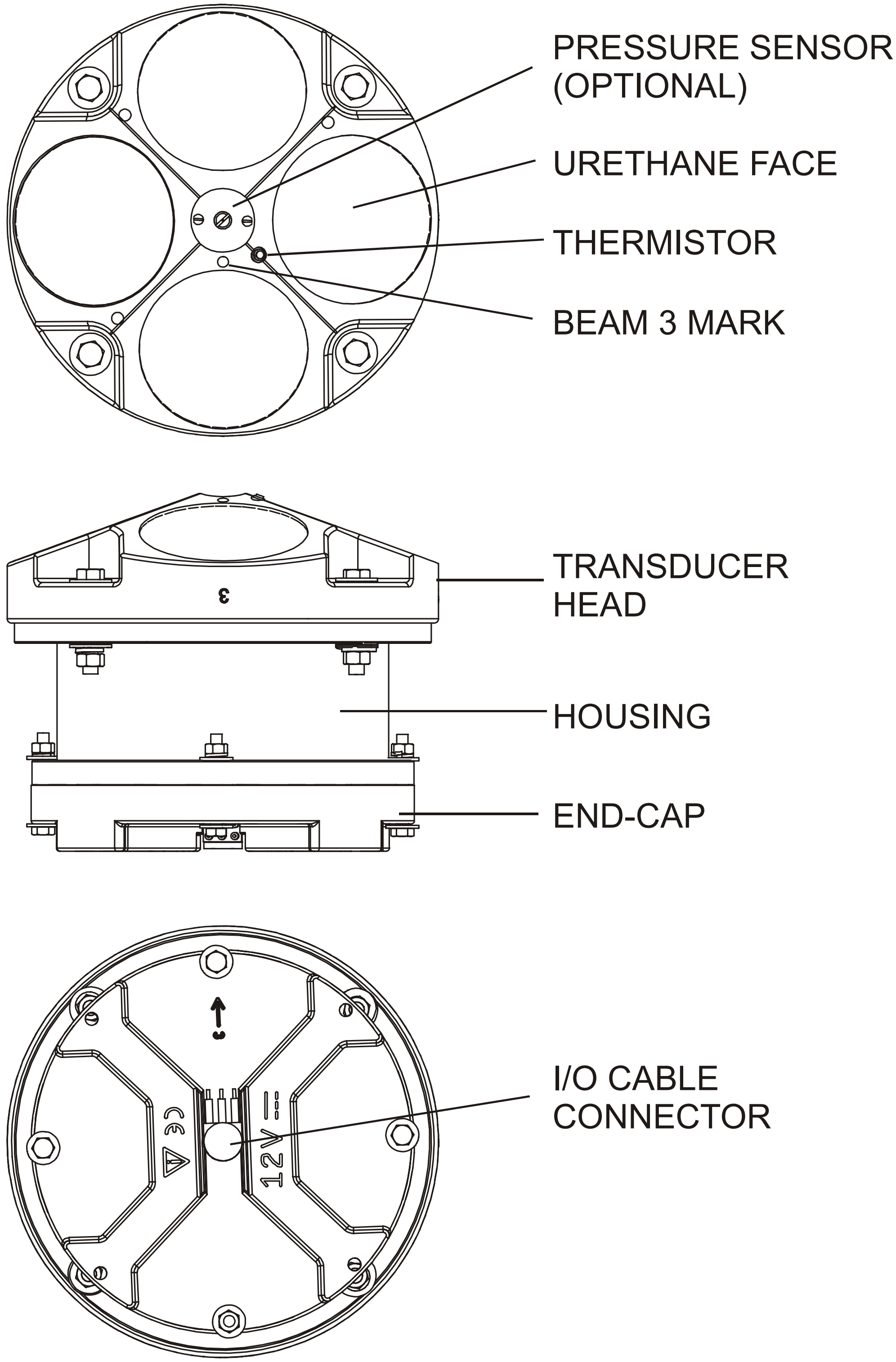


Figure 1. Rio Grande ADCP Overview

3.2 I/O Cable Overview

Always remove the retaining strap on the end-cap underwater-connect cable and dummy plug when disconnecting them. **Failure to do so will break the retainer strap.**

Do not apply any upward force on the end-cap connector as the I/O cable is being disconnected. **Stressing the end-cap connector may cause the ADCP to flood.** Read the Maintenance guide for details on disconnecting the I/O cable.

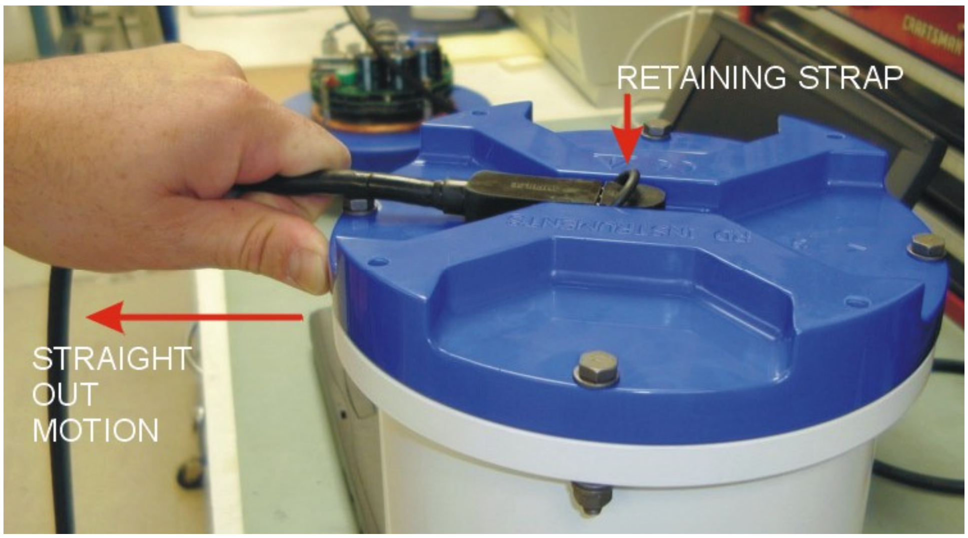


Figure 2. Connecting and Disconnecting the I/O Cable

> **NOTE.** The Rio Grande End-Cap is red to differentiate it from the Monitor and Sentinel ADCPs. Do not swap end-caps between a Rio Grande and a Monitor/Sentinel. The pin-outs are different on both the I/O cable connector and the internal I/O cable.

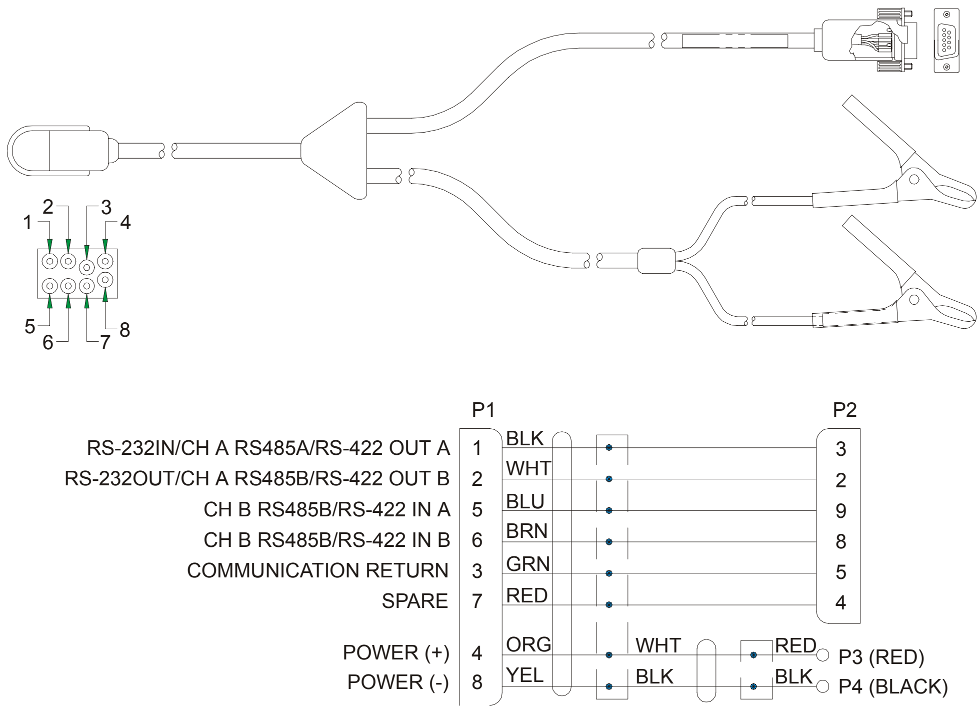


Figure 3. I/O Cable Overview

3.3 Optional Flash Memory Card

Flash memory cards (see Figure 4, page 7) are available in 16, 20, 40, 85 and 220-MB cards. The internal recorder holds two cards for a maximum of 440 MB of recording space. The PC Card recorder is located on the Digital Signal Processor (DSP) board inside the Workhorse's electronics. To recover data, the card can be removed and used in a personal computer (PC), or left in the Workhorse, and accessed by using *WinSC* (see the *WinSC* User's Guide).

NOTE. The WorkHorse Rio Grande does not come with flash memory, but has the same capacity as a WorkHorse Sentinel.

NOTE. *WinSC* is not provided with WorkHorse Rio Grande systems, but is available for free download at www.rdinstruments.com.

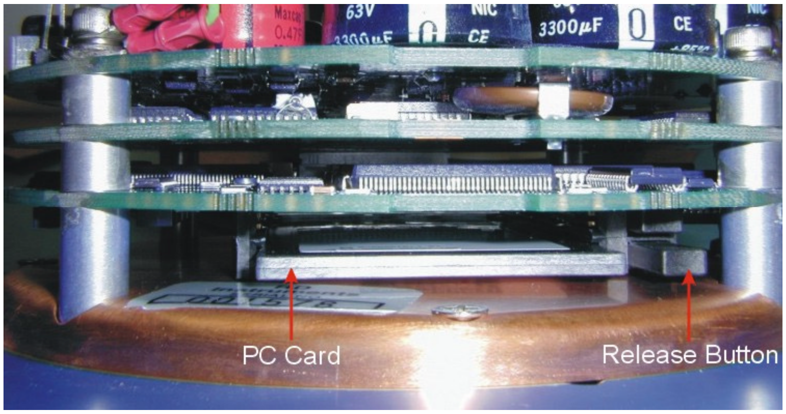


Figure 4. Memory Card Overview

3.4 Spare Parts

The following parts are included in the spare parts kit.

Table 2: Spare Parts

Description	Part number
O-ring, face	2-260
Desiccant, sealed bag	DES3
Lubricant, silicone, 5.3 oz, Dow-Corning	DC-111
Fuse, 3.0 Amp, 250V	GMA-3A

4 WorkHorse Care

This section contains a list of items you should be aware of every time you handle, use, or deploy your WorkHorse. *Please refer to this list often*.

4.1 General Handling Guidelines

- Never set the transducer on a hard or rough surface. **The urethane faces may be damaged.**
- Always remove the retaining strap on the end-cap underwater-connect cable and dummy plug when disconnecting them. **Failure to do so will break the retainer strap.**
- Do not apply any upward force on the end-cap connector as the I/O cable is being disconnected. **Stressing the end-cap connector may cause the ADCP to flood.** Read the Maintenance guide for details on disconnecting the I/O cable.
- Do not expose the transducer faces to prolonged sunlight. **The urethane faces may develop cracks.** Cover the transducer faces on the Workhorse if it will be exposed to sunlight.
- Do not expose the I/O connector to prolonged sunlight. **The plastic may become brittle.** Cover the connector on the Workhorse if it will be exposed to sunlight.
- Do not store the ADCP in temperatures over 75 degrees C. **The urethane faces may be damaged.** Check the temperature indicator inside the shipping case. It changes color if the temperature limit is exceeded.
- Do not scratch or damage the O-ring surfaces or grooves. **If scratches or damage exists, they may provide a leakage path and cause the ADCP to flood.** Do not risk a deployment with damaged O-ring surfaces.
- Do not lift or support a WorkHorse by the external I/O cable. **The connector or cable will break.**

4.2 Assembly Guidelines

- Read the Maintenance guide for details on WorkHorse re-assembly. Make sure the housing assembly O-rings stay in their groove when you re-assemble the WorkHorse. Tighten the hardware as specified. **Loose, missing, stripped hardware, or damaged O-rings can cause the WorkHorse transducer to flood.**

- Place a light amount of DC-111 lubricant on the end-cap connector pins (rubber portion only). **This will make it easier to connect or remove the I/O cable and dummy plug.**
- Do not connect or disconnect the I/O cable with power applied. An exception to this is the external battery case. The external battery case connector is always “hot” when batteries are installed. When you connect the cable with power applied, you may see a small spark. **The connector pins may become pitted and worn.**
- The WorkHorse I/O cable is *wet* mate-able, <u>not</u> *under water* mate-able.

4.3 Deployment Guidelines

- Align the compass whenever the battery pack or recorder module is replaced, or when any ferrous metals are relocated inside or around the WorkHorse housing. **Ferro-magnetic materials affect the compass.**
- The AC power adapter is not designed to withstand water. **Use caution when using on decks in wet conditions.**
- Avoid using ferro-magnetic materials in the mounting fixtures or near the Workhorse. **Ferro-magnetic materials affect the compass.**

5 Setup the WorkHorse Rio Grande ADCP

Figure 5 illustrates how to connect the WorkHorse cables and adapters on your workbench. The internal battery plugs into a connector on the top circuit board.

You will need a container of water large enough to submerge the Work-Horse's transducer head into during testing (two to three inches of water is sufficient). Testing the WorkHorse out of water may cause some tests to fail but causes no harm to the WorkHorse.

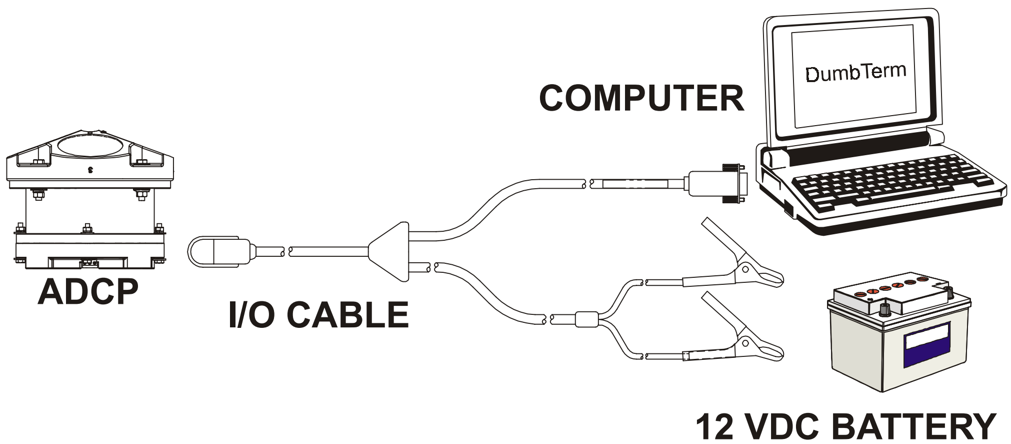


Figure 5. WorkHorse Rio Grande Connections

5.1 Serial Communication

The standard communications settings for a WorkHorse Rio Grande is RS-232, 9600-baud, no parity, 8 data bits and 1 stop bit. If the serial protocol is set for RS232 and your computer expects RS422, you will need an RS232 to RS422 adapter between the WorkHorse cable and your computer. You can set the WorkHorse for baud rates other than 9600 baud.

RS422. The WorkHorse Rio Grande is normally set for RS232, but it can be changed to RS422 by changing a switch setting. The switch is in plain view on the top circuit board, near the cable connectors. Its settings are plainly marked on the board. This user's guide assumes that you use RS232.

5.2 What if the WorkHorse Does Not Respond

If your WorkHorse does not respond, check the serial port, cables, and power. If necessary, refer to the Troubleshooting Guide in the WorkHorse technical manual.

6 Software

RDI has utility programs to help you set up, use, test, and trouble-shoot your WorkHorse ADCP. Each program has a help file that you can print, or you can view help while running the program.

Table 3: WorkHorse Software Main Modules

Program Name	Description
DumbTerm	Windows ADCP communication program. Use this program to "talk" to the ADCP and to run test script files. *DumbTerm* is included on the RDI Tools CD. For detailed information on how to use *DumbTerm*, see the *RDI Tools User's Guide*.
WinADCP	Gives users a visual display of the entire set of data. You can zoom in on a portion of the data for closer analysis and you can export data to text or MatLab files. For detailed information on how to use *WinADCP*, see the *WinADCP User's Guide*.
Documentation CD	The Documentation CD has an Adobe Acrobat® (*.pdf) electronic version of the WorkHorse Technical Manual. Use the Documentation CD to search for information. For detailed information on how to use Adobe Acrobat® and the Documentation CD, see the Read This First guide.

6.1 System Requirements

The WorkHorse software requires the following:

- Windows 95®, Windows 98®, or Windows® NT 4.0 with Service Pack 4 installed
- Pentium class PC 233 MHz (350 MHz or higher recommended)
- 32 megabytes of RAM (64 MB RAM recommended)
- 6 MB Free Disk Space (20 MB recommended)
- One Serial Port (two High Speed UART Serial Ports recommended)
- Minimum display resolution of 800 x 600, 256 color (1024 x 768 recommended)

6.2 Software Installation

To install the WorkHorse software, do the following.

a. Insert the compact disc into your CD-ROM drive and then follow the browser instructions on your screen. If the browser does not appear, complete Steps “b” through “d.”

b. Click the **Start** button, and then click **Run**.

c. Type **<drive>:launch**. For example, if your CD-ROM drive is drive D, type **d:launch**.

d. Follow the browser instructions on your screen

6.3 Utility Software

The following DOS programs (on the RDI Tools CD) have been provided to supplement features not yet implemented into the Windows environment. RDI will incorporate these features in future releases. These programs will be installed to the directory C:\Program Files\Rd Instruments\Utilities when you run the RDI Tools installation program.

Table 4: WorkHorse DOS Utility Software

Program Name	Description
BBLIST	Executable program that can be operated through the Windows environment. This program will display binary data in tabular format as well as convert the data into an ASCII file.
BBBATCH	Automatically converts a named binary data set to a named ASCII data set using an existing format file. Use this program to convert binary files unattended through a DOS batch file.
BBCONV	Executable program that cannot be operated through the Windows environment. Removes user selected data from binary files and stores the information into ASCII comma delimited format. See BCONV.DOC for decoder file format.
BBMERGE	Executable program that cannot be operated through the Windows environment. BBMERGE merges ASCII comma delimited format data described by a decoder (.DEC) file into the raw BroadBand ADCP data file "infilename", resulting in an output ADCP data file called "outfilename". See BCONV.DOC for decoder file format.
BBSUB	Executable program that cannot be operated through the Windows environment. BBSUB starts copying ensembles from 'infilename' to 'outfilename' starting with the user specified “Start” and “End” ensemble number. This is intended to allow users to subsection binary data files.
SS	Executable program that can be operated through the Windows environment. SS allows you to quickly calculate the speed of sound in the water.
SURFACE	Executable program that cannot be operated through the Windows environment. Surface estimates the range from the ADCP to the water surface or bottom from the echo intensity data. This program does not change the original data. It creates a text file with the estimated ranges. Intended for customers to estimate where to cut off their data.
CHECKDAT	Executable program that cannot be operated through the Windows environment. CHECKAT will scan a data file for missing ensembles, ensemble number out of order, bad checksum ensembles and ensembles with bit errors. If the DOS redirect command (> symbol) is used then the output will be placed into a file.
C++ Code Library	The C++ Code library has been provided to help you in the creation of your own programs. These files are provided as is and in general are not supported. Use at your own discretion. The files are located in the directory: C:\Program Files\Rd Instruments\Utilities\C_Code.

7 Power

The Rio Grande requires a DC supply between 10.5 volts and 18 volts. Either an external DC power supply or battery can provide this power. If you are using a battery, use the largest rated amp-hour battery as possible. A car battery should last one to two days powering a 600-kHz ADCP.

NOTE. Check that the battery voltage is above 10 Volts DC. Rio Grande ADCPs will work at 10 volts; however, batteries with voltages below 11 volts are at or near their end of life and are approaching uselessness.

7.1 Bench-Top Battery Power Requirements

While the WorkHorse is awake and responding to commands, it consumes approximately 2.2 watts. A single internal battery pack supplies this power level for about five days. When the WorkHorse is asleep, it consumes less than one mw. A standard battery pack supplies sleep power for years. At every opportunity, the WorkHorse will “sleep” to conserve power while deployed.

7.2 Operation Modes

The WorkHorse has two modes of operation: *command mode*, and *ping mode* (also referred to as “Deployment Saver” Mode). Depending on what mode the ADCP is in; it will go either to sleep or to resume pinging.

In the Command Mode

Whenever you wake up your WorkHorse, power dissipation increases from less than one mw to around 2.2 w. If you leave the WorkHorse in command mode without sending a command for more than five minutes, the WorkHorse automatically goes to sleep. This protects you from inadvertently depleting batteries.

In the Ping Mode

After you send commands to the WorkHorse that tells it to start collecting data, the WorkHorse goes into deployment saver mode. If power is somehow removed and later restored, the WorkHorse simply picks up where it left off and continues to collect data using the same setup.

8 Testing Your WorkHorse

Use the following steps to test the ADCP.

a. Interconnect and apply power to the system as described in "Setup the WorkHorse Rio Grande ADCP," page 10.

b. Start the *DumbTerm* program (for help on using *DumbTerm*, see the RDI Tools User's Guide).

c. Press **<F2>** and run the script file TestWH.txt. The TestWH.txt script file runs PS0, PS3, PA, PC2, and the PC1 tests. The results of the tests will be printed to the screen and saved to the log file WH_RSLTS.txt. The WH_RSLTS.txt file will be created in the same directory that *DumbTerm* is running from.

Table 5 lists the tests *DumbTerm* runs, gives you guidelines for running the tests, and tells you what the results mean.

Table 5: WorkHorse ADCP Tests

Test	Guidelines	Results
PS0	Displays system parameters.	Verify the information is consistent with what you know about the setup of your system.
PA	Extensive pre-deployment test that tests the signal path and all major signal processing subsystems. This test may not pass unless the WorkHorse transducer face is immersed water.	All tests must pass.
PC2	Continuously updates sensor display. Rotate and tilt WorkHorse and watch the readings on the display change.	Satisfy yourself that the readings make sense.
PC1	Beam continuity test. Follow instructions to rub each beam in turn to generate a noise signal the WorkHorse uses to verify the transducer beam is connected and operational.	All beams must pass.

9 Compass Calibration

The main reason for compass calibration is battery replacement. Each new battery carries a different magnetic signature. The compass calibration algorithm corrects for the distortions caused by the battery to give you an accurate measurement. You should be aware of the following items:

- We recommend against calibrating the WorkHorse while on a ship. The ship's motion and magnetic fields from the hull and engine will likely prevent successful calibration.
- If you think your mounting fixture or frame has some magnetic field or magnetic permeability, calibrate the WorkHorse inside the fixture. Depending on the strength and complexity of the fixture's field, the calibration procedure may be able to correct it.

> **NOTE.** If you will deploy your WorkHorse looking up, calibrate it looking up. If you will deploy it looking down, calibrate it looking down.

9.1 Preparing for Calibration

a. Place the WorkHorse on a piece of strong cardboard on top of a smooth wooden (non-magnetic) table. If a wooden table is not available, place the WorkHorse on the floor as far away from metal objects as possible. Use the cardboard to rotate the WorkHorse during calibration—this way you will not scratch the WorkHorse.

b. Connect the WorkHorse as shown in Figure 5, page 10.

c. Start *DumbTerm*. See the RDI Tools User's Guide for assistance on using *DumbTerm*.

9.2 Compass Calibration Verification

Compass calibration verification is an automated built-in test that measures how well the compass is calibrated. The procedure measures compass parameters at every 5º of rotation for a full 360º rotation. When it has collected data for all required directions, the WorkHorse computes and displays the results.

> **NOTE.** Verify the compass if you have just replaced the battery (Sentinel only), memory module (optional for Rio Grande ADCPs), or any ferrous metals is relocated inside or around the WorkHorse housing.

Start the test with the AX-command and follow the instructions. **Place the ADCP in the same orientation as it will be deployed.** The WorkHorse can be vertical (it can rest on its end cap), or it can be tilted (it could rest on a transducer face). Whatever its tilt, the tilt must remain constant as you rotate the WorkHorse. When prompted, rotate the WorkHorse smoothly and slowly. Pay particular attention to the Overall Error. For example;

```
HEADING ERROR ESTIMATE FOR THE CURRENT COMPASS CALIBRATION:
   OVERALL ERROR:
      Peak Double + Single Cycle Error (should be < 5():  ( 1.55(
   DETAILED ERROR SUMMARY:
      Single Cycle Error:                                ( 1.54(
      Double Cycle Error:                                ( 0.07(
      Largest Double plus Single Cycle Error:            ( 1.61(
      RMS of 3rd Order and Higher + Random Error:        ( 0.31(
```

If the overall error is less than 5°, the compass does not require alignment. You can align the compass to reduce the overall error even more (if desired).

9.3 Compass Calibration Procedure

The built-in automated compass calibration procedure is similar to the alignment verification, but requires three rotations instead of one. The WorkHorse uses the first two rotations to compute a new calibration matrix and the third to verify the calibration. It will not accept the new matrix unless the calibration was carried out properly, and it asks you to verify that you want to use the new calibration if it is not as good as the previous calibration. While you are turning the WorkHorse for the two calibration rotations, the WorkHorse checks the quality of the previous calibration and displays the results. It compares these results with the results of the third calibration rotation.

There are two compass calibrations to choose from; one only corrects for hard iron while the other corrects for both hard and soft iron characteristics for materials rotating with the ADCP. Hard iron effects are related to residual magnetic fields and cause single cycle errors while soft iron effects are related to magnetic permeability that distorts the earth’s magnetic field and causes double cycle errors. In general, the hard iron calibration is recommended because the effect of hard iron dominates soft iron. If a large double cycle error exists, then use the combined hard and soft iron calibration.

a. Start *DumbTerm*.

b. Start the test with the AF-command and choose the calibration type.

c. Place the ADCP in the same orientation as it will be deployed.

d. When prompted, rotate the WorkHorse slowly 360 degrees.

e. The second rotation requires the WorkHorse to be tilted on an adjacent beam. Follow the on-screen instructions to orient the unit correctly. Tilt an upward-looking WorkHorse with a block under one side of the end cap. A 35-mm block gives you an 11º tilt. When prompted, rotate the WorkHorse slowly 360 degrees.

f. If the calibration procedure is successful, it records the new calibration matrix to nonvolatile memory. The WorkHorse will not change its matrix unless the calibration is properly carried out.

g. If the calibration procedure is not successful, return your WorkHorse to the original factory calibration, by using the AR-command. Try using the AR-command if you have trouble calibrating your compass. In some circumstances, a defective compass calibration matrix can prevent proper calibration.

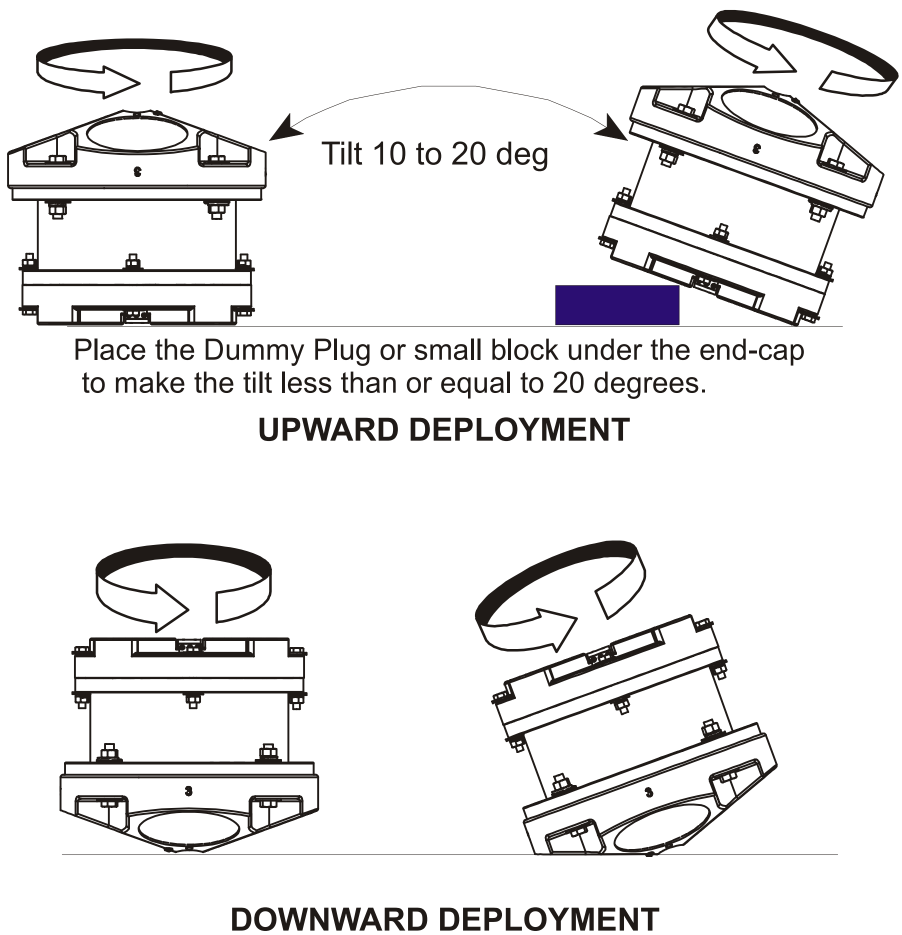


Figure 6. Compass Alignment

10 Internal Pressure Sensor

If you have the optional pressure sensor installed in your ADCP, use the AZ-command to zero out the pressure sensor at the deployment site.

a. Connect and apply power to the system as described in Figure 5, page 10.

b. Start *DumbTerm* and wakeup the ADCP (press the **END** key).

c. Type **AZ** and press the **Return** key.

d. Exit *DumbTerm*.

10.1 Pressure Sensor Maintenance

In order to read the water pressure (depth), water must be able to flow through the copper screw on the pressure sensor. Antifoulant paint will block the sensor's port (a small hole that is drilled through the copper screw). You should tape off the screw during anti-fouling paint application.

This means that the sensor port is not fully protected from bio fouling. The sensor port is surrounded by the antifouling paint, but bio fouling may build up on the screw, and eventually clog the sensor port. However, most organisms do not seem to find the small amount of unpainted surface attractive. If it is logistically possible to periodically inspect/clean the pressure sensor screw, it is highly recommended. This tradeoff situation must be analyzed for individual deployments. Unfortunately, the location of the deployment site usually dictates action in this regard.

NOTE. The pressure sensor is optional. It may not be included on your system.

CAUTION.

The pressure sensor is filled with silicone oil. Never poke a needle or other object through the copper screw while the screw is installed over the pressure sensor. You will perforate the sensor, causing it to fail.

Do not remove the cover disc or attempt to clean the surface of the pressure sensor. The diaphragm is very thin and easy to damage.

Do not remove the pressure sensor. It is not field replaceable.

11 Deployment Guide

Use the following steps and the Quick Reference card to setup the Work-Horse for a deployment.

11.1 Deployment Checklist

- ❑ Test the ADCP using *DumbTerm*
- ❑ Seal the ADCP for deployment
    - ❑ Install new o-rings; use silicone lubricant
    - ❑ Use fresh desiccant (2 bags) inside ADCP
- ❑ Visually inspect the ADCP
    - ❑ Check the transducer head condition
    - ❑ All mounting hardware installed
    - ❑ Transducer faces clean and free from defects
- ❑ Verify compass alignment using *DumbTerm*; if necessary, re-calibrate
- ❑ Are biofouling precautions needed?
- ❑ Zero pressure sensor (optional) at deployment site with AZ-command

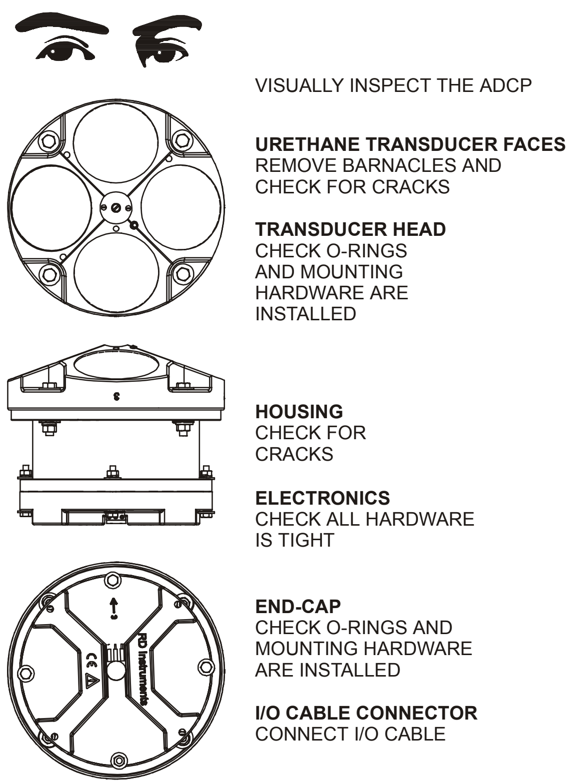


Figure 7. Visual Inspection before Deployment

11.2 Prepare the ADCP for Deployment

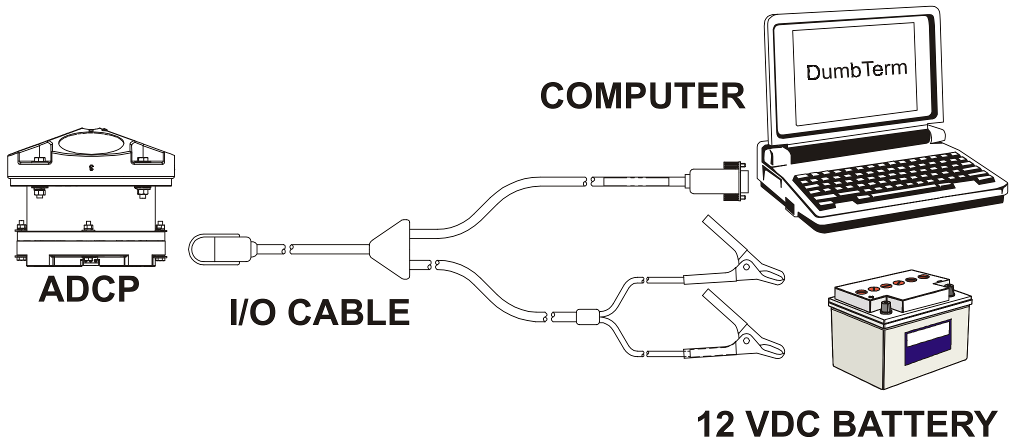


Figure 8. Prepare the ADCP

Things to remember while preparing the ADCP.

- Use the Deployment Checklist to verify that the ADCP is ready for the deployment.
- Test the ADCP using *DumbTerm*. Some tests will fail if the ADCP is not placed in water while the tests are being run.
- *Desiccant* lasts a year at specified WorkHorse deployment depths and temperatures. Remember that desiccant rapidly absorbs moisture from normal room air. Replace the desiccant whenever the WorkHorse housing or end-cap is removed.
- Verify the compass calibration.

11.3 Deployment Software

Real-Time data collection involves a series of independent steps. Using RDI's Software will ensure that the ADCP is setup correctly.

- Test your WorkHorse (*DumbTerm*)
- Plan your deployment (*WinRiver* or *VmDas*)
- Transfer your "plan" into the WorkHorse and start data collection (*WinRiver* or *VmDas*)
- Verify data integrity (*WinADCP*)
- Display and process your data (*WinADCP*, *WinRiver* or *VmDas*)

The WorkHorse software is designed to allow you to set up your WorkHorse to get the best possible data without having to understand and use WorkHorse commands. *WinRiver* and *VmDas* help you create the commands necessary to deploy the ADCP.

NOTE. Refer to the *VmDas*, and *WinRiver* Guides for information on how to use these programs.

11.4 Deploy the ADCP

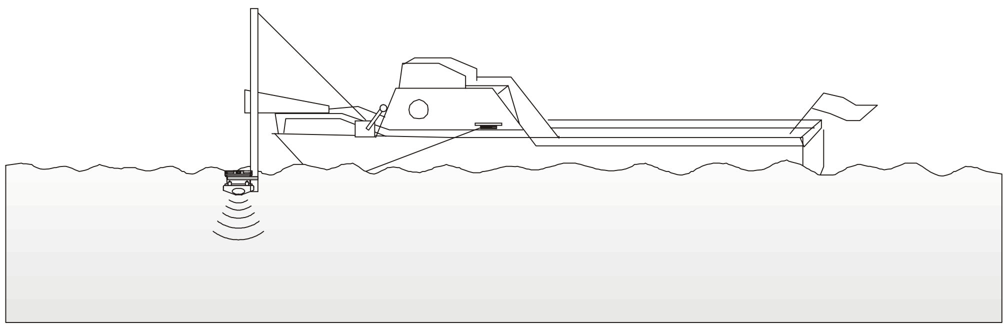


Figure 9. Real-Time Deployment

Things to remember while deploying the ADCP.

- For real-time data collection, you should use a 10.5 to 18 VDC battery.
- *Tilts*. The Workhorse corrects data for tilts as large as 15°, but tilts reduce the effective range and increase the depth of surface contamination.
- *Anti-fouling paint*. You are free to use any anti-fouling paint or other anti-fouling material you wish over any surface of the Workhorse. However, you should consider the following:
  1. Ensure that your coating can be used safely on plastic in general and polyurethane specifically.
  2. Apply it thinly and evenly to the transducer faces.
  3. Poorly applied coatings on the transducer could adversely affect instrument performance.
- *Magnetic material*. Keep the Workhorse's compass away from magnetic material when you deploy the instrument. Check for magnetic fields by smoothly moving a compass around and near the Workhorse and its mounting frame.

11.5 Send the Deployment Commands

Use *VmDas*, or *WinRiver* (see the respective software user's guides) to send the commands to the ADCP.

Things to remember while deploying the ADCP.

- *Ping beeps*. Whenever the Workhorse pings, an internal beeper makes an audible beep. The beep consumes negligible energy and tells you the Workhorse is pinging.

12 Reviewing the Data

12.1 'Where' was the Data?

The quickest way to find out the depth of each depth cell is to display your recorded data using *WinADCP*. The velocity display tells you the distance to the center of each cell. The computed distance assumes that the speed of sound is constant from the transducer to the depth cell. The actual distance is proportional to the average sound speed; if the average sound speed is 1% less than the sound speed at the transducer, the distance to the depth cell is 1% less than the displayed distance.

12.2 'When' was the Data?

The time recorded with each data record is the time of the beginning of the first ping of the ensemble. *Plan* sets the ping interval so pings occur uniformly across the ensemble interval (as opposed to putting all the pings at the beginning of the interval). It leaves a few seconds at the end of each ensemble to allow time for data recording. Hence, the average time of the ensemble is midway between the recorded ensemble time and the time of the next ensemble.

12.3 'What' is the Data?

The WorkHorse records velocity data in units of mm/s. Calibration depends on how well the WorkHorse knew the speed of sound (which it computed based on its measured temperature and the salinity value it was given). A salinity error of 5 ppt introduces less than 0.5% velocity error.

13 A Few Principles of Operation

Consult RDI's Primer (ADCP Principles of Operation: a Practical Primer, Second Edition for BroadBand ADCPs) to learn more about WorkHorse principles of operation. The following are a few points from the Primer that may be worth knowing:

- Horizontal velocity measurement accuracy is unaffected by vertical stratification.
- Stratification has negligible affect on the ability of the WorkHorse to penetrate through the water; concentration of suspended particles is the main factor influencing profiling range.
- WorkHorse measurements are automatically corrected for tilts up to ±20°. In addition to correcting for the beam pointing angles, the WorkHorse maps depth cells to other cells at the same depth.
- If you want to make measurements near the surface from a bottom-mounted WorkHorse, you should minimize the tilt.
- Depth cells are most sensitive to velocities at the center of the depth cell and less sensitive at the top and bottom. This sensitivity is reflected by what we call a 'triangular weighting function'. The details of this weighting function are rarely important for interpretation and use of your data.
- The actual maximum range can be different from the range predicted in *Plan*. *Plan* corrects for range variations caused by temperature and salinity, but it assumes typical scattering conditions. Weak backscatter can sometimes reduce range by a factor of two or more.
- The maximum profiling range decreases with time as the battery voltage falls. This is because transmit power depends on battery voltage. Transmit power is optimized for about 13 volts.

14 Technical Support

If you have technical problems with your instrument, contact our field service group in any of the following ways:

RD Instruments

9855 Businesspark Ave.

San Diego, California 92131

(858) 693-1178

FAX (858) 695-1459

Sales - rdi@rdinstruments.com

Field Service – rdifs@rdinstruments.com

RD Instruments Europe

5 Avenue Hector Pintus

06610 La Gaude, France

+33(0) 492-110-930

+33(0) 492-110-931

rdi@rdieurope.com

rdifs@rdieurope.com

Web: www.rdinstruments.com

WorkHorse Sentinel ADCP User's Guide

WorkHorse Sentinel ADCP User's Guide

P/N 957-6163-00 (January 2001)

RD Instruments
Acoustic Doppler Solutions

Table of Contents

List of Figures

List of Tables

RD Instruments
Acoustic Doppler Solutions

WorkHorse Sentinel User's Guide

1 Introduction

Thank you for purchasing the RD Instruments (RDI) WorkHorse. This guide is designed to help first time WorkHorse users to set up, test, and deploy their ADCP.

This guide is designed for use *with* the other WorkHorse Technical Manual books. Where needed, there are references to detailed information and figures contained in the WorkHorse Technical Manual.

WorkHorse Sentinel deployments are most often Self-Contained but can be Real-Time. Typically, deployments are considered to be Self-Contained when the ADCP is remotely deployed and powered using internal batteries. In this configuration, no external connections to the ADCP are made during the deployment. However, the ADCP can be connected to external power. This power can be provide either by an external battery case or from shore. This type of deployment is still considered Self-Contained, but this quick reference guide may not consider all of the possibilities of this application.

Real-Time use refers to the fact you are viewing the data as the ADCP collects it via a personal computer. This data is also stored on the computer to allow for data playback and processing at a later time.

NOTE. When you receive your WorkHorse, look for a set up card that shows all of the pieces you should have in your box. If anything is missing or damaged, contact RDI immediately.

2 WorkHorse Sentinel ADCP Applications

The WorkHorse Sentinel ADCP is designed so that it can be used as a fully self-contained system. This means that it contains its own battery for power and internal recorder for the storage of all data that you have set it up to collect. Using the internal battery and recorder, the WorkHorse Sentinel can be used for several-month autonomous current profile deployments from temporary or permanent mountings in the ocean, near-shore, harbors, and lakes.

WinSC is the software package for self-contained ADCP setup, data collection, and data review. For detailed information on how to use *WinSC*, see the *WinSC* User's Guide. *Plan* (part of *WinSC*) lets you enter known or "best-guess" values for the various ADCP profiling parameters and shows predictions of expected results. For detailed information on how to use *Plan*, see the *WinSC* User's Guide.

Table 1: WorkHorse Self-Contained Application Guide

Application	Blue Water	Costal and Continental Shelf
Autonomous deployment	**Sentinel using WinSC**	**Sentinel using WinSC**
	• Oceanography	• Environmental monitoring
	• Energy transport	• Costal engineering
	• Environmental monitoring	• Enabling safe movement
	• Engineering stress determination	• Measuring Power plant discharge
	• Circulation/model studies	• Protecting coastal land forms
	• Boundary layer studies	• Detecting sewer outfall
		• Monitoring sensitive environments
		• Planning new ports
Lowered	**Sentinel using WinSC**	
	• Deep water oceanography	

The WorkHorse Sentinel ADCP is also able to be used in real time applications that either take advantage of the internal battery power, or external battery power, and can be used to collect data internally as well as externally. When considering real time applications, RDI offers you choices in software packages that are intended to directly meet your needs. *VmDas* is the most often used software package for ADCP setup, real-time data collection, and data review. For detailed information on how to use *VmDas*, see the *VmDas* User's Guide.

Table 2: WorkHorse Real-Time Application Guide

Application	Blue Water	Costal and Continental Shelf
Real-Time deployment	**Sentinel using VmDas**	**Sentinel using VmDas**
	• Oil production platforms	• Port and harbor monitoring
	• Current mapping	• Water quality studies
Boat Mount (portable)	**Sentinel using VmDas**	**Sentinel using VmDas**
	• Oceanography	• Plume tracking
	• Boundary layer studies	• Environmental surveys
	• Fisheries	• Planning new ports
	• Plankton biomass	• Current mapping
Towed	**Sentinel using VmDas**	**Sentinel using VmDas**
	• Towed fish positioning	• Towed fish positioning
	• Boundary layer studies	• Water quality studies
	• Circulation/model studies	
Offshore oil and gas	**Sentinel using VmDas**	
	• Seismic prospecting	
	• Exploration drilling	
	• Field development	
	• Production	

Table 3: WorkHorse Special Applications

Sentinel using WinRiver	Sentinel using Waves
• River, stream and channel discharge	• Coastal protection and engineering
• Suspended sediment load estimation	• Port design and operation
• Plume tracking	• Environmental monitoring
• Bridge scouring	• Shipping safety
• Simultaneous bathymetry discharge, flow structure	

NOTE. For information on how to use a Sentinel in river discharge measurements, see the *WinRiver* User's Guide. For information on how to use a Sentinel to monitor waves, see the *Waves* User's Guide.

3 System Overview

The Sentinel ADCP system consists of an ADCP, cables, battery pack, flash memory card, and software. Both battery capacity and memory can be increased with upgrades for longer deployments. The Sentinel can also be used for direct-reading current profile operation. They only require the addition of a Windows® compatible computer to configure the ADCP and replay collected data.

3.1 Sentinel ADCP Overview

The transducer assembly contains the transducer ceramics and electronics. Standard acoustic frequencies are 300, 600, and 1200kHz. See the outline drawings in the WorkHorse Installation Guide for dimensions and weights.

I/O Cable Connector – Input/Output (I/O) cable connects the WorkHorse ADCP to the computer.

Beam-3 Mark – The Beam-3 mark shows the location of Beam-3 (Forward).

Urethane Face – The urethane face covers the transducer ceramics. Never set the transducer on a hard surface. The urethane face may be damaged.

Housing – The standard WorkHorse housing allows deployment depths to 200 meters.

Thermistor – The Thermistor measures the water temperature.

Pressure Sensor – The Optional pressure sensor measures water pressure (depth).

Transducer Head – The WorkHorse electronics and transducer ceramics are mounted to the transducer head. The numbers embossed on the edge of the transducer indicates the beam number. When assembling the unit, match the transducer beam number with the Beam 3 mark on the end-cap.

End-Cap – The end-cap holds the I/O cable connector. When assembling the unit, match the Beam 3 mark on the end-cap with beam 3 number on the transducer.

Internal Battery Pack – The internal battery pack has 400 watt-hours (Wh) of usable energy at 0 C. When fresh, the voltage is +42 VDC. When depleted, the voltage drops to 30 VDC or less.

Flash Memory Card – Flash memory cards are available in 16, 20, 40, 85 and 220-MB cards. The standard configuration is one 16MB card.

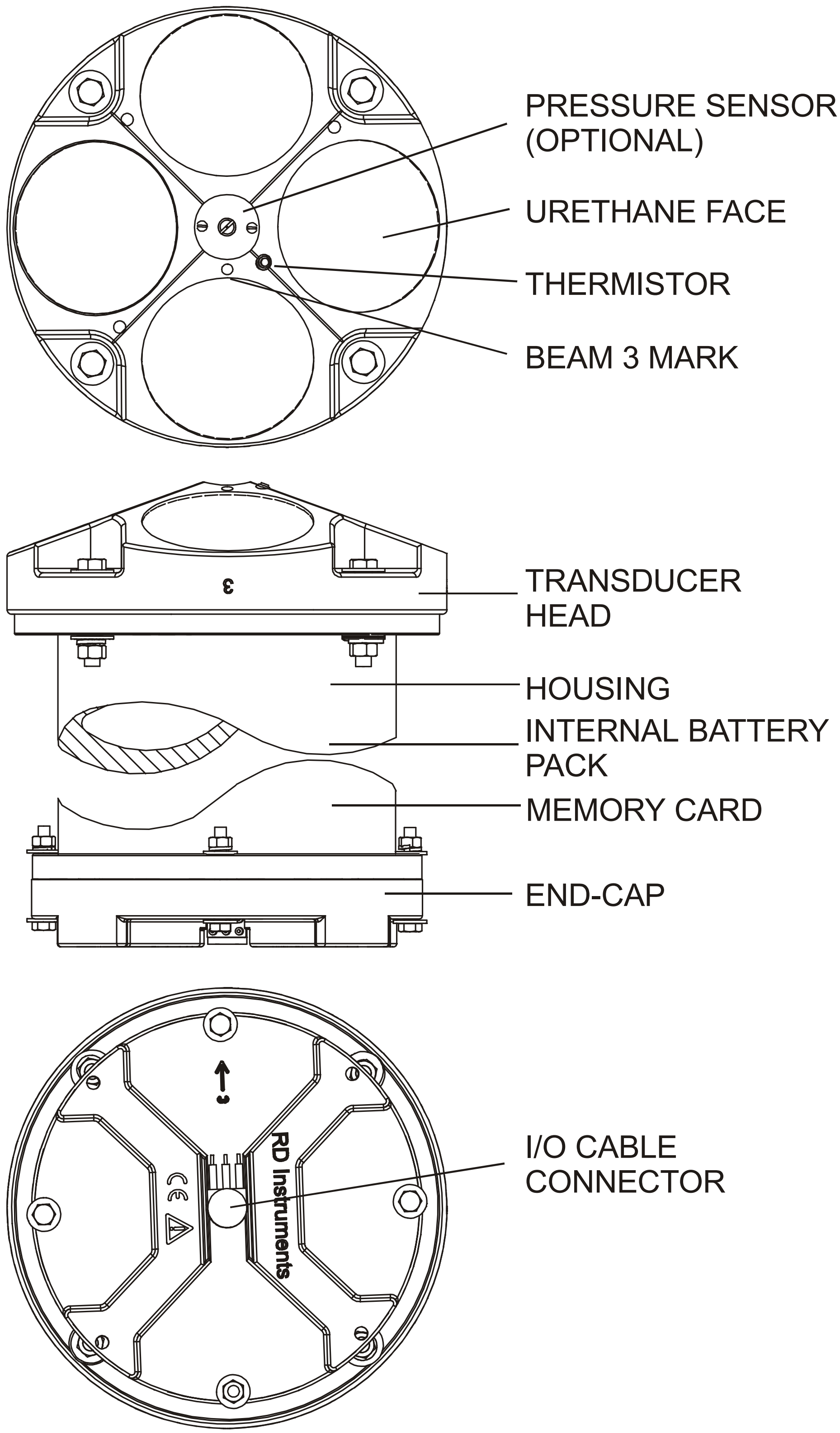


Figure 1. Sentinel ADCP Overview

3.2 I/O Cable Overview

Always remove the retaining strap on the end-cap underwater-connect cable and dummy plug when disconnecting them. **Failure to do so will break the retainer strap.**

Do not apply any upward force on the end-cap connector as the I/O cable is being disconnected. **Stressing the end-cap connector may cause the ADCP to flood.** Read the Maintenance guide for details on disconnecting the I/O cable.

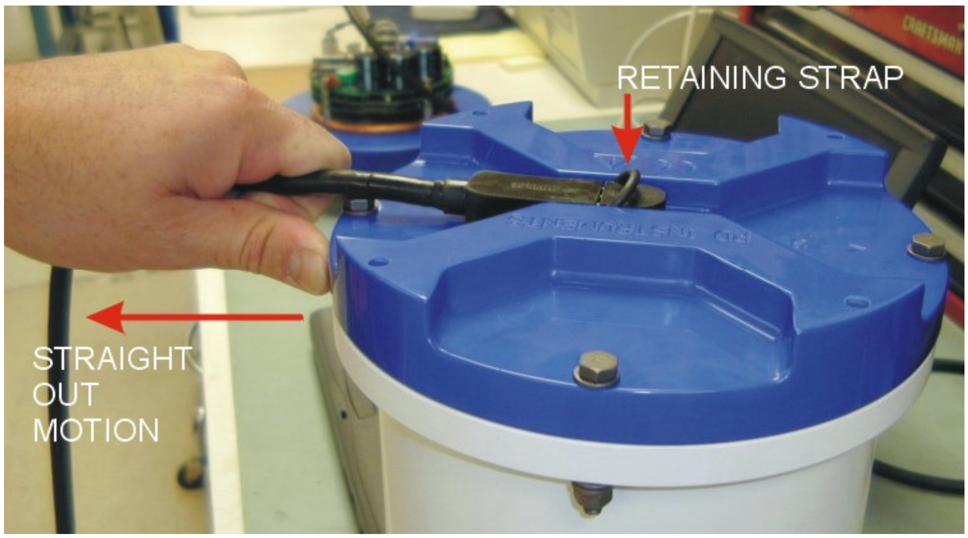


Figure 2. Connecting and Disconnecting the I/O Cable

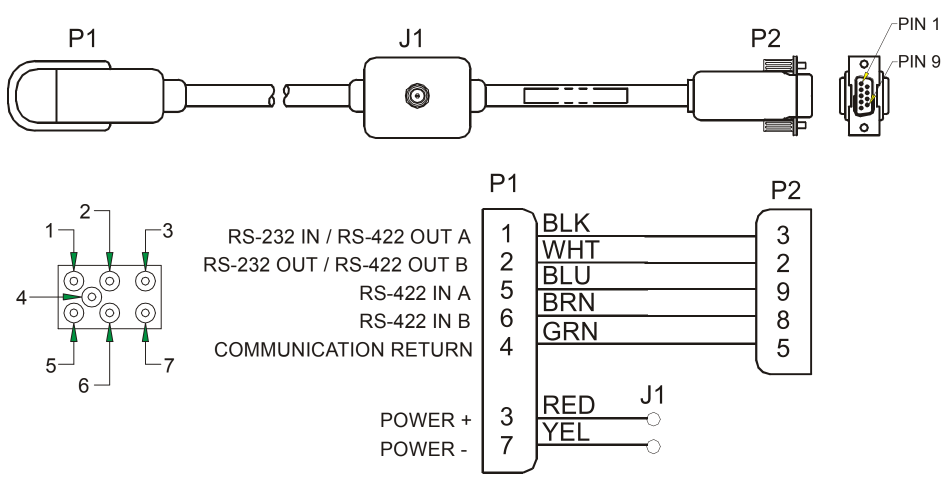


Figure 3. I/O Cable Overview

3.3 Battery Pack Overview

WorkHorse Sentinel ADCPs require +20 to 60 VDC to operate. The standard AC Adapter runs on any standard AC power and supplies +24 VDC to run the Workhorse when the batteries are not connected.

If both the battery (either Sentinel internal batteries or the External Battery Pack) and power supply are connected, the Workhorse will select the *highest* voltage source for use. The batteries (when fresh) supply +42 VDC and the power supply output is +24 VDC. The Workhorse will draw all power from the battery if the battery voltage is above +24 VDC (the power supply will have no effect).

NOTE. The +24 VDC AC adapter does not override the battery voltage! Substitute your own power supply with a voltage of +45 to 60 VDC to override the +42 VDC alkaline battery packs.

Batteries should be replaced when the voltage falls below 30 VDC (measured across the battery connector under no-load conditions).

NOTE. Battery replacement induces both single and double cycle compass errors. The compass accuracy should be verified after replacing the battery pack. The compass does not have to be recalibrated if the compass verification passes specification.

These compass effects can be avoided by using an external battery pack. The external battery housing holds two batteries, and can easily be replaced on-site. If properly used, no compass calibration will be required. It provides an option for extended ADCP deployments.

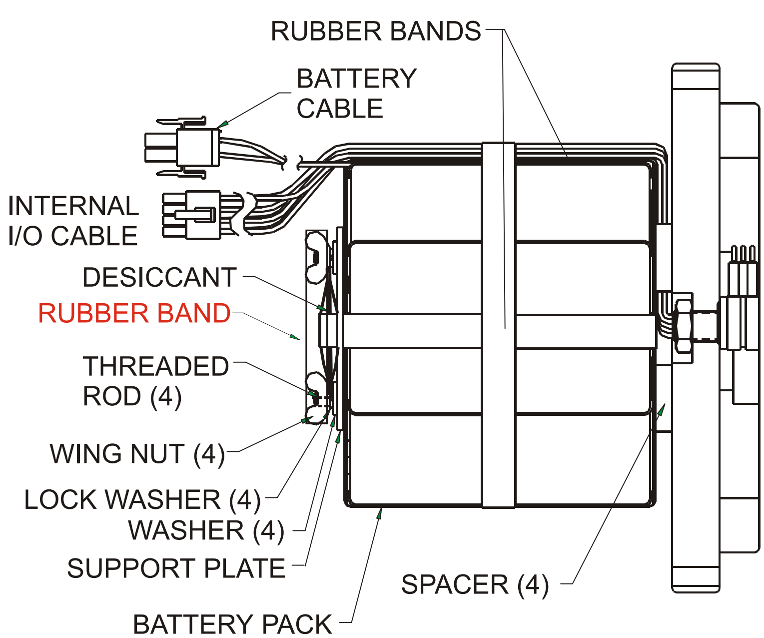


Figure 4. Battery Pack Overview

CAUTION. The Workhorse Sentinel battery pack is held in place by four sets of washers, lock washers, and wing nuts. If the wing nuts are not tight, the assembly of washers and wing nut can become loose and eventually fall onto the PIO board. **This has caused the PIO board to short out.** Place a rubber band around the wing nuts to help hold them in place.

3.4 Flash Memory Card Overview

Flash memory cards are available in 16, 20, 40, 85 and 220-MB cards. The internal recorder holds two cards for a maximum of 440 MB of recording space. The PC Card recorder is located on the Digital Signal Processor (DSP) board inside the Workhorse's electronics. To recover data, the card can be removed and used in a personal computer (PC), or left in the Workhorse, and accessed by using *WinSC* (see the *WinSC* User's Guide).

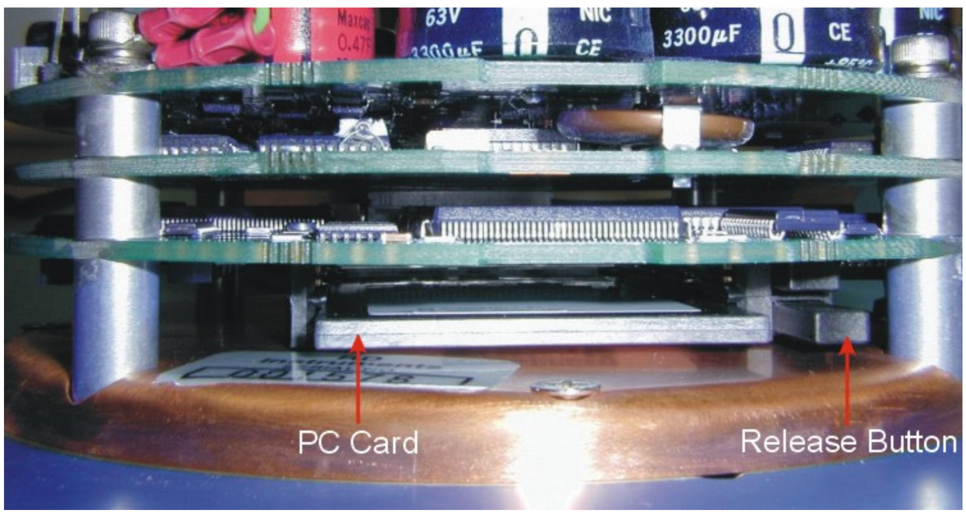


Figure 5. Memory Card Overview

3.5 Spare Parts

The following parts are included in the spare parts kit.

Table 4: Spare Parts

Description	Part number
O-ring, face	2-260
Desiccant, sealed bag	DES3
Lubricant, silicone, 5.3 oz, Dow-Corning	DC-111
Fuse, 3.0 Amp, 250V	GMA-3A

4 WorkHorse Care

This section contains a list of items you should be aware of every time you handle, use, or deploy your WorkHorse. *Please refer to this list often*.

4.1 General Handling Guidelines

- Never set the transducer on a hard or rough surface. **The urethane faces may be damaged.**
- Always remove the retaining strap on the end-cap underwater-connect cable and dummy plug when disconnecting them. **Failure to do so will break the retainer strap.**
- Do not apply any upward force on the end-cap connector as the I/O cable is being disconnected. **Stressing the end-cap connector may cause the ADCP to flood.** Read the Maintenance guide for details on disconnecting the I/O cable.
- Do not expose the transducer faces to prolonged sunlight. **The urethane faces may develop cracks.** Cover the transducer faces on the Workhorse if it will be exposed to sunlight.
- Do not expose the I/O connector to prolonged sunlight. **The plastic may become brittle.** Cover the connector on the Workhorse if it will be exposed to sunlight.
- Do not store the ADCP in temperatures over 75 degrees C. **The urethane faces may be damaged.** Check the temperature indicator inside the shipping case. It changes color if the temperature limit is exceeded.
- Do not scratch or damage the O-ring surfaces or grooves. **If scratches or damage exists, they may provide a leakage path and cause the ADCP to flood.** Do not risk a deployment with damaged O-ring surfaces.
- Do not lift or support a WorkHorse by the external I/O cable. **The connector or cable will break.**

4.2 Assembly Guidelines

- Read the Maintenance guide for details on WorkHorse re-assembly. Make sure the housing assembly O-rings stay in their groove when you re-assemble the WorkHorse. Tighten the hardware as specified. **Loose, missing, stripped hardware, or damaged O-rings can cause the WorkHorse transducer to flood.**

- Place a light amount of DC-111 lubricant on the end-cap connector pins (rubber portion only). **This will make it easier to connect or remove the I/O cable and dummy plug.**
- Do not connect or disconnect the I/O cable with power applied. An exception to this is the external battery case. The external battery case connector is always "hot" when batteries are installed. When you connect the cable with power applied, you may see a small spark. **The connector pins may become pitted and worn.**
- The WorkHorse I/O cable is *wet* mate-able, <u>not</u> *under water* mate-able.

4.3 Deployment Guidelines

- Align the compass whenever the battery pack or recorder module is replaced, or when any ferrous metals are relocated inside or around the WorkHorse housing. **Ferro-magnetic materials affect the compass.**
- The AC power adapter is not designed to withstand water. **Use caution when using on decks in wet conditions.**
- Avoid using ferro-magnetic materials in the mounting fixtures or near the Workhorse. **Ferro-magnetic materials affect the compass.**

5 Setup the WorkHorse Sentinel ADCP

Figure 6 illustrates how to connect the WorkHorse cables and adapters on your workbench. The internal battery plugs into a connector on the top circuit board.

NOTE. When you first receive your WorkHorse, the battery is not installed.

You will need a container of water large enough to submerge the Work-Horse's transducer head into during testing (two to three inches of water is sufficient). Testing the WorkHorse out of water may cause some tests to fail but causes no harm to the WorkHorse.

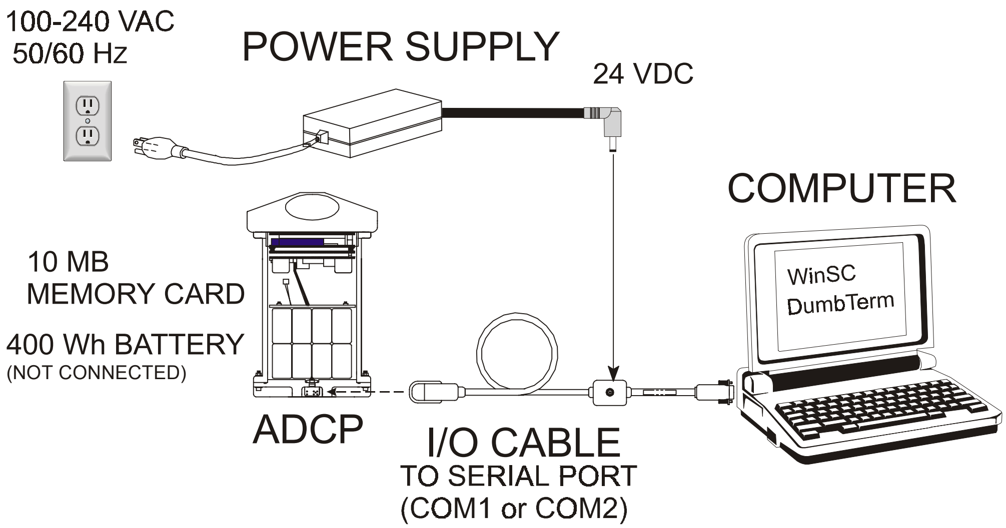


Figure 6. WorkHorse Sentinel Connections

5.1 Serial Communication

The standard communications settings are RS-232, 9600-baud, no parity, 8 data bits and 1 stop bit. Self-contained applications receive no benefit from setting a faster baud rate.

You can set the WorkHorse for baud rates other than 9600 baud. If you make the new baud rates permanent, *WinSC* will search for the correct set-tings, (and will try COM2 but not COM3 or COM4). If you tell *WinSC* these settings, you will save time required for searching. If you have trou-ble connecting to the WorkHorse, use *WinSC's* **Auto Detect**, which searches for the WorkHorse's current serial port and baud rate.

RS422. The WorkHorse Sentinel is normally set for RS232, but it can be changed to RS422 by changing a switch setting. The switch is in plain view on the top circuit board, near the cable connectors. Its settings are plainly marked on the board. If the serial protocol is set for RS422 and your computer expects RS232, you will need an RS232-RS422 adapter between the WorkHorse cable and your computer. This user's guide assumes that you use RS232. There is no reason to use RS422 for Self-Contained operation.

5.2 What if the WorkHorse Does Not Respond

If your WorkHorse does not respond, check the serial port, cables, AC power, and battery connection. If necessary, refer to the Troubleshooting Guide in the WorkHorse technical manual.

NOTE. WorkHorse Sentinels are shipped from the factory without the battery installed in the housing. Be sure to install the battery before deployment!

6 Software

RDI has utility programs to help you set up, use, test, and trouble-shoot your WorkHorse ADCP. Each program has a help file that you can print, or you can view help while running the program.

Table 5: WorkHorse Software

Program Name	Description
DumbTerm	Windows ADCP communication program. Use this program to "talk" to the ADCP and to run test script files. *DumbTerm* is included on the RDI Tools CD. For detailed information on how to use *DumbTerm*, see the *RDI Tools User's Guide*.
WinADCP	Gives users a visual display of the entire set of data. You can zoom in on a portion of the data for closer analysis and you can export data to text or MatLab files. For detailed information on how to use *WinADCP*, see the *WinADCP User's Guide*.
Documentation CD	The Documentation CD has an Adobe Acrobat® (*.pdf) electronic version of the WorkHorse Technical Manual. Use the Documentation CD to search for information. For detailed information on how to use Adobe Acrobat® and the Documentation CD, see the Read This First guide.

NOTE. See "WorkHorse Sentinel ADCP Applications," page 2 to see what software package to use for collecting data.

6.1 System Requirements

The WorkHorse software requires the following:

- Windows 95®, Windows 98®, or Windows® NT 4.0 with Service Pack 4 installed
- Pentium class PC 233 MHz (350 MHz or higher recommended)
- 32 megabytes of RAM (64 MB RAM recommended)
- 6 MB Free Disk Space (20 MB recommended)
- One Serial Port (two High Speed UART Serial Ports recommended)
- Minimum display resolution of 800 x 600, 256 color (1024 x 768 recommended)

6.2 Software Installation

To install the WorkHorse software, do the following.

a. Insert the compact disc into your CD-ROM drive and then follow the browser instructions on your screen. If the browser does not appear, complete Steps “b” through “d.”

b. Click the **Start** button, and then click **Run**.

c. Type **<drive>:launch**. For example, if your CD-ROM drive is drive D, type **d:launch**.

d. Follow the browser instructions on your screen

6.3 Utility Software

The following DOS programs (on the RDI Tools CD) have been provided to supplement features not yet implemented into the Windows environment. RDI will incorporate these features in future releases. These programs have been installed to the directory C:\Program Files\Rd Instruments\Utilities.

Table 6: WorkHorse DOS Utility Software

Program Name	Description
BBLIST	Executable program that can be operated through the Windows environment. This program will display binary data in tabular format as well as convert the data into an ASCII file.
BBBATCH	Automatically converts a named binary data set to a named ASCII data set using an existing format file. Use this program to convert binary files unattended through a DOS batch file.
BBCONV	Executable program that cannot be operated through the Windows environment. Removes user selected data from binary files and stores the information into ASCII comma delimited format. See BCONV.DOC for decoder file format.
BBMERGE	Executable program that cannot be operated through the Windows environment. BBMERGE merges ASCII comma delimited format data described by a decoder (.DEC) file into the raw BroadBand ADCP data file "infilename", resulting in an output ADCP data file called "outfilename". See BCONV.DOC for decoder file format.
BBSUB	Executable program that cannot be operated through the Windows environment. BBSUB starts copying ensembles from 'infilename' to 'outfilename' starting with the user specified "Start" and "End" ensemble number. This is intended to allow users to subsection binary data files.
SS	Executable program that can be operated through the Windows environment. SS allows you to quickly calculate the speed of sound in the water.
SURFACE	Executable program that cannot be operated through the Windows environment. Surface estimates the range from the ADCP to the water surface or bottom from the echo intensity data. This program does not change the original data. It creates a text file with the estimated ranges. Intended for customers to estimate where to cut off their data.
CHECKDAT	Executable program that cannot be operated through the Windows environment. CHECKAT will scan a data file for missing ensembles, ensemble number out of order, bad checksum ensembles and ensembles with bit errors. If the DOS redirect command (> symbol) is used then the output will be placed into a file.
C++ Code Library	The C++ Code library has been provided to help you in the creation of your own programs. These files are provided as is and in general are not supported. Use at your own discretion. The files are located in the directory: C:\Program Files\Rd Instruments\Utilities\C_Code.

6.4 WorkHorse Software Philosophy

Self-contained data collection involves a series of independent steps. Using *WinSC's* Deployment Wizard will ensure that the ADCP is setup correctly.

- Test your WorkHorse (*WinSC*)
- Plan your deployment (Plan can be run separately or run inside *WinSC*)
- Transfer your "plan" into the WorkHorse and start data collection (*WinSC*)
- Transfer the data from the WorkHorse's PC Card recorder to your computer (*WinSC*)
- Verify data integrity (*WinSC*)
- When you are satisfied that your recorded data is safely backed up, erase the WorkHorse PC Card recorder (*WinSC*)
- Display and process your data (*WinADCP* and *WinSC*)

The WorkHorse software is designed to allow you to set up your WorkHorse to get the best possible data without having to understand and use WorkHorse commands. *Plan* creates *command files*. These files hold the commands that will be sent to the WorkHorse to start the deployment.

6.5 File Naming Conventions

The WorkHorse software gives you a complete record of information that might help you understand your data. To help you associate these files with your data, they use the same deployment name. Be careful not to lose these files!

NOTE. Choose and use Deployment Names carefully: they help you identify and organize all the data and log files associated with each deployment.

Raw Data files produced by *WinSC* have the following filename format:
DeployName000.nnn

Where:

DeployName	is a user-entered name for the deployment (up to 128 characters),
000	is the deployment number (changes with each stop/restart),
nnn	is the recorder card number, which is incremented when the recorder card is full (.000 = card one, .001 = card two)

The file extensions have the following meaning:

DeployName.WHP	WorkHorse command file created by *Plan*.
DeployName.SCL	Deployment log file created by *WinSC*. This file contains all of the commands sent to the WorkHorse (from *.WHP) and the WorkHorse's system information before deployment.
DeployName.DPL	Binary deployment status file. This file keeps track of which steps were completed when using the deployment wizard.

7 Batteries and Power

All WorkHorse tests and operations work equally well using internal battery packs, external battery packs, or the AC power adapter.

7.1 AC Adapter

The AC Adapter runs on any standard AC power and supplies 24 VDC to run the WorkHorse when the batteries are not connected. Substitute your own power supply with a voltage of 45 to 60 VDC to override the 42 VDC alkaline battery packs.

NOTE. The 24 VDC AC adapter does not override the battery voltage!

NOTE. If you collect data using the AC adapter, the profiling range is reduced compared with standard battery voltage.

NOTE. Transmitted power increases or decreases depending on the input voltage. A fresh battery provides +42 VDC. Batteries spend most of their life at a nominal voltage of +33 VDC.

The transmitted power is decreased 1 DB if the input voltage drops from 42 VDC to 33 VDC. For a 300kHz WorkHorse ADCP, each DB will result in a decrease in range of one default depth cell.

7.2 Alkaline Battery Pack Capacity

RDI specifies its battery packs to have 400 watt-hours (Wh) of usable energy at 0°C.

7.3 External Battery Pack

The External Battery Pack holds two 400 watt-hours (Wh) batteries. To avoid affecting the compass, place the external battery case at least 30-cm away from the Sentinel WorkHorse.

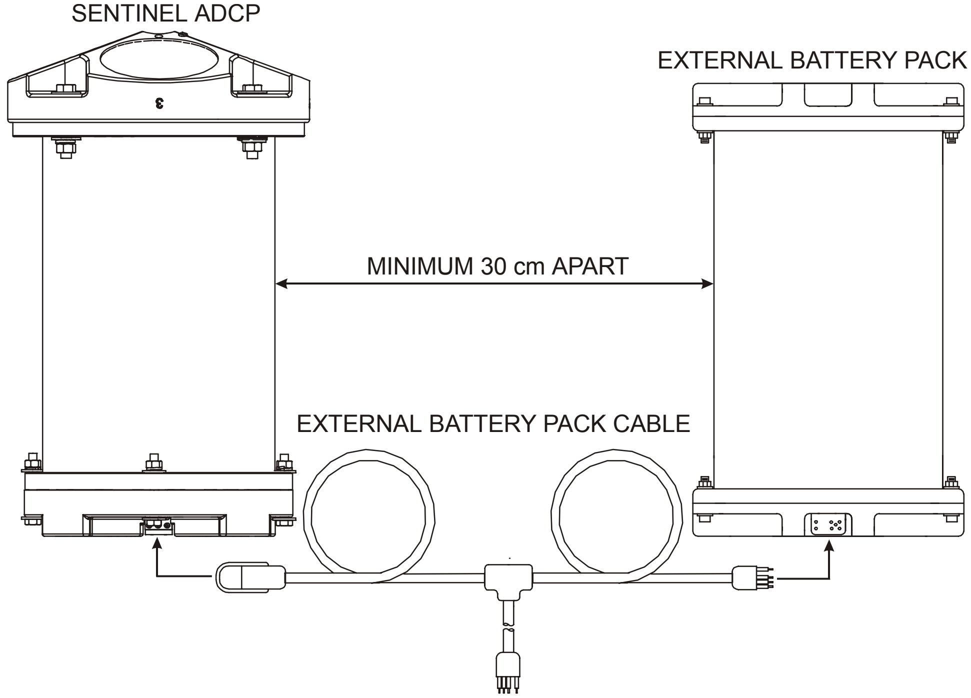


Figure 7. External Battery Pack Connection

7.4 Reusing Alkaline Batteries

Because many deployments will use only a fraction of the capacity of a single battery pack, you may wish to reuse your battery packs. With experience, you should be able to reuse batteries successfully, but keep in mind the following:

- Standard WorkHorse battery packs hold 28 'D-cell' alkaline batteries with a voltage, when new, of approximately 42 VDC.
- When the capacity of a battery pack is 50% used, the voltage (measured across the battery connector under no-load conditions) falls to approximately 32-35 volts. However, keep in mind that this voltage is not an accurate predictor of remaining capacity.
- Batteries should be replaced when the voltage falls below 30 VDC (measured across the battery connector under no-load conditions).
- Battery packs differ from one to another.
- If your deployment is important, weigh the cost of a new battery pack against the risk of lost data.

7.5 Bench-Top Battery Power Requirements

While the WorkHorse is awake and responding to commands, it consumes approximately 2.2 watts. A single internal battery pack supplies this power level for about five days. When the WorkHorse is asleep, it consumes less than one mw. A standard battery pack supplies sleep power for years. At every opportunity, the WorkHorse will “sleep” to conserve power while deployed.

7.6 Operation Modes

The WorkHorse has two modes of operation: *command mode*, and *ping mode* (also referred to as “Deployment Saver” Mode). Depending on what mode the ADCP is in; it will go either to sleep or to resume pinging.

In the Command Mode
Whenever you wake up your WorkHorse, power dissipation increases from less than one mw to around 2.2 w. If you leave the WorkHorse in command mode without sending a command for more than five minutes, the WorkHorse automatically goes to sleep. This protects you from inadvertently depleting batteries.

In the Ping Mode
After you send commands to the WorkHorse that tells it to start collecting data, the WorkHorse goes into deployment saver mode. If power is somehow removed and later restored, the WorkHorse simply picks up where it left off and continues to collect data using the same setup.

8 Testing Your WorkHorse

Use the following steps to test the ADCP.

a. Connect and power up the ADCP as shown in Figure 6, page 11.

b. Start *WinSC* (for help on using *WinSC*, see the *WinSC* User's Guide)

c. At the **Welcome** screen, click **Test an ADCP**. Click **OK**. This will run the pre-deployment tests Deploy?, System?, TS?, PS0, PA, PC2, RS, and PC1. The results of the tests will be printed to the screen and saved to the log file (*.scl).

Table 7, page 19 lists the tests *WinSC* runs, gives you guidelines for running the tests, and tells you what the results mean.

Table 7: WorkHorse ADCP Tests

Test	Guidelines	Results
Deploy?	This will show a list of the deployment commands and their current setting.	Verify the command settings.
System?	This will show a list of the system commands and their current setting.	Verify the command settings.
TS?	This will show the current setting of the real time clock.	Verify the clock setting.
PS0	Displays system parameters.	Verify the information is consistent with what you know about the setup of your system.
PA	Extensive pre-deployment test that tests the signal path and all major signal processing subsystems. This test may not pass unless the WorkHorse transducer face is immersed water.	All tests must pass.
PC2	Continuously updates sensor display. Rotate and tilt WorkHorse and watch the readings on the display change.	Satisfy yourself that the readings make sense.
RS	This will show the amount of used and free recorder space in megabytes.	Verify the recorder space is sufficient for the deployment.
PC1	Beam continuity test. Follow instructions to rub each beam in turn to generate a noise signal the WorkHorse uses to verify the transducer beam is connected and operational.	All beams must pass.

9 Compass Calibration

The main reason for compass calibration is battery replacement. Each new battery carries a different magnetic signature. The compass calibration algorithm corrects for the distortions caused by the battery to give you an accurate measurement. You should be aware of the following items:

- We recommend against calibrating the WorkHorse while on a ship. The ship's motion and magnetic fields from the hull and engine will likely prevent successful calibration.
- If you think your mounting fixture or frame has some magnetic field or magnetic permeability, calibrate the WorkHorse inside the fixture. Depending on the strength and complexity of the fixture's field, the calibration procedure may be able to correct it.

> **NOTE.** If you will deploy your WorkHorse looking up, calibrate it looking up. If you will deploy it looking down, calibrate it looking down.

9.1 Preparing for Calibration

a. Place the WorkHorse on a piece of strong cardboard on top of a smooth wooden (non-magnetic) table. If a wooden table is not available, place the WorkHorse on the floor as far away from metal objects as possible. Use the cardboard to rotate the WorkHorse during calibration—this way you will not scratch the WorkHorse.

b. Connect the WorkHorse as shown in "Setup the WorkHorse Sentinel ADCP," page 11.

c. Start *DumbTerm*. See the RDI Tools User's Guide for assistance on using *DumbTerm*.

9.2 Compass Calibration Verification

Compass calibration verification is an automated built-in test that measures how well the compass is calibrated. The procedure measures compass parameters at every 5º of rotation for a full 360º rotation. When it has collected data for all required directions, the WorkHorse computes and displays the results.

> **NOTE.** Verify the compass if you have just replaced the battery, memory module, or any ferrous metals is relocated inside or around the WorkHorse housing.

Start the test with the AX-command and follow the instructions. **Place the ADCP in the same orientation as it will be deployed.** The WorkHorse can be vertical (it can rest on its end cap), or it can be tilted (it could rest on a transducer face). Whatever its tilt, the tilt must remain constant as you rotate the WorkHorse. When prompted, rotate the WorkHorse smoothly and slowly. Pay particular attention to the Overall Error. For example;

```
HEADING ERROR ESTIMATE FOR THE CURRENT COMPASS CALIBRATION:
   OVERALL ERROR:
      Peak Double + Single Cycle Error (should be < 5():  ( 1.55(
   DETAILED ERROR SUMMARY:
      Single Cycle Error:                                ( 1.54(
      Double Cycle Error:                                ( 0.07(
      Largest Double plus Single Cycle Error:            ( 1.61(
      RMS of 3rd Order and Higher + Random Error:        ( 0.31(
```

If the overall error is less than 5°, the compass does not require alignment. You can align the compass to reduce the overall error even more (if desired).

NOTE. *WinSC* does the compass verification as part of the Deployment Wizard (see "Verify the Compass," page 30).

9.3 Compass Calibration Procedure

The built-in automated compass calibration procedure is similar to the alignment verification, but requires three rotations instead of one. The WorkHorse uses the first two rotations to compute a new calibration matrix and the third to verify the calibration. It will not accept the new matrix unless the calibration was carried out properly, and it asks you to verify that you want to use the new calibration if it is not as good as the previous calibration. While you are turning the WorkHorse for the two calibration rotations, the WorkHorse checks the quality of the previous calibration and displays the results. It compares these results with the results of the third calibration rotation.

There are two compass calibrations to choose from; one only corrects for hard iron while the other corrects for both hard and soft iron characteristics for materials rotating with the ADCP. Hard iron effects are related to residual magnetic fields and cause single cycle errors while soft iron effects are related to magnetic permeability that distorts the earth's magnetic field and causes double cycle errors. In general, the hard iron calibration is recommended because the effect of hard iron dominates soft iron. If a large double cycle error exists, then use the combined hard and soft iron calibration.

a. Start *DumbTerm*.

b. Start the test with the AF-command and choose the calibration type.

c. Place the ADCP in the same orientation as it will be deployed.

d. When prompted, rotate the WorkHorse slowly 360 degrees.

e. The second rotation requires the WorkHorse to be tilted on an adjacent beam. Follow the on-screen instructions to orient the unit correctly. Tilt an upward-looking WorkHorse with a block under one side of the end cap. A 35-mm block gives you an 11º tilt. When prompted, rotate the WorkHorse slowly 360 degrees.

f. If the calibration procedure is successful, it records the new calibration matrix to nonvolatile memory. The WorkHorse will not change its matrix unless the calibration is properly carried out.

g. If the calibration procedure is not successful, return your WorkHorse to the original factory calibration, by using the AR-command. Try using the AR-command if you have trouble calibrating your compass. In some circumstances, a defective compass calibration matrix can prevent proper calibration.

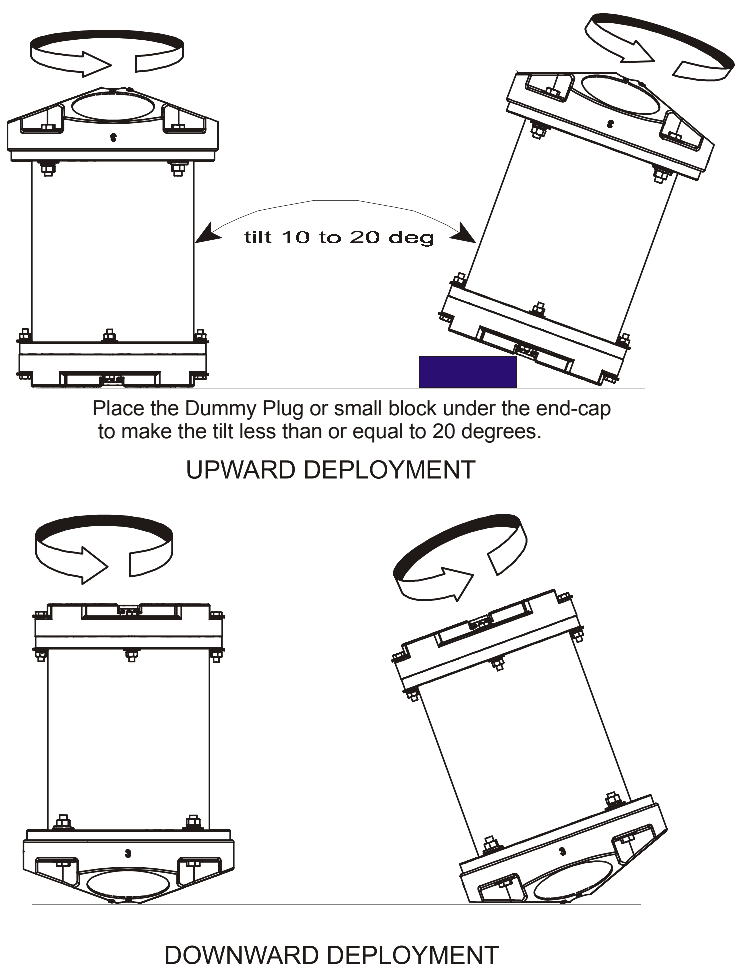


Figure 8. Compass Alignment

10 Internal Pressure Sensor

If you have the optional pressure sensor installed in your ADCP, use the AZ-command to zero out the pressure sensor at the deployment site.

a. Connect and apply power to the system as described in "Setup the WorkHorse Sentinel ADCP," page 11.

b. Start *DumbTerm* and wakeup the ADCP (press the **END** key).

c. Type **AZ** and press the **Return** key.

d. Exit *DumbTerm*.

10.1 Pressure Sensor Maintenance

In order to read the water pressure (depth), water must be able to flow through the copper screw on the pressure sensor. Antifoulant paint will block the sensor's port (a small hole that is drilled through the copper screw). You should tape off the screw during anti-fouling paint application.

This means that the sensor port is not fully protected from bio fouling. The sensor port is surrounded by the antifouling paint, but bio fouling may build up on the screw, and eventually clog the sensor port. However, most organisms do not seem to find the small amount of unpainted surface attractive. If it is logistically possible to periodically inspect/clean the pressure sensor screw, it is highly recommended. This tradeoff situation must be analyzed for individual deployments. Unfortunately, the location of the deployment site usually dictates action in this regard.

NOTE. The pressure sensor is optional. It may not be included on your system.

CAUTION.

The pressure sensor is filled with silicone oil. Never poke a needle or other object through the copper screw while the screw is installed over the pressure sensor. You will perforate the sensor, causing it to fail.

Do not remove the cover disc or attempt to clean the surface of the pressure sensor. The diaphragm is very thin and easy to damage.

Do not remove the pressure sensor. It is not field replaceable.

11 Deployment Guide

Use the following steps and the Quick Reference card to setup the Work-Horse for a Self-Contained deployment.

11.1 Deployment Checklist

- ❑ Test the ADCP using *WinSC*
- ❑ Seal the ADCP for deployment
    - ❑ Install new o-rings; use silicone lubricant
    - ❑ Use fresh desiccant (2 bags) inside ADCP
    - ❑ Install and connect the battery
    - ❑ Check Recorder PC card is installed
- ❑ Visually inspect the ADCP
    - ❑ Check the transducer head condition
    - ❑ Check the zinc anode condition (High Pressure Housing only)
    - ❑ Check the housing paint condition (High Pressure Housing only)
    - ❑ All mounting hardware installed
    - ❑ Transducer faces clean and free from defects
- ❑ Verify the compass alignment using *WinSC*; if necessary, re-calibrate
- ❑ Check recorder status using *WinSC*
- ❑ Are biofouling precautions needed?
- ❑ Verify battery and recorder space requirements
- ❑ Zero pressure sensor (optional) at deployment site with AZ-command
- ❑ Install the dummy plug; use silicone lubricant

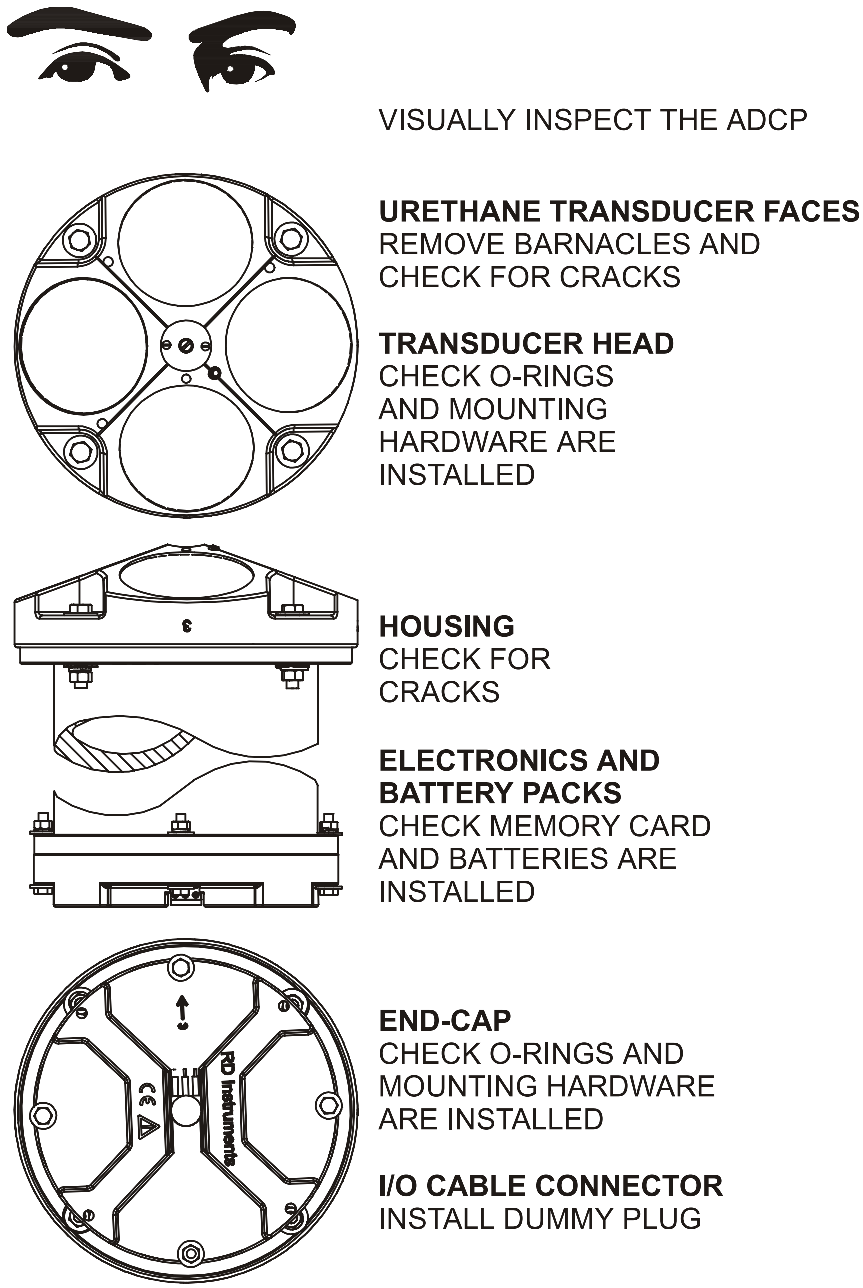


Figure 9. Visual Inspection before Deployment

11.2 Prepare the ADCP for Deployment

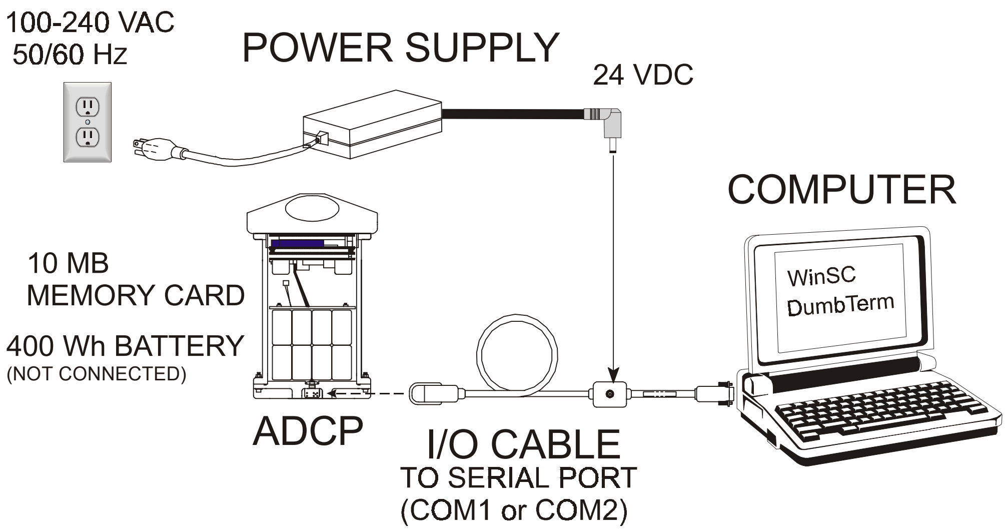


Figure 10. Prepare the ADCP

Things to remember while preparing the ADCP.

- Use the Deployment Checklist to verify that the ADCP is ready for the deployment.
- Test the ADCP using *WinSC*. Some tests will fail if the ADCP is not placed in water while the tests are being run.
- Use the AC power supply while testing the ADCP. Save the batteries for deployments.
- *Desiccant* lasts a year at specified WorkHorse deployment depths and temperatures. Remember that desiccant rapidly absorbs moisture from normal room air. Replace the desiccant whenever the WorkHorse housing or end-cap is removed.
- Verify the compass calibration.

11.3 Use the Deployment Wizard

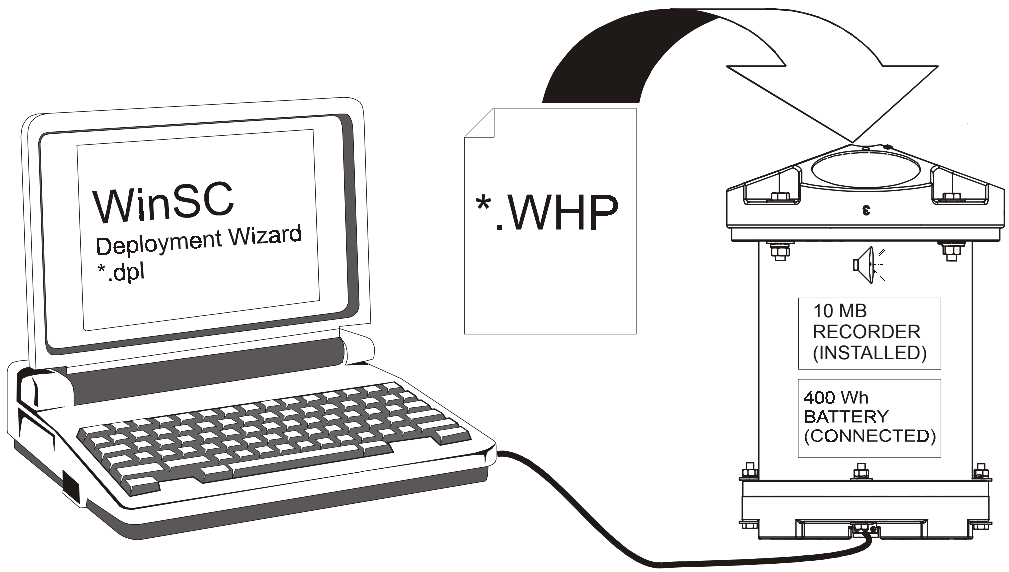


Figure 11. Using the Deployment Wizard

There are five steps the **Deployment Wizard** helps lead you through; Planning, Setting the ADCP's clock, Compass Verification, Pre-Deployment Tests, and sending/verifying the commands to the ADCP. RDI highly recommends using the wizard each time you deploy the ADCP. The deployment wizard will start whenever a new deployment file is created. To use the deployment wizard, do the following.

a. Connect and power up the WorkHorse.

b. Start *WinSC*.

c. Start the Deployment Wizard by doing *one* of the following.

- At the **Welcome** screen, click **Configure an ADCP for a New Deployment**. Click **OK**.
- Click **File**, **New Deployment** (the deployment wizard will start automatically).
- If you are working on an open deployment file (*.dpl), on the **Functions** menu, click **Deployment Wizard**.

> **NOTE.** Choose and use Deployment Names carefully: they help you identify and organize all the data and log files associated with each deployment.

11.3.1 Plan the Deployment

The first step in the Deployment Wizard is planning. When you click **Next**, the program *Plan* will start. For more information on *Plan*, see the WinSC User's Guide. If you want to skip this step, check the **Skip** box, or click **Next** to begin using *Plan*.

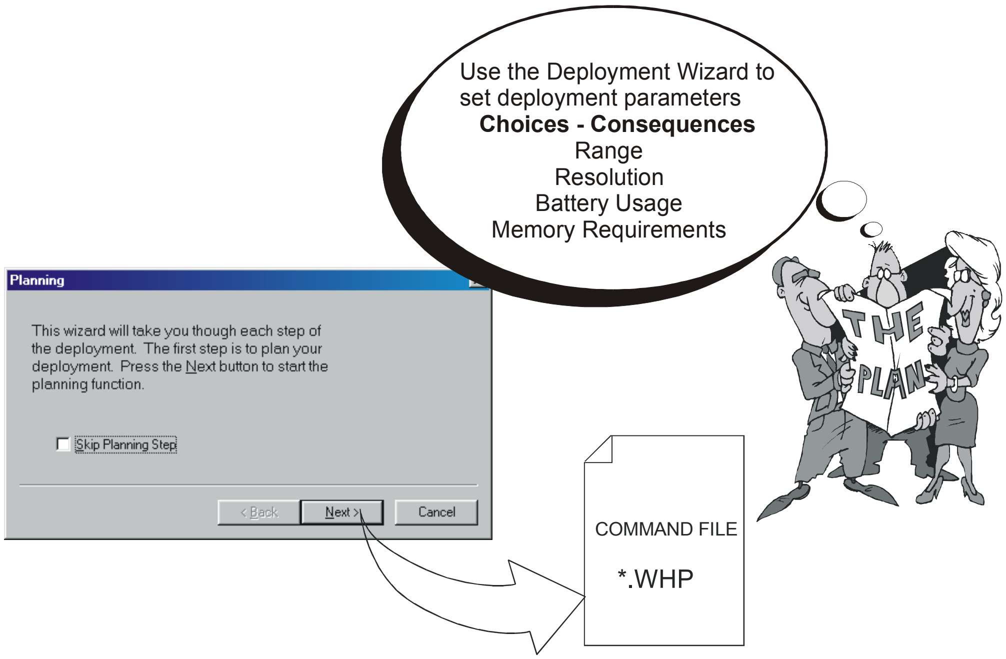


Figure 12. Plan the Deployment

Things to remember while using *Plan*.

- *Plan* can be run separately or within *WinSC*.
- *Plan* allows you to make choices and see the consequences for the *entire* deployment. Once you decide on the optimum deployment setup, it creates a *Command File* with the commands you will later use to set up the WorkHorse for deployment.
- *Plan* assumes that the WorkHorse is set to its factory defaults (it includes commands in the Command File that put the WorkHorse back to the factory defaults), and it adjusts only a subset of the available commands. Expert users may add other commands to the Command File.
- *Uniform sample times*. Start sample intervals on the minute by using a delayed start up. Instead of having your 10-minute sample intervals start at 15:36:47, delay startup a few minutes to have samples start at 15:40:00.

11.3.2 Set the ADCP's Clock

The second step in the Deployment Wizard will set the ADCP's clock to the computer's time and date using the TS-command. For more information on the TS-command, see the Command and Output Data Format Guide. If you want to skip this step, check the **Skip** box or click **Next** to begin setting the clock.

> **NOTE.** *WorkHorse time* is set from your computer's time. Be sure your computer is set to the time appropriate for your deployments before you use *WinSC* to start data collection.

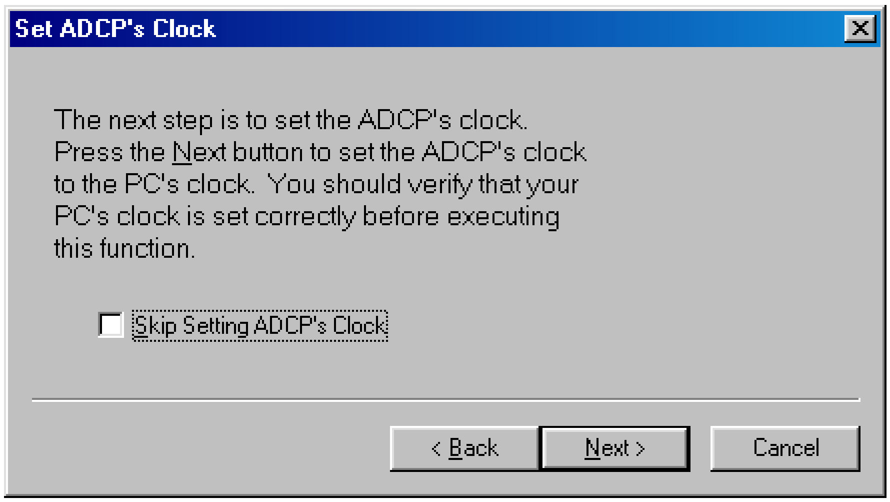


Figure 13. Deployment Wizard – Setting the Clock

11.3.3 Verify the Compass

The third step in the Deployment Wizard will verify the compass using the AX-command. For more information on the compass verification, see "Compass Calibration Verification," page 20. If you want to skip this step, check the **Skip** box or click **Next** to begin verifying the compass.

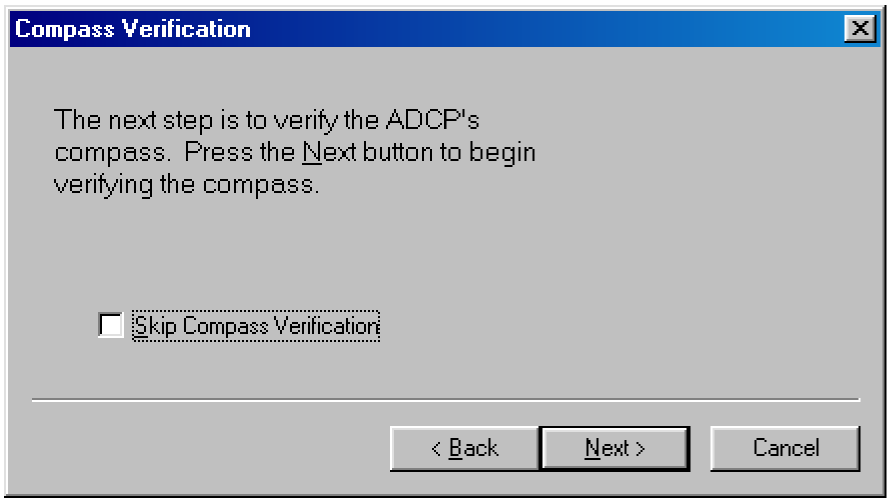


Figure 14. Deployment Wizard – Compass Verification

11.3.4 Run the Pre-Deployment Tests

The fourth step in the Deployment Wizard will run the pre-deployment tests Deploy?, System?, TS?, PS0, PA, PC2, RS, and PC1-commands. For more information on how to test your ADCP, see "Testing Your WorkHorse," page 18. If you want to skip this step, check the **Skip** box or click **Next** to begin the pre-deployment tests.

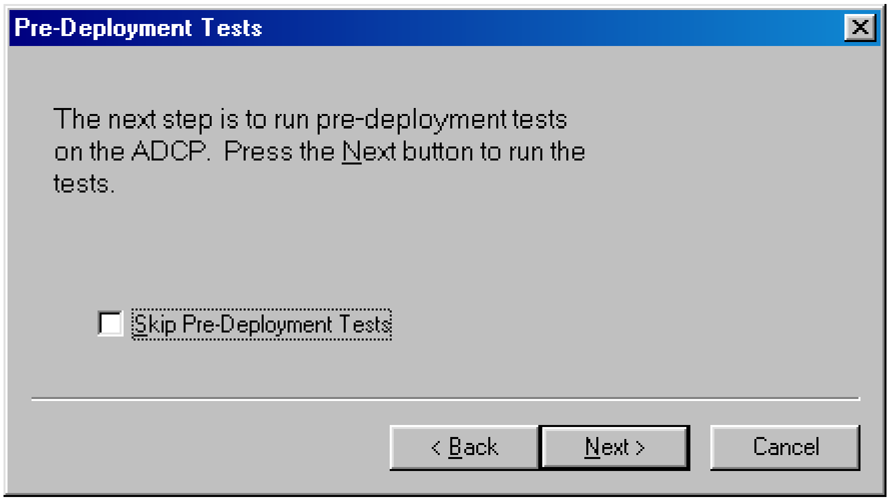


Figure 15. Deployment Wizard – Test the ADCP

11.3.5 Send the Commands

The fifth and final step in the Deployment Wizard will send the commands from the command file to the ADCP. Click **Next** to send the commands. When the commands have been sent to the ADCP, you should see a message "*You have successfully deployed the ADCP*." Click **OK**.

NOTE. If you have created a new deployment file, you will be prompted to name the deployment. Choose and use Deployment Names carefully: they help you identify and organize all the data and log files associated with each deployment.

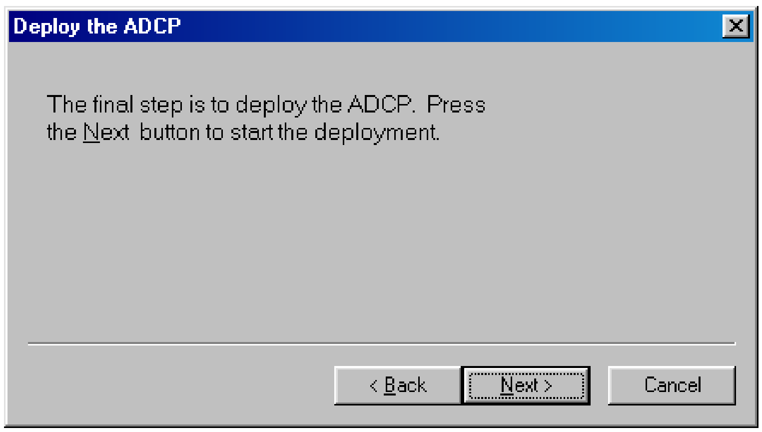


Figure 16. Deployment Wizard – Send the Commands

- The WorkHorse must be using battery power and be sealed, ready for deployment.
- *Ping beeps*. Whenever the WorkHorse pings, an internal beeper makes an audible beep. The beep consumes negligible energy and tells you the WorkHorse is pinging. If your command file has a Time of First Ping command, the ADCP will wait until that time to begin pinging, and therefore you will not hear it beep.
- View the deployment log file. This file shows all of the commands sent to the WorkHorse and the ADCP's response. If a command generates an error message, correct the problem and re-send the commands.

CAUTION

Do not send a break, any other command, or run any other programs once the commands have been sent to the ADCP or your commands will be over-written.

Disconnect the I/O cable before turning off power to the computer. Some computers may send a break signal out the serial ports when shutting down.

11.4 Deploy and Recover the ADCP

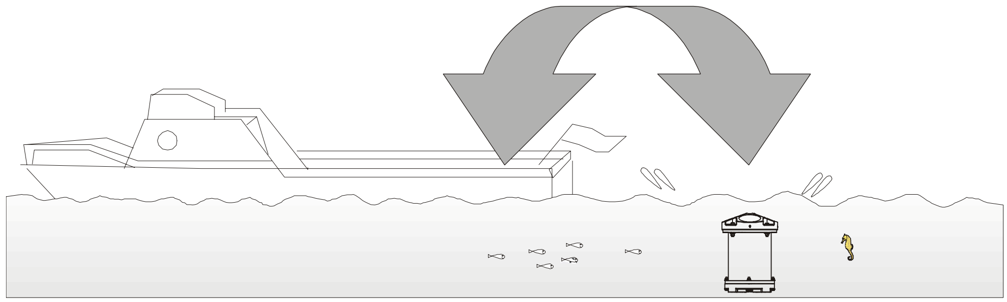


Figure 17. Deploy and Recover the ADCP

Things to remember while deploying the ADCP.

- Data files are *.SCL (deployment log file) and *000.000 (raw data). For example, if your deployment file is named Test.dpl, then the deployment log file will be Test.scl and the raw data file will be Test000.000.
- *Tilts*. The WorkHorse corrects data for tilts as large as 15°, but tilts reduce the effective range and increase the depth of surface contamination.
- *Anti-fouling paint*. You are free to use anti-fouling paint or other anti-fouling material over any surface of the WorkHorse. However, you should consider the following:
  1. Ensure that your coating can be used safely on plastic in general and polyurethane specifically.
  2. Apply it thinly and evenly to the transducer faces.
  3. Poorly applied coatings on the transducer could adversely affect instrument performance.
- *Magnetic material*. Keep the WorkHorse's compass away from magnetic material when you deploy the instrument. Check for magnetic fields by smoothly moving a compass around and near the WorkHorse and its mounting frame.

11.5 Recover the Data

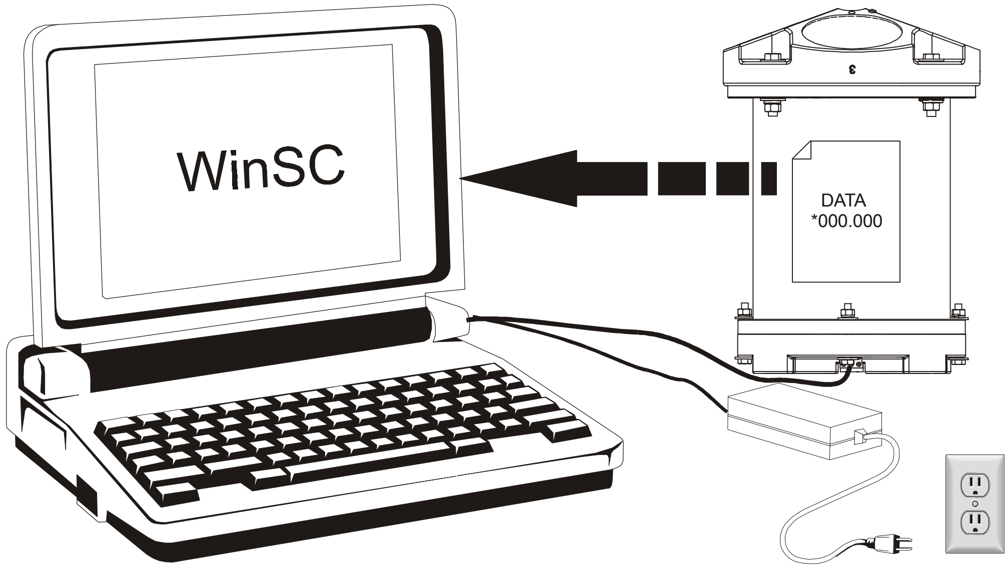


Figure 18. Recover the Data

Data are recorded internally on flash memory PC Cards that can be removed and plugged into many PC computers (especially laptops) and read the same as from any hard drive. If your computer is able to read the WorkHorse's flash card, recovering the data is as simple as copying from one disk to another.

However, be aware that because each computer uses different PC Card drivers, installing PC Card drivers on a laptop is not necessarily easy. If you cannot read the memory cards in your computer, use *WinSC* to read the data through the WorkHorse's serial port. RDI can supply or recommend laptops that can read our PC Card flash cards. Remove the flash cards by pushing a button on one side of the PC Card (see Figure 5, page 8). PC cards are installed with the label side toward the face of the transducer.

WinSC reads data files from the WorkHorse PC Card recorder via the serial port and saves the data to the computer's hard disk. It uses the WorkHorse's current Deployment Name to create a new directory for the data on the computer's hard drive. You can specify a different destination directory when you run *WinSC*. When *WinSC* is finished, you will find on your PC all the same files that are on your WorkHorse, and in the exact same format. *WinSC* transfers all data files even if you have recorded more than one deployment. *WinSC* transfers data using an error-correcting protocol (YMODEM), so you can be confident about the integrity of the data files.

11.6 Verify and View the Data

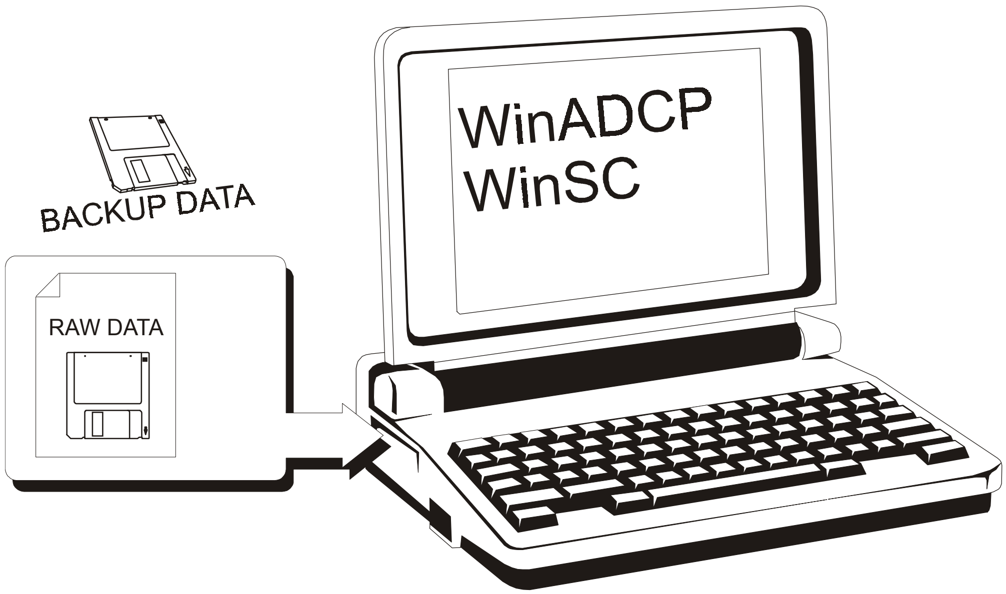


Figure 19. Verify and View the Data

WinSC rapidly scans each ensemble in your data files and checks them for integrity and quality. Its primary purpose is to ensure that you have properly transferred the data to your computer, but it also does some simple error and problem checking. Keep in mind that *WinSC* does not check every possible problem with your data.

> **NOTE.** Check your data carefully and back it up before erasing the WorkHorse's data recorder.

WinADCP plays back data in a variety of formats (i.e. profiles, time series, and color contour plots). To view the data using *WinADCP*, open the raw data file.

To zoom in on the data, hold down the **Space Bar** and then click and hold the **Left mouse button** to create a "rubber band" selection box. When the mouse button is released, the selected portion of the Whole set is marked by a blinking box outline. The blinking box outlines a set of data called the Selected Set.

> **NOTE.** The Whole Set or Sub Set form must be selected (the title bar color is highlighted) before the space bar is pressed.

11.7 Erase the Recorder

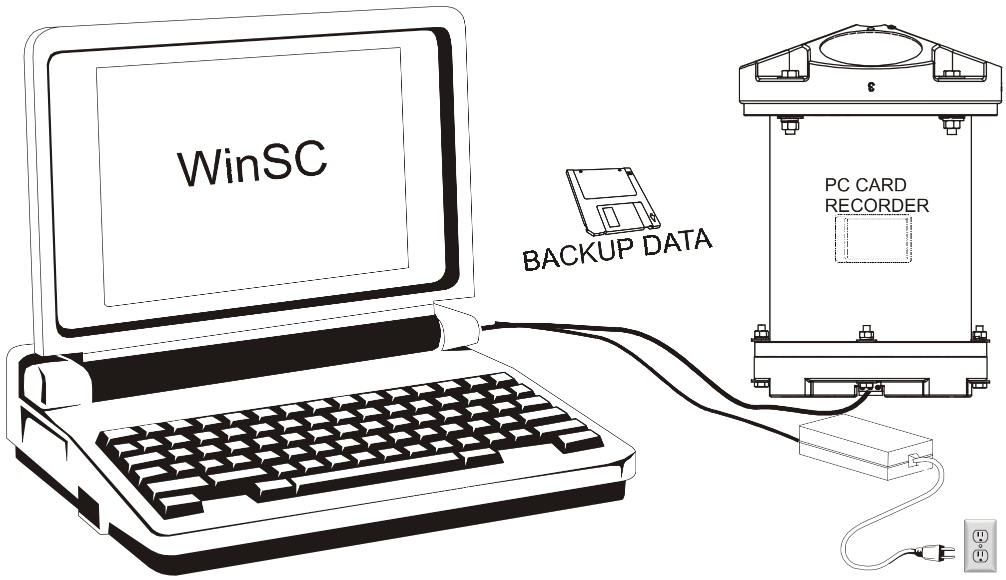


Figure 20. Erase the Recorder

WinSC can be used to erase the data recorder inside the WorkHorse. When instructed, *WinSC* erases all files in the recorder (be sure your data are safely backed up!). If you read the PC Card by putting it into your computer, you may delete the file(s) using the DOS delete command. Before you can delete the file, you must use the DOS attribute command to reset the read-only attribute.

12 Backing Up Data

Once you have recovered the data from your PC Card recorder, you should get in the habit of backing up all data files. Here are several examples of how to backup data.

- Use PKZIP to condense the files and store them on floppy disks. PKZIP has the ability to store large files (span) onto several disks.
- Remove the original PC Card containing data and store it in a safe place. Install another PC Card in its place.
- Backup your data to a CD-RW or other device.
- Download the data to another computer.

13 Reviewing the Data

13.1 'Where' was the Data?

The quickest way to find out the depth of each depth cell is to display your recorded data using *WinADCP*. The velocity display tells you the distance to the center of each cell. The computed distance assumes that the speed of sound is constant from the transducer to the depth cell. The actual distance is proportional to the average sound speed; if the average sound speed is 1% less than the sound speed at the transducer, the distance to the depth cell is 1% less than the displayed distance.

13.2 'When' was the Data?

The time recorded with each data record is the time of the beginning of the first ping of the ensemble. *Plan* sets the ping interval so pings occur uniformly across the ensemble interval (as opposed to putting all the pings at the beginning of the interval). It leaves a few seconds at the end of each ensemble to allow time for data recording. Hence, the average time of the ensemble is midway between the recorded ensemble time and the time of the next ensemble.

13.3 'What' is the Data?

The WorkHorse records velocity data in units of mm/s. Calibration depends on how well the WorkHorse knew the speed of sound (which it computed based on its measured temperature and the salinity value it was given). A salinity error of 5 ppt introduces less than 0.5% velocity error.

14 A Few Principles of Operation

Consult RDI's Primer (ADCP Principles of Operation: a Practical Primer, Second Edition for BroadBand ADCPs) to learn more about WorkHorse principles of operation. The following are a few points from the Primer that may be worth knowing:

- Horizontal velocity measurement accuracy is unaffected by vertical stratification.
- Stratification has negligible affect on the ability of the WorkHorse to penetrate through the water; concentration of suspended particles is the main factor influencing profiling range.
- WorkHorse measurements are automatically corrected for tilts up to ±20°. In addition to correcting for the beam pointing angles, the WorkHorse maps depth cells to other cells at the same depth.
- If you want to make measurements near the surface from a bottom-mounted WorkHorse, you should minimize the tilt.
- Depth cells are most sensitive to velocities at the center of the depth cell and less sensitive at the top and bottom. This sensitivity is reflected by what we call a 'triangular weighting function'. The details of this weighting function are rarely important for interpretation and use of your data.
- The actual maximum range can be different from the range predicted in *Plan*. *Plan* corrects for range variations caused by temperature and salinity, but it assumes typical scattering conditions. Weak backscatter can sometimes reduce range by a factor of two or more.
- In self-contained deployments, the maximum profiling range decreases with time as the battery voltage falls. This is because transmit power depends on battery voltage. Transmit power is optimized for about 32 volts. RDI's alkaline battery packs start at 42 VDC, but spend most of their useful lives within a few volts of 32 VDC.

15 Technical Support

If you have technical problems with your instrument, contact our field service group in any of the following ways:

RD Instruments	**RD Instruments Europe**
9855 Businesspark Ave.	5 Avenue Hector Pintus
San Diego, California 92131	06610 La Gaude, France
(858) 693-1178	+33(0) 492-110-930
FAX (858) 695-1459	+33(0) 492-110-931
Sales - rdi@rdinstruments.com	rdi@rdieurope.com
Field Service - rdifs@rdinstruments.com	rdifs@rdieurope.com

Web: www.rdinstruments.com

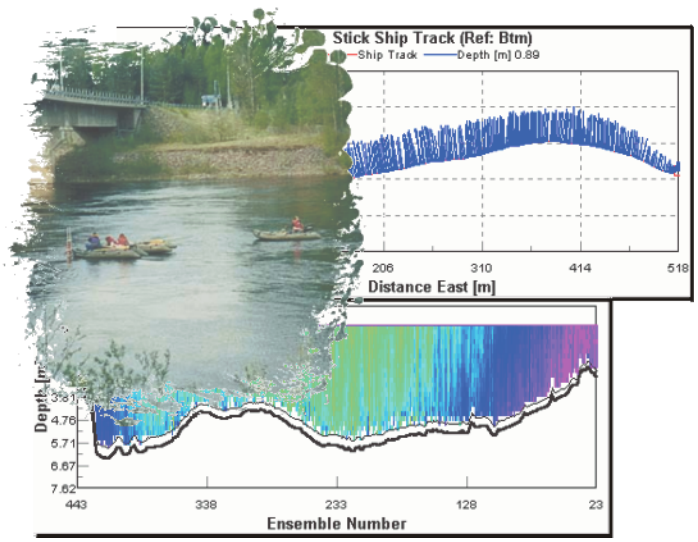
NOTES

NOTES

WinRiver User's Guide

WinRiver

User's Guide



RD Instruments

Acoustic Doppler Current Profilers

P/N 957-6096-00 (June 2000)

Table of Contents

List of Figures

List of Tables

NOTES

WinRiver User's Guide

1 Introduction

The *WinRiver* User's Guide is divided into three main sections:

Quick Start Guide – The Quick Start Guide has simple instructions for a typical discharge measurement using the ADCP only (no GPS or Depth Sounder).

WinRiver Tutorial – The tutorial has detailed explanations on how to create a configuration file and procedures for acquiring and processing discharge data.

Additional Topics

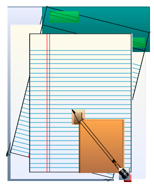
- ADCP and discharge measurement basics
- The *WinRiver* configuration file
- Water profiling modes
- Integrating GPS and Depth Sounders
- Troubleshooting

Making accurate discharge measurements is less difficult than you probably believe now. You will soon see that you need to use only a few keystrokes on the computer to collect data in the field.

Please take the time to read this entire manual. It will be useful to have the ADCP and a computer available to follow along. You may also want to keep the other ADCP Technical manuals handy for reference when you want more detail.

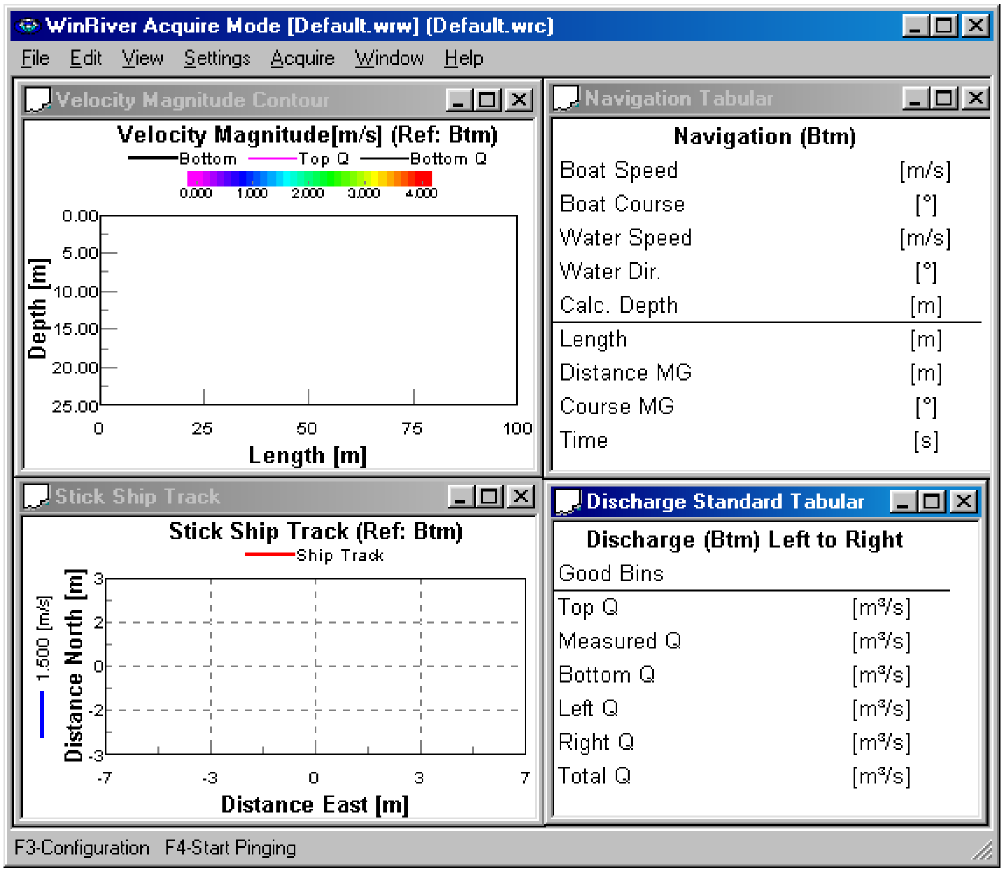
2 Quick Start Guide

Connect the ADCP and computer as shown in your Read This First book. Mount the ADCP on the boat at the desired depth. If you have not already installed the *WinRiver* and *DumbTerm* programs do so as outlined in the Read This First book. Run *DumbTerm* to verify the ADCP is functioning properly.

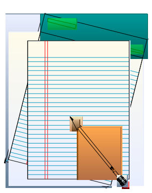


Use this area for notes.

2.1 Start *WinRiver*

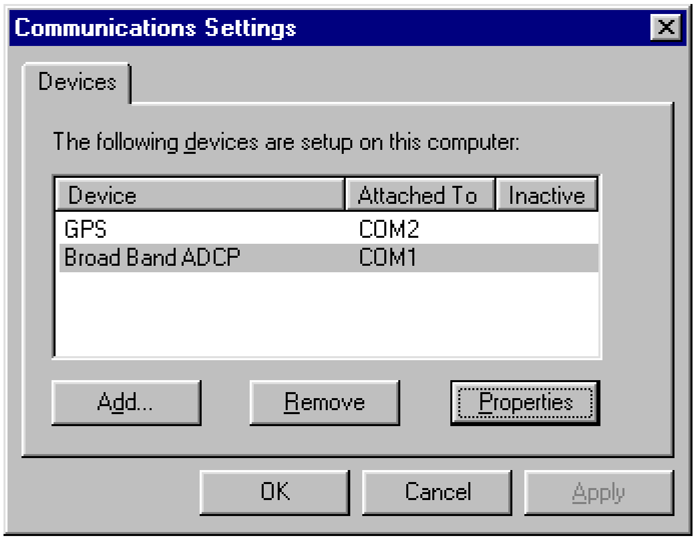


Step 1. Start *WinRiver* in the Acquire mode. If you are in the Playback mode, click **File**, **Acquire Mode**.

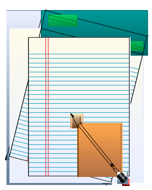


Use this area for notes.

2.2 Setup Communications



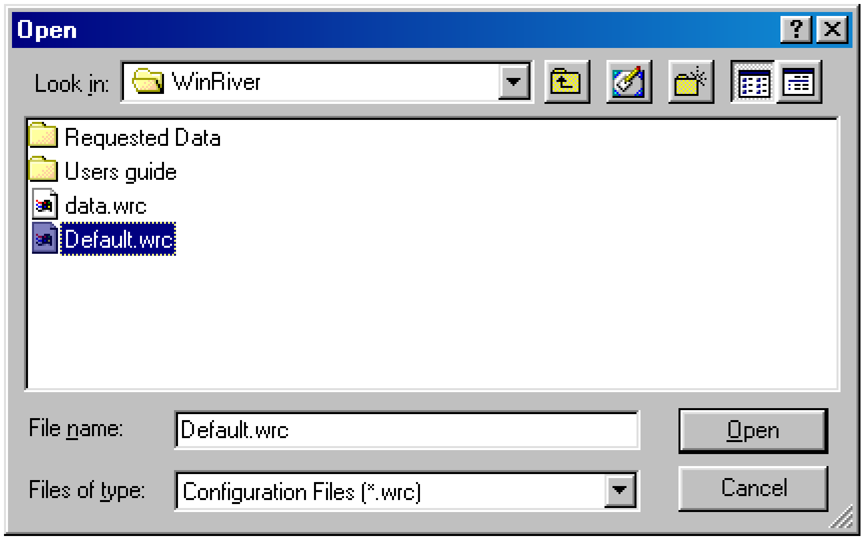
On the **Settings** menu, click **Communications** to specify the communications port parameters and devices (ADCP, GPS and/or Depth sounder).



Use this area for notes.

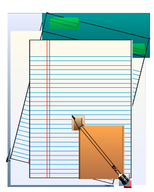
NOTE. If you want to change the Com Port selection, use the **Remove** button and then **Add** the port back in. If you want to change the baud rate or other properties, click the **Properties** button.

2.3 *WinRiver* Configuration File



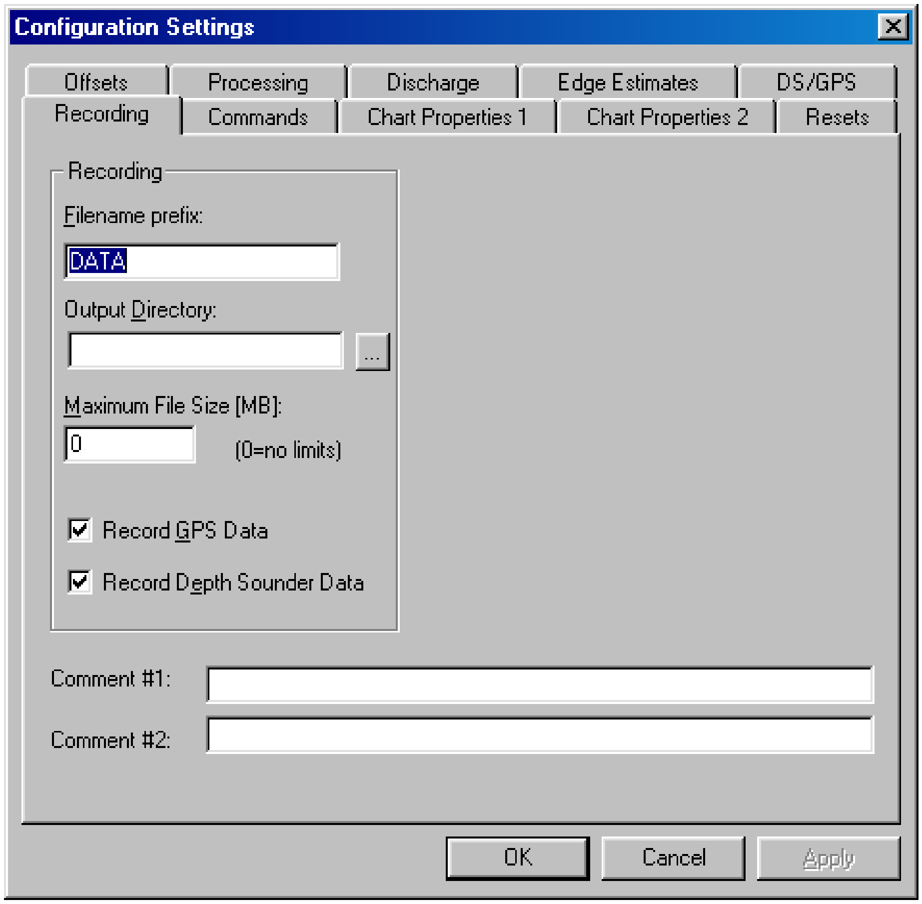
***Step 2*.** The configuration file stores all the processing parameters. Create a new configuration file by clicking **File**, **New Configuration File.** Open a configuration by clicking **File**, **Open Configuration File** (you can customize *WinRiver* to automatically load the last used configuration file or be prompted to load the file manually when the Acquire mode is started).

When creating a configuration file for data collection the most important parts in a configuration file are the **Commands** and **Recording** tabs (see next page). The rest of the parameters can be changed during playback and do not influence data collection.

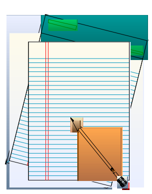


Use this area for notes.

2.4 Configuration File – Recording Tab



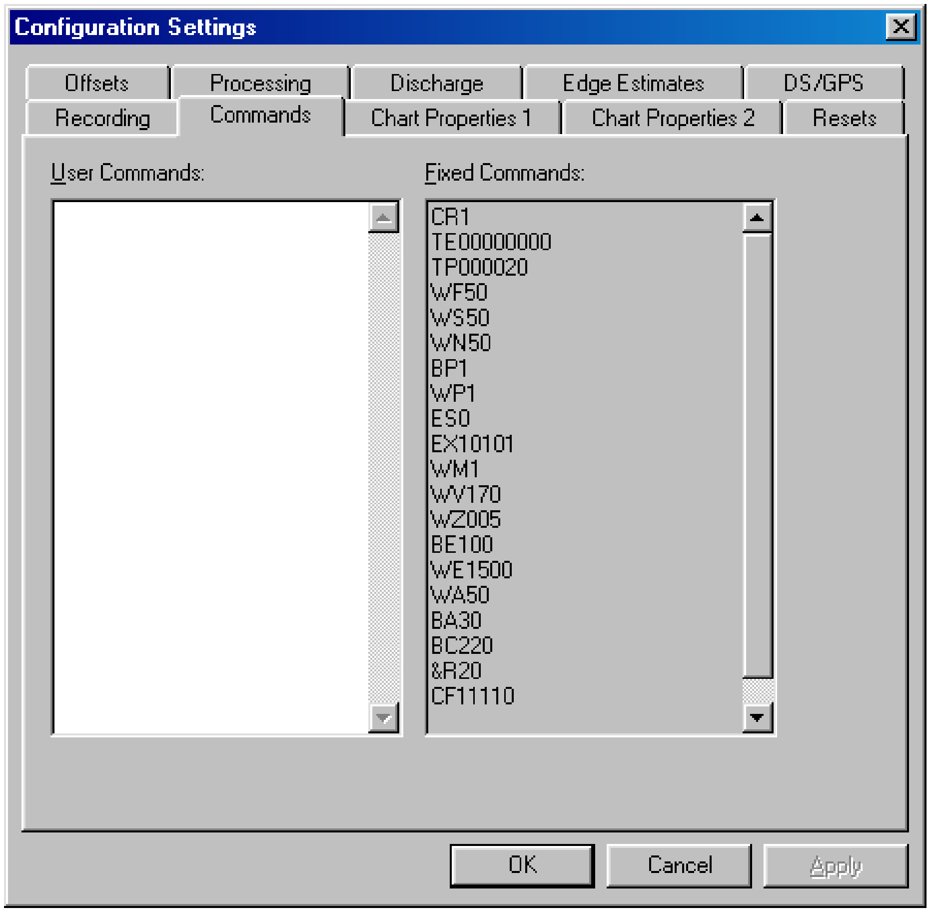
Step 3. The **Recording** tab lists the parameters used to define where the data is recorded during data collection. *WinRiver* uses the **Filename Prefix** to create the data file names made during data collection. Use the **Output Directory** field to select where the data file will be stored.



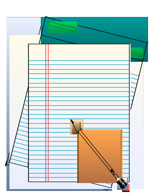
Use this area for notes.

NOTE. The configuration file names (*w.000 and *w.001) are keyed to the file name prefix.

2.5 Configuration File – Commands Tab



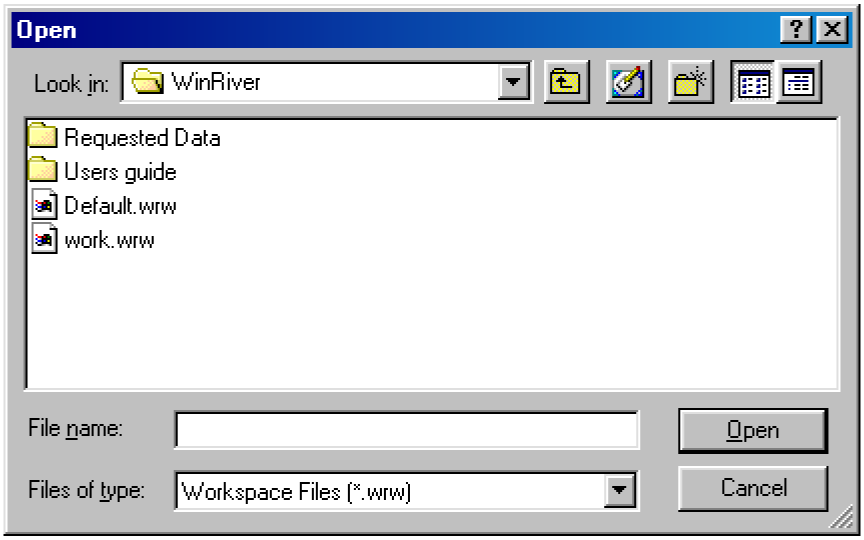
Step 4. You can directly control the profiling parameters sent to the ADCP using the User Commands box. To cover the whole profile, set the depth cell size (WS-command) and number of depth cells (WN-command) according to the maximum depth of the river. See "ADCP Commands," page 80 for more details.



Use this area for notes.

NOTE. The default commands will work on rivers up to 25 meters deep.

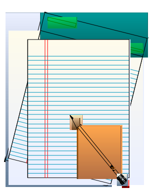
2.6 *WinRiver* Workspace File



***Step 5*.** A Workspace file contains the windows and arrangement of the windows that you are interested in. To open a workspace file click **File**, **Open Workspace File** (you can customize *WinRiver* to automatically load the last used workspace file when the Acquire mode is started).

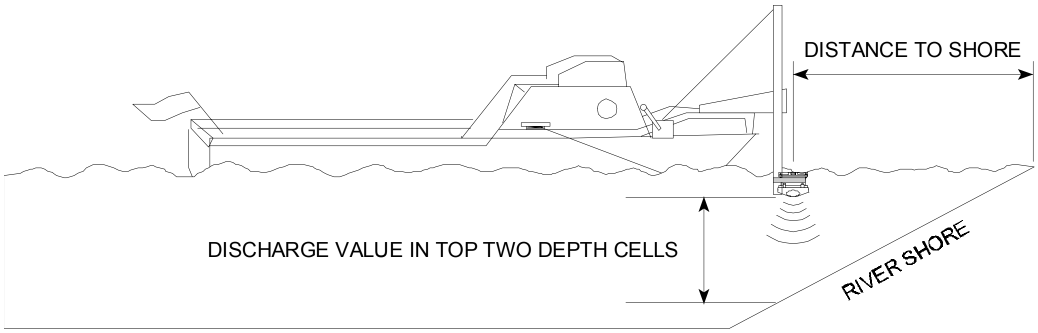
To create a new Workspace file set up the displays the way you prefer, and then click **File**, **Save Workspace File**. You will need to do this step for both Acquire and Playback modes.

NOTE. Click **File**, **New Workspace File** to bring up the default workspace.



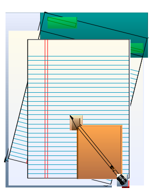
Use this area for notes.

2.7 Perform Pre-Run



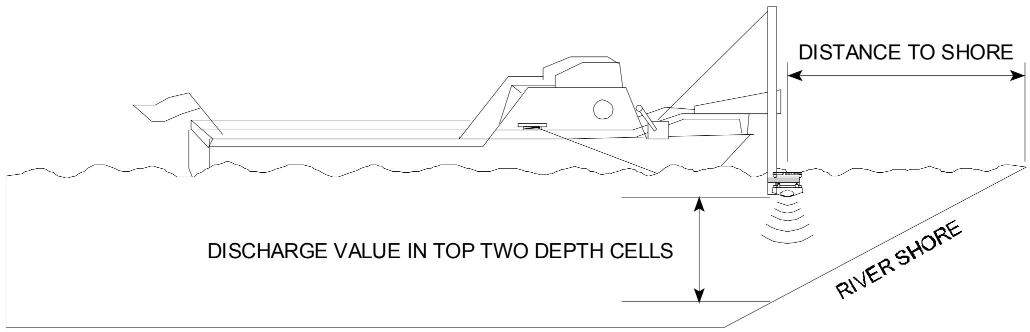
Step 6. On the **File** menu click **Start Pinging** (you can customize *WinRiver* to automatically start pinging when the Acquire mode is started).

On the **View** menu, select **Tabular Views**, **Discharge Standard Tabular** if this window is not visible. Move out from the shore until the water is deep enough to show **Good Bins** of two or greater. Values of 0.0 are acceptable, but "bad" values are invalid. Mentally note or mark this position with a float. This is the starting/stopping position for this shore. You will later start/stop data file recording at this location depending on the direction of your transect. Move out from the shore traveling *slowly* with the bow of the boat pointed upstream. When you approach the other shore, note or mark the closest distance to shore where two the top two depth cells show discharge values. This will be the start/stopping point for this shore.



Use this area for notes.

2.8 Acquire Data – Near Shore



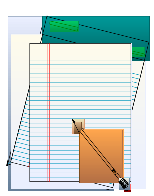
Step 7. Starting near the edge position determined during the pre-run, move out from the shore until the water is deep enough to show a discharge value in the top two depth cells. This is the starting position for this transect. Press **F5** to begin recording.

When prompted, enter the beginning distance to the bank and define if this is the left or right bank. The edge distance parameters will be saved to the configuration file (*w.000) associated with the raw ADCP data file recorded.

NOTE. When facing downstream, the left bank is on your left side.

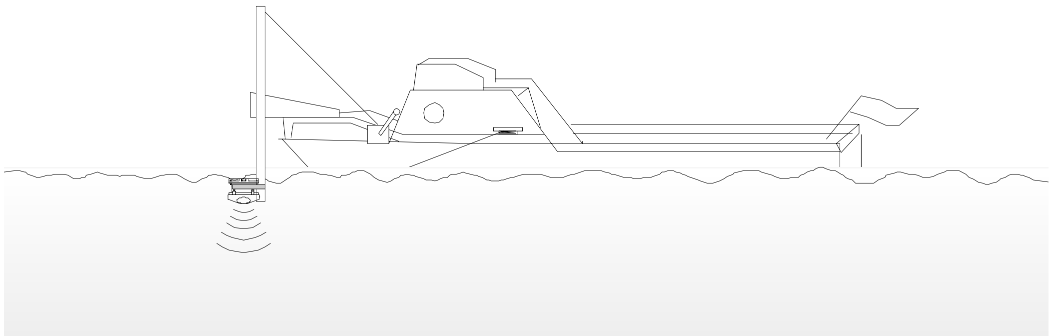
Hold this position until 4 or 5 measurements are recorded. If you made a false start, you can click **F5** to stop recording and restart at the edge by clicking **F5** to record to a new file. The Left/Right bank toggles at the end of each transect, so click **F5** once more to stop recording, and **F5** again to start recording so the bank is back to the correct side.

NOTE. The edge distance parameters can be changed during Playback mode if a mistake was made by selecting the **Edge Estimates** tab in the **Settings**, **Configurations Settings** menu and right-clicking the box.

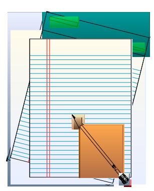


Use this area for notes.

2.9 Acquiring Data – River Transect

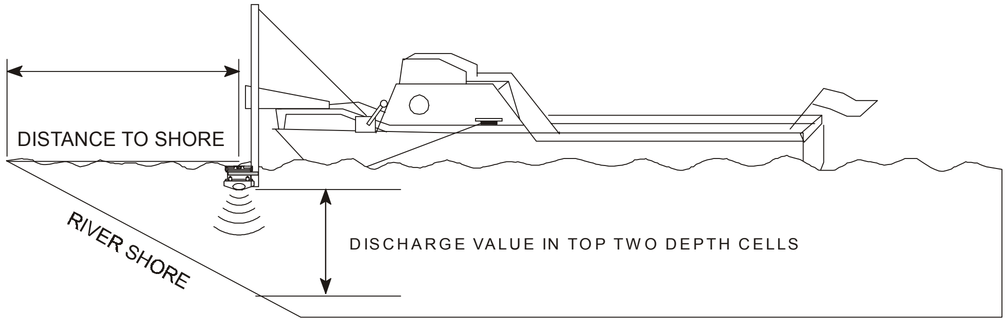


***Step 8*.** Move across the river as *slowly* as possible. For the best measurement results, the boat's speed over the bottom should be no greater than the water speed of the river. Pointing the bow of the boat upstream and slowly crabbing across the river will help to maintain a transect path that is perpendicular to the flow.



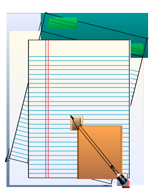
Use this area for notes.

2.10 Acquire Data – End Shore



***Step 9*.** Continue across the river until you reach the edge position determined during the pre-run on the opposite shore. You should have discharge values in only the top two depth cells. Stop at this position and wait for 4 or 5 measurements to be recorded. Press **F5** to stop recording. When prompted, enter the ending distance to the bank. That parameter will be saved to the configuration file (*w.000).

***Step 10*.** Repeat steps 7 through 9 as many times as required for your application. An even number of *at least four* transects are recommended. When you are finished acquiring the data, press **F4** to stop the ADCP pinging. Turn off the power to the ADCP and disconnect the cable. Remember to replace the dummy plug to protect the connector.



Use this area for notes.

2.11 Playback Data

a. Start *WinRiver* in the Playback mode. If you are in the Acquire mode, click **File**, **Playback Mode**.

b. On the **File** menu click **Open ADCP Raw Data File** and select the file to be played. WinRiver automatically creates a *w.001 configuration file.

- If the *w.000 configuration file exists, all of the values in the **Settings** menu, **Configuration Settings** tabs except the **Chart Properties 1** and **2** tabs will be used. The values will be grayed out. No changes can be made unless the item is right-clicked. Items that you decide to change during data playback will be saved in the *w.001 configuration file. The *w.000 files will not be changed.
- If a *w.000 configuration file does not exist you can modify all of the items in the *w.001 configuration file.

c. Create a new Workspace file by clicking **File**, **New Workspace File**. To open a workspace file, click **File**, **Open Workspace File**.

d. On the **Playback** menu, click **Play** to start playing the data. To quickly process the data select **Last Ensemble**. The playback tool bar has functions to start, stop, rewind, and go to the end of the data file.

e. To quickly see what files are in use look at the *WinRiver* Title Bar. This lists the files in use.

Figure 1. *WinRiver* Playback Mode Title Bar

work.wrw =	Workspace file in use
DATAw.000 =	Unique configuration file (created during data collection)
data.wrc =	Configuration file in use
DATAr.000 =	Raw ADCP data file in use

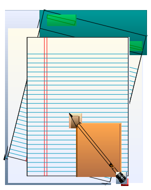
2.12 Compute Total Discharge

Discharge History Tabular View

File Name	# Ens.	Start Time	Total Q [m^3/s]	Start Bank	Left Dist. [m]	Left Ens#	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Rig
T118006r	422	10:13:30	11357.96	Left	15.24	507	27.99	2276.48	7926.40	1085.43	1
T118007r	185	10:32:07	11772.48	Right	15.24	222	27.17	2701.81	8027.83	985.90	1
T118008r	142	10:47:13	11754.44	Left	15.24	225	16.43	2709.58	8001.03	993.28	1
Average	250		11628.29				23.86	2562.62	7985.09	1021.54	
Std. Dev.	151		234.29				6.45	247.83	52.56	55.46	
Std./| Avg.|	0.60		0.02				0.27	0.10	0.01	0.05	

Play back the individual data files with their associated configuration files in the Playback mode. After playing through the data file, press **View**, **Tabular Views**, **Discharge Tabular Views**, **Discharge History** to obtain the total discharge for each measurement.

As each data file is played in the Playback mode, the file is added to the **Discharge History Tabular** screen. To remove a file from the table, double-click the file name. You will be prompted to clear only the selected file or the entire table. The **Discharge History Tabular** display will automatically calculate the average and other statistics useful in determining the discharge value.



Use this area for notes.

3 *WinRiver* Tutorial

WinRiver is RDI's real-time discharge data collection program. This program creates a configuration file to operate the ADCP, checks each command, and verifies that the ADCP has received the commands. This part of the tutorial will help you create a configuration file.

3.1 How to Customize WinRiver

a. To create a Workspace file open all the windows you want to see during data collection. Open and arrange the views you are interested in. When you have the displays set up the way you prefer, on the **File** menu, click **Save Workspace File**. You will need to do this step for both Playback and Acquire modes. To return to the default workspace, on the **File** menu, click **Open New Workspace**.

b. You can change the size of the fonts in windows by right clicking on the widow and selecting **Properties**. Choose the font for labels and data.

c. On the **Settings** menu, click **Units**. You can switch the displays between **SI** (metric) and **English** units.

d. On the **Settings** menu, click **Reference**. Select the desired reference.

e. On the **Settings** menu, click **User Options**. The **User Options** menu sets how *WinRiver* behaves in Acquire and Playback modes.

Acquire Mode Tab

Upon Entering Acquire Mode

- **Prompt for Configuration File** – If this option is selected you will be prompted to select a configuration file to load.
- **Start Pinging Immediately** – Select this option if you want the ADCP to begin pinging as soon as the Acquire mode is started.
- **Start Recording Immediately** – Select this option if you want the ADCP to begin recording as soon as the Acquire mode is started.

Upon Exiting Acquire Mode

- **Confirm Exit if Recording** – If this option is selected you will be prompted to confirm exiting the Acquire mode if recording. This helps prevent accidentally exiting during a transect.

Display Tab

- **X Axis Contour Plots/Time Series Type** – Select if the X-Axis on Contour Plots and Time Series will use **Ensemble Number**, **Elapsed Time**, or **Length** (distance traveled during the transect).

- **Number of Ensembles to Average** – Averaging applies to displays and ASCII Out data only.
- **Display Only Averaged Ensembles** – Check this box to display only the averaged ensembles.
- **Maximum Number of Ensembles on Plots** – This limits the number of ensembles displayed on contour and time series plots.

General Tab

Workspace Files

- **Load Last Workspace On Startup** – Select this option if you want the same plots and displays opened as soon as the Acquire or Playback mode is started. *WinRiver* saves separate setting for both modes in the *.wrw file.
- **Auto Save Workspace On Close** – Select this option if you want to automatically save any changes to the workspace whenever *WinRiver* is exited or you switch modes.

Configuration Files

- **Load Last Configuration On Startup** - Select this option if you want the last configuration file to be loaded as soon as *WinRiver* is started.
- **Auto Save Configuration On Close** - Select this option if you want to automatically save any changes to the configuration file whenever a new configuration file is loaded or *WinRiver* is exited.

Expert Tab

- **Velocity Display** – Select **Transform to Earth Coordinates** to view velocity data in Earth coordinates. To view the velocity data in the coordinate system the data was collected in, select **As Received From ADCP**.

3.2 File Naming Convention

There are five files associated with the *WinRiver* software. These files are:

- ***Data Files*** (*r.NNN) – These files contain all data sent from the ADCP and other devices during data collection. Refer to the ADCP Technical Manual for a complete description of the format of raw ADCP data files. For any specific deployment, raw data files contain the most information and are usually the largest. Data for this file type is collected through *WinRiver*'s Acquire mode. *WinRiver*'s Playback mode accepts raw ADCP data files for display or reprocessing.

- ***Configuration Files*** (*.wrc, *w.000, *w.001) – These ASCII files contain user-specified setup and deployment information. These files share information between *WinRiver's* Acquire and Playback modes. You can create different configuration files to suit specific applications through the **Settings** menu, **Configuration Settings**.

NOTE. In the **Settings** menu, **User Options**, **General** tab you can specify if the last configuration file opens on startup and/or auto save the configuration file on close of the application. Configuration files can be loaded/saved through the **File** menu.

- ***Workspace Files*** (*.wrw) – Binary file that contains information about open views, their size, and position. Contains workspace information about Acquire and Playback modes. Normally, Acquire will have different window selections and sizes than the Playback mode.

NOTE. In the **Settings** menu, **User Options**, **General** tab you can specify if the last workspace opens on startup and/or auto save the workspace on close of the application. Workspace files can be loaded/saved through the **File** menu.

- ***Navigation Files*** (*n.NNN) – These files contain ASCII data collected from an external navigation device during data acquisition. *WinRiver* reads the navigation data from a user-specified serial port.

- ***Depth Sounder Files*** (*d.NNN) – These files contain ASCII data collected from an external Depth Sounder device during data acquisition. *WinRiver* reads the depth data from a user-specified serial port.

- ***ASCII-Out Files*** (*t.NNN) – These files contain a fixed format of ASCII text that you can create during post-processing. During playback, you can subsection, average, scale, and process data.

You also can write this data to an ASCII file. You can then use these files in other programs (spreadsheets, databases, and word processors).

- ***Summary Files*** (*.sum) – These files contain ASCII information about the whole transect. The information is written at the end of the file or subsection.

3.2.1 Data Files

File Name Format: *ddddMMMx.NNN*

dddd Filename prefix (set in **Settings** menu, **Configuration Settings**, **Recording** tab)

MMM *TRANSECT* number. This number starts at 000 and increments each time you stop and then start data collection.

x File type (assigned during data collection or playback)

r – Raw ADCP data
w – copy of the configuration file created during Acquire mode
c – Unique configuration file (DOS *TRANSECT* only)
n – Navigation GPS data
d – Depth Sounder data
t – ASCII-out data (This convention is the default for ASCII-out data, but you can use other names and extensions.)

NNN File sequence number. This number starts at 000 and increments when the file size reaches the user-specified limit (set in **Settings** menu, **Configuration Settings**, **Recording** tab).

Examples:

NOAA001r.000 (Deployment name = NOAA, ADCP data file, transect number = 001, file number = 000)

SN11005w.000 (Deployment name = SN11, configuration data file, transect number = 005, file number = 000)

3.2.2 Configuration Data Files

File Name Format (*.wrc, *w.000, or *w.001)

Extension	Description
*.wrc	Original configuration file used to collect data.
*w.000	Copy of the *.wrc configuration file created when the transect is completed (recording stopped) that saves the **Setting** menu, **Configuration Settings** items.
*w.001	This file contains the changes (if any) made to the *w.000 file.

The *w.000 Configuration Data File is a copy of the *wrc configuration file used to collect data. The Playback mode will automatically load the *w.000 configuration file that was created while acquiring the data and the *w.001 file if it exists. Any editing changes made to the *w.000 file are saved to the *w.001 file. If a *c.000 (DOS TRANSECT unique configuration file) exists, it will be used and saved as a *w.001 file.

All items except the **Chart Properties 1** and **2** tabs in the **Setting** menu, **Configuration Settings** will be grayed out in the Playback mode meaning that the values are used from the *w.000 configuration file. Once the data file has been loaded changes can be made to the configuration file by right-clicking the item. Select between the following choices.

Right-Click Option	Description
Use *w.000 value	Returns the item to the value as data was collected.
Enable for Editing	Changes the value for the current *w.001 file only. Editing changes are saved to the *w.001 file.
Edit and Freeze	Changes the value for the current *w.001 file and will stay in effect for each data file used in the Playback mode. Use this mode if the same correction is needed for playing back subsequent transects. For example, if the ADCP depth was incorrectly set for all transects, after loading the first data file, change the ADCP depth by right-clicking the **ADCP Depth** on the **Settings** menu, **Configuration Settings**, **Offsets** tab and select **Edit and Freeze**. Enter the correct value. When the next data file is opened, the correct ADCP depth value will be in effect.

3.2.3 Navigation Data Files

Navigation Data Files are ASCII files created during Acquire. These files are not used to playback data.

File Name Format (ddddMMMn.NNN)

dddd = File prefix

MMM = Transect number

n = File type (Navigation)

NNN = File sequence number

The external device sending the navigation data determines the format of the navigation data file. The navigation device can be any external device linked to *WinRiver* by a serial communication port.

The navigation data should be ASCII, with a carriage return and line feed (CR/LF) generated after each data transmission. *WinRiver* receives the data from the navigation device and writes it to the navigation file. Every time an ADCP ensemble is received, *WinRiver* also writes the ensemble number and the computer time to the navigation file. Here is a sample navigation data format and program sequence.

a. Navigation device sends data to the serial port. For example:

```
$GPGGA,190140.00,3254.81979,N,11706.15751,W,2,6,001.3,00213.4,M,-
032.8,M,005,0262*6F
$GPGSA,M,3,1,14,22,16,,,18,19,,,,,3.5,1.3,3.3*08
$GPVTG,108.0,T,,,000.3,N,000.6,K*21
```

b. *WinRiver* writes this information to the ASCII (*n.000) navigation data file and to the *r.000 raw data file. *WinRiver* only uses the data in the *r.000 file.

c. *WinRiver* receives an ensemble of data from the ADCP and writes the ensemble number and computer time to the navigation data file in the following format:

```
<CR/LF>$RDENS,nnnnn,ssssss,PC<CR/LF>
```

where:

nnnnn = sequential ensemble number

ssssss = computer time in hundredths of seconds

3.2.4 Depth Sounder Data Files

Created during Acquire. These files are not used to playback data.

File Name Format (ddddMMMd.NNN)

dddd = File prefix

MMM = Transect number

d = File type (Depth Sounder)

NNN = File sequence number

The external device sending the depth data determines the format of the depth sounder data file. The depth sounder device can be any external device linked to *WinRiver* by a serial communication port.

The depth sounder data should be ASCII, with a carriage return and line feed (CR/LF) generated after each data transmission. *WinRiver* receives the data from the depth sounder device and writes it to the depth sounder data file. Every time an ADCP ensemble is received, *WinRiver* also writes the ensemble number and the computer time to the depth sounder data file. Here is a sample depth sounder data format and program sequence.

a. Depth sounder device sends data to the serial port. For example:

```
$SDDBT,0084.5,f,0025.7,M,013.8,F
```

b. *WinRiver* writes this information to the ASCII (*d.000) depth sounder data file and to the *r.000 raw data file. *WinRiver* only uses the data in the *r.000 file.

c. *WinRiver* receives an ensemble of data from the ADCP and writes the ensemble number and computer time to the depth sounder data file in the following format:

```
<CR/LF>$RDENS,nnnnn,ssssss,PC<CR/LF>
```

where:

nnnnn = sequential ensemble number

ssssss = computer time in hundredths of seconds

3.2.5 ASCII-Out Files

ASCII-out files contain a fixed format of text that you can create during post-processing by using the **File** menu, **Start ASCII Out** during Playback mode. During playback, you can subsection, average, scale, and process data. You also can write this data to an ASCII file. You can then use these files in other programs (spreadsheets, databases, and word processors).

The same control over data scaling, averaging, subsectioning, and processing available during playback influences the ASCII-out file. *WinRiver always* writes velocity data (in earth coordinates) to the ASCII-out file. For example, you may select only depth cells (bins) 4 through 9 for display on the screen, metric units (m, m/s), and use speed of sound corrections for a portion of data to be sent as ASCII-out. *WinRiver* will scale, display, and write the velocity data to the ASCII-out file based on your processing specifications.

Example ASCII-Out File

```
This is WinRiver comment line #1
This is WinRiver comment line #2
    50     25     91     50      1     16      1
0 3 27 8 18 37 26    29      1   -2.860    1.870  248.030   14.500
-0.27     0.18     0.05     0.04     0.00    15.16     0.00    11.08    31.32    25.80    28.85
30.04
2.04         7.30         1.16        -0.98         1.52
31.0098587   -91.6261329    -0.08     0.37          2.0
94.5          40.2          16.6        1299.2          50.0           0.0           0.0  6.54  22.95
15 ft BT dB 0.43  0.161
  6.54      4.20    225.21   -3.0   -3.0   -0.7    1.2   72.5   73.0   73.0   74.7  100      -3.87
  8.18      3.05    237.19   -2.6   -1.7   -0.3    0.3   80.3   82.5   81.2   82.0  100      -2.63
  9.82      3.94    236.55   -3.3   -2.2   -0.2    1.0   81.6   87.6   83.3   82.0  100      -3.41
 11.46      3.91    245.09   -3.5   -1.6   -0.4   -0.1   83.6   87.5   84.9   83.2  100      -3.13
 13.11      4.55    242.24   -4.0   -2.1   -0.3    0.9   83.6   86.6   85.8   82.7  100      -3.76
 14.75      1.94    224.59   -1.4   -1.4    0.0    0.8   88.5   92.4   85.1   82.9  100      -1.79
 16.39      3.84    175.29    0.3   -3.8    0.5    1.6   89.8   94.1   85.5   85.1  100      -2.84
 18.03      2.89    258.70   -2.8   -0.6   -0.3   -0.1   85.8   86.7   86.7   85.0  100      -1.91
 19.67      4.54    223.45   -3.1   -3.3    0.1    1.4   85.2   86.5   89.1   86.5  100      -4.20
 21.31      3.66    239.28   -3.2   -1.9   -0.2    0.2   86.2   92.2   91.8   89.6  100      -3.10
 22.95      2.08    228.31   -1.6   -1.4    0.3   -0.3   87.1   96.1   92.3   89.7  100      -1.89
 24.59    -32768    -32768 -32768 -32768 -32768 -32768   89.2   94.8   91.8   92.7    0 2147483647
 26.23    -32768    -32768 -32768 -32768 -32768 -32768   88.3    255   93.5   93.1    0 2147483647
 27.87    -32768    -32768 -32768 -32768 -32768 -32768   90.4    255  100.3   93.0    0 2147483647
 29.51    -32768    -32768 -32768 -32768 -32768 -32768   94.6    255    255    255    0 2147483647
```

3.3 Setup Communications with the ADCP, GPS, and Depth Sounder

a. Start *WinRiver* in the Acquire mode. If you are in the Playback mode, click **File**, **Acquire Mode**.

b. Go to **Settings**, **Communications**, press the **Add** button.

c. Select the device you want to use, press **Next** and select the correct communication port (COM1, COM2,...) and its parameters. Only the communication ports installed and available on your system will be displayed.

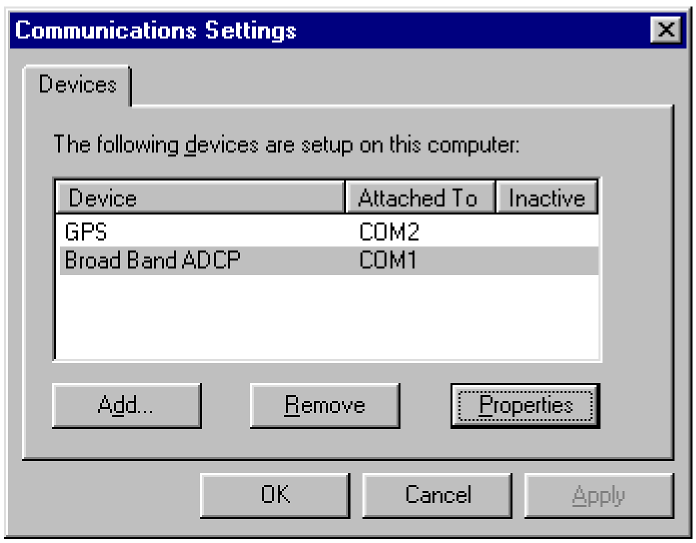


Figure 2. Communications Port Setting Screen

d. To temporally inactive a device, click on the device to be inactivated and click the **Properties**, **General** tab. Select the **Inactive** box. The device would not be used during data collection, but its' parameters would be remembered.

e. On the **Properties**, **General** tab there is another option for the ADCP to use the "===" string instead of a break. Only Rio Grande firmware 10.05 and above accepts this option.

3.4 Creating a *WinRiver* Configuration File

In the following, you will be creating a configuration file that will be used to program both the ADCP and *WinRiver* software processing.

a. In the Acquire or Playback mode, click **File**, **New Configuration File**.

b. To change configuration parameters click **Settings**, **Configuration Settings**.

c. When creating a configuration file for Acquire mode the most important parts in a configuration file are the **Commands** and **Recording** tabs. Set them to the desired parameters. The rest of the parameters can be changed during playback and do not influence data collection.

d. For correct data display while acquiring data you can enter the following values.

- On the **Offsets** tab set the **ADCP Transducer Depth**.
- On the **Discharge** tab, specify if you have any preference how to calculate discharge and if you know the shape of your edge bank.
- On the **DS/GPS** tab, select **Depth Sounder** to be used in processing if you are using a depth sounder and you do not have valid bottom track data.

e. When creating a configuration file for Playback mode, items will be read from the corresponding *w.000 file and *w.001 (if it exists) or *c.000 (DOS Transect configuration file) and will not be accessible in the **Settings**, **Configuration Settings** menu. To modify an item, see “Configuration Data Files,” page 19.

f. Once you have set the parameters save the configuration file by clicking **File**, **Save Configuration File**. Click **File**, **Save Configuration File As** to save the configuration file under a unique name.

3.5 Configuration Settings

This section has detailed explanations of each of the **Setting** menu, **Configuration Setting** tabs needed to create a configuration file. There are ten tabs that configure different portions of the configuration file.

Offsets Tab	Recording Tab
Processing Tab	Commands Tab
Discharge Tab	Chart Properties 1 Tab
Edge Estimates Tab	Chart Properties 2 Tab
DS/GPS Tab	Resets Tab

3.5.1 Offsets Tab

The Offsets tab lets you set system alignment offsets that only affect the displays, **not** the raw data files. *WinRiver* saves these settings in the configuration file.

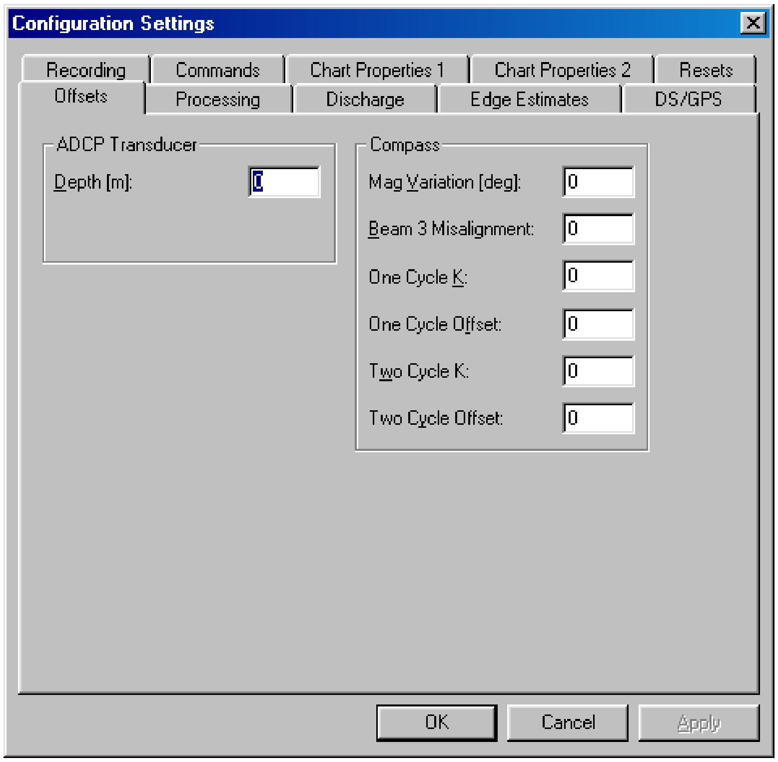


Figure 3. Offsets Tab

The functions of this submenu are:

- **ADCP Transducer Depth** - Use the **Transducer Depth** field to set the depth from the water surface to the ADCP transducer faces. *WinRiver* uses this value during data collection and post-processing to create the vertical depth scales on all displays. *WinRiver* also uses the depth value to estimate the unmeasured discharge at the top part of the velocity profile. Therefore, depth affects the estimate of total discharge on the data collection and post-processing displays. The depth value does not affect raw data, so you can use different values during post-processing to refine the vertical plot scales and discharge estimates.

NOTE. The ADCP's ED-command (Depth of Transducer) is used for internal ADCP speed of sound processing and is stored in the raw ADCP file leader. The ED-command has no effect on the vertical depth scales in *WinRiver*. **For normal transect work, do not add an ED-command.**

- **Magnetic Variation** – Use the **Magnetic Variation** field to account for magnetic variation (declination) at the deployment site. East magnetic declination values are positive. West values are negative. *WinRiver* uses magnetic variation in the data collection and Playback displays to correct ADCP velocities and bottom-track velocities.

> **NOTE.** The ADCP’s EB-command (Heading Bias) and EX-command (Coordinate Transformation) process ADCP data before creating the raw data. The Magnetic Variation field in WinRiver processes the raw data received from the ADCP for data display. The magnetic variation field is not converted to an EB-command (raw data is not effected). This allows you to use the Magnetic Variation field to make changes during post-processing. **For normal transect work, do not add an EB-command.**
>
> The WinRiver compass corrections will only be applied to the profile data when the data was collected in Beam, Instrument, or Ship coordinates.

- **Beam 3 Misalignment** – *WinRiver* uses the **Beam 3 Misalignment** value to align the ADCP’s north reference (Beam 3) to the ships bow.
- **Compass Correction** – See “Compass Correction,” page 54, for details on how to do the compass correction.

3.5.2 Processing Tab

The **Processing** tab lets you set several system processing options and save them to a configuration file. Most values in the **Processing** tab affect the displays during data collection and post-processing. *WinRiver* saves these values only to the configuration file, not to the raw data files.

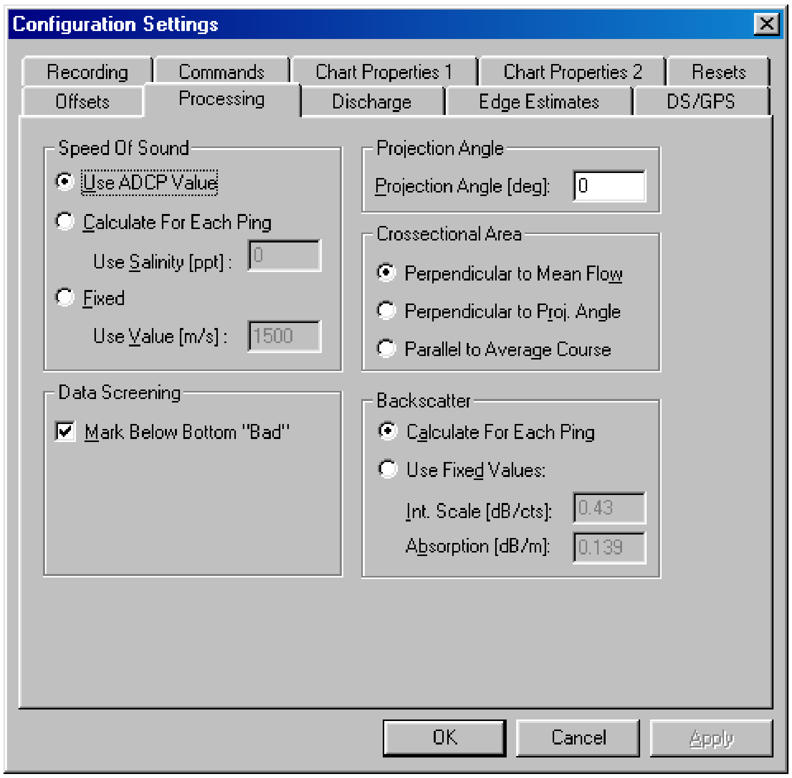


Figure 4. Processing Tab

The functions of this submenu are:

- **Speed of Sound** – The **Speed Of Sound** box lets you correct velocity data for speed of sound variations in water. *WinRiver* can make these corrections dynamically with every ping or use a fixed speed of sound value. Use the **Use ADCP Value** option to select the value being used by the ADCP. The EC and EZ-commands determine the ADCP's speed of sound value. Choosing the **Use ADCP Value** tells *WinRiver* not to do any speed of sound scaling of velocity data after it is received from the ADCP. Use the **Fixed** option to set a fixed value for sound speed. Select this option if you made a mistake during data collection. *WinRiver* uses the fixed value to re-scale the velocity data from the ADCP.

Selecting the **Calculate For Each Ping** option uses the **Salinity Value**, ADCP transducer depth, and the water temperature at the transducer head to compute speed of sound for each raw ADCP ensemble. *WinRiver* then uses this value to scale the ADCP velocity data dynamically. *WinRiver* uses scaled velocity data in the displays and for discharge calculations.

- **Data Screening** – Select **Mark Below Bottom Bad** to mark data below the ADCP-detected bottom or Depth Sounder detected bottom (if selected for processing).
- **Projection Angle** – This is the angle used to calculate the projected velocity that is displayed in the Projected Velocity contour plot.
- **Cross Sectional Area** – Cross Sectional Area can be calculated using three different methods: as perpendicular to the mean flow, perpendicular to the projection angle, or parallel to the average course.
- **Backscatter** – *WinRiver* uses the **Echo Intensity Scale** value to convert the ADCP signal strength (AGC) from counts to dB before correcting it for absorption and beam spreading. Echo intensity in decibels (dB) is a measure of the signal strength of the returning echo from the scatterers. It is a function of sound absorption, beam spreading, transmitted power, and the backscatter coefficient. For more information on echo intensity, see RDI's *Principles of Operation: A Practical Primer*. The echo intensity scale is temperature dependent based on the following formula. Echo intensity scale = 127.3 / (Te + 273) where Te is the temperature (in °C) of the ADCP electronics and is calculated by WinRiver unless overridden by the user. Speed of Sound is based on temperature and salinity and uses that value unless overridden by the user.
- **Sound Absorption Coefficient**. The sound absorption coefficient, which is used to estimate echo intensity in decibels (sometimes called *un-calibrated backscatter*), is a function of frequency. *WinRiver* range-normalizes echo intensity using the formula:

I[dB] = (Echo Intensity Scale[dB/counts]) x I[counts]

+ 20 x Log(R) [spreading]

+ 2 x (Sound absorption coefficient) x R [absorption]

Where *R* = Distance from transducer to ADCP depth cell in meters.

3.5.3 Discharge Tab

WinRiver uses these setting to determine what formulas and calculations will be used to determine the discharge value.

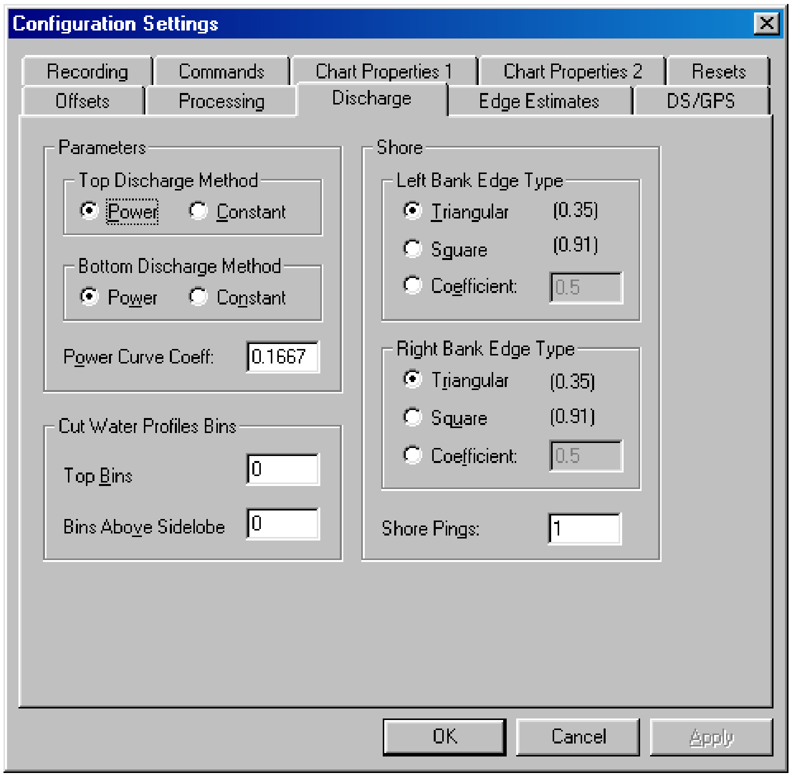


Figure 5. Discharge Tab

- **Parameters** – There are two methods available in *WinRiver* to estimate discharge in the unmeasured top/bottom parts of the velocity profile based on the Top/Bottom Discharge Method settings. The two methods are **Constant** and **Power**. The **Power Curve Coefficient** can be changed if the **Power** Method is used. The default is set to 1/6. The Power fit is always used to file in "missing" data in the profile. For more details, see the *WinRiver* help file.
- **Cut Water Profiles Bins** – You can select additional bins to be removed from the top or bottom measured discharge.
- **Shore** – The **Left/Right Bank Edge Type** is used in estimating shore discharges. You can select a predefined shape of the area as **Triangular** or **Square**, or set a coefficient that describes the shore. Several pings can be averaged as determined by **Shore Pings** in order to estimate the depth and mean velocity of the shore discharge. For more details, see the *WinRiver* help file.

3.5.4 Edge Estimates Tab

This menu lets you estimate the near-shore discharge, that is, near the banks of a channel where the ADCP cannot collect data. These settings should account for the beginning and ending areas of the transect not measured by the ADCP.

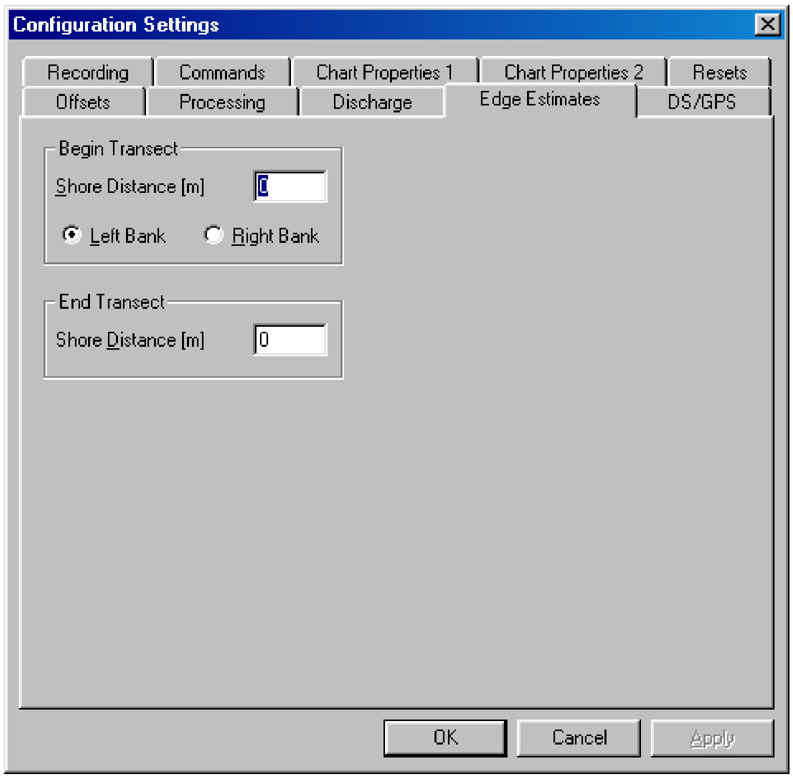


Figure 6. Edge Estimates Tab

Begin Transect

- Shore Distance – Enter the distance to the shore at the beginning of the transect.
- Left/Right bank. Define if the shore when you start the transect is the left or right bank. When facing downstream, the left bank is on your left side.

End Transect

- Shore Distance – Enter the distance to the shore at the end of the transect.

3.5.5 DS/GPS Tab

The depth sounder is another external sensor that can be used to track the depth of the water. Areas with weeds or high sediment concentrations may cause the ADCP to lose the bottom.

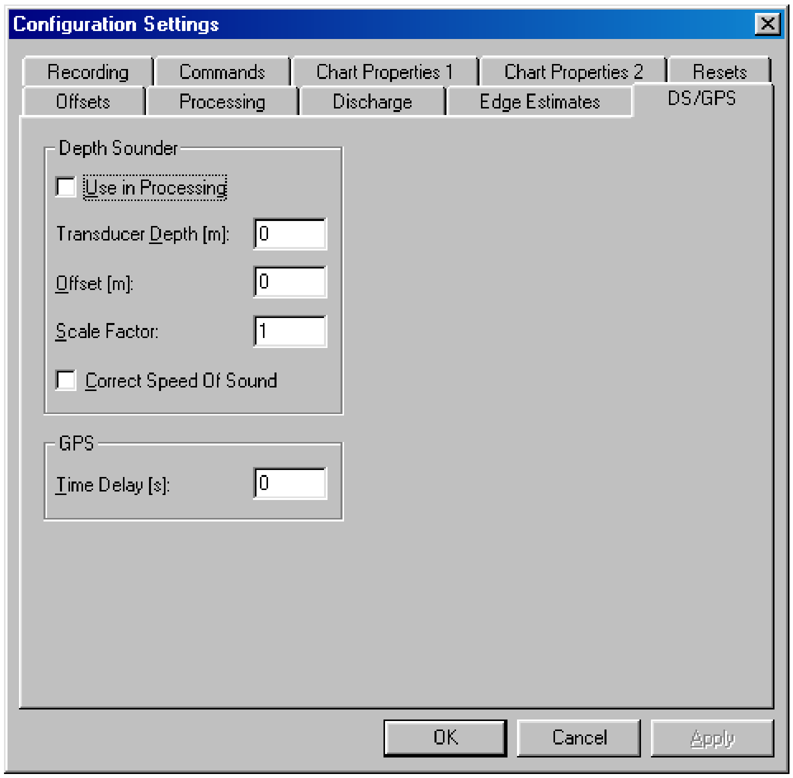


Figure 7. DS/GPS Tab

<u>Depth Sounder</u>

- **Use in Processing** – This will instruct *WinRiver* to use the depth sounder value in the discharge calculation rather then the ADCP beam depths.
- **Transducer Depth** – Use the **Transducer Depth** to set the depth from the surface of the water to the Depth Sounder transducer face.
- **Offset** – In addition to the **Transducer Depth**, you can also add an additional offset to reconcile any differences between the ADCP bottom track depths and those reported by the DBT NMEA string. Entering a value in the **Offset** box enables this additional offset.
- **Scale Factor** – Many depth sounders only allow a fixed value of 1500 m/s for sound speed. You can apply a scaling factor to the

raw NMEA depth sounder output by entering a number in place of the **Correct Speed Of Sound** command. Note that the depths reported by the DBT NMEA string do not include the depth of the sounder, so the scaling is applied to the range reported from the depth sounder to the bottom.

- **Correct Speed Of Sound** – *WinRiver* can scale the depth sounder depths by the sound speed used by *WinRiver* by selecting the **Correct Speed Of Sound** box.

GPS

- **Time Delay** – If desired, you can allow for a lead-time between the GPS position updates and the ADCP data. Inserting a value in the **Time Delay** box does this. If you enter a value of 1, the lead is set for 1 second. This assumes GPS data is one second old compared to the ADCP.

NOTE. The recommended value is zero.

3.5.6 Recording Tab

The **Recording** tab lists the parameters used to define where the data is recorded during data collection.

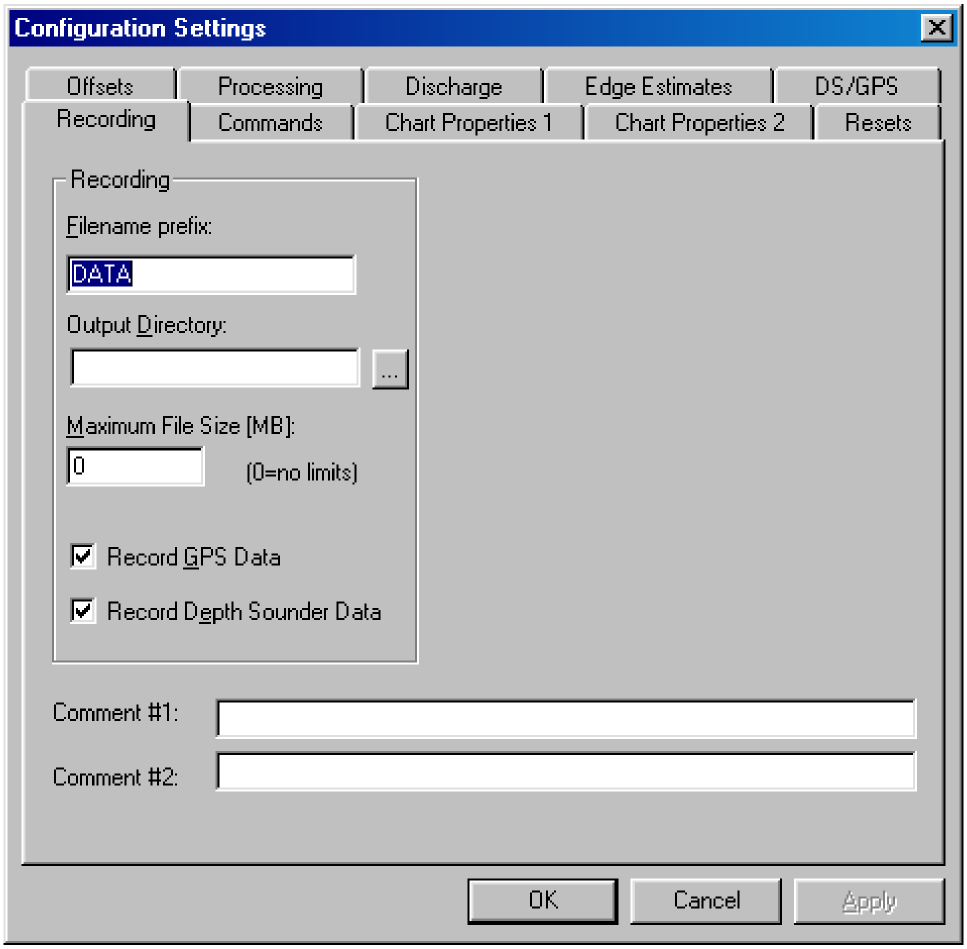


Figure 8. Recording Tab

- **Filename Prefix** – *WinRiver* uses the **Filename Prefix** to create the data file names made during data collection. Use the **Output Directory** field to select where the data file will be stored.

  During data collection, if the **Filename prefix** is set to TEST, *WinRiver* creates data files with the prefix TEST (TEST####.###) and stores them in the directory specified in the **Output Directory** field until the disk is full. *WinRiver* will then stop data collection and alert you to the disk space problem.

- **Maximum File Size** – Use the **Maximum File Size** field to limit the size of a data file. The default for the maximum data file size is unlimited. If you set the Maximum File Size to 1.44, then when the size of the recorded data file reaches 1.44 MB, the file name extension increments.
- If you want to record ASCII GPS and Depth Sounder data, select the appropriate box.

NOTE. If you want to use the depth sounder data in place of the ADCP depth, then you must select **Use in Processing** on the **DS/GPS** tab.

NOTE. If you use GPS or Depth Sounder devices during data collection the data will always be written to the raw ADCP data file. Collecting ASCII GPS or Depth Sounder files is not required and are not used by WinRiver.

- **Comment #1, #2** – Use these two lines for your notes.

3.5.7 Commands Tab

You can directly control the profiling parameters sent to the ADCP using the User Commands box. The ADCP Technical Manual explains all direct commands in detail. The **Fixed Commands** box lets you view the direct commands that will always be sent to the ADCP.

> **CAUTION.** The fixed commands are sent before any user commands. Sending a **User Command** will OVERRIDE the **Fixed Commands**.

When the Acquire mode is first started, the commands in the **Fixed Commands** box are sent by *WinRiver* to the ADCP to set its profiling parameters. In the following, we will describe each command and give guidelines for setting these commands for acquiring reliable discharge data. Refer to the ADCP Technical Manual for more detailed information about each command.

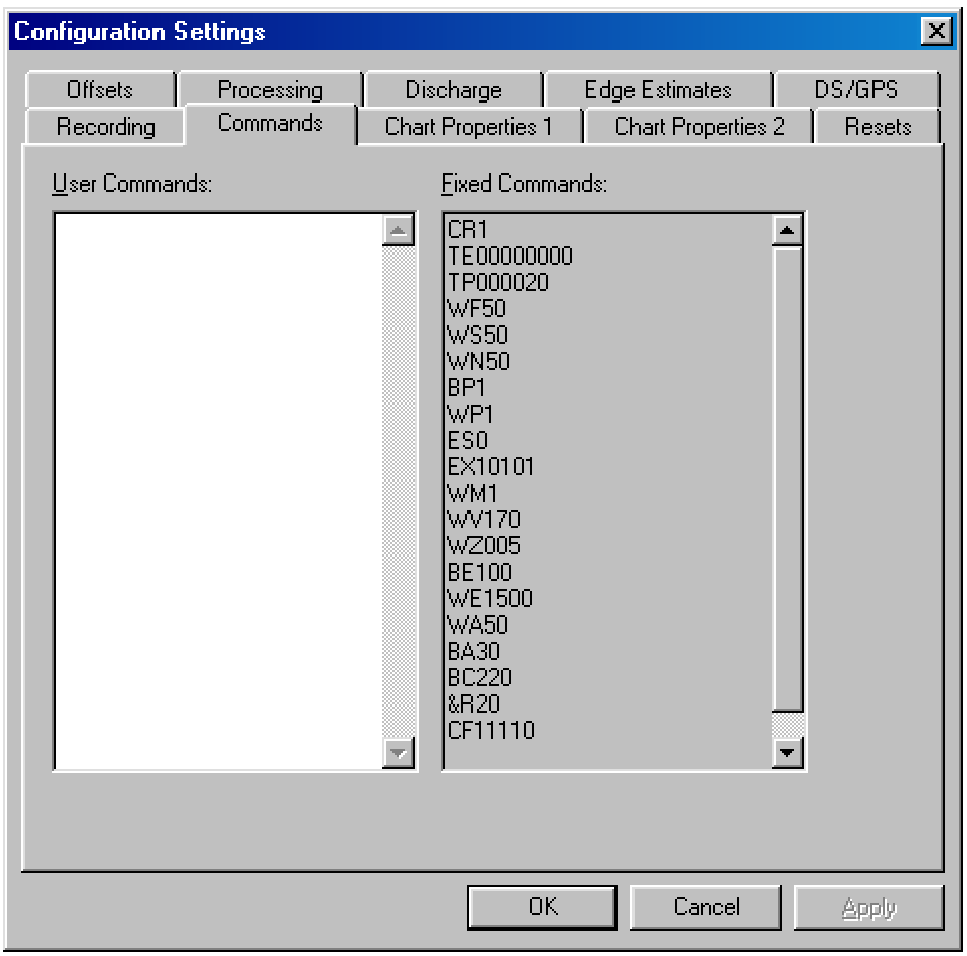


Figure 9. Commands Tab

Table 1: ADCP Commands

Command	Choices	Description
CR1	Sets factory defaults	This is the first command sent to the ADCP to place it in a "known" state.
TE00:00:00.00	Time per ensemble	Ensemble interval is set to zero.
TP00:00.20	Time between pings	Sets the time between pings to 0.2 seconds.
WF50	Blank after transmit	Moves the location of the first depth cell 50 cm away from the transducer head (see Table 2, page 37).
WS50	Depth cell size	Bin size is set to 0.5 meters (see Table 2, page 37).
WN50	Number of depth cells	Number of bins is set to 50 (see Table 2, page 37).
BP1	Bottom track pings	The ADCP will ping 1 bottom track ping per ensemble.
WP1	Pings per ensemble	The ADCP will ping 1 water track ping per ensemble.
ES0	Salinity	Salinity of water is set to 0 (freshwater).
EX10101	Coordinate transformations	Sets Ship coordinates, use tilts, and allow bin mapping to ON.
WM1	Water mode	Sets the ADCP to Water Track mode 1.
WV170	Ambiguity velocity	Sets the maximum relative radial velocity between water-current speed and Workhorse speed to 170 cm/s.
WZ005	Mode 5 Ambiguity Velocity	Sets the minimum radial ambiguity for profiling Mode 5 (WM5) and Mode 8 (WM8) Ambiguity Velocity to 5 cm/s.
BE100	Bottom Track Error Velocity Maximum	Sets maximum error velocity for good bottom-track water-current data to 100mm/s.
WE1500	Water Track Error Velocity Threshold	Sets the maximum error velocity for good water-current data to 1500mm/s.
WA50	False Target Threshold Maximum	Sets a false target (fish) filter to 50 counts.
BA30	Evaluation Amplitude Minimum	Sets the minimum value for valid bottom detection to 30 counts.
BC220	Correlation Magnitude Minimum	Sets minimum correlation magnitude for valid bottom track velocity data to 220 counts.
&R20	Bottom Illumination	The &R command is used to set the "Bottom Illumination". This value determines the size of the Bottom Track transmit pulse in relation to the Depth. &R is entered in percent. If you were bottom tracking in 100m of water and had &R=20, the Bottom Track transmit pulse would be 20% of 100m, or 20m. If &R=30, then the transmit pulse would be 30m.
CF11110	Flow control	CF11110 selects automatic ensemble cycling, automatic ping cycling, binary data output, enables serial output, and disables data recording.

Table 2: Recommended User Commands

Command	Choices	Description
WS and WN	Depth cell size and number	To cover the whole profile, set the depth cell size and number of depth cells according to the maximum depth of the river.

NOTE. The default commands will work for rivers up to 25 meters deep.

3.5.8 Chart Properties 1 Tab

The **Chart Properties 1** tab lets you select display and scaling options for all graphics screens in real-time. By selecting the appropriate minimum and maximum values for the displays, specific features in the data become more visible. *WinRiver* saves all scaling information to the configuration file.

> **NOTE.** To quickly access the graph scales right-click on the graph and select Properties.

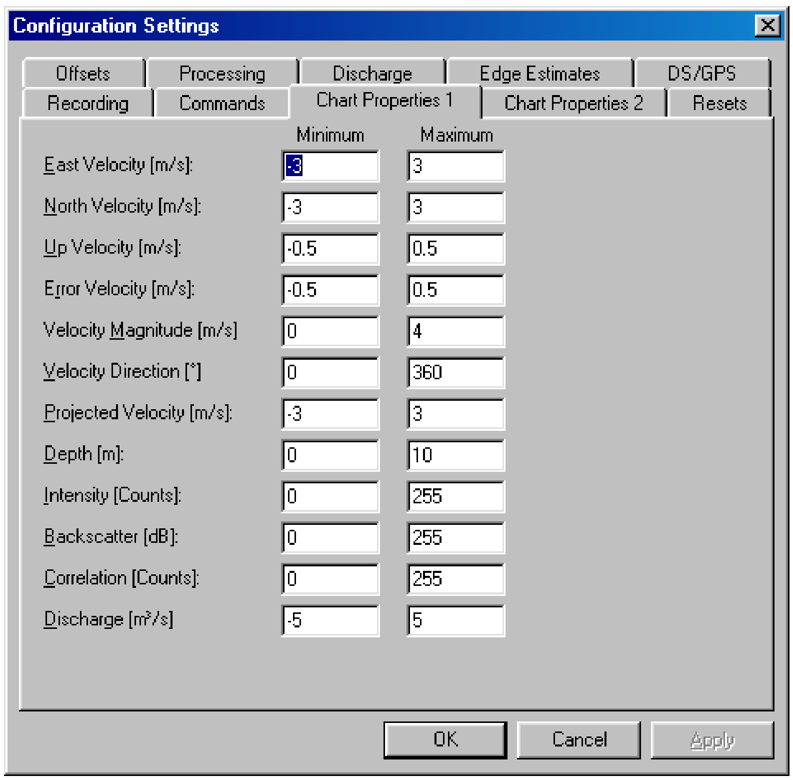


Figure 10. Chart Properties 1 Tab

Scalable parameters include the following.

East Velocity (in m/s or ft/s)	Velocity Magnitude (in m/s or ft/s)	Intensity (in counts)
North Velocity (in m/s or ft/s)	Velocity Direction (in degrees)	Backscatter (in dB)
Up Velocity (in m/s or ft/s)	Projected Velocity (in m/s or ft/s)	Correlation (in counts)
Error Velocity (in m/s or ft/s)	Depth (in m or ft)	Discharge

> **NOTE.** If the Auto Save Configuration file mode is on (see Users Option menu) the chart properties will be re-saved to the *w.oo1 file. The file will play back with the same chart properties the next time the file is opened.

3.5.9 Chart Properties 2 Tab

The **Chart Properties 2** tab lets you select display and scaling options for all graphics screens in real-time. By selecting appropriate the minimum/maximum values for the displays, specific features in the data become more visible. *WinRiver* saves all scaling information to the configuration file.

> **NOTE.** To quickly access the graph scales right-click on the graph and select Properties.

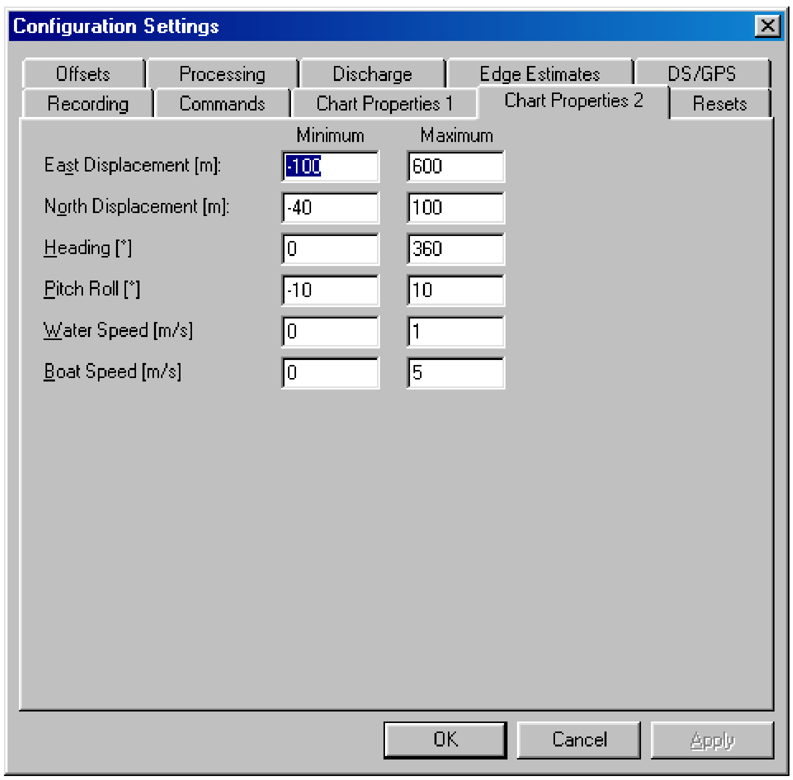


Figure 11. Chart Properties 2 Tab

Scalable parameters include the following.

East Displacement (in m or ft)

North Displacement (in m or ft)

Heading (in degrees)

Pitch, Roll (in degrees)

Water Speed (in m/s or ft/s)

Boat Speed (in m/s or ft/s)

> **NOTE.** If the Auto Save Configuration file mode is on (see Users Option menu) the chart properties will be re-saved to the *w.oo1 file. The file will play back with the same chart properties the next time the file is opened.

3.5.10 Resets Tab

Use the **Unfreeze** button on the **Resets** tab after you are finished playing data from one site and are ready to begin playing data from another site.

The **Unfreeze** button unfreezes all frozen items (blue text). The next *w.001 configuration file will control the plot parameters and all other parameters will be read from the *w.000 file. This has the same function as exiting *WinRiver* and restarting it in the Playback mode.

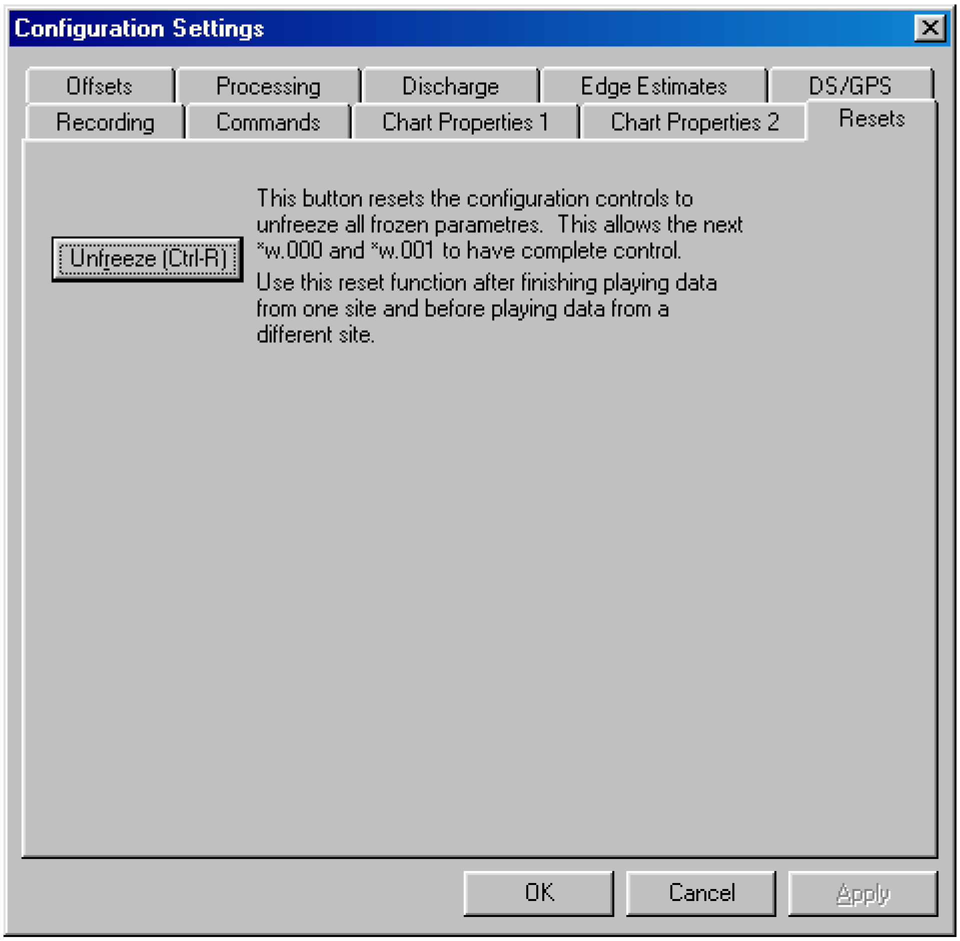


Figure 12. Resets Tab

3.6 Acquiring Discharge Data

Starting WinRiver in the Acquire mode loads the direct commands from the configuration file to the ADCP and controls data recording for acquisitions of individual transect discharge data. Data can be displayed in tabular, ship's track, profile, or contour formats. *WinRiver* calculates discharge as it is calculated in real-time and accumulated as a transect is made across the river.

NOTE. It is a good idea to run *DumbTerm* before collecting data at a particular site to check the ADCP's operation. *DumbTerm* runs a series of tests and creates a log file that records the results of the tests that are performed.

a. Start *WinRiver* in the Acquire mode. If you are in the Playback mode, click **File**, **Acquire Mode**.

Table 3: *WinRiver* Shortcut Keys

Key	Description
F1	Help
F3	Configuration Setting menu
F4	Acquire mode = Start/Stop Pinging, Playback mode = Start/Stop Play
F5	Acquire mode = Start/Stop Transect, Playback mode = Next Data File
F6	File subsection (Playback mode only)
F7	User Options
F8	Configuration Items
Ctrl-A	Output ASCII data file (Playback mode only)
Ctrl-C	Copy
Ctrl-L	View Command Log (Acquire mode only)
Ctrl-M	Switch to Acquire/Playback mode
Ctrl-N	New Configuration File
Ctrl-O	Open ADCP Raw Data File (Playback mode only)
Ctrl-P	Print (Playback mode only)
Ctrl-S	Save Configuration File
Ctrl-R	The Unfreeze button unfreezes all frozen items (blue text).
Shift-F4	Set ADCP Clock
Minus	Previous Ensemble (Playback mode only)
Space	Next Ensemble (Playback mode only)
Home	First Ensemble (Playback mode only)
End	Last Ensemble (Playback mode only)
Z	Zoom to data

b. You may want to record a note about the instrument setup or factors such as wind conditions, the passage of other vessels, and any other noteworthy events that occur during your transect of the channel. Use the **Settings** menu, **Configuration Setting**, **Recording** tab and type **<This is a Note>** to add a comment to the configuration file.

NOTE. The note will be saved to the configuration file (a *w.000 file is created for every transect), not with the data file.

c. Press **F4** to start the ADCP pinging. The Acquire **Tabular** window will now show *ADCP PINGING*.

In a few seconds, you will see changing values in several of the data windows. The ensemble number will update, the time displayed just below the ensemble number will change to show the ADCP time of each ensemble, the position sensors will update, and so on. And, if you have the ADCP in sufficiently deep water, you will see velocity profiles on the graph. *WinRiver* will not display meaningful data if your system is not in water.

In general, after you have started the ADCP pinging, there is no reason to stop pinging until you are finished and ready to remove the ADCP from the water. An exception would be if you were operating off of batteries with limited capacity. Then stopping pinging will conserve power.

NOTE. You can let the ADCP ping even if it is not in the water. Unlike many other acoustic devices, no damage to the ADCP will occur. It is often useful to operate it out of the water to test configuration files, practice with *WinRiver*, or perform other tests.

d. Before going forward, on the **Settings** menu, click **Reference**. Choose **Bottom Track** from the list. This will ensure that the velocity reference for the data display is set to bottom track. When bottom track is used as the velocity reference, the speed of the ADCP over ground is subtracted from the measured relative velocity to give true Earth referenced water velocity. You can always determine what velocity reference is in use by looking at the text lines just above and below the scales at the top and bottom of the graph display. At the end of each line is an indication of the reference being used.

3-6.1 Performing a Pre-Run

It is a good idea to perform a pre-run transect before actually acquiring data. This gives you the opportunity to ensure that the ADCP is working as expected with the loaded configuration file. You will also determine the starting/stopping locations at each side of the channel. As you cross, you can monitor the depth to see if there are areas with abrupt depth changes. Later, during data acquisition, you will want to cross very slowly over these regions to help bottom tracking maintain a valid lock on the bottom.

a. On the **View** menu, select the **Tabular**, **Discharge Standard Tabular** (see Figure 13). When making an individual discharge measurement, you want to start and stop the recording of data in water sufficiently deep to allow valid data to be recorded. Use the tabular display to determine when the water is deep enough to give a discharge value in the top two depth cells (**Good Bins** = 2 or more). You will be using a power fit for the extrapolation of the top and bottom, and at least two depth cells with valid discharge are needed in order to compute a more accurate power fit.

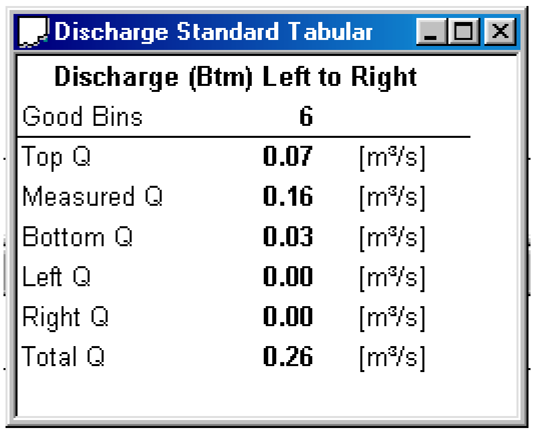


Figure 13. Discharge Standard Tabular Display

b. Move out from the shore until the water is deep enough to show a discharge value in the top two depth cells. Mentally note or mark this position with a float. This is the starting/stopping position for this shore. You will later start/stop data file recording at this location depending on the direction of your transect.

c. Move out from the shore traveling slowly with the bow of the boat pointed upstream. On the **View** menu, select **Contour Plots**, **Velocity**, **Velocity Magnitude Contour**. The display will look similar to that shown in Figure 14, page 43. Use this display to see how the water depth changes as you make your transect. Note regions where the bottom depth changes quickly.

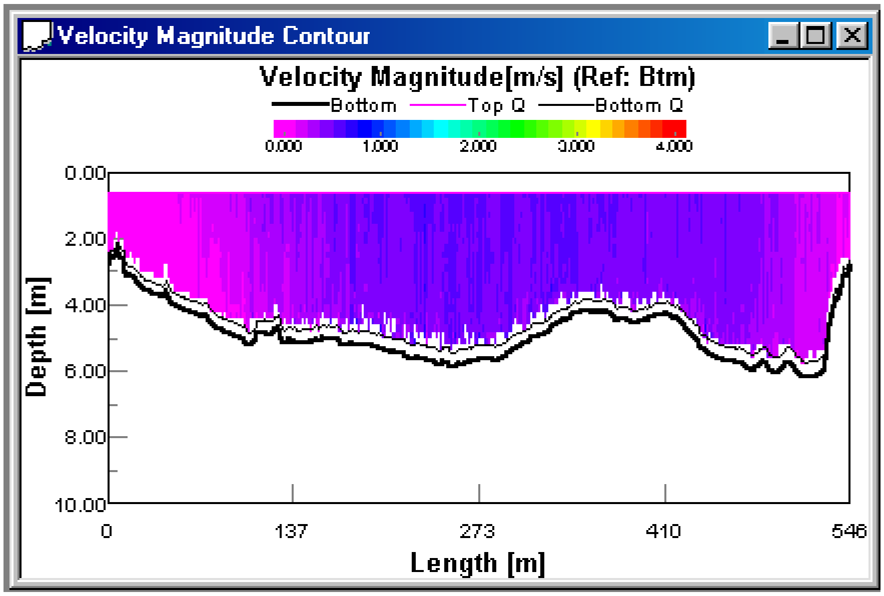


Figure 14. Velocity Magnitude Contour Plot

d. As you approach the other shore, change the display back to tabular, and note or mark the closest distance to shore where two the top two depth cells show discharge values. This will be the start/stopping point for this shore.

3-6.2 Holding Position at the Starting Channel Edge

a. Starting at one of your marked edges, use the **Discharge Standard Tabular** display to ensure that you have at least two valid discharge measurements.

b. While holding position at the location where you have two valid cells of data, determine the edge distance to shore, and then press **F5** to start data recording. You will be prompted for a starting distance to shore. A unique configuration file, *w.000, will be created and saved in the same directory as the raw data file. This configuration file will contain the starting edge distance as well as the ending edge distance you will enter later at the end of the transect.

> **NOTE.** Data processing continues while WinRiver is prompting for the edge distance.

c. Holding position for 4 to 5 ensembles after beginning the recording of data, enter the value for the starting shore distance. The extra ensembles that are recorded to the raw data file during this stationary period will help to ensure that you have a good starting ensemble for estimation of the side discharge. This must be enabled on the **Settings** menu, **Configuration Settings**, **Discharge** tab, **Shore Pings** box.

3-6.3 Crossing the Channel

a. Once several ensembles are recorded at the edge, slowly move away from the shore. Head for the desired ending point on the other side of the channel. Avoid fast accelerations, and keep the transect speed at or less than the water speed. Since you will be crossing slowly, you will be forced to point the bow nearly upriver and crab across. The slower you cross, the better your results will be.

b. As you make your transect, take some time to experiment with the different display options. The display scales can be changed on the **Chart Properties 1** and **2** tabs or right-click on a plot and select **Properties**.

c. You can see the discharge for the top, middle and bottom layers on the **Discharge Tabular** screen.

3-6.4 Holding Position at the Ending Channel Edge

Continue across the river until you reach the edge position determined during the pre-run on the opposite shore. You should have discharge values in at least the top two depth cells. Stop at this position and wait for 4 or 5 measurements to be recorded. Press **F5** to stop recording data. You will be prompted to enter the ending edge distance. Enter the value of the distance to shore.

3-6.5 Acquiring Discharge Data for Multiple Transects

Congratulations, you have just completed your first discharge measurement. You can now repeat the discharge measurement procedure to make additional transects. You will typically use **F5** to start and stop recording data for each passage across the channel while letting the ADCP ping continuously. An even number of transects is recommended, and the discharge from each individual transect can be averaged together to provide a discharge measurement for the site with lower variance than that of a single transect (see “Compute Total Discharge,” page 14). A new data and configuration file will be created each time you start and stop recording, and the starting and ending edge distances along with any entered notes will be saved in the unique configuration file.

When you have finished your desired number of transects and you are ready to stop data collection, press **F4** to stop pinging.

4 Post-Processing of Discharge Data

The Playback mode of *WinRiver* is used for post-processing data to get a total discharge value for the channel. Within the Playback mode, you can subsection the data to remove bad ensembles and change your averaging interval.

Modifying the *WinRiver* configuration file in the **Setting**, **Configuration Settings** tabs allows you to re-scale the raw data file to correct for variables that may have been incorrectly set during data collection such as the transducer depth, the salinity value or the edge distances.

4.1 Loading a Data File

a. Start *WinRiver* in the Playback mode. If you are in the Acquire mode, click **File**, **Playback Mode**.

b. On the **File** menu click **Open ADCP Raw Data File** and select the file to be played. WinRiver automatically creates a *w.001 configuration file.

- If the *w.000 configuration file exists, all of the values in the **Settings** menu, **Configuration Settings** tabs except the **Chart Properties 1** and **2** tabs will be used. The values will be grayed out. No changes can be made unless the item is right-clicked. Items that you decide to change during data playback will be saved in the *w.001 configuration file. The *w.000 files will not be changed.
  - If a *w.000 configuration file does not exist you can modify all of the items in the *w.001 configuration file.

c. Create a new Workspace file by clicking **File**, **New Workspace File**. To open a workspace file, click **File**, **Open Workspace File**.

d. On the **Playback** menu, click **Play** to start playing the data. To quickly process the data select **Last Ensemble**. The playback tool bar has functions to start, stop, rewind, and go to the end of the data file.

4.2 Viewing Discharge Data

The Playback data display options are the same as those for the Acquire mode. Take some time to experiment with the formats, and refer to the *WinRiver* help file for more details on the **Playback** menu and available displays.

a. *WinRiver* can single-step through the data or run through at maximum speed. You can toggle between the pause/resume states by pressing **F4**. When the pause-state is enabled, *SPACEBAR-STEP* is displayed in the Status Bar. Press the space bar to single step through each ensemble of data.

When the data file is played through to the end, press **Home** to rewind it to the beginning. Press **End** to play the data file to the end.

b. On the **Setting**, **Reference** menu, choose **Bottom Track** as the velocity reference. You will want to use this reference for data display and the calculation of discharge. In this reference, the boat's velocities are subtracted from the measured velocities to present true water velocities.

c. Use the **Setting** menu, **Configuration Setting**, **Chart Properties 1** and **2** tabs or right-click the display and select **Properties** to change the scaling fields of the different data displays.

d. Press **Z** to zoom in on the **Ship Track** and **Stick Ship Track** plots, and then **End** to play back the data file completely.

4.3 Subsection a File

You can use the **Ensemble File Subsection** box to subsection raw data files before display, writing to ASCII files, or printing a display. *WinRiver* resets all elapsed data counters (Made Good, Length, Time) and total discharge values (Q) at the start of your subsection, so it computes the elapsed information or discharge for the subsection only. For example, you could subsection the middle 500-meters of a 2-km river transect. Replaying the subsectioned data would then show the discharge in that 500-m section of the river.

a. Start *WinRiver* in the Playback mode. If you are in the Acquire mode, click **File**, **Playback Mode**.

b. On the **File** menu click **Open ADCP File**. Select the data file to be subsectioned.

c. On the **Settings** menu, click **File Subsection**.

d. To select a portion of the data file, uncheck the **Select All Ensembles** box. Enter the **First Ensemble Number** and **Last Ensemble Number** and select **OK**.

e. Play the subsectioned data file. To quickly process the entire data set, click **Playback**, **Last Ensemble**. When subsectioning, *WinRiver* tries to jump to the **First Ensemble Number** in the data file before processing. If *WinRiver* cannot jump to that ensemble number, it resets the data file to the beginning of the file. If *WinRiver* reaches the end-of-file before finding the **Last Ensemble Number**, it sets the last ensemble number to the last ensemble number read from the file.

f. To return to the entire data file, On the **Settings** menu, click **File Subsection**. Check the **Select All Ensembles** box. Replay the data file.

4.4 Creating an ASCII-Out Data File

Playback can be used to create ASCII-Out data files. These files are, as the name implies data files that are in a text format that can be directly read by you or imported into other post processing software.

a. Start *WinRiver* in the Playback mode. If you are in the Acquire mode, click **File**, **Playback Mode**.

b. On the **File** menu click **Open ADCP File**. Select the data file to be converted.

c. On the **File** menu, click **Start ASCII Out**. Type the name of the data file you want the data to be written to. The symbol "->" and the file name will indicate successful opening of the file.

d. *WinRiver* will jump to the first ensemble, playback the data file, and then close the ASCII file.

4.5 Print a Plot or Display

a. Start *WinRiver* in the Playback mode. If you are in the Acquire mode, click **File**, **Playback Mode**. Printing is only available in the Playback mode.

b. On the **File** menu click **Open ADCP File**. Select the data file to be played.

c. Play the data file. To quickly process the entire data set, click **Playback**, **Last Ensemble**.

d. Click on the plot/display to be printed. The title bar will be highlighted.

e. On the **File** menu, click **Print Setup**. Select the desired setting and printer.

f. On the **File** menu click **Print Preview**. If the display is acceptable, click **Print**.

5 Integrating GPS and Depth Sounder Data

WinRiver can integrate both GPS data and depth sounder data into real-time discharge calculations. These devices are used when environmental conditions make it difficult to get unbiased boat velocity and/or depth using bottom tracking. See “Unable to Bottom Track,” page 94 in the Trouble Shooting section of this guide for more details on these conditions. This section addresses the GPS and Depth Sounder requirements for integration.

GPS Requirements

- The GPS must be a high quality, accurate differential GPS system.
- The GPS must be capable of outputting GGA and GSA (optional) data strings via the NMEA0183 format. The GGA string contains GPS positions. The GSA string provides optional diagnostic information, and it is not required.
- Two serial ports are required on your computer to accept both ADCP and differential GPS data.

Depth Sounder Requirements

- The depth sounder must be capable of outputting the DBT data string via the NMEA0183 format.
- A third serial port is required on your computer to accept the depth sounder data if you are also acquiring differential GPS in addition to ADCP data.

5.1 How to Use Depth Sounders

The depth sounder is another external sensor that can be used to track the depth of the water. Areas with weeds or high sediment concentrations may cause the ADCP to lose the bottom. *WinRiver* will display the corrected depth (depth of water from the surface) in the **Navigation** tabular screen (See Figure 16, page 51).

NOTE. In conditions where a depth sounder is required to measure water depth, a GPS is also required to measure the boat speed.

5.1.1 System Interconnections with the Depth Sounder

a. Connect the depth sounder system to your computer using a serial interface (see your depth sounder manual for details). You must have a depth sounder capable of serial NMEA 0813 output with DBT format in feet.

b. Configure the depth sounder to output the DBT data string via the NMEA0183 format.

c. Connect the ADCP system and the GPS to your computer as described in System Interconnection with GPS. Apply power to the system (see the ADCP Technical Manual for details).

d. **Three** serial ports are required on your computer to accept the depth sounder and differential GPS in addition to ADCP data. For laptops, two PCMCIA serial cards may be used to provide the second and third ports.

5.1.2 Enabling the Depth Sounder Port

In order to use the depth sounder data, the depth sounder must be enabled. To enable depth sounder communications with *WinRiver*, do the following steps.

a. In the Acquire mode, select the **Settings**, **Communications** menu click the **Add** button.

> **NOTE.** *WinRiver* can be customized to begin pinging as soon as the Acquire mode is started. On the **File** menu, click **Stop Pinging**. You are not allowed to change communications parameters while pinging.

b. Choose **Depth Sounder**, then click **Next**. Choose the COM port that the depth sounder is connected to.

> **NOTE.** Three serial ports are required on your computer to accept ADCP, differential GPS data, and depth sounder data.

c. Click **Next**. Enter the Depth Sounder communication Baud Rate, Parity, and Stop Bit settings.

d. Click **Next**. Verify the port and communication settings. Click **Next**.

> **NOTE.** If you do not want to use depth sounder for this transect, you can select the Inactive box. This will disable depth sounder, but retain the communication settings.

e. Click **Finish**.

f. Start pinging. You can select **View**, **Device Logs**, **Depth Sounder Log**. That will open a window in which all the characters coming from the port assigned for the depth sounder are shown. If the communication parameters are set properly you should see "$ DBT" strings on the display.

5.1.3 Using Depth Sounder Data

Once the Depth Sounder communications port is set up the data is recorded. To use and view the Depth Sounder data rather than the ADCP beam depths, do the following.

a. On the **Settings**, **Configuration Settings**, **DS/GPS** tab, select the **Use in Processing** box. The ADCP beam depths will be replaced by the Depth Sounder data.

b. Under the **Setting** menu, **Configuration Settings**, **Recording** tab you can select to collect depth sounder data to an ASCII file (*d.*).

> **NOTE.** The Depth Sounder data is ALWAYS recorded to the raw ADCP data file. The ASCII files (*d.*) are only recorded if requested and are not used by WinRiver..

c. On the **Settings**, **Configuration Settings**, **DS/GPS** tab, enter the depth from the surface of the water to the depth sounder's transducer face in the **Transducer Depth** box.

d. In addition to the **Transducer Depth** command, you can also add an additional offset to reconcile any differences between the ADCP bottom track depths and those reported by the DBT NMEA string. Enter a value in the **Offset** box.

e. You can apply a scaling factor to the raw NMEA depth sounder output by entering a number in the **Scale Factor** box. Note that the depths reported by the DBT NMEA string do not include the depth of the sounder, so the scaling is applied to the range reported from the depth sounder to the bottom.

f. Many depth sounders only allow a fixed value of 1500 m/s for sound speed. *WinRiver* can scale the depth sounder depths by the sound speed used by *WinRiver* by selecting the **Correct Speed of Sound** box.

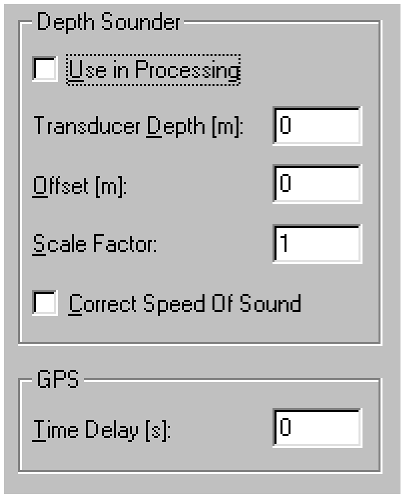


Figure 15. Depth Sounder Offsets

g. Save the configuration file with a unique name by selecting **Save Configuration File As** from the **File** menu. In naming the configuration file, use a name that will indicate that the depth sounder is being used in place of bottom track depths in the discharge calculation, i.e. RDGPS_DS.wrc for GPS and depth sounder.

> **NOTE.** The decoded data will be displayed in the **Navigation Tabular** view if the **Settings**, **Configuration Settings**, **DS/GPS** tab, **Use in Processing** box is selected.

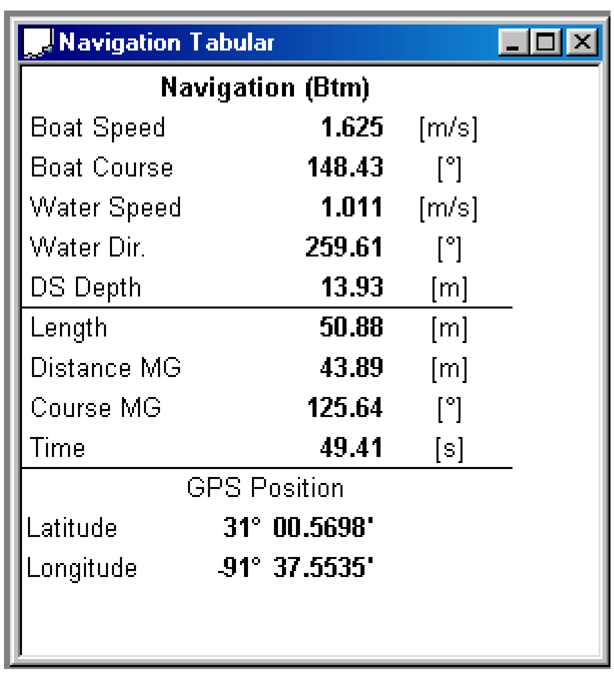


Figure 16. Viewing Depth Sounder Data

5.2 How to Use GPS

In high flow (flood) or high sediment concentration conditions, the ADCP may make biased bottom track measurements. The bias is caused by two different environmental sources:

- Fluid layer of sediment flowing along the bed of the stream (Moving Bottom)
- High sediment concentration in the water column near the bottom (Water Bias)

The consequences of these environmental sources and the biased ADCP bottom track are:

- Discharge computed with the ADCP is biased low
- The vessel track (shiptrack) is biased upstream

NOTE. The ADCP is not malfunctioning – but measuring the environment as designed.

5.2.1 Using GPS Versus Bottom Track

When the ADCP cannot make unbiased bottom track measurements, an external differential GPS system should be used as the velocity reference. *WinRiver* can integrate the GPS data, replacing the bottom track velocity to compute real-time discharge. If the ADCP can detect the bottom to obtain depth, then there is no need to use a depth sounder.

In some cases, the suspended sediment concentrations are very high, and the ADCP cannot make a valid detection of the bottom depth. In this case, a depth sounder can be used to provide the depth for the real-time discharge calculation. In conditions where a depth sounder is required to measure water depth, a GPS is also required to measure the boat speed.

To use GPS as a vessel speed reference, three conditions must be met:

1. The GPS must be a high quality, accurate differential GPS system.

2. The compass used to rotate ADCP velocities to earth coordinates must be accurate and unbiased. The internal ADCP compass must be corrected for magnetic effects caused by any ferromagnetic objects, e.g. steel tools or motor, on the boat or in the nearby environment. The Compass Correction section describes the procedures to correct the internal ADCP compass heading data for local magnetic variation and to calibrate the compass for one-cycle deviation errors. These corrections will help to reconcile the magnetic coordinate system of the ADCP with the GPS true earth coordinate system. You must be able to acquire valid bottom-track data to perform these corrections. If you anticipate moving bottom conditions during

flood season, you should determine the compass corrections before flood season.

3. Transects must be made slowly to obtain the best quality discharge data when using GPS as the velocity reference. Slow boat speeds will reduce the error contribution to the discharge calculation caused by incorrectly rotating the ADCP velocities into the differential GPS earth coordinate system. This rotation is necessary to put both the ADCP velocities and the boat velocities determined by the GPS into the same coordinate system.

NOTE. Bottom-track must be enabled in order to use the GPS data even though it is not used as the velocity reference.

NOTE. If you can obtain valid bottom track data, and you use this as your reference system, there is no need to perform the compass correction procedures. Both the water and boat velocities are in the same coordinate system, and no rotation from one coordinate system to another is required.

5.2.2 System Interconnections with GPS

a. Connect the GPS system to your computer using a serial (RS- 232 or RS- 422) interface (see the GPS Manual for details).

b. Mount the differential GPS antenna as close to the ADCP as possible – less than one meter horizontally is the optimum distance. Apply power to the GPS.

c. Configure the GPS to output GGA, GSA (optional), and VTG (optional) data strings via the NMEA0183 format. The GGA string contains GPS positions. The GSA string provides optional diagnostic information, and it is not required. The VTG string provides velocity information calculated by the GPS.

d. Connect the ADCP system to your computer using a serial (RS- 232 or RS- 422) interface. Apply power to the system (see the ADCP Technical Manual for details).

e. Two serial ports are required on your computer to accept both ADCP and differential GPS data.

5.2.3 Enabling the GPS Port

To enable GPS communications with *WinRiver*, do the following steps.

a. On the **Settings**, **Communications** menu click the **Add** button.

b. Choose **GPS**, then click **Next**. Choose the COM port that the GPS is connected to.

NOTE. Two serial ports are required on your computer to accept both ADCP and differential GPS data.

c. Click **Next**. Enter the GPS communication Baud Rate, Parity, and Stop Bit settings.

d. Click **Next**. Verify the port and communication settings. Click **Next**.

NOTE. Selecting the **Inactive** box will disable GPS, but retain the communication settings.

e. Click **Finish**. The GPS data will be recorded to the raw data file.

Optional Settings

- GPS Latitude and Longitude data can be saved to a separate ASCII file by choosing **Record GPS Data** on the **Settings**, **Configuration Settings**, **Recording** tab.
- For best results, make sure the ADCP is using ship coordinates (EX**10**nnn command (default value), where the nnn values are set to 0 or 1 as desired) in the **Settings**, **Configuration Settings**, **Commands** tab.
- If desired, you can allow for a lead-time between the GPS position updates and the ADCP data. This is done by inserting a value in the **GPS Time Delay** box in the **Settings**, **Configuration Settings**, **DS/GPS** tab. For example, if the lead-time is set for 1 second, this assumes that the GPS data is one second old compared to the ADCP. The recommended value is zero.

5.3 Compass Correction

The following section describes the procedure to correct the ADCP's compass for use with the GPS data. The first correction to the compass is for local magnetic variation and the second correction is for one-cycle magnetic deviation errors.

CAUTION. *Both of these corrections are important because an uncorrected difference between the earth coordinate system of the differential GPS and the ADCP's internal magnetic compass will translate into significant errors in the discharge calculation.*

If you plan on using GPS, it is strongly recommended that you perform the compass correction procedures outlined in this section. A new compass correction should be determined if you are working more than 10-40 miles from the site where the last correction was performed, if you will be working in significantly different temperatures from the last compass calibration, or if your ADCP mounting has changed.

NOTE. We recommend installing the ADCP with beam 3 forward for making discharge measurements (refer to the installation guide) and for the compass correction procedures. If beam 3 is not forward, you will need to carefully measure the rotation angle of beam 3.

NOTE. If you have a Rio Grande ADCP with firmware 10.05 or greater, perform the Method 3 calibration before you do the Magnetic Variation Correction.

5.3.1 Magnetic Variation Correction

Local magnetic variation correction can be estimated by referring to a chart of the local area, but many times this information is not adequately precise. Use the following steps to determine the local magnetic variation.

a. Find a calm low current area where there is no moving bottom affects to do the compass correction. You must be collecting and using GPS data and be able to bottom track in the chosen location.

b. Create or open a workspace file (see "How to Customize WinRiver," page 15) that has the **Standard**, **Navigation**, and **Compass Calibration** tabular displays, and a **Ship Track** display.

c. On the **Settings** menu, **Reference**, set the reference to **GPS (GGA)**.

d. On the **Settings**, **Configuration Settings**, **Offsets** tab, set the **Magnetic Variation** value and compass correction (**One Cycle K** and **One Cycle Offset**) values to zero. Ensure that the **Beam 3 Misalignment** angle is set to the Beam 3 misalignment.

e. Mark a starting point. This should be a point that you can easily reference to (an end of a pier, or a stationary marker).

f. Start *WinRiver* in the Acquire mode. Press **F4** to start pinging. Press **F5** to start recording.

g. Drive a straight track with constant heading (accelerate slowly and maintain a slow steady speed) for at least 200 meters (the longer the course the better) as shown in Figure 17, page 56. Monitor the heading display in the **Standard Tabular** view, and adjust your course to stay on a constant heading (not a constant course).

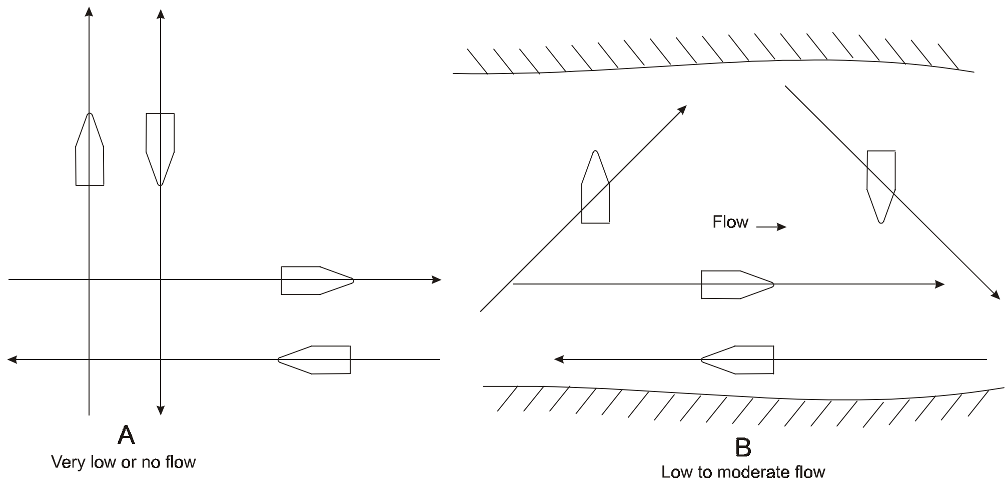


Figure 17. Reciprocal Constant Heading Tracks for Determining Magnetic Variation

h. Record the value of **GC-BC** from the **Compass Calibration Tabular** screen as shown in Figure 18. This is the compass error on this course (variation + deviation). Press **F5** to stop recording.

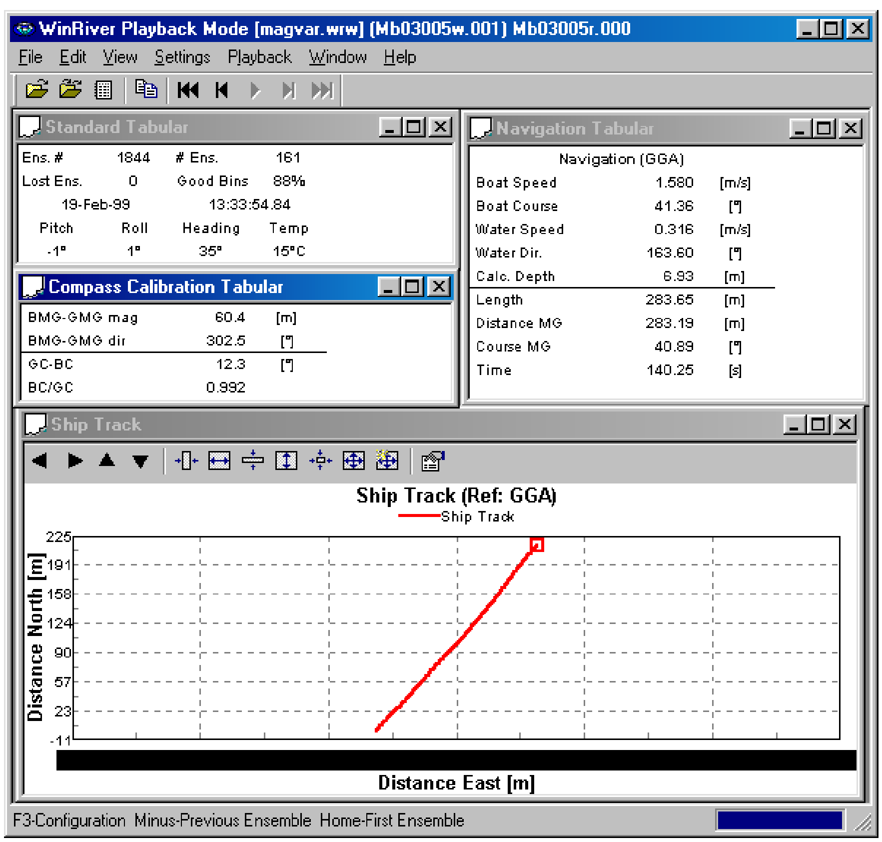


Figure 18. Determining Local Magnetic Variation

i. Drive a track along the opposite heading direction as shown in Figure 17, page 56. Press **F5** to start recording.

j. Record the value of **GC-BC**. Use the average of the two values to estimate the magnetic variation. Use as many pairs of reciprocal tracks along other heading directions as desired to get a better value (a total four vectors, that is two track pairs in approximately orthogonal directions, is recommended). Average the values of **GC-BC** for all of the tracks. This averaged value is the local magnetic variation.

k. Modify the **Configuration Settings**, **Offsets** tab and enter the **Magnetic Variation** value. In the example below, we have entered a magnetic variation of 12.2 degrees.

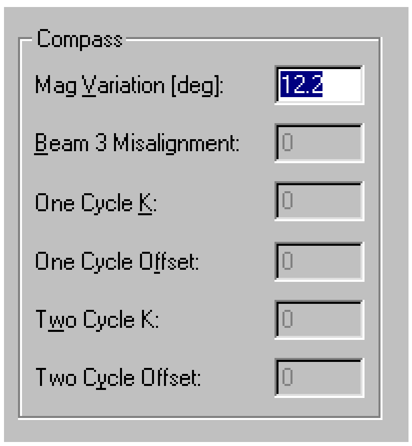


Figure 19. Entering Local Magnetic Variation

NOTE. In the Acquire mode it is a good idea to rename the configuration file to reflect that it has been corrected for magnetic variation. For example, if you original file was RDGPS1.wrc, then the modified file could be named RDGPS2.wrc to show that it has undergone one level of correction. In the Playback mode, simply edit the *w.001 file and freeze the values to apply them to all subsequent transects.

l. Start *WinRiver* in the Playback mode. When the data is played back, average the **GC-BC** value for two reciprocal headings. This value should be close to zero if the correction was made correctly (Figure 20).

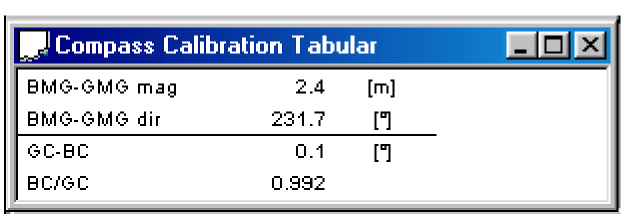


Figure 20. Data Corrected for Local Magnetic Variation

5.3.2 One-Cycle Compass Correction

Ferrous objects in the vicinity of the ADCP can affect the internal flux-gate compass. These affects will show up as one and two cycle errors in the compass heading. The one-cycle error can be corrected by using one of two methods described later in this section. The two-cycle error is typically negligible, but can be checked by using the AX-command as outlined in the Maintenance manual. Perform the AX-command with the ADCP mounted in the boat, and drive the boat in a small circle. If the two-cycle error is more than 0.5 degrees, check to see if there are any large ferrous objects close to the ADCP mounting that can be removed.

There are three methods of compass corrections. The first two require you to drive in a circle, starting and stopping at exactly the same point. Bottom-track may show that you have not returned to the same location. This non-closure error is caused by the one-cycle compass deviation, and it can be estimated from the magnitude and direction of the non-closure.

After you have driven in a circle, the magnitude of the non-closure error is indicated by the **Distance MG** (Made Good) value. The ratio between distance made good and the length of the track (**Distance MG** and **Length**, respectively) is the one-cycle magnitude of the compass error and the one-cycle offset is the **Course MG** angle.

There are three ways to determine and correct this non-closure error. The first procedure is the preferred method for BroadBand and WorkHorse ADCPs such as the Sentinel and Monitor. It provides a more accurate estimation of the one cycle compass error than the second method, but it requires that you have a stable dock or marker that you can drive away from in your boat and then return to within 30 cm (1 ft.). If you do not have a marker that will allow this kind of accuracy, use the second procedure to determine the one-cycle error. For both of these procedures, you must be in a location where you can obtain valid bottom track data.

The third method provides the easiest way to calibrate the compass for on-cycle errors but it can only be used with the WorkHorse Rio Grande ADCPs with firmware version 10.05 and higher. If you have a Rio Grande with an earlier version of firmware, contact RDI to upgrade the firmware. You do not need to be able to collect valid bottom track data for this third method to work. This procedure can be performed at sites with a "moving bottom".

Method 1 (Preferred)

To reduce the error, do the following steps.

a. Find a calm low current area where you can obtain valid bottom tracking data to perform the compass calibration procedure. Mark a starting point that you can easily return to and maintain position (an end of a pier, or a stationary buoy). You will need to be able to return to this location to within about 30 cm (1 ft.) (even closer is better!).

b. Make sure that *bottom track is the velocity reference* for the Method 1 compass calibration procedure. On the **Settings** menu, **Reference**, set the reference to **Bottom Track**.

c. On the **File** menu, select **Save Configuration File As** and create a new configuration file from the file that was modified for the magnetic variation. We suggest naming the configuration file to reflect that Bottom Tracking is being used and that the magnetic variation correction has been applied, i.e. *BTM2.wrc.

d. Create or open a workspace file (see "How to Customize WinRiver," page 15) that has the **Standard**, **Navigation**, and **Compass Calibration** tabular displays, and a **Ship Track** display.

e. Start *WinRiver* in the Acquire mode. Press **F4** to start pinging. Press **F5** to start recording.

f. Drive in a circular course with a circumference of about 1000 meters or larger (as large as possible). It is important to make a large circular track to make a good estimate of the one-cycle compass correction factors, and it is also important to make the path as close to a true circle as possible. Use the **Ship Track** screen to help make the circular course at a slow steady speed. If your location does not allow you to run a large circular course, you can run several continuous circles (say 3 to 5) being sure to pass your original starting point as you complete each circle. You would then use the combined course length from all of the circles in determining the one-cycle errors as described in the following steps. In Figure 21, page 60, three circular tracks were made to provide a total track length of 1754.50 meters.

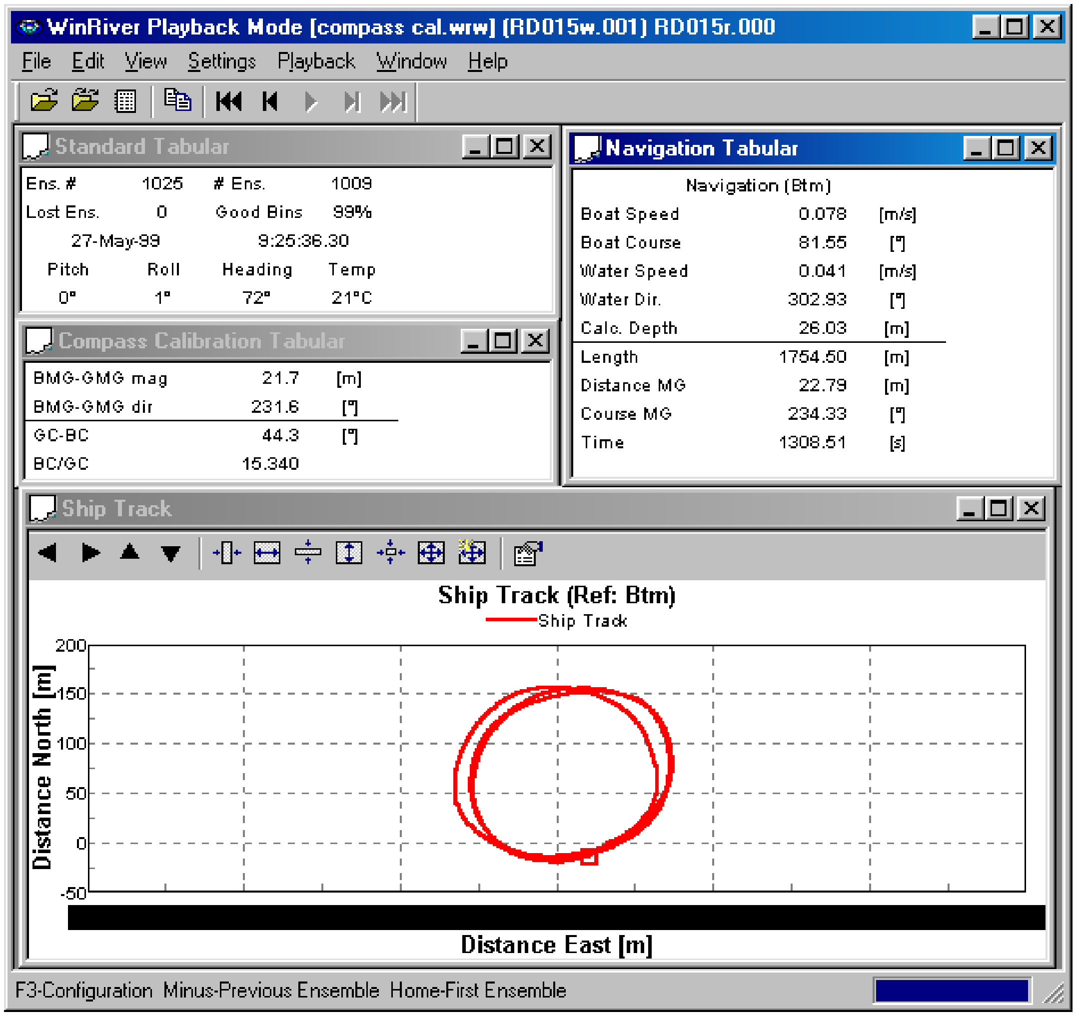


Figure 21. Method 1 Compass Correction Procedure

g. Come back as close as you can to the starting point (within 30 cm or less). Press **F5** to stop recording.

h. Record the **Course MG**, **Distance MG**, and **Length** values m the **Navigation Tabular** display. For example, in Figure 21, the **Course MG** is 234.33°, the **Distance MG** is 22.79 meters, and the **Length** is 1754.50 meters.

i. Take the ratio between **Distance MG** and **Length**; this is the magnitude of the one-cycle error (**One Cycle K**). In our example as shown in Figure 22, page 61, you would determine the ratio as 22.79/1754.50 = 0.0129. The **Course MG** 234.33° is the one-cycle error offset (**One Cycle Offset**).

j. On the **Settings**, **Configuration Settings**, **Offset** tab, enter the values for the **One Cycle K** and **One Cycle Offset**.

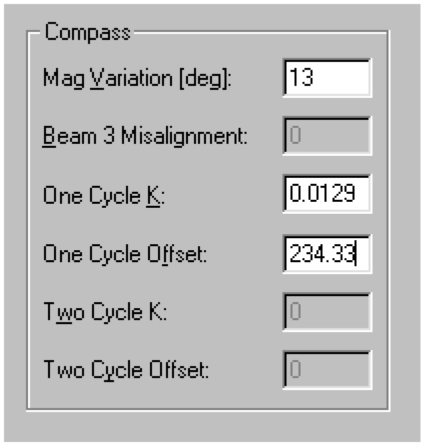


Figure 22. Entering the Compass Corrections

k. If the ADCP is mounted with beam 3 pointed in a direction other than forward along the ship's centerline, determine the clockwise rotation of beam 3 relative to the ship's centerline and insert the value in the **Beam 3 Misalignment** box.

l. Apply the One Cycle K and One Cycle offset corrections to the configuration file that contains the magnetic variation corrections.

m. Start *WinRiver* in the Playback mode and replay the data using the corrected configuration file. The circle non-closure error as indicated by **Distance MG** should now be minimized (Figure 23, page 62). If the compass has been adequately corrected, the ratio of **Distance MG** to **Length** should be 0.01 or less (2.83/1754.50 = 0.0016).

n. You can now use the corrected configuration file for acquiring discharge measurements.

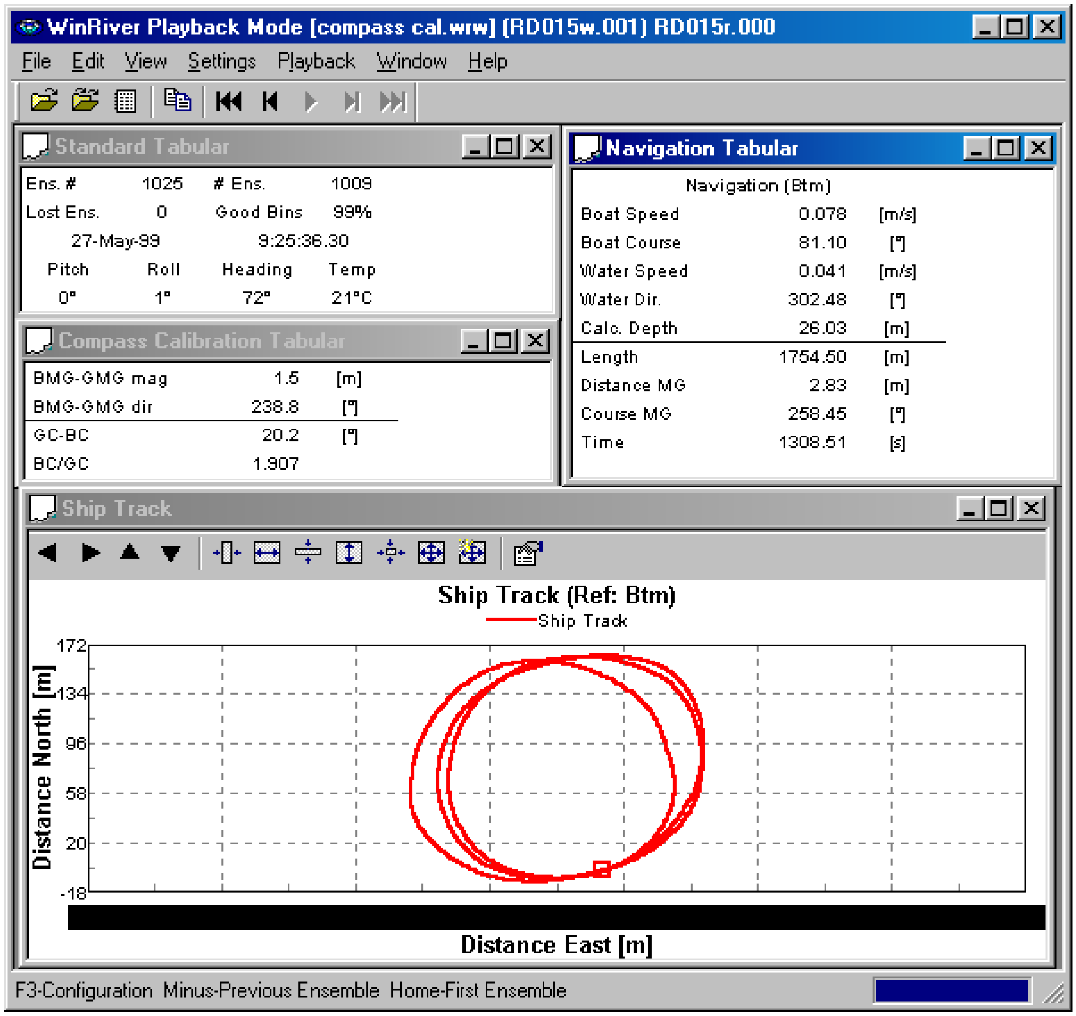


Figure 23. Method 1 Compass Correction Procedure with Correction Applied

NOTE. It is a good idea to rename the configuration file to reflect that the compass corrections have been applied. For example, if the configuration file with magnetic variation has been named *M2.wrc, then the new file could be named *M3.wrc to indicate that both the magnetic variation and the one-cycle corrections have been applied.

To apply the corrections to subsequent data files during Playback, right-click each of the shore estimates boxes and bank type (left/Right) on the **Settings** menu, **Configuration Setting**, **Shore Estimate** tab and select **Use *w.000 value**. The value will become grayed out. Click **Apply**. Now save the configuration file as a unique name. When a new data file is opened, the shore estimate values will be taken from the *w.000 file and the compass corrections will already be applied.

Method 2

If you don't have a marker available that allows you to return to the same location (within 30 cm), you can still determine the one-cycle correction factors. For this procedure, *GPS is used as the reference* rather than the dock or stationary marker used in Method 1. The magnitude of the non-closure error is estimated by the magnitude of the **BMG-GMG** vector, and the **BMG-GMG** angle is the course made good direction. The ratio between distance made good and the length of the track (**BMG-GMG** and **Length**, respectively on the *WinRiver* display in Figure 25, page 65) is the magnitude of the one-cycle compass error and the one-cycle offset is the **BMG-GMG** angle.

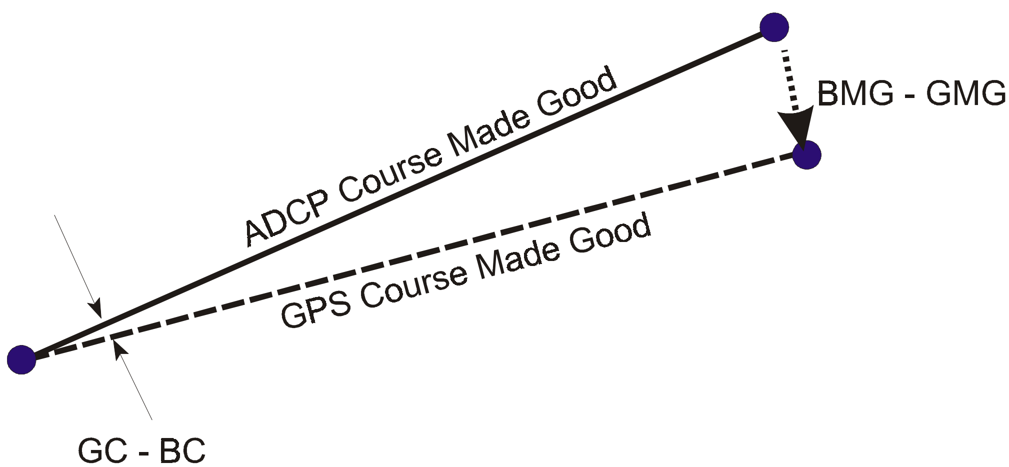


Figure 24. GPS Versus Bottom Track

To reduce the error, do the following steps.

a. Find a calm low current area where you can obtain valid bottom tracking data to perform the compass calibration procedure. Mark a starting point. You will need to be able to return to this general location to within about 3 meters (10 feet).

b. Make sure that *GPS (GGA) is the velocity reference* for the method 2 compass calibration procedure. On the **Settings** menu, **Reference**, set the reference to **GPS (GGA)**.

c. On the **File** menu, select **Save Configuration File As** and create a new configuration file from the file that was modified for the magnetic variation. We suggest naming the configuration file to reflect that GPS is being used and that the magnetic variation correction has been applied, i.e. *S2.wrc.

NOTE. GPS is used for the velocity reference in Method 2, while Bottom-Track is the reference in Method 1.

d. Create or open a workspace file (see How to Customize WinRiver) that has the **Standard**, **Navigation**, and **Compass Calibration** tabular displays, and a **Ship Track** display.

e. Start *WinRiver* in the Acquire mode. Press **F4** to start pinging. Press **F5** to start recording.

f. Drive in a circular course with a circumference of about 1000 meters or larger (as large as possible). It is important to make a large circular track to make a good estimate of the one-cycle compass correction factors, and it is also important to make the path as close to a true circle as possible. Use the **Ship Track** screen to help make the circular course at a slow steady speed. If your location does not allow you to run a large circular course, you can run several continuous circles (say 3 to 10) being sure to pass as close as possible to your original starting point as you complete each circle. You would then use the combined course length from all of the circles in determining the one-cycle errors as described in the following steps. In Figure 25, page 65, three circular tracks were made to provide a total track length of 1731.76 m.

g. Monitor the **BMG-GMG** vector display in the Compass Calibration Tabular display as you come back to your starting location. Press **F5** to stop recording.

h. Record the **BMG-GMG** vectors (magnitude and direction) and **Length** values. For example, in Figure 25, page 65, the **BMG-GMG Direction** is 231.6°, the **BMG-GMG Magnitude** is 21.7 m, and the **Length** is 1731.76 m.

i. Take the ratio between **BMG-GMG Magnitude** and **Length**; this is the magnitude of the One-Cycle Error (**One Cycle K**). In our example as shown in Figure 25, page 65, you would determine the ratio as 21.7/1731.76 = 0.0125. The **BMG-GMG Direction** 231.6° is the One-Cycle Error Offset (**One Cycle Offset**).

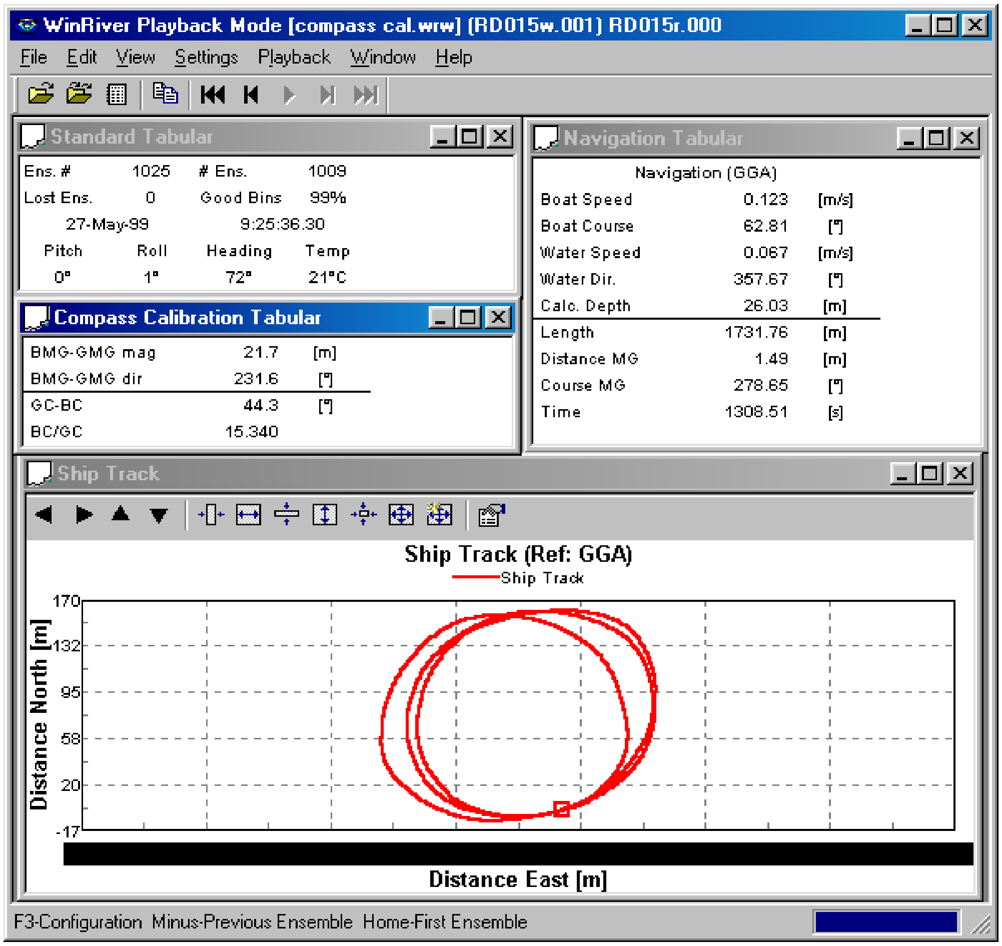


Figure 25. Method 2 Compass Correction Procedure

j. On the **Settings**, **Configuration Settings**, **Offset** tab, enter the values for the **One Cycle K** and **One Cycle Offset**.

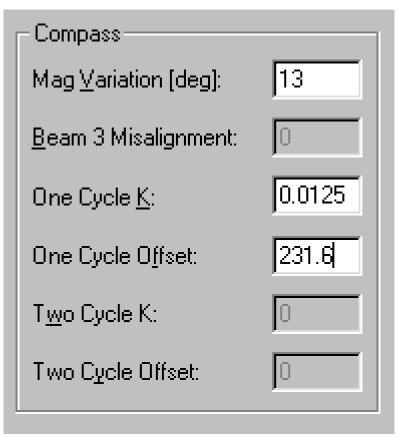


Figure 26. Entering the Corrections for Method 2 Compass Correction Procedure

k. If the ADCP is mounted with beam 3 pointed in a direction other than forward along the ship's centerline, determine the clockwise rotation of beam 3 relative to the ship's centerline d insert the value in the **Beam 3 Misalignment** box.

> **NOTE.** It is a good idea to rename the configuration file to reflect that the compass correction has been applied. For example, if the configuration file with magnetic variation has been named *S2.CFG, then the new file could be named *S3.CFG to show that both the magnetic variation and the one-cycle corrections have been applied.

l. Start *WinRiver* in the Playback mode and replay the data using the corrected, GPS-referenced configuration file. The circle non-closure error indicated by the **BMG-GMG Magnitude** will be minimized. If the compass has been adequately corrected, the ratio of **BMG-GMG Magnitude** to **Length** should be 0.01 or less (2.4/1731.50 = 0.0013 in Figure 27).

m. You can now use the corrected configuration file for acquiring discharge measurements.

> **NOTE.** RDI recommends using a bottom-track referenced configuration file (Method 1). If you have a Rio Grande ADCP, RDI recommends using Method 3.

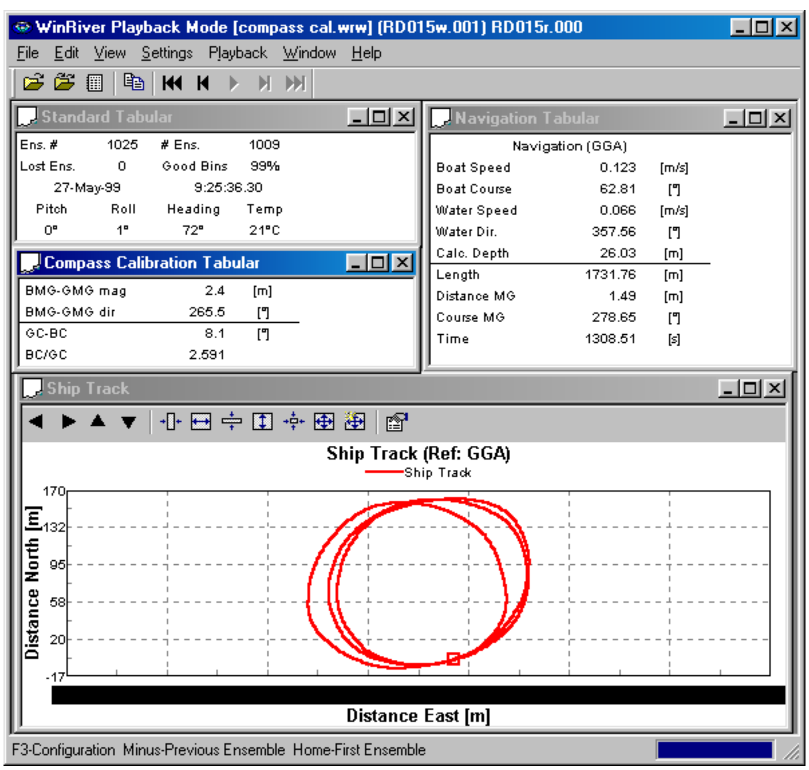


Figure 27. Method 2 Compass Correction with Correction Applied

Method 3

This procedure is used to correct the Rio Grande's internal flux-gate compass for one-cycle deviation errors. The compass correction procedure given here can be used in place of the Method 1 or 2 compass correction procedures if you are using a Rio Grande with firmware version 10.05 and higher.

> **NOTE.** The Rio Grande firmware has been modified to allow the correction of the one-cycle errors with the AF command. BroadBand and other WorkHorse ADCPs, such as the Sentinel and Monitor, do not have this capability.

a. Mount the Rio Grande ADCP in the boat as it will be used to acquire data.

b. Start *DumbTerm* and press the **END** key to send a BREAK and establish communication with the Rio Grande. Refer to the *DumbTerm* help file for details on using the *DumbTerm* program. *DumbTerm* is a simple "dumb terminal" program that can be used to send direct commands to the ADCP. You will be using the AF-command to examine the compass performance and correct the one-cycle magnitude and offset correction factors.

c. During this procedure, you will drive your boat in continuous, small circles. You can accomplish this by adjusting the throttle to just above idle and steering either hard left or hard right. You will want to reduce any pitch and roll effects during the turn (do not move about the boat, this may cause the boat to change how it sits in the water) and avoid any accelerations. If you are working on a river, you will find that you drift downstream as your perform the circles. This will not affect the correction procedure.

d. Press **F3** to turn on the *DumbTerm's* logging capability, and enter a desired filename for the log file.

e. While you continue to drive the boat in circles, type **AF** at the command prompt. The following represents what you will see on the screen:

```
>AF
-----------------------------------------------------------------------
                         Field Calibration Procedure
Choose calibration method:
     a.  Remove hard iron error (single cycle) only.
     b.  Remove hard and soft iron error (single + double cycle).
     c.  Calibration for a single tilt orientation (single + double cycle).
     d.  Help.
Quit.
```

f. Choose option "c" to Calibrate the compass for a single tilt orientation, and the following will be displayed:

```
C
----------------------------------------------------------------------
Field Calibration Procedure
          Calibration for Constant Tilt Applications (e.g., Rivers)
Select one:
     a.  Start calibration procedure.
     b.  Zero calibration coefficients (only constant tilt coefs).
     c.  Display correction coefficients.
     d.  Instructions.
     e.  Quit.
```

g. Choose option "a" to start the calibration procedure. As you turn a circle in the boat, the program will accumulate data as you point in different heading directions. Once the data is accumulated, the total compass error will be displayed as highlighted below. In the example shown, a large magnet was place close to the ADCP to create a large one-cycle error that results in a Total Error of 7.8°. You will not likely see such a large compass error when you perform the calibration yourself.

```
A
-----------------------------------------------------------------------
                    RDI Compass Error Estimating Algorithm

   Press any key to start taking data after the instrument is setup.

Rotate the unit in a plane until all data samples are acquired...
   rotate less than 5ø/sec.  Press Q to quit.

 N       NE       E        SE       S        SW        W        NW       N
 ^                ^                 ^                  ^                 ^

Accumulating data ...
Calculating compass performance ...

                          >>> Total error:   7.8ø <<<

Press D for details or any other key to continue...
```

h. When prompted, press **D** for details, and you will see a message similar to the following:

```
D

HEADING ERROR ESTIMATE FOR THE CURRENT COMPASS CALIBRATION:
   OVERALL ERROR:
      Peak Double + Single Cycle Error (should be < 5ø):  ± 7.78ø

   DETAILED ERROR SUMMARY:
      Single Cycle Error:                  ± 8.09ø
      Double Cycle Error:                  ± 1.28ø
      Largest Double plus Single Cycle Error: ± 9.37ø
      RMS of 3rd Order and Higher + Random Error:    ± 0.64ø

      Orientation:    Down
      Average Pitch:   0.05ø         Pitch Standard Dev:    0.77ø
      Average Roll:    0.22ø         Roll Standard Dev:     0.30ø

Successfully evaluated compass performance for the current compass calibra-
tion.

Press C to display Percent Horizontal Field Components
     Relative to Calibration or any other key to continue....
```

i. At this point, check the Pitch and Roll Standard Deviation values as highlighted above. These values should be below 1°. It is best to use data with less than 1° standard deviation in both pitch and roll. If the boat pitched more than 1° during the turn, you will be given a warning message that the compass performance data may be suspect, and if the boat has pitched more than 3° during the turn, the AF command will stop.

j. Press **C** at the prompt to display the horizontal field components.

```
   Percent Horizontal Field Component Relative to Calibration:
          a0 + a1*cosé + b1*siné + a2*cos2*é + b2*sin2*é
          a0 =                                            55.895%
          a1 =                                             6.361%
          b1 =                                            -4.755%
          a2 =                                             0.115%
          b2 =                                            -1.244%

Press any key to continue...
Calibration parameters have been updated in NRAM.
```

k. The last message indicates that the compass parameters have been updated to NRAM to correct for one-cycle errors. Press any key to return to the command prompt.

l. You can now evaluate the corrected compass by typing **AX** at the command prompt. You will need to continue turning in circles to accumulate data on all headings as you did for the AF command. The screen display will be as follows:

```
>AX
----------------------------------------------------------------------------
                    RDI Compass Error Estimating Algorithm

   Press any key to start taking data after the instrument is setup.

Rotate the unit in a plane until all data samples are acquired...
   rotate less than 5ø/sec.  Press Q to quit.

 N       NE       E        SE       S       SW        W        NW       N
 ^                ^                 ^                 ^                 ^
Accumulating data ...
Calculating compass performance ...

                          >>> Total error:   0.8ø <<<

Press D for details or any other key to continue...
```

m. Note the total compass error shown on the screen (highlighted above). This value should now be reduced because the one-cycle errors were corrected by the AX command procedure.

n. At the prompt type **D** for details to see the following display.

```
HEADING ERROR ESTIMATE FOR THE CURRENT COMPASS CALIBRATION:

   OVERALL ERROR:
      Peak Double + Single Cycle Error (should be < 5ø):  ± 0.84ø

   DETAILED ERROR SUMMARY:
      Single Cycle Error:                   ± 0.29ø
      Double Cycle Error:                   ± 0.66ø
      Largest Double plus Single Cycle Error: ± 0.94ø
      RMS of 3rd Order and Higher + Random Error:    ± 0.60ø

      Orientation:    Down
      Average Pitch:   0.21ø         Pitch Standard Dev:    0.78ø
      Average Roll:    0.17ø         Roll Standard Dev:     0.27ø

Successfully evaluated compass performance for the current compass calibra-
tion.

    Press C to display Percent Horizontal Field Components
       Relative to Calibration or any other key to continue....
```

o. Press any key to complete the compass evaluation. As you can see from the display summary above, the one-cycle error was reduced from 8.09° (see step h) to 0.29°. Note that the double-cycle error was not corrected. For typical deployments this value will be much smaller. In the example data shown above, a large magnet was in the vicinity of the ADCP causing the relatively large double cycle error.

p. You can now use the Rio Grande with its corrected compass and a configuration file that contains the magnetic variation correction to collect discharge measurement data with integrated GPS.

6 ADCP Measurement Basics

The ADCP is an Acoustic Doppler Current Profiler. It measures vertical profiles of the water's velocity using acoustic energy. A pulse of energy (known as a *ping*) is transmitted into the water much like a submarine's SONAR but at much higher frequencies. This energy is reflected off particles suspended in (and moving with) the water and some of it returns to the ADCP. The ADCP measures the Doppler shift (change in frequency) of the reflected energy and from this, computes the velocity of the water relative to the ADCP. We won't go into the details in this manual. If you would like to learn more about how the ADCP measures velocity, please read the BroadBand ADCP Primer.

The ADCP also measures its own speed and direction across the bottom of the channel using the same technique used to measure the velocity of the water. The details of the measurement are different since the bottom is solid (or nearly so) compared to the water. The BroadBand ADCP Primer also has additional details concerning how bottom tracking operates.

6.1 Velocity Profiles

As the ADCP processes the signal reflected off the particles in the water, it divides the water column into a number of discrete segments stacked in the vertical. These segments are called *depth cells*. The ADCP determines the velocity and direction of each depth cell. If we graph the velocity as a function of depth, we get a velocity profile from near the surface to near the bottom. The thickness of the depth cells is something that you get to select (within certain constraints set by the instrument's design and the laws of physics). With a 1200 kHz ADCP these depths cells can be as small as 5 cm, or 10 cm for a 600 kHz system. So in water a few meters deep, you can make many simultaneous velocity measurements in the vertical dimension.

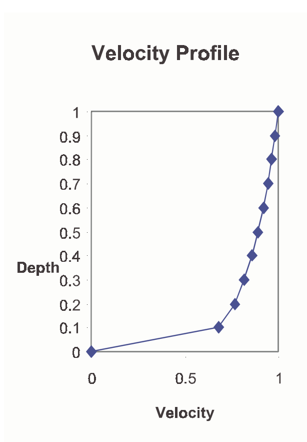


Figure 28. Velocity as a Function of Depth

6.2 Bottom Track

When water profiling, the ADCP measures the speed and direction of the water relative to the ADCP. So, an ADCP moving north at 1 m/s in calm water or water flowing south at 1 m/s past a stationary ADCP will both produce the same output from the ADCP for water velocity (see Figure 29). An ADCP moving north at 1 m/s through water flowing south at 1 m/s would produce an apparent water velocity of 2 m/s toward the south. The ADCP *bottom track* measures the speed and direction of the bottom motion relative to the ADCP. By subtracting the ADCP velocity from the apparent (relative) water velocity, the true velocity of the water (with respect to the bottom) is determined.

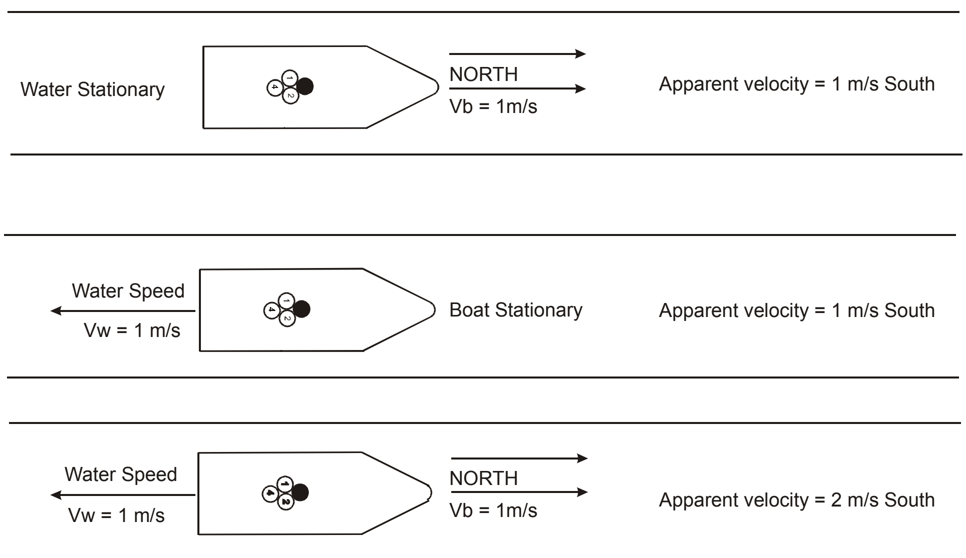


Figure 29. Boat versus Water Velocity

6.3 Other Data

The ADCP also records several other pieces of information that are related to the measurement of the velocity of the water. These are briefly described below.

Temperature. The ADCP has a sensor in the transducer head to measure the temperature of the water at the ADCP. Measurement of the velocity of the water (and the bottom) depends on the speed of sound in the water at the ADCP. The ADCP uses the measured water temperature along with a user-input value of salinity to calculate the sound speed.

Compass. The ADCP has a flux-gate compass that measures the orientation of the ADCP relative to the earth's magnetic field. If you have requested earth coordinates for data collection (EX-command) the compass data will be used by the ADCP to output velocities in earth coordinates. *WinRiver* will use the heading information to transform the raw data to earth coordinates before display if it has been collected in beam, instrument or ship coordinates.

Pitch and Roll. The ADCP also has pitch and roll sensors. These allow either the ADCP or the *WinRiver* software to correct the velocity measurements for rocking or tilting of the ADCP.

Intensity. The ADCP also records the intensity of the acoustic echoes received back from the energy scattered off the particles suspended in the water. This information is useful for verifying ADCP operation. It also provides a visual display of how sediment backscatter is distributed.

Correlation. The amplitude of the correlation function, in each depth cell, output by the ADCP is quality assurance for your data.

ADCP Percent Good. The ADCP can average data from individual pings internally to create ensemble data before sending it out. If for some reason, one ping of the ensemble has bad data, that information is not used in the average. Single ping ensembles are recommend, and in this case, the percent-good will be 100% (good data) or 0% (bad data).

Transect Percent Good. *WinRiver* presents a percent good value that is different from that in the raw ADCP data. Within *WinRiver*, this value represents the percentage of discharge calculations that are valid in a particular depth cell.

Real-time Clock. The ADCP has a real-time clock that measures time to 0.01-second precision and is accurate to within a few seconds per month for operating temperatures between 5 and 40 degrees Celsius. The date and time of a ping or ensemble is output as part of the data. The time between ensembles multiplied by the boat velocity is the displacement of the boat between ensembles. This is used to compute the discharge as well as to plot the boat trajectory.

7 Discharge Measurement Basics

A typical discharge measurement is calculated from several transects of data. Referring to Figure 30, a transect goes across the river from point A to point B, and the total discharge (ΣQ_1) is recorded. A second transect is then made starting at point B and ending at point A, and the second total discharge (ΣQ_2) is determined. Continue this process until you have the desired number of transects. An even number of at least four transects is recommended to calculate the discharge at a site. The actual river discharge estimate will then be the average of the *N* individual transect discharge values (see equation 1).

$$\Sigma Q = \frac{(\Sigma Q_1 + \Sigma Q_2 + \Sigma Q_3 + \Sigma Q_4 + ...)}{N} \quad (1)$$

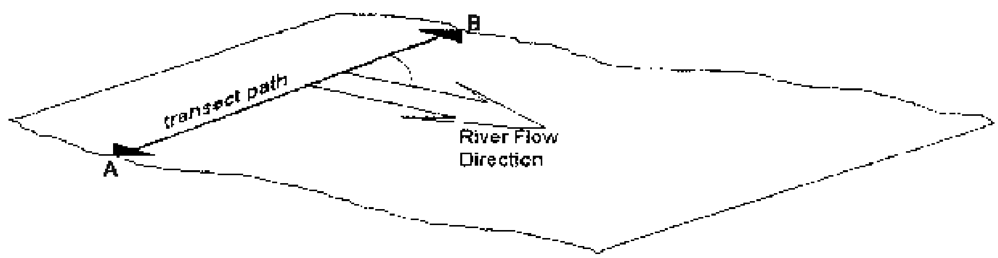


Figure 30. Transect Path

7.1 Path Independence

Discharge is the accumulated flow crossing perpendicular to the boat's path (see Figure 31, page 75). Any arbitrary line can define the cross-section across the river. It does not need to be straight across the river. The ADCP measures the actual path of the boat from the change in the boat's position. As well, it measures the flow across the path throughout the water depth. You do not need tag lines or even try to steer a straight course. This makes it much easier and safer to obtain a discharge measurement, particularly at high flood stages or at sites with high traffic or wide channels.

The *WinRiver* software calculates the discharge using this information. *WinRiver* can replace bottom tracking by using GPS data to measure the boat velocity and an external depth sounder to measure water depth.

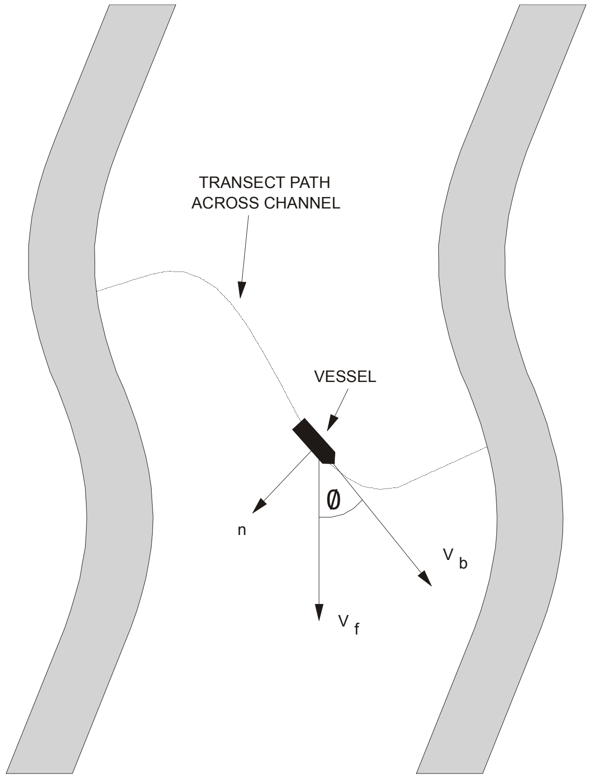


Figure 31. Discharge Calculation is Independent of the Boat's Path

7.2 Directly Measured Flow and Estimated Regions

The ADCP measures most of the water velocity from just in front of the ADCP to 6% above the bottom. At the channel edges, where the water is very shallow, the water depth is too shallow for the ADCP to profile. The *WinRiver* software will estimate the discharge in these regions using several input values from the user. Each of these unmeasured regions will be discussed below. Refer to Figure 32, page 76 for an illustration of the unmeasured areas.

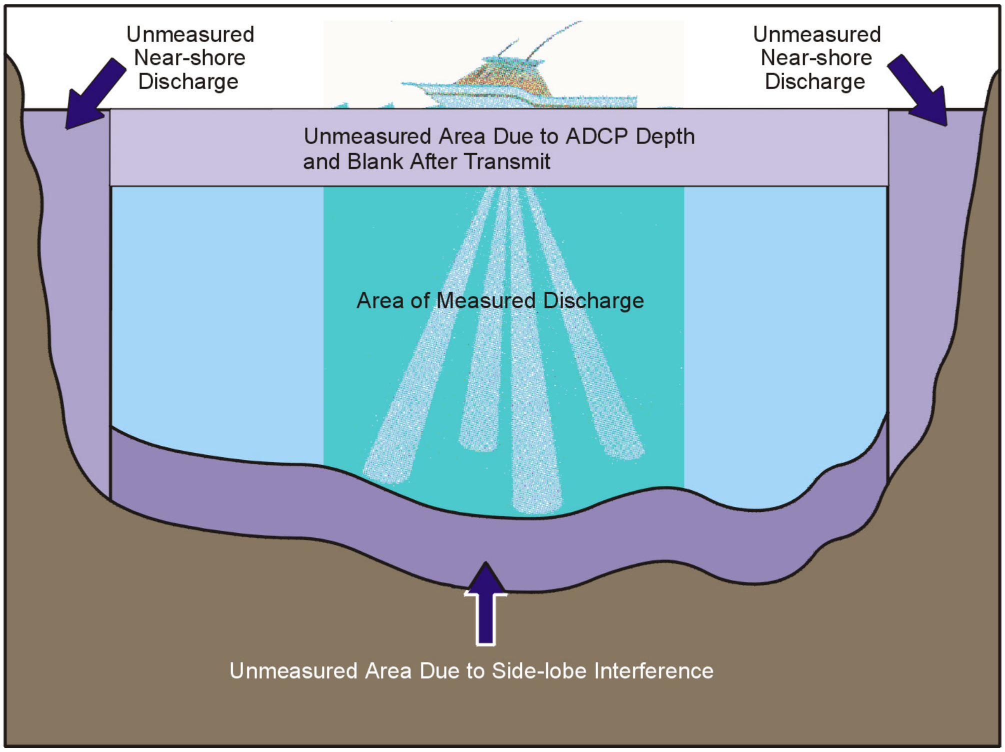


Figure 32. Unmeasured Regions in the Water Column

7.2.1 Near Surface Region

ADCP Depth. The acoustic transducers of the ADCP need to be completely covered with water. A typical transducer depth is around 20 cm, which will totally immerse the ADCP. This allows reasonable boat speeds before air is pulled beneath the transducer (which blocks the acoustic energy from getting into the water) and allows for some rocking of the boat. In calm water, you may be able to put the ADCP less deep and you may need to put it deeper if the water is rough or very fast.

Blank After Transmit. The same transducer is used to receive the acoustic energy after transmitting a pulse. A short time (or a short sound travel distance) must pass before receiving is possible. This delay is called the blanking distance, and it allows the ADCP to ring down and become acoustically quiet before receiving the return signal. For the 600 kHz and 1200 kHz Rio Grande ADCPs, this distance is 25 cm.

Pulse Structure – Lag. For general profiling (mode 1), the acoustic pulse sent out is actually two or more distinct pulses that are closely spaced. The spacing is called the lag. One lag is required beyond the blanking distance to start processing the data in the first bin.

The distance below the surface to the middle of the first cell for Mode 1 general purpose profiling is the sum of the ADCP depth, the blanking distance, and (bin +transmit length + lag)/2. For a 600 kHz ADCP in mode 1 with 50-cm depth cells, the distance to the top of the first depth cell is about 90 cm (see Table 4, page 86). The ADCP and the software will automatically calculate this distance for you (you have to tell the software the depth of the transducer).

7.2.2 Bottom Region

Side Lobes. There is also a shallow layer of water near the bottom for which the data is not used to compute discharge. When the ADCP sends out an acoustic pulse, a small amount of energy is transmitted in *side lobes* rather than in the direction of the ADCP beam. Side lobe reflection from the bottom can interfere with the water echoes. This gives erroneous velocities for the water near the bottom. *WinRiver* does not use data in the region that may be affected. The ADCP has beams oriented at 20 degrees from the vertical, and the thickness of the side lobe layer is 6% of the distance from the transducers to the bottom (see Figure 33).

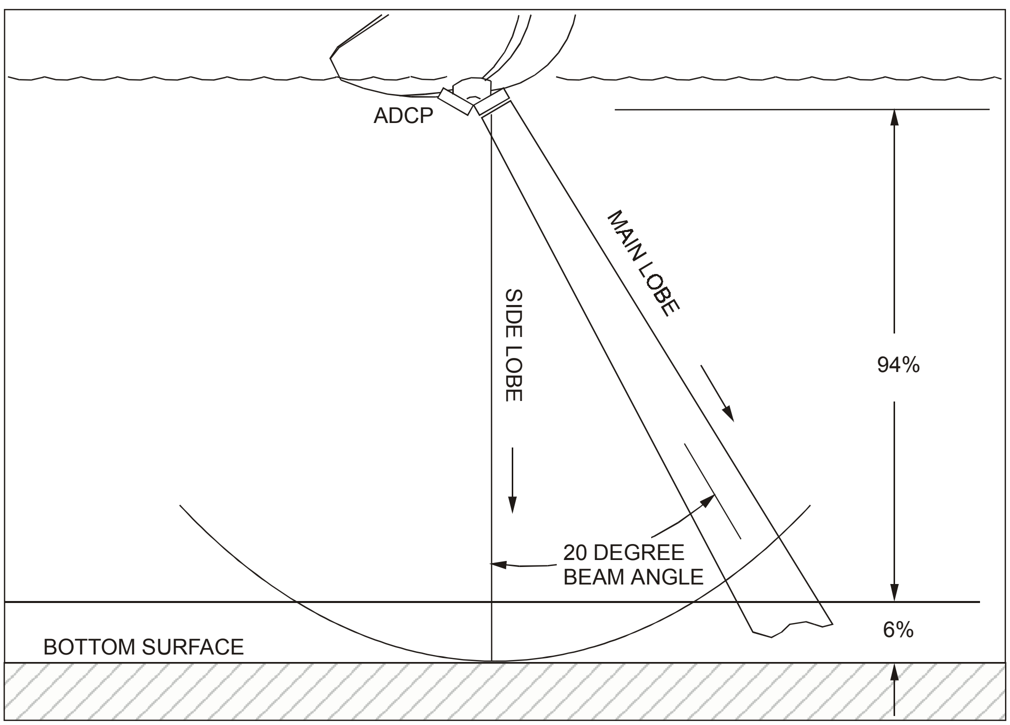


Figure 33. Side Lobes

Pulse length. *WinRiver* also does not use any data within one depth cell of the bottom or the side lobe layer. The reason is that in the last depth cell, energy at the front of the pulse is reflecting off of the bottom while energy at the rear of the pulse is reflecting off of the water. The energy reflected from the front of the pulse contaminates the reflection from the rear of the pulse. So, no data from within the 6% side lobe layer plus one depth cell from the bottom is used.

7.2.3 Channel Edges

Minimum Depth. From the discussion of the top and bottom layers, you have probably deduced that there is a minimum depth in which you may acquire meaningful data. As you approach the sides of your channel, the water will become too shallow for the ADCP to make a valid measurement. The edges are determined by the last segment to have two valid bins and bottom track.

7.3 Computation of Discharge

Measured Flow. *WinRiver* computes the discharge from the first depth cell to the last good cell not affected by the bottom or side lobes. But what about the discharge in the top layer that isn't measured at all, the layer above the bottom that isn't used because of effects due to the bottom, and the edges that are too shallow to obtain a valid measurement? The discharge in these regions is extrapolated from the good data that was measured.

Extrapolation: Top and Bottom. The extrapolation of the discharge (see Figure 34, page 79) in the top and bottom layers can be done two ways with *WinRiver*. One-way is to use the velocity from the depth cell closest to the surface or bottom as the velocity across the missing region: this is called *constant* extrapolation. The other technique is to fit a power law curve to the data in the good part of the profile and extend the curve to the boundaries. The power law method for the top and bottom portion is a good choice for typical flow conditions. You can select the exponent in the power law method to get the best fit to the profiles in your channel. The formulas describing the details of the extrapolation are provided in the *WinRiver* help file.

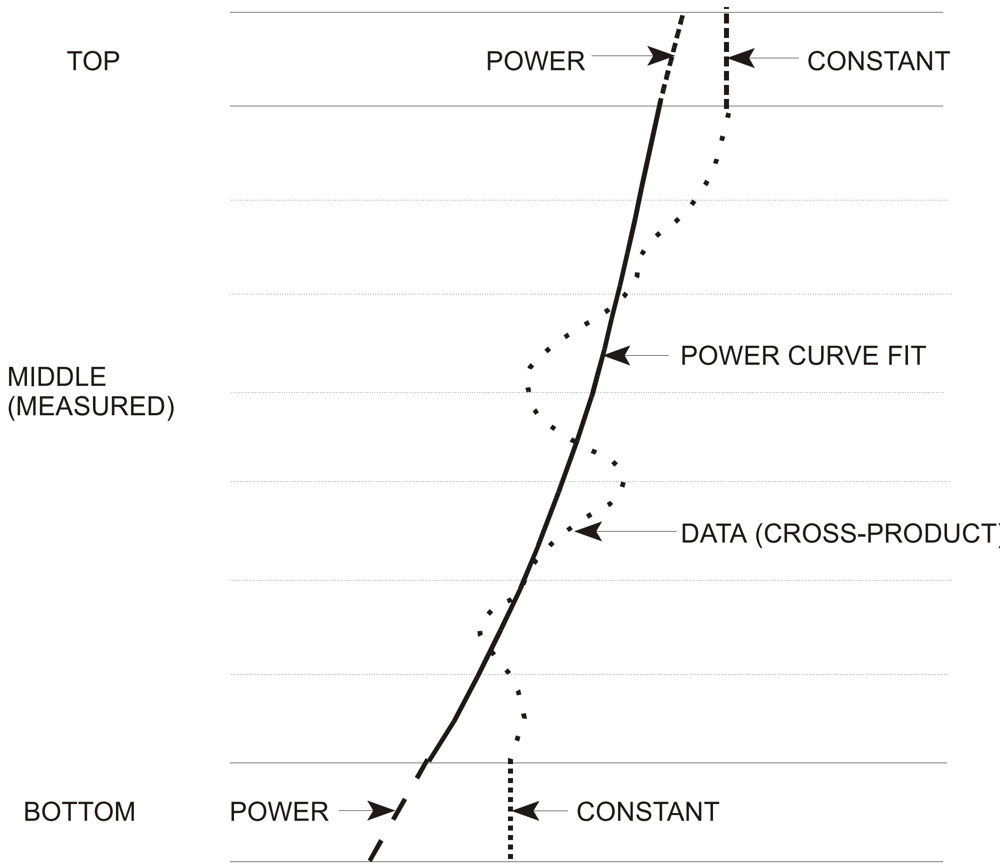


Figure 34. Discharge Extrapolation Method

Extrapolation: Sides. *WinRiver* includes a method to estimate the side discharge using the data from the ensemble closest to the shore on either side. This is not done while you are acquiring the data but at a later time when you play back the data. *WinRiver* uses the user supplied edge distances in estimating the side discharge. Again, the details of the calculations are in the *WinRiver* help file. You will learn the actual procedure later in this manual.

Extrapolation: Bad velocity bins. As *WinRiver* calculates the discharge through the water column (Middle measured discharge), the bins with bad velocities are noted. After the power fit is computed, these bins are "re-filled" using the fitted power curve and accumulated into the "Mid Q" total discharge.

Examining the discharge profile will identify the bins with estimated discharge. That is, anywhere there is a discharge value in a bin and there is not a corresponding good velocity for that bin, the discharge was estimated.

8 ADCP Commands

These commands are contained in the **Direct Commands** portion of the *WinRiver* configuration file. These commands are added to the configuration file in the **Setting** menu, **Configuration Settings**, **Commands** Tab. When the Acquire mode is first started, these commands are sent by *WinRiver* to the ADCP to set its profiling parameters. In the following, we will describe each command and give guidelines for setting these commands for acquiring reliable discharge data. Refer to the Commands book for more detailed information about each command.

8.1 Send Commands to the ADCP

a. Start *WinRiver* in the Acquire mode. If you are in the Playback mode, click **File**, **Acquire Mode**.

b. Click **Setting** menu, **Configuration Settings**, **Commands** Tab.

c. Enter the commands in the **User Commands** box.

d. Save the Configuration file by clicking, **File**, **Save Configuration File** or **File**, **Save Configuration File As** to save the file as a unique name.

e. Click **File**, **Start Pinging**. The **Command Log** window will open automatically and show the commands sent to the ADCP and the response from the ADCP. After the commands have been successfully sent, this window closes.

f. To view this window again on the **View** menu, click **Command Log**. This will show the history of the dialog between *WinRiver* and ADCP.

Water Mode (WM – Command)

Three modes are available for water profiling in the Rio Grande, Mariner, and Workhorse ADCPs with the High Resolution Water Profiling upgrade. They are Water Modes 1 (all ADCPs), 5, and 8. Each mode has its own envelope of operation. Mode 1 is the general-purpose mode, and should be used for most flow conditions. Modes 5 and 8 are the high-resolution modes, and they are for use in shallow water with relatively low velocities.

Maximum Bottom Depth (BX – Command)

Set the maximum bottom tracking depth (BX-command) to 50% greater than the maximum expected depth. This will keep the ADCP from trying to search deeper than a realistic bottom depth.

NOTE. The maximum bottom tracking range is 98 m for the 600 kHz and 28 m for the 1200 kHz in water with 10°C temperature and 0.0 ppt salinity.

Depth Cell Size (WS – Command)

This command sets the length of the water for one cell measurement. Refer to Table 4, page 86 for recommended settings. The cells size range is 0.10–8 m (WS10 to WS800) for the 600 kHz and 0.05– 4 m (WS5 to WS400) for the 1200 kHz.

Number of Depth Cells (WN – Command)

Set the number of water profiling depth cells (WN command) to cover the maximum expected water depth plus 2 additional cells. As a rule of thumb,

WN = Maximum Expected Depth (in centimeters) / WS + 2

Blanking Distance (WF – Command)

The blanking distance should be set to 25 cm (WF25) to maximize the ADCP performance and minimize the unmeasured layer thickness at the surface. If you see trouble in your data, try doubling the blanking distance.

Pings per Ensemble (WP and BP– Commands)

Single ping ensembles are recommended for performing discharge measurements (WP1 and BP1). Averaging in either space or time can be done to the data by *WinRiver* while collecting data in the **ACQUIRE** module or later during post-processing in the **PLAYBACK** module to reduce the standard deviation of the velocity measurements. The advantage of having the *WinRiver* software do the averaging rather than the ADCP is that the raw data remains unchanged and you have the flexibility to vary the averaging interval to suit your application.

Ensemble-Out Data (WD – Command)

This command selects the types of data collected by the ADCP. The default setting is WD111100000, which tells the ADCP to collect velocity, correlation magnitude, echo intensity, and percent-good status data.

If you want to maximize your ping rate, you can do so by reducing the amount of data that must be transferred serially for each ensemble. To do this, you can choose not to record percent-good status by selecting WD111000000.

Mode 1 Ambiguity Velocity (WV – Command)

The Mode 1 ambiguity velocity represents the maximum relative velocity (ADCP motion plus the maximum actual water velocity) the ADCP can measure along a beam. This must be set correctly to avoid ambiguity errors. The default value of 170 cm/s (WV170) corresponds to a horizontal relative velocity of about 5 m/s, and the maximum ambiguity velocity of 480 cm/s (WV480) corresponds to a maximum relative velocity of 15 m/s. Use the default ambiguity velocity for most applications. If you plan on using Mode 1 in flows faster than 5 m/s, use the following formula to set WV.

WV = Maximum Relative Water Velocity x sin (Beam Angle) x 1.5

Where Beam Angle = 20° for the Rio Grande ADCP

Mode 5 and 8 Ambiguity Velocity (WZ – Command)

The ambiguity velocity for modes 5 and 8 is set using the WZ command. The default value is WZ05, and this value should be used for all moving boat applications.

Time Between Pings (TP – Command)

The TP command sets the time between pings, and ensures that you will not have ping-to-ping interference. This value should be set to 0.2 seconds (TP000020) for the 600 kHz system and 0.05 seconds (TP000005) for the 1200 kHz system. These values were determined by considering the travel time for the bottom track ping to travel to its maximum possible range.

Sensor Source (EZ – Command)

The EZ-command selects the source of environmental sensor data. The Rio Grande default value is EZ1011101, which tells the ADCP to use internal heading, pitch, roll, and temperature sensors.

Coordinate System (EX – Command)

There are four different coordinate systems that can be used for ensemble averaging: beam, instrument, ship, and earth. Refer to the EX-command in the Command book for a description of each of the coordinate systems. We recommend using ship's coordinates for your measurements. We recommend 4-beam solutions only because an error velocity will be calculated and presented for each ADCP ensemble. If you have consistent trouble with bottom tracking or are working in a location where one beam will be masked due to dam walls or pier pilings, modify the EX command to EX10111 to allow for 3-beam solutions.

WinRiver transforms the raw data to earth's coordinates before displaying it in either the Acquire or Playback modes. This transformation does not change the contents of the original raw data file.

Salinity (ES- Command)

It is critical to set the salinity (ES command) to the proper value. All of the velocities and distances measured by the ADCP are proportional to the speed of sound. If ES is set to the wrong value, it can produce an error in the calculated discharge.

WinRiver can re-scale the raw ADCP data to correct for the speed of sound if the ES0 command was set incorrectly in the configuration file when the data was taken. The re-scaled data displayed by *WinRiver* will reflect the corrected sound speed, though the raw data file will not be corrected.

NOTE. The discharge calculated using 35.0 ppt is 8-10% higher than the discharge calculated using 0.0 ppt. If you obtain discharge values that are consistently too high by this margin, check the salinity setting in *WinRiver*.

Transducer Depth (ED – Command)

This value is used by the ADCP to calculate the speed of sound at the transducer face. It is not necessary to set the command if the ADCP depth is less than five meters. The default value is ED000. Enter the depth value in decimeters. For example, a 10-meter transducer depth would be entered as ED100.

8.2 *WinRiver* Processing Commands

These commands affect how the raw ADCP data is displayed and the discharge is calculated within the Acquire and Playback modes. They do not affect the raw data. When you play the data back, the velocities, depths, and discharge values will reflect whatever processing commands are contained in the loaded configuration file.

ADCP Depth

Set the depth of the ADCP transducer faces below the surface. The depths of the ADCP data presented in *WinRiver* will be determined from this value. If you need to re-scale your velocities within *WinRiver* by recalculating the sound speed, *WinRiver* will use the ADCP depth and the salinity you have entered along with the temperature measured by the ADCP to calculate a new sound speed value for each ensemble.

Magnetic Variation (Declination)

Use a chart to determine the local magnetic variation in your area. If there is an eastern variation in your area, the output of the ADCP's magnetic compass when pointed to true North will read less than 360°. If the local variation is to the West, the magnetic compass will read greater than 0° if pointed to true North. East variations are positive (entered as **12.5°**) and West variations are negative (entered as **–12.5 °**). The magnetic variation value does not affect the calculated discharge unless you are using GPS. This is because both the water velocity and the boat velocity (from bottom tracking) are measured in the same coordinate system (ADCP magnetic compass), while GPS positions are reported in true earth coordinates.

Salinity

If you select COMPUTE FOR EVERY ENSEMBLE for the Speed of Sound Correction field, *WinRiver* will use this value of salinity to re-compute the sound speed and scale the raw ADCP velocities.

Speed of Sound Correction

This command directs *WinRiver* to one of three choices:

- **Default to the ADCP** – (recommended setting) this setting will perform unity scaling to the raw ADCP velocities. The sound speed calculated by the ADCP using the ED, ES, and temperature measured at the ADCP transducer head will be used for *WinRiver* data display. When the ADCP depth is less than five meters the sound speed calculation is not significant and it is not necessary to set the ED command.
- **Compute for every ensemble** – *WinRiver* will use the salinity and transducer depth values entered in *WinRiver* along with the ADCP measured temperature to calculate a new sound speed for each ensemble. The new sound speed will be used to scale the velocities in each ensemble before display. Note: changes only affect the processed data, not the raw data. If desired, you can save the changes by saving the data as a processed data file.
- **Enter Value** – *WinRiver* will use this fixed value to scale the raw ADCP velocities for display on the screen. Again, changes only affect the processed data, not the raw data.

Absorption Coefficient

The sound absorption coefficient is used to estimate the relative backscatter in dB (decibels). The relative backscatter when expressed in dB is a measure of the intensity of the returning echo from the scatterers. It is a function of sound absorption, beam spreading, transmitted power, and the backscatter coefficient. The sound absorption coefficient itself is dependent on frequency, temperature, and salinity.

Extrapolation Method

- ***Top and Bottom Estimation*** – two methods, CONSTANT or POWER, are provide to extrapolate the discharge in the upper and lower layers of the water that are not directly measured by the ADCP. Constant extrapolation uses the velocity at the nearest depth cell for the remainder of the water column. Power extrapolation fits a power curve to the directly measured portion of the water column, and then uses that power law fit to compute the discharge in the unmeasured portions. The details of both computations are documented in the *WinRiver* help file. A good starting point is to use power for both the top and bottom layers. After you have taken some data on one of your channels, you can see how good the power law fit actually is by looking at the PROFILES: DISCHARGE display in **PLAYBACK**. You can then try other exponents in **PLAYBACK** to attempt to improve the fit.

- ***Power Curve Coefficient*** – this value is used in the power extrapolation fit. An exponent of 0.1667 ($1/6^{th}$ power law) is a theoretical solution for open channel flow. For more information on the theory of power law for flow resistance see Chen, Cheng-Lun, "Unified Theory on Power Laws for Flow Resistance", Journal of Hydraulic Engineering, Vol. 117, No. 3, March 1991, 371-389.
- ***Left/Right Bank Edge Type*** – Use this field to describe the geometry of your edges. Choose triangular, square, or a user-specified coefficient.

Velocity Reference

Use the **Settings** menu, **Reference** to set the velocity reference. Bottom track should always be used for river measurements from a moving vessel. With this setting, true water velocities will be presented in the *WinRiver* displays because the boat velocity has been subtracted from the relative velocities measured by the ADCP. If NONE is chosen as the velocity reference, relative velocities will be displayed.

Mark "Bad" Below Bottom

This feature is toggled on and off in the **Processing** tab of the **Settings**, **Configuration Setting** menu. Any values that are below the measured bottom will be marked as bad.

> **NOTE.** The Mark "Bad" Below Bottom setting only affects the data display. Cells below the bottom and those within the side lobe layer are never used in the discharge calculation.

Note

A note can be added to the configuration file in the **Recording** tab of the **Settings**, **Configuration Setting** menu.

Max File Size

This feature specifies the file size in bytes. *WinRiver* will parse the data for a transect into several files of the size specified giving them the names DEMO001R.000, DEMO001R.001, DEMO001R.002, etc. The default value is unlimited file size.

9 Water Profiling Modes

This section explains all of the water-profiling modes available for the Workhorse Rio Grande and Mariner ADCPs and Workhorse ADCPs with the high-resolution water profiling upgrade installed. For each mode, we provide a general description, an explanation of the best place to use this mode, specifics about the mode, and any setup considerations. Use Table 4 as a guide for choosing the appropriate mode for your water flow conditions. Some details are contained here but not all. As RDI learns more from your experiences, we will be able to add information to help you better collect data.

Table 4: Workhorse River Water Modes

	Mode 1	Mode 5	Mode 8
Typical application	Fast water of all depths. Rough and dynamic situations. Good in streams too fast or deep for modes 5 & 8.	Slow, shallow streams with velocities < 0.5 m/sec with low shear and/or turbulence.	Shallow streams with velocities < 1 m/sec and with moderate shear (rough bed) and/or turbulence. Works in shallow water where mode 5 does not work well.
Minimum recommended cell size (meters)	**0.50*** 0.25	**0.10** 0.10	**0.10** 0.10
Recommended Cell Size (meters)	**0.50** 0.25	**0.25** 0.10	**0.25** 0.10
Single ping standard deviation (cm/s) (using rec. cell size)	**18.0** 18.0	**0.3** 0.4	**5.2** 7.8
First range cell (meters)	**0.87** 0.56	**0.50** 0.35	**0.50** 0.35
Minimum profiling range (meters)	**1.7** 1.0	**1.6** 0.9	**0.9** 0.6
Maximum profiling range (meters)	**45** 12	**7.0** 3.5	**7.0** 3.5
Maximum relative velocity (m/s)	10 m/sec	0.5 m/sec	1 m/sec

* 600 kHz values are in **bold** font, and 1200 kHz values are in regular font.
Specifications are for 25 cm blank, 10° C temperature, and 0.0 ppt salinity.

NOTE. The ranges in Table 4, page 86 are measured from the transducer face. Add the transducer depth to determine the actual minimum and maximum profiling depths.

NOTE. Maximum range depends on water temperature and depth cell size. Use PLAN to compute the maximum range for a particular ADCP set-up and water temperature. The standard deviation of modes 5 & 8 varies with water speed, boat speed, bedform roughness, channel depth, and turbulence.

9.1 General Purpose Profiling - Mode 1

General Description - This is our most robust mode of operation. It allows for good data collection in all environments.

Best Use Areas - Mode 1 is good for all areas. It works well in areas of slow currents, turbulent currents, strong shears, low backscatter concentrations (or where signal returns are apt to be weak), high background noise (such as being used from a ship), and in areas where the water changes from shallow (1 m) to deep (>6 m).

Specifics - The standard deviation determined by the bin size (WS command) and the ambiguity velocity (WV). The ambiguity velocity tells the ADCP what maximum velocity it will see. If you are operating the ADCP from a moving platform, the maximum velocity would be the ADCP's maximum speed (motion through the water) plus the maximum water speed. We call this the maximum "apparent velocity" the ADCP will see.

Setup Considerations - To set the Mode 1 ambiguity velocity correctly, you must have an idea of the maximum apparent velocity to set the WV command. Use the following formula to set the WV-command:

WV = (max. apparent velocity in cm/s) * (sin B) * (1.5)

Where:

- B = Beam angle (20 degrees for the Rio Grande)
- (1.5) = Safety margin. You can reduce this safety margin if you are sure you will not exceed the maximum apparent velocity. We recommend a minimum safety margin of 1.1.

NOTE.

The **minimum** suggested setting for the WV-command is 100 cm/s (WV100), which corresponds to an apparent horizontal velocity of 3 m/s.

The **default** setting for the WV-command is 170 cm/s (WV170), which corresponds to an apparent horizontal velocity of 5 m/s.

The **maximum** setting for the WV-command is 480 cm/s (WV480), which corresponds to an apparent horizontal velocity of 15 m/s. Higher settings will produce bad velocity data.

The values shown here do not include a safety factor.

Table 5: Mode 1 Minimum and Maximum Profiling Ranges

Frequency	Cell Size (m)	Profiling Range (m)	
		Minimum	Maximum
600	0.50	1.7	45.0
	1.00	2.7	52.0
	2.00	4.8	60.0
	4.00	9.0	67.0
1200	0.25	1.0	12.0
	0.50	1.6	14.0
	1.00	2.6	16.0
	2.00	4.7	18.0

Specifications are for 25 cm blank, 10° C temperature, and 0.0 ppt salinity.

NOTE. The ranges in Table 5 are measured from the transducer face. Add the transducer depth to determine the actual minimum and maximum profiling depths.

9.2 High Resolution Profiling - Mode 5

General Description - Mode 5 is our high-precision, shallow-water mode. Mode 5 allows for very low standard deviation (less than 3 cm/s) in shallow water. Mode 5 should be used with bottom tracking enabled.

Best Use Areas - Mode 5 is ideal for shallow water with water currents less than 50 cm/s.

Mode 5 is not good for areas where there is shear, turbulence, background noise, or fast ADCP motion (above 0.5 to 1 m/s). If high shears, turbulence, background noise, or fast ADCP motion occurs, the ADCP will not collect data.

9.3 High Resolution Profiling - Mode 8

General Description - Mode 8 is our medium-precision shallow-water mode. The standard deviation of Mode 8 is about 10 times greater than Mode 5 for the same size depth cell and water speed. Mode 8 should be used with bottom tracking enabled.

Best Use Areas - Mode 8 is ideal for shallow water (8 m and less), where there is any shear, turbulence, background noise, or fast ADCP motion (maximum 1-2 m/s). Mode 8 can be used in fixed measurements or slow-moving platform measurements where the water velocity flows are very low. However, Mode 5 is better suited for those areas.

Note that if the shears, turbulence, background noise, or ADCP motion is too great, the ADCP will not collect data.

9.3.1 Mode 5 and 8 Specifics

Mode 5 and 8 use short encoded pulses that travels to the bottom, where it is reflected, and then back up to the ADCP. When the signal is received at the transducer face, the ADCP transmits another pulse. The ADCP knows how long to wait before sending the second transmission because Bottom-Track measures the water depth. For this reason, it is important to use bottom tracking for downward-looking deployments.

For Modes 5 and 8, two pulses are processed to create the velocity estimate. The standard deviation for Mode 5 and 8 is very low because there is a relatively long lag between the two pulses. Mode 5 estimates the velocity based on the Doppler shift, and its algorithm is sensitive to ambiguities. Therefore, this mode is highly sensitive to conditions with high shear, turbulence, and fast ADCP motion. Mode 8 makes the estimation based on a proprietary scheme. Mode 8 has no ambiguity problems, and therefore it can operate in areas that Mode 5 cannot. However the method of estimating velocity used by Mode 8 has a higher standard deviation as compared to Mode 5 operation. Use an ambiguity velocity value of 5 cm/s WZ005 (lag setting) for most deployments to allow for the deepest possible profiling range. The ADCP automatically adjusts this setting higher based on the depth of the water measured by bottom tracking.

There are some applications where you may wish to obtain only valid data near the ADCP when the bottom is out of range of the system. In these cases, the setting of WZ005 will still work. It allows the system to collect data as deep as it can.

The profiling range of the high-resolution modes is limited by two factors: (1) the very short encoded pulses used, and (2) the maximum velocity water velocity. These pulses do not put much energy in the water, so the signal return is weak. The deeper the profile, the slower the water must move or an ambiguity error will occur. Higher boat and water velocities will result in maximum profiling ranges that can be half of the values specified in Table 6, page 91.

9.3.2 Comparision of Water Modes 5 and 8

Water-Profiling Mode 5

Mode 5 advantages compared to Mode 8 (see Table 4, page 86):

- Mode 5 gives a lower single-ping standard deviation than Mode 8 for the same size depth cell (bin)

Mode 5 disadvantages compared to Mode 8:

- A larger minimum profiling depth may be required than Mode 8
- A reduction in the maximum velocity the ADCP can measure
- Does not work well in dynamic water environments that have water velocity changes greater than 50 cm/s (e.g., eddies, shear)

Water-Profiling Mode 8

Mode 8 advantages compared to Mode 5 (see Table 4, page 86):

- May be able to profile in shallower water the Mode 5
- An increase in the maximum velocity the ADCP can measure
- Works in dynamic water environments that have water velocities changes up to 100 cm/s (e.g., turbulence, eddies, shear)

Mode 8 disadvantages compared to Mode 5:

- The single-ping standard deviation is about 10 times greater than Mode 5 for the same size depth cell (bin) and relative water speed.

9.3.3 Mode 5 and 8 Minimum Profiling Range Capability

Mode 5 and 8 must have a minimum water depth in order to profile. Table 6 shows the minimum profiling range as a function of system frequency and cell size. The minimum profiling capability is dependent upon cell size (WS) and the blanking distance (WF) for each system frequency.

Table 6: Mode 5 and 8 Minimum and Maximum Profiling Ranges

Frequency	Cell Size (m)	Profiling Range (m) Mode 5		Profiling Range (m) Mode 8	
		Minimum	Maximum	Minimum	Maximum
600 kHz	0.10	0.9	7.0	0.6	7.0
	0.25	1.6	7.0	0.9	7.0
	0.50	2.2	7.0	1.4	7.0
1200 kHz	0.10	0.9	3.5	0.6	3.5
	0.25	1.6	3.5	0.9	3.5

Specifications are for 25 cm blank, 10° C temperature, and 0.0 ppt salinity. Relative water velocity is 0.5 m/s for Mode 5 and 1 m/s for Mode 8.

NOTE. The ranges in Table 6 are measured from the transducer face. Add the transducer depth to determine the actual minimum and maximum profiling depths.

10 Troubleshooting

Use the following suggestions to guide you if you are having trouble obtaining reliable discharge data. If you cannot arrive at a solution after trying the suggested solutions below, send a description of the problem, some example data files along with their associated configuration files, and a *DumbTerm* log file to your local representative or to RD Instruments via email. We will assist in analyzing the problem.

Email: rdifs@rdinstrumets.com

10.1 Why can't I see my data?

If you do not see any data on contour plots or other displays during Playback mode, check the following items.

- **Mark Below Bottom "Bad"** is selected in the **Configuration Settings**, **Processing** tab and you do not have valid bottom depth data.
- Your reference data is not valid. If your reference is GPS on the **Settings**, **Reference** menu and you did not have GPS active during data collection; your data will always be invalid.
- Check the contour or profile plots minimum and maximum depth axis is setup properly. On the **Velocity Tabular** view, look at the left column where the depth of the water profile depth cells are displayed and set the minimum and maximum depth accordingly on the **Configuration Settings**, **Chart Properties 1** tab.
- On the **Velocity Tabular** view, if you see negative depths, your system is up-looking and you need to adjust the **ADCP Transducer Depth** on the **Configuration Settings**, **Offsets** tab.
- The data is not present. Check the commands sent to the ADCP on the **Configuration Settings**, **Commands** tab. For example, sending WD 11**0** 100 000 will override the default WD 11**1** 100 000 command and tell the ADCP to **not** collect echo intensity data. This will result in displaying "Bad" on Tabular views and not displaying at all on contour or profile plots.

10.2 Lost Ensembles

If you occasionally see the message *ADCP ENSEMBLE LOST* on the screen and you notice that ensemble numbers are missing either when acquiring data or playing it back, then you may have the serial communications speed set too high for your computer or you are inadvertently holding a key down too long. Since a computers keyboard has a higher priority than its serial port, serial data can get lost if the keyboard is used too long at the same time that serial data is being received. One solution is to minimize the amount that you use the keyboard while the computer is receiving data from the ADCP. Another solution is to lower the serial communications speed of the ADCP and the computer; this reduces the computer's load with respect to serial port processing. A third option is to use a computer equipped with a 16550 UART, which buffers the serial port, allowing the computer to keep up with the flow of data.

To change the ADCP and computer baud rate use *DumbTerm* to communicate with the ADCP. Send a CB-command with the desired baud rate value (see the Command book). Press **F5** to change the serial port baud rate to match the ADCP. Enter **CK** to save the new baud rate for the ADCP. This must be done before pressing **END** to send a Break signal or the ADCP will reset back to the default 9600-baud rate. Press **END** to check the communications using the new baud rate.

Another source of the problem is interference in the transmission of data. Try not to place the ADCP's underwater cable near a generator, the engine, or other large electrical equipment. Do not coil the ADCP's underwater cable around large metal objects.

10.3 Missing Depth Cell Data

Missing depth cell data will be marked as bad in the data displays. The data within these cells has not met echo intensity, correlation, or percent-good thresholds. Bad cells do not generally effect a discharge measurement because discharge is extrapolated for missing bins.

10.4 Unable to Bottom Track

If you are losing bottom track, indicated by “bad” bottom track velocities or no depth indicated, then one or more of the following is possible:

- The depth set in the BX-command is not deeper than the maximum depth of the channel: increase BX and try again.
- Change the EX10101 command to EX10111 to allow for 3-beam solutions.
- If there are abrupt depth changes in your river channel, bottom track may have trouble locking on to the rapidly changing depths as you transect. If you know where the abrupt changes are located in your channel try to move slowly over these regions.
- There is something blocking one or more of the beams. It may be air being pulled below the transducer: try putting the ADCP deeper in the water. Some kind of debris has become caught on near the ADCP and is interfering with the beams: check the ADCP and its mount to see if debris has become entangled on the ADCP.
    - The bottom has grass, weeds, brush, or other submerged materials that are disrupting the beams near the bottom: try moving to a different nearby location to see if the problem changes.
    - There is a high sediment concentration near the bottom, and there is not enough contrast between the suspended sediment layer and the actual bottom to determine the true bottom range. Some users have found success detecting the bottom in these conditions by substituting a lower frequency ADCP, i.e. a 300 kHz in place of a 600 kHz, but at some point the sediment concentration will be so high the ADCP won’t work.

If you cannot get valid bottom track depths using the suggestions above, an echo sounder can be used in place of bottom tracking.

10.5 Biased Bottom Track Velocities

If one or more of the following occurs, it is an indication of bias in the bottom tracking data:

- The *course made good* is longer than expected.
- The shiptrack plot shows an upstream offset compared to the actual track taken by the boat.
- If you hold station at a position in the channel, the shiptrack indicates that you are moving upstream.

The bias can be caused by two different environmental sources:

- High sediment concentration in the water column (Water Bias)
- Fluid layer of sediment flowing along the bed of the stream (Moving Bottom)

These two environmental sources produce biased values for ADCP bottom track, which in turn will bias the discharge calculation. The consequences of the these environmental sources and the biased ADCP bottom track are:

- Discharge computed with the ADCP is biased low
- The vessel track (shiptrack) is biased upstream

NOTE. The ADCP is not malfunctioning – but measuring the environment as designed.

If you obtain biased bottom track data at your river site, you can use GPS as the velocity reference in place of bottom tracking as described in the section on "Integrating GPS and Depth Sounder Data," page 48. *WinRiver* can calculate discharge in real-time using the GPS data in place of bottom track velocities.

10.6 Inconsistent Discharge Values

If the measured discharge is lower than expected and not reproducible to better than 5%, you may be experiencing one or more of the following conditions:

- Biased Bottom Track (see the previous section)
- There are tidal or other time dependent factors affecting the discharge.

A small repeatable difference in discharge values can be expected between transects made going different directions across the channel. This difference can be caused by several factors:

- Wind can cause the boat to heel causing the ADCP depth to be slightly deeper when traveling in one direction versus another.
- The ADCP may be mounted so that it is shadowed from the flow when a transect is made with the ADCP on the downstream side of the boat. Mounting the ADCP from the front of the boat may reduce the difference in discharge values between reciprocal transects.

10.7 Trouble Profiling in High Turbidity Conditions

In flows with very high sediment concentrations, the acoustic energy transmitted by the ADCP into the water undergoes high levels of absorption. The ADCP will not receive enough returned energy to make valid velocity measurements. In this case, the echo intensity profile will show the received signal level reaching the noise floor before the bottom is encountered. Some ADCP users have been able to successfully profile in these conditions by using a lower frequency system, i.e. a 600 kHz rather than a 1200 kHz, or a 300 kHz rather than a 600 kHz.

10.8 Trouble Profiling with Modes 5 and 8

Modes 5 and 8 are designed for use in shallow and slow moving water, and though they provide reduced standard deviation over Mode 1, they are highly sensitive to shear and turbulence. We strongly recommend Mode 1 for most profiling conditions. If you are having trouble profiling using Modes 5 or 8, review the section on “Water Profiling Modes,” page 86. Check that the maximum relative water speed (water plus boat speed) and profiling range do not exceed the limitations given in Table 4, page 86. Both Modes 5 and 8 must have a minimum water depth to profile. These depths are listed in Table 6, page 91.

If the relative velocity and minimum and maximum depth requirements for modes 5 and 8 are met, and you still cannot get reliable performance, there may be turbulence and shear conditions in your river channel which are causing these modes to fail. You will need to profile using general purpose profiling Mode 1.

United States Geological Survey Open File Report 01-1

Discharge Measurements Using a Broad-Band Acoustic Doppler Current Profiler

By Michael R. Simpson

United States Geological Survey
OPEN-FILE REPORT 01-1

8016-20

SACRAMENTO, CALIFORNIA
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Placer Hall, Suite 2012
6000 J Street
Sacramento, CA 95819-6129

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

FIGURES

Chapter 1. Theory of Operation

1.1.–1.40. Graphic illustrations showing:

FIGURES—Continued

TABLES

TABLES—Continued

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
centimeter per second (cm/s)	.3281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.3147	cubic foot per second (ft^3/s)
cubic meter per second per second ($m^3/s/s$)	35.3147	cubic foot per second per second ($ft^3/s/s$)
decibel per meter (dB/m)	.3048	decibel per foot (dB/ft)
decimeter (dm)	3.937	inch (in.)
kilometer (km)	.6214	mile (mi)
meter (m)	3.281	foot (ft)
meter per second (m/s)	3.281	foot per second (ft/s)
millimeter (mm)	.03937	inch (in.)
millimeter per second (mm/s)	.03937	inch per second (in./s)
square meter per second per second ($m^2/s/s$)	10.7639	square foot per second per second ($ft^2/s/s$)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \cdot °C) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations and Acronyms

dB	decibel
Hz	hertz
hp	horsepower
K, kB	kilobyte
kHz	kilohertz
Mb	megabyte
ppt	parts per thousand
rpm	revolutions per minute
s	second
V	volt
W	watt
AC	alternating current
ADCP	acoustic Doppler current profiler
ASCII	American standard code for information interchange
BB-ADCP	broad-band acoustic Doppler current profiler
BNC	bayonet style coaxial
CD-ROM	compact disk, read-only memory
CFG	configuration (file)
CPU	central processing unit
CV	coefficient variation
DC	direct current
DOI	U.S. Department of the Interior
EGA	extended graphics array
GPS	Global Positioning System
IBM	International Business Machines
LCD	liquid crystal display
LED	luminescent electronic display
MS DOS	Microsoft Disk Operating System
PC	personal computer
QA	quality assurance
RDI	R.D. Instruments, Inc.
RSSI	reflected signal strength indicator
USGS	U.S. Geological Survey

Discharge Measurements Using a Broad-Band Acoustic Doppler Current Profiler

By Michael R. Simpson

INTRODUCTION

The measurement of unsteady or tidally affected flow has been a problem faced by hydrologists for many years. Dynamic discharge conditions impose an unreasonably short time constraint on conventional current-meter discharge-measurement methods, which typically last a minimum of 1 hour. Tidally affected discharge can change more than 100 percent during a 10-minute period. Over the years, the U.S. Geological Survey (USGS) has developed moving-boat discharge-measurement techniques that are much faster but less accurate than conventional methods. For a bibliography of conventional moving-boat publications, see Simpson and Oltmann (1993, page 17).

The advent of the acoustic Doppler current profiler (ADCP) made possible the development of a discharge-measurement system capable of more accurately measuring unsteady or tidally affected flow. In most cases, an ADCP discharge-measurement system is dramatically faster than conventional discharge-measurement systems and has comparable or better accuracy. In many cases, an ADCP discharge-measurement system is the only choice for use at a particular measurement site.

ADCP systems are not yet “turnkey”; they are still under development, and for proper operation, require a significant amount of operator training. Not only must the operator have a rudimentary knowledge of acoustic physics, but also a working knowledge of ADCP operation, the manufacturers' discharge-measurement software, and boating techniques and safety.

Purpose and Scope

The purpose of this report is to describe ADCP operating techniques, fundamental ADCP theory, ADCP discharge-measurement theory, and vessel mounts and operating techniques required for ADCP discharge measurements. It is not intended to replace the “hands-on,” USGS-approved training required for all ADCP discharge-measurement system operators. This report only describes the Microsoft Disk Operating System (MS DOS) version of the discharge-measurement software, Transect, and will have to be revised to include future versions that run under Microsoft Windows. The report also only describes the configuration and use of the R.D. Instruments, Inc. (RDI), broad-band ADCP (BB-ADCP). Subsequent modifications to the BB-ADCP will be included in updates to this report if these modifications significantly change the configuration of the ADCP or if discharge-measurement techniques must be changed. This report also will be updated if another manufacturer’s ADCP is used to measure discharge by a significant number of USGS users.

A Short History of Acoustic Doppler Current Profiler Discharge Measurement

In 1982, an ADCP was used to measure the discharge of the Mississippi River at Baton Rouge, Louisiana (Christensen and Herrick, 1982). The test results were encouraging, differing less than 5 percent from simultaneous measurements made with conventional moving-boat methods. However, the computer software and hardware were incapable of processing the velocity data provided by the profiler on a real-time basis; the discharge measurements had to be computed after the fact. Although this technology looked very promising at the time of these tests, computer and Doppler signal-processing technology had not progressed to the level needed to collect and compute reliable river and estuarine discharge measurements.

In 1985, the USGS purchased a narrow-band ADCP to be used for the development of a discharge-measurement system (an explanation of the differences between narrow-band and BB-ADCPs is given in chap. 1). This discharge-measurement system was successful (Simpson and Oltmann, 1993) but, because of minimum depth limitations, the narrow-band ADCP was usable only in rivers and estuaries with depths greater than 3.4 meters (m) [11.5 feet (ft)].

Because of depth and measurement precision limitations of the narrow-band ADCP, the ADCP manufacturer began exploring a slightly different area of acoustic technology, which has been termed "broad-band." In 1991, a prototype BB-ADCP was developed and tested. The BB-ADCP short-term random error (standard deviation of measured water velocities) was reported to be an order of magnitude lower than that of the narrow-band system and, because of this, could be optimized for shallow-water operation.

The USGS was interested in this technology because of its application to shallow water and purchased one of the first production models of the BB-ADCP from RDI in February 1992 to be evaluated for use in the measurement of river discharge. This evaluation is ongoing in the California District and has been joined by several other districts of the USGS. Morlock (1996) evaluated the BB-ADCP for discharge measurement at selected locations throughout the United States. This evaluation compared discharges measured utilizing a BB-ADCP with discharges measured at 12 stream-gaging sites having stable stage-discharge relations. The results of the evaluation showed that the BB-ADCP system can be used to accurately measure discharge at sites similar to those measured by Morlock (1996).

The manufacturer has since developed smaller versions of the BB-ADCP. Two such instruments are the "Workhorse" with a bottom-tracking option (chap. 1) and the "Rio Grande," which is a Workhorse with built-in bottom-tracking capability. Because the manufacturer has four types of ADCPs capable of measuring river discharge (narrow-band, broad-band, Workhorse, and Rio Grande), they will be referred to as ADCP discharge-measurement systems in this report, and the instrument will be referred to as an ADCP, unless details specific to a particular model are discussed.

The ADCP discharge-measurement system may be the only feasible, accurate method for measuring discharge in tidally affected rivers and estuaries, as well as in rivers or canals with unsteady flow (Simpson and Oltmann, 1993). The ADCP also has proven useful as a substitute for conventional discharge-measurement techniques in many upland rivers with depths too deep for wading measurements.

On the other hand, the setup and operation of the ADCP for discharge measurements is complicated, compared with conventional methods. Configuration of the ADCP for discharge-measurement use requires a working knowledge of conventional discharge-measurement principles, as well as a basic knowledge of acoustics and Doppler shift measurement techniques. With the help of this report, attendance at a USGS-approved ADCP discharge-measurement course, and the manufacturer's documentation, it is hoped that an interested individual can gain the skills needed to accurately measure river discharge using an ADCP.

CHAPTER 1: THEORY OF OPERATION

Basic Acoustic Velocity Measurement Principles

Before the operational aspects of an ADCP measurement can be understood, some of the basic physical properties of sound and sound propagation through different mediums must be examined. This chapter introduces basic acoustic Doppler velocity measurement principles and some of the problems associated with such measurements. Much of the information in this chapter was taken from R.D. Instruments, Inc. (1989, 1996).

The Physics of Sound

What commonly is perceived as sound is a vibration of our eardrums caused by the arrival of pressure waves. The eardrum transfers the pressure-wave information to parts of the inner ear where the mechanical energy of the pressure waves is converted to an electrical signal. The brain interprets this electrical signal as sound.

Sound waves can occur in most media (water, air, and solids) and are similar to water waves; sound waves have crests and troughs that correspond to bands of high and low air pressure, and water waves have crests and troughs that correspond to high and low water-level elevations. Pitch (frequency) of sound waves increases as the wavelength (the distance between the wave peaks) becomes shorter. This frequency, or pitch, usually is expressed in hertz (Hz). One hertz equals one wave (cycle) per second. The human ear can hear frequencies from about 40 Hz to about 24 kilohertz (kHz) (24,000 Hz). These frequencies are dubbed the “sonic” frequencies. Sound frequencies below about 40 Hz are called “subsonic,” and sound frequencies above 25,000 Hz are called “ultrasonic.”

The Doppler Principle Applied to Moving Objects

The ADCP uses sound to measure water velocity. The sound transmitted by the ADCP is in the ultrasonic range (well above the range of the human ear). The lowest frequency used by commercial ADCPs is around 30 kHz, and the common range used by the USGS for riverine measurements is between 300–3,000 kHz.

The ADCP measures water velocity using a principle of physics discovered by Christian Johann Doppler (1842) (fig. 1.1). Doppler’s principle relates the change in frequency of a source to the relative velocities of the source and the observer. Doppler (1842) stated his principle in the article, “Concerning the Coloured Light of Double Stars and Some Other Constellations in the Heavens,” while working in Prague, Czechoslovakia. The Doppler principle can be described best using the water-wave analogy (figs. 1.2, 1.3).

Figure 1.1. Christian Johann Doppler.

Figure 1.2 shows a stationary observer watching a series of waves that are passing at a rate of one wave per second. This rate is analogous to a transmit frequency of 1 Hz. In figure 1.3, the wave observer is boating toward the wave source at a rate of four wavelengths per second. Because the waves are passing at a rate of one wave per second, the observer notices the passage of five waves during each second of his boating trip. He senses that the rate of the passing waves is 5 Hz, though the wave source is still emitting waves at 1 Hz. This phenomenon is known as the Doppler effect.

Many people have experienced the Doppler effect while on a busy street. The sound of a car horn seems to drop in frequency as the car passes and recedes from the observer. The apparent lowering of frequency is called the Doppler shift (fig. 1.3). The car is a moving sound-wave source; therefore, when the car is approaching an observer, the frequency of the sound waves striking the observer’s ear drums is proportional to the speed of the car (in wavelengths per second) plus the frequency of the car horn in hertz. When the car is receding from the observer, the frequency of the sound waves striking the observer’s ear drums is proportional

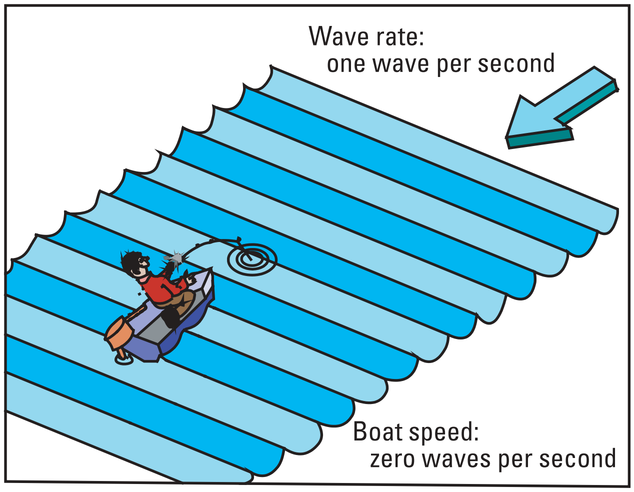


Figure 1.2. Stationary wave observer.

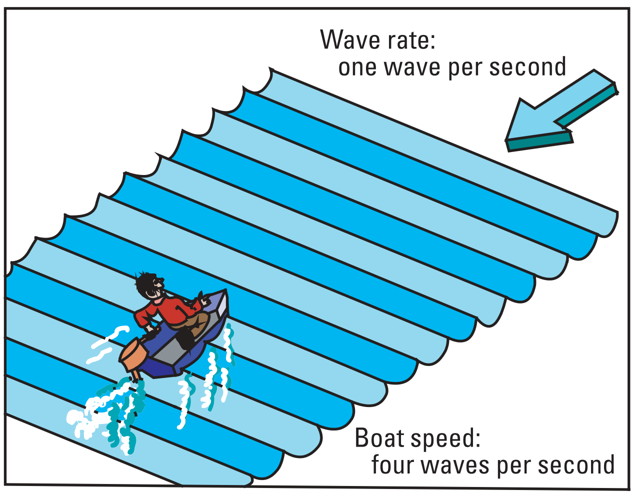


Figure 1.3. Moving wave observer.

to the frequency of the car horn (in hertz) minus the speed of the car (in wavelengths per second). If the exact source frequency is known and the observed frequency can be calculated, equation 1.1 can be used to calculate the Doppler shift due to the relative velocities of the source and observer (R.D. Instruments, Inc., 1989):

$$F_D = F_S\left(\frac{V}{C}\right) \quad (1.1)$$

where

F_D = the Doppler shift frequency, in hertz;

F_S = the transmitted frequency of the sound from a stationary source, in hertz;

V = relative velocity between the sound source and the sound wave receiver (the speed at which the observer is walking toward the sound source), in meters per second; and

C = the speed of sound, in meters per second.

Note that:

- If the observer walks faster (V increases), the Doppler shift (F_D) increases
- If the observer walks away from the sound (V is negative), the Doppler shift (F_D) is negative
- If the frequency of the sound (F_S) increases, the Doppler shift (F_D) increases
- If the speed of sound (C) increases, the Doppler shift (F_D) decreases

Measuring Doppler Shifts Using Acoustic Backscatter

An ADCP applies the Doppler principle by bouncing an ultrasonic sound pulse off small particles of sediment and other material (collectively referred to as backscatterers) that are present, to some extent, even in optically clear water. A magnified view of the water column and the backscatterers “illuminated” by the sound pulse are shown in figure 1.4. There are, of course, exceptions to every rule, and in tow tanks and some natural rivers, backscatterer density can be too low for the proper operation of an ADCP.

The ADCP transmits an acoustic “ping,” or pulse into the water column and then listens for the return echo from the acoustic backscatterers in the water column. Upon receiving the return echo, the ADCP’s onboard signal-processing unit calculates the Doppler shift using a form of autocorrelation (the signal is compared with itself later). A schematic diagram of a transmitted acoustic pulse (ping) and the resulting reflected acoustic energy are shown in figure 1.5. Note

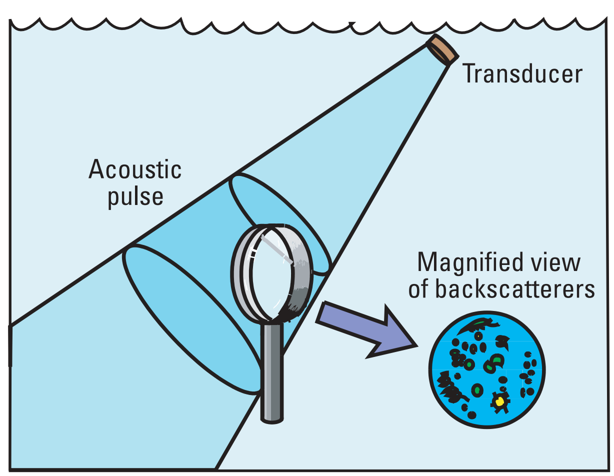


Figure 1.4. Magnified view of backscatterers.

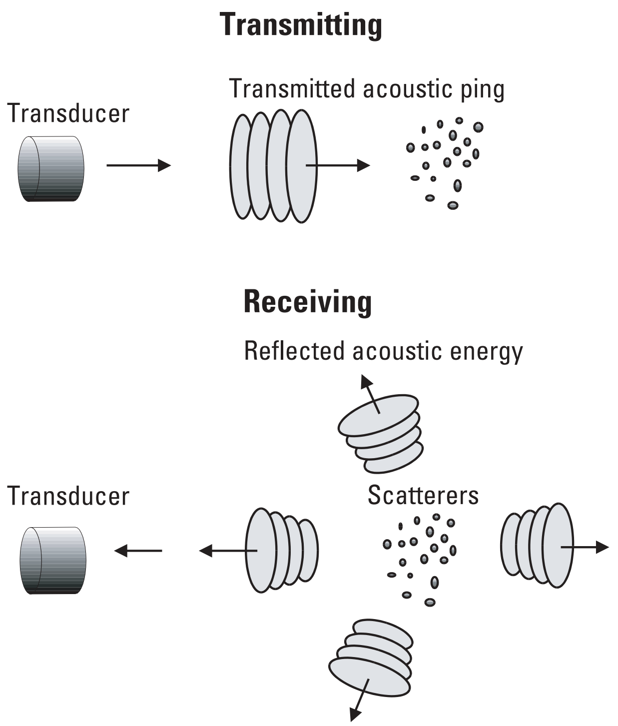


Figure 1.5. An acoustic pulse being backscattered.

that very little reflected acoustic energy is reflected back (backscattered) towards the transducer in figure 1.5; most of the acoustic energy is absorbed or reflected in other directions.

Measuring Doppler Shifts From a Moving Platform

When the scatterers are moving away from the ADCP, the sound (if it could be perceived by the scatterers) shifts to a lower frequency. This shift is proportional to the relative velocity between the ADCP and the scatterers (fig. 1.5). Part of this Doppler-shifted sound is backscattered towards the ADCP, as if the scatterers were the sound source (fig. 1.6). The sound is shifted one time (as perceived by the backscatterer) and a second time (as perceived by the ADCP transducer) (R.D. Instruments, Inc., 1989).

Because there are two Doppler shifts, equation 1.1 becomes equation 1.2:

$$F_D = 2\,F_D\left(\frac{V}{C}\right) \qquad (1.2)$$

If the sound source and receiver move, relative to the Earth, but stay at a fixed distance from one another, there is no Doppler shift. The Doppler shift exists only when sound sources and receivers move in relation to

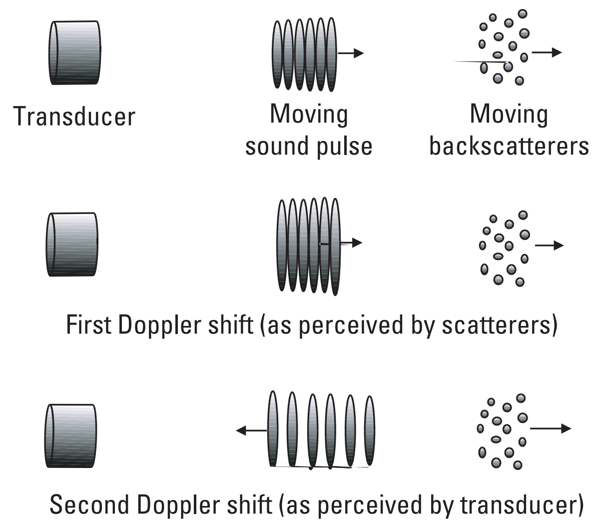


Figure 1.6. Reflected pulse showing two Doppler shifts.

each other. The Doppler shift between the source and the Earth exactly cancels the opposite shift between the Earth and the receiver (R.D. Instruments, Inc., 1989).

Radial Motion

Only radial motion, which is a change in distance between the source and receiver, will cause a Doppler shift. Figure 1.7 shows 1-second boat tracks in three different directions, relative to the wave source. Boat vector A is parallel with the wave direction; therefore, vector A encounters the full component of Doppler shift. Boat vector B is moving at an angle to the wave direction and encounters only a part of the Doppler shift component, whereas boat vector C (normal to the wave source) encounters no Doppler shift.

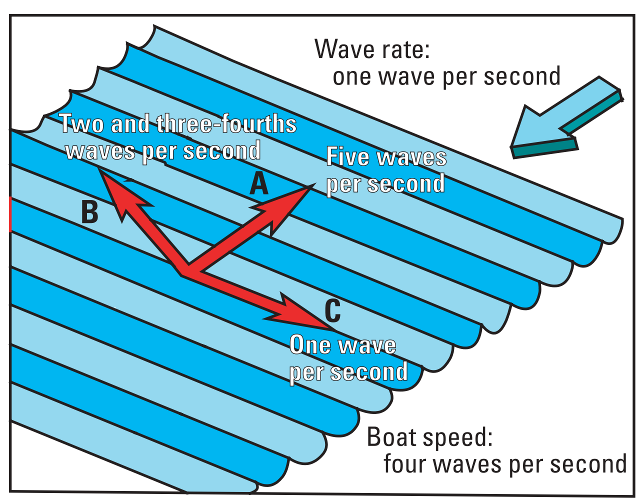


Figure 1.7. Effect of radial motion on Doppler shift.

Mathematically, this means the Doppler shift results from the velocity component in the direction of the line between the source and receiver (R.D. Instruments, Inc., 1989) as shown in equation 1.3:

$$F_D = 2F_S\left(\frac{V}{C}\right)\cos(\theta) \qquad (1.3)$$

where

θ = the angle between the relative-velocity vector and the line between the ADCP and scatterers (fig. 1.8).

Acoustic Doppler Current Profiler Beam Geometry

Calculating Three-Dimensional Velocity Components

In a vessel-mounted system, the transducers are mounted near the water surface and aimed downward. Figure 1.9 shows a typical ADCP. Note that there are four independently working acoustic beams with each beam angled 20–30º from the vertical axis of the transducer assembly. This configuration of beams is the so-called “Janus” configuration, named after the Greek God, Janus, who could simultaneously look forward and backward.

Beam Scenarios

To visualize the three-dimensional capabilities of the “Janus” configuration, refer to figure 1.10 while reading the following scenarios:

- If the starboard (90º left of forward) beam has a positive Doppler shift, the port (90º right of forward) beam has a negative Doppler shift, and the forward and aft beams have no Doppler shift, then the water is flowing from starboard to port (or the water is still and the boat is sliding starboard)
- If the forward beam has a negative Doppler shift, the aft beam has a positive Doppler shift, and the

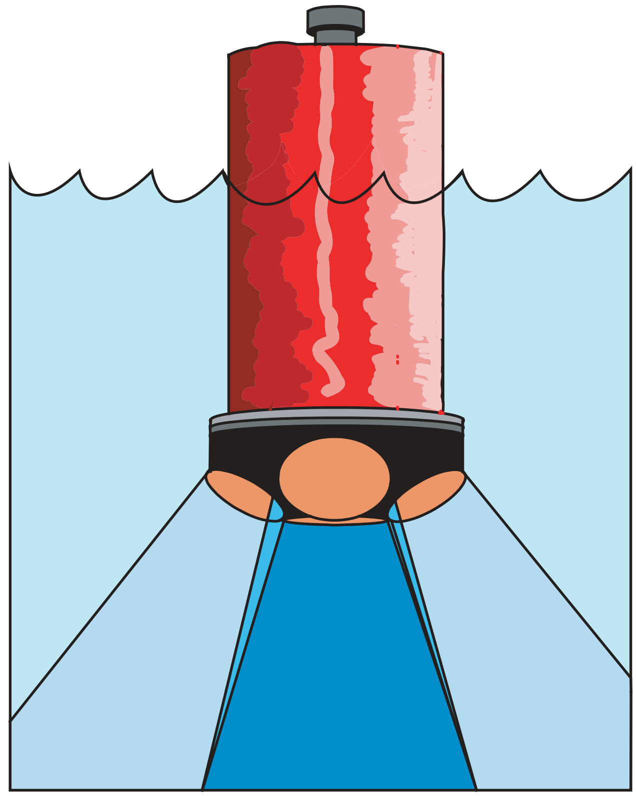


Figure 1.9. Downward-looking, convex-head acoustic Doppler current profiler.

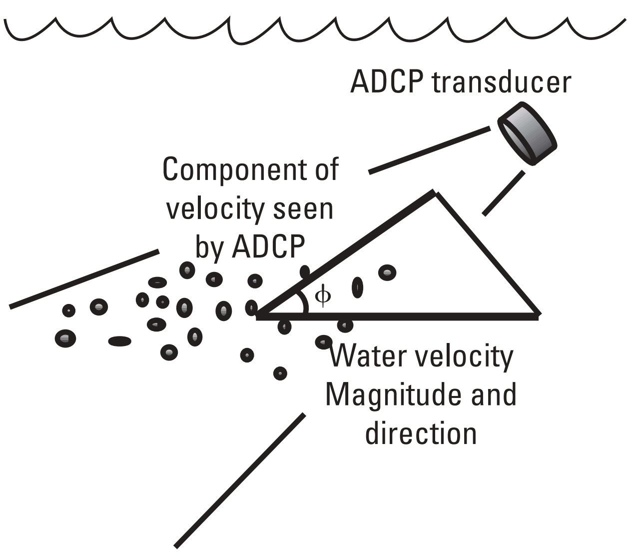


Figure 1.8. Velocity components. ADCP, acoustic Doppler current profiler.

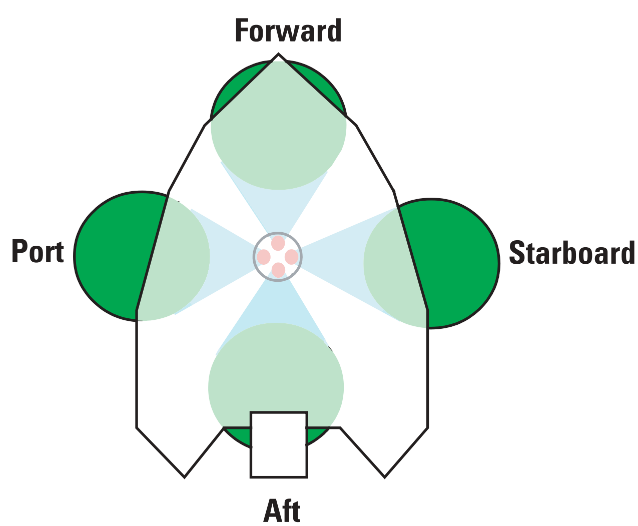


Figure 1.10. Boat-mounted acoustic Doppler current profiler with the “Janus” configuration.

starboard and port beams have no shift, then the water is flowing under the boat from aft to forward (or the water is still and the boat is backing)

- If the forward and port beams have a positive Doppler shift of magnitude 1 and the aft and starboard beams have a negative Doppler shift of magnitude 1, then water is passing under the boat from a point halfway between forward and port with a magnitude of the square root of 2, or 1.414 (or the water is still and the boat is crabbing toward the forward port quarter at a magnitude of 1.414)
- If all four beams have a positive Doppler shift, the water is flowing upward toward the hull of the boat (or the water is still and all personnel on the boat should don their life jackets)

The computation of velocity in three dimensions (x, y, z) requires at least three acoustic beams (figs. 1.11 and 1.12). Figure 1.11 shows a northwest-moving water-velocity vector and the resulting Doppler shifts from each of three acoustic beams (a hypothetical, three-beam sonar). Because the water-velocity vector is almost exactly at right angles to beam 2, the resulting Doppler shift on beam 2 is small. The water-velocity vector is approaching and is almost aligned with beam 3; therefore, beam 3 has a large, positive Doppler shift. The water-velocity vector is receding from, and is almost aligned with, beam 1; therefore, beam 1 has a large negative Doppler shift.

Figure 1.12 shows a northeast-moving water-velocity vector. Note that because the water-velocity vector almost is at right angles to beam 3, the resultant Doppler shift is small. The water-velocity vector is approaching beam 1 at an angle; therefore, beam 1 has a large positive Doppler shift. Beam 2 has a large negative Doppler shift because the water-velocity vector is receding from, but not perfectly parallel with, beam 2. This configuration also could measure vertical velocities. If all three beams have positive Doppler shifts, then a vertical component of water velocity moving toward the transducers is present. By using simple trigonometry, velocity components in three orthogonal coordinates can be calculated from Doppler shifts measured with three sonar beams.

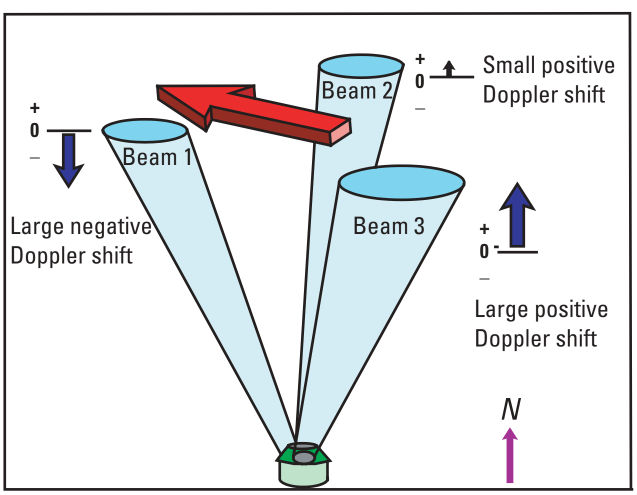


Figure 1.11. Northwest-moving water-velocity vector and the resulting Doppler shifts from a hypothetical, three-beam sonar.

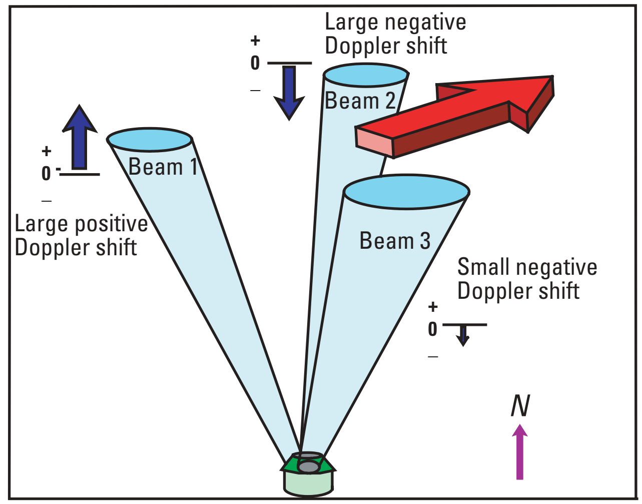


Figure 1.12. Northeast-moving water-velocity vector and the resulting Doppler shifts for a hypothetical, three-beam sonar.

The Fourth Beam and Error Calculations

Some ADCP manufacturers use a four-beam configuration and the fourth redundant beam is used to compute an error velocity. This error velocity can be used to test the assumption that flow volume of water bounded by the four measurement beams is homogeneous. Velocity homogeneity means that the water velocities do not change significantly in magnitude or direction within the confines of the acoustic beam footprint. Figure 1.13 shows a homogeneous velocity field bounded by the four beams of an ADCP.

If a velocity field existed as in figure 1.13, the ADCP would provide a nearly zero error velocity. Error velocity is defined as the difference between a velocity measured by one set of three beams versus a velocity measured by the other set of three beams during the same time frame. A difference between these two measurements could be caused by a bad or corrupt beam velocity or by nonhomogeneity (fig. 1.14). In practice, a small error velocity almost always exists because complete homogeneity of the velocity field rarely occurs during field measurements.

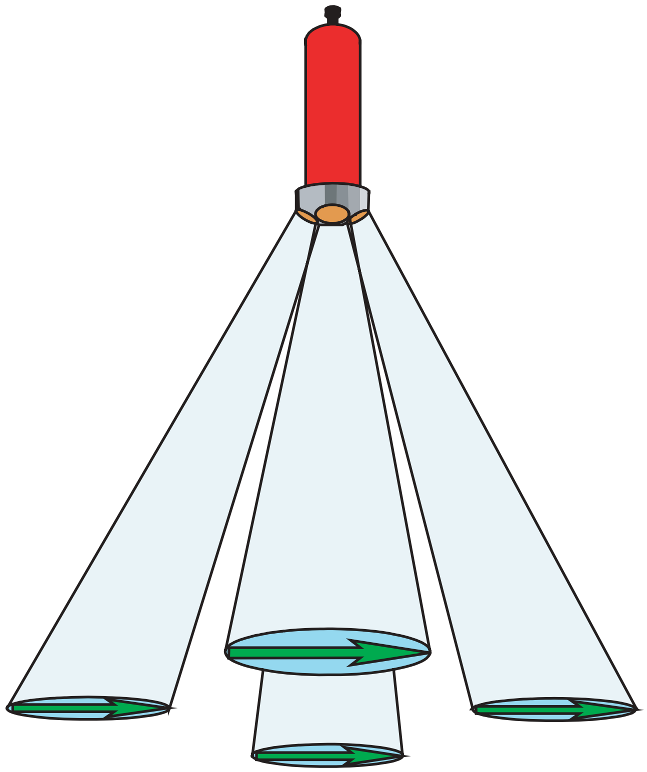


Figure 1.13. Acoustic Doppler current profiler measuring a homogeneous velocity field.

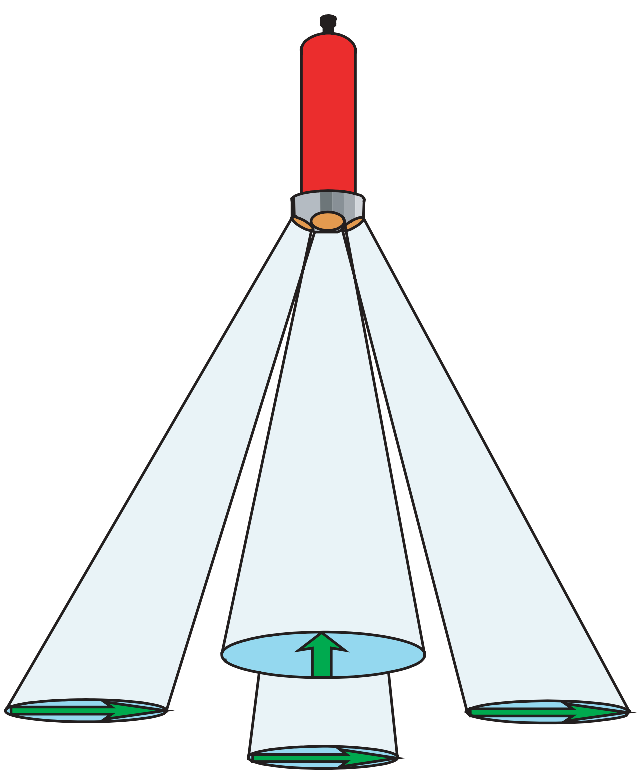


Figure 1.14. Nonhomogeneous velocity field bounded by the acoustic Doppler current profiler beams.

Acoustic Doppler Current Profiler Water-Velocity Profile Measurements

Acoustic Doppler Current Profiler-Measured Profiles Compared with Conventional Current Meter Measurements

The ADCP is best known for its capability to measure profiles of water velocity. A velocity profile can be compared roughly to using a number of point-velocity meters that are suspended in the vertical axis of a water-velocity field (fig. 1.15). Theoretically, the velocity measured by each conventional current meter is analogous to the velocities measured at the center of ADCP depth cells (fig. 1.15). However, the analogy between a string of current meters and an ADCP profile is not perfect. Current meters measure water velocity at individual points in the vertical profile, whereas velocities that are measured by the ADCP and assigned to individual depth cells are really the center-weighted mean of velocities that are measured throughout the sample window (fig. 1.15).

Time Gating: Measuring Doppler Shifts from Different Depths

The ADCP profiling capability is accomplished by time gating (and sampling) the received echo at increasingly longer time intervals as the acoustic-beam wave fronts vertically traverse the water column (fig. 1.16).

The analogy of a Navy sonar operator can be used to understand time gating. The sonar operator presses a button on the sonar console causing a “ping” to be transmitted by the ship’s sonar transducer. As soon as the ping is transmitted, the sonar operator activates a stopwatch and begins listening to the returned echo. The sound from the ping travels through the water very

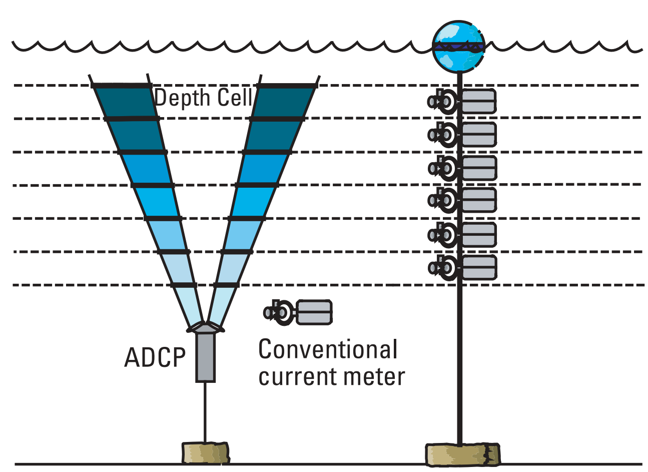


Figure 1.15. Analogy of a conventional current-meter string to an acoustic Doppler current profiler (ADCP) profile.

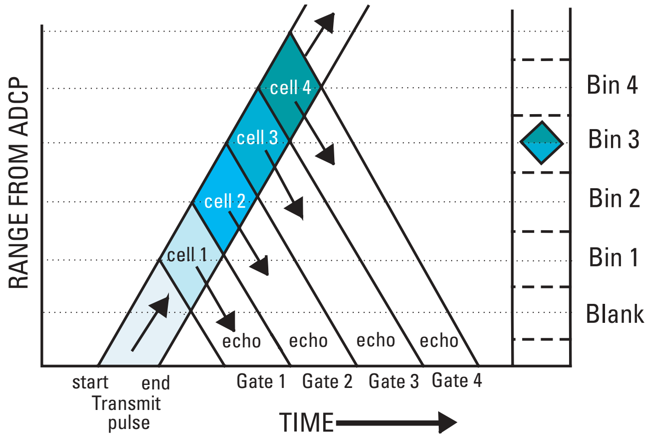


Figure 1.16. Acoustic Doppler current profiler (ADCP) time gating. Adapted from R.D. Instruments, Inc., (1989).

fast, but at a finite speed that can be calculated. The operator hears a continuous, low-intensity echo that is caused by the sound reflecting off of particles in the water as the ping speeds toward the ocean floor. The operator hears an abrupt increase in echo amplitude and frequency and immediately presses the stop button on the stopwatch. The echo anomaly was caused by a submerged submarine. The operator then calculates the distance to the submarine using the elapsed time from the stopwatch and a speed-of-sound equation (Urick, 1975). The speed of the submarine, relative to the Navy ship, also can be calculated and is proportional to the Doppler shift of the returned echo.

If the sonar operator was replaced by a computer-controlled receiver and time circuit, the received echo could be recorded and "sliced up" into small pieces with each piece corresponding to a received time. Each slice (depth cell) would be from an increasingly deeper part of the water column. The speed of the particles in each depth cell could be measured by calculating the Doppler shift of the echo in each depth cell. For this purpose, most ADCPs contain a computer-controlled receiver and timer circuit for each acoustic beam, as well as sophisticated signal-processing hardware to calculate Doppler shifts.

The ADCP transmits a ping along each acoustic beam and then time gates the reception of the returned echo on each beam into depth cells. Speed and direction are then calculated (using a center-weighted mean of the velocities measured in the depth cell) and assigned to the center of each depth cell (bin) over the measured vertical.

Bottom Tracking

To measure absolute water velocities (water velocities relative to the Earth), the ADCP must sense and measure the velocity of the ADCP, relative to the river bottom (bottom tracking). If the velocity of the water is known, relative to the ADCP, and the velocity of the ADCP is known, relative to the river bottom, then the water velocity, relative to the bottom, can be calculated. The bottom-track pulse is somewhat longer than the water-track pulse to properly ensonify the bottom (fig. 1.17). All ADCP instruments that are designed to measure discharge have the ability to calculate vessel velocity using a bottom-track pulse. The bottom-track ping also is used to measure the profiled depth range from each beam. These depth-range measurements are averaged to obtain a depth for the measured velocity profile.

Acoustic Doppler Current Profiler Limitations for Velocity-Profile Measurements

Range Limitations

Reception and calculation of Doppler shift from a returned echo requires sophisticated electronic circuitry as well as high-speed digital signal-processing algorithms. The ADCP contains circuitry and micro-processors capable of resolving very small changes in echo Doppler shift that are needed for accurate water-velocity and bottom-velocity measurement. However, there are some problems associated with echo reception and water-velocity measurement using ADCPs.

In an ADCP, the backscattered echo amplitude falls off as a function of range, frequency, and pulse width, as well as the attenuating properties of the water mass. In ADCP systems, the uncertainty (random error) of the returned velocity measurement is strongly affected by changes in the backscattered echo amplitude. Figure 1.18 shows a spectrograph illustrating the relationship among transmit frequency, echo amplitude, and spectral width. For accurate water-

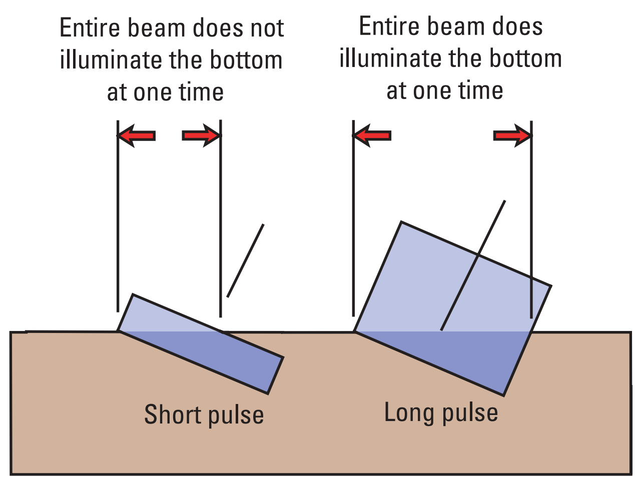


Figure 1.17. Short and long bottom-track pulse. Adapted from R.D. Instruments, Inc., (1989).

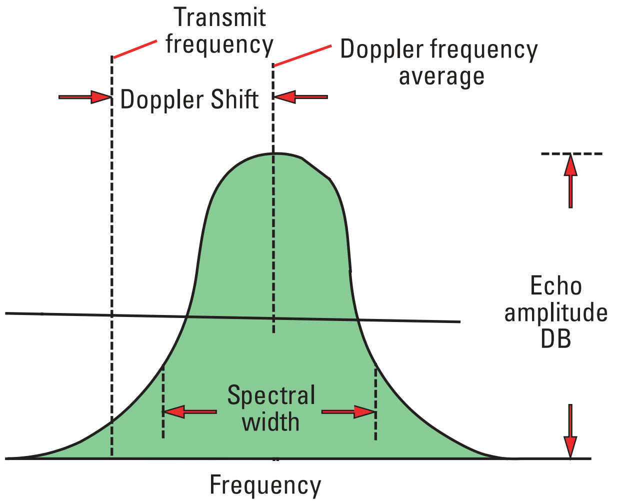


Figure 1.18. Spectrograph of received Doppler signal. DB, decibels.

velocity measurement, the returned signal should have a very small spectral width (as shown by the dotted line labelled "Doppler frequency average" in figure 1.18), but, in reality, there are several factors that "spread" or "smear" the returned frequencies over a larger part of the frequency spectrum, as bounded by the solid line in figure 1.18.

The first factor is the finite duration of the acoustic transmit pulse. If the pulse is t seconds long, the reflected signal has a frequency spread of 1/t Hz, about the center frequency (Urick, 1975). This effect is the dominant source of spectral spreading of the received Doppler shifted echo. This spectral spreading causes increased random error in the determination of Doppler shift and, therefore, increased random error in the measurement of water velocity. The smaller the pulse width, the greater the amount of random error.

Figure 1.19 shows a signal being backscattered from scatterers of different sizes that are moving at different speeds, which results in the arrival of signals at differing phases. Because the autocorrelation technique needs accurate phase information to calculate frequency shift, this spreading effect causes random error in the determination of Doppler shift.

In natural waters, the reflected signal is affected significantly by scatterer velocities in the cloud of particulate matter that is "illuminated" by the ultrasonic pulse (fig. 1.20). The result of this cloud-scattering effect is to increase the spectral width of the return signal.

Although the dominant source of spectral spreading is the transmit pulse length, the measured spectral width can be an indicator of velocity uncertainty. As the signal-to-noise ratio decreases near the end of the profile, the spectral width increases. This increase translates directly into velocity uncertainty.

Thus, changes in spectral width are related to velocity uncertainty, especially in the last one-third of the profiling range (R.D. Instruments, Inc., 1989).

The echo amplitude is the measure of the energy in the echo and varies with a dynamic range of many

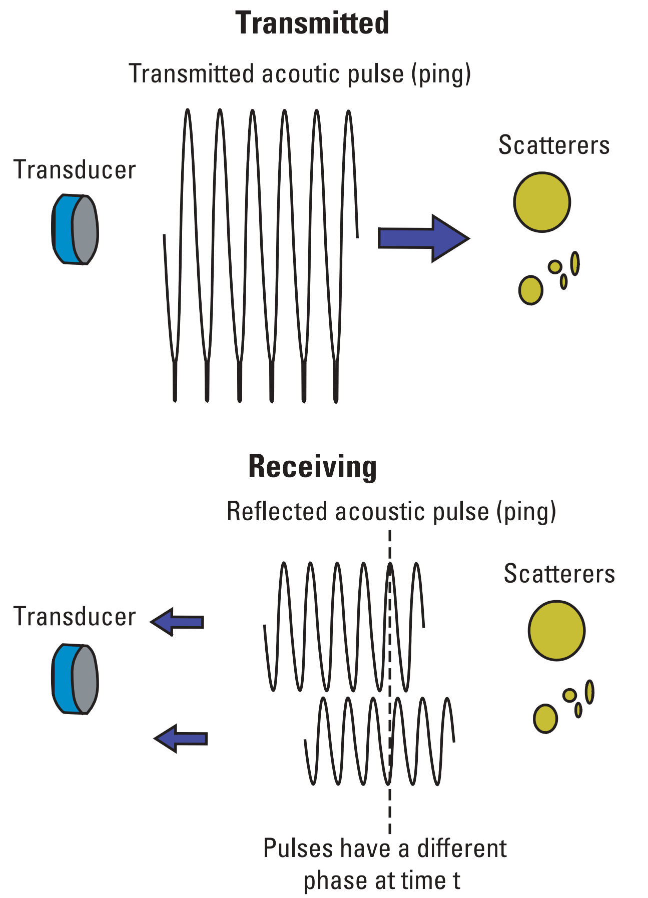


Figure 1.19. Phase change due to size and speed differences of scatterers.

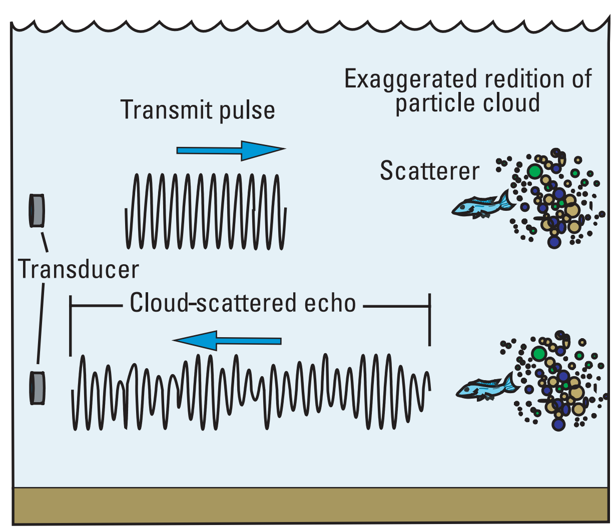


Figure 1.20. Echo returned from a cloud of particles.

orders of magnitude; therefore, it is converted to decibels. The echo amplitude is a function of several things:

- •Transmit pulse power
- •Transmit pulse length
- •Reflective quality of scatterers
- •Quantity of scatterers
- •Absorption coefficient of the water

When the echo amplitude is high, the signal-to-noise ratio of the returned echo is high. However, when the echo amplitude drops below a certain level, the signal-to-noise ratio drops, increasing the spectral width, which, in turn, increases the uncertainty of the velocity measurement. This effect increases with range because the echo signal-to-noise ratio decreases with range. The signal-to-noise ratio also can decrease if there are too few particles in the water column. Ironically if there are too many particles (as with a very high sediment concentration), signal-to-noise ratio, from the far bin, echoes can be reduced because of absorption, beam spreading, and attenuation.

Side-Lobe Interference

Most transducers that are developed using present technology have parasitic side lobes that are emitted 30–40º off the main beam acoustic beam. Side-lobe interference is caused when the parasitic side lobe of an acoustic beam strikes the bottom before the main beam finishes traversing the total depth (fig. 1.21).

When the side lobe strikes the bottom, it usually swamps the receivers with an increased amplitude signal that smears the velocity information that is being gathered from the main-beam echo. On a 1,200-kHz BB-ADCP system, the loss of vertical profiling range because of this effect is approximately 15 percent with 30º-beam angles and 6 percent with 20º-beam angles.

Figure 1.22 shows a screen shot of a typical Doppler profile showing the backscattered amplitude or, using an RDI-coined term, the “reflected signal

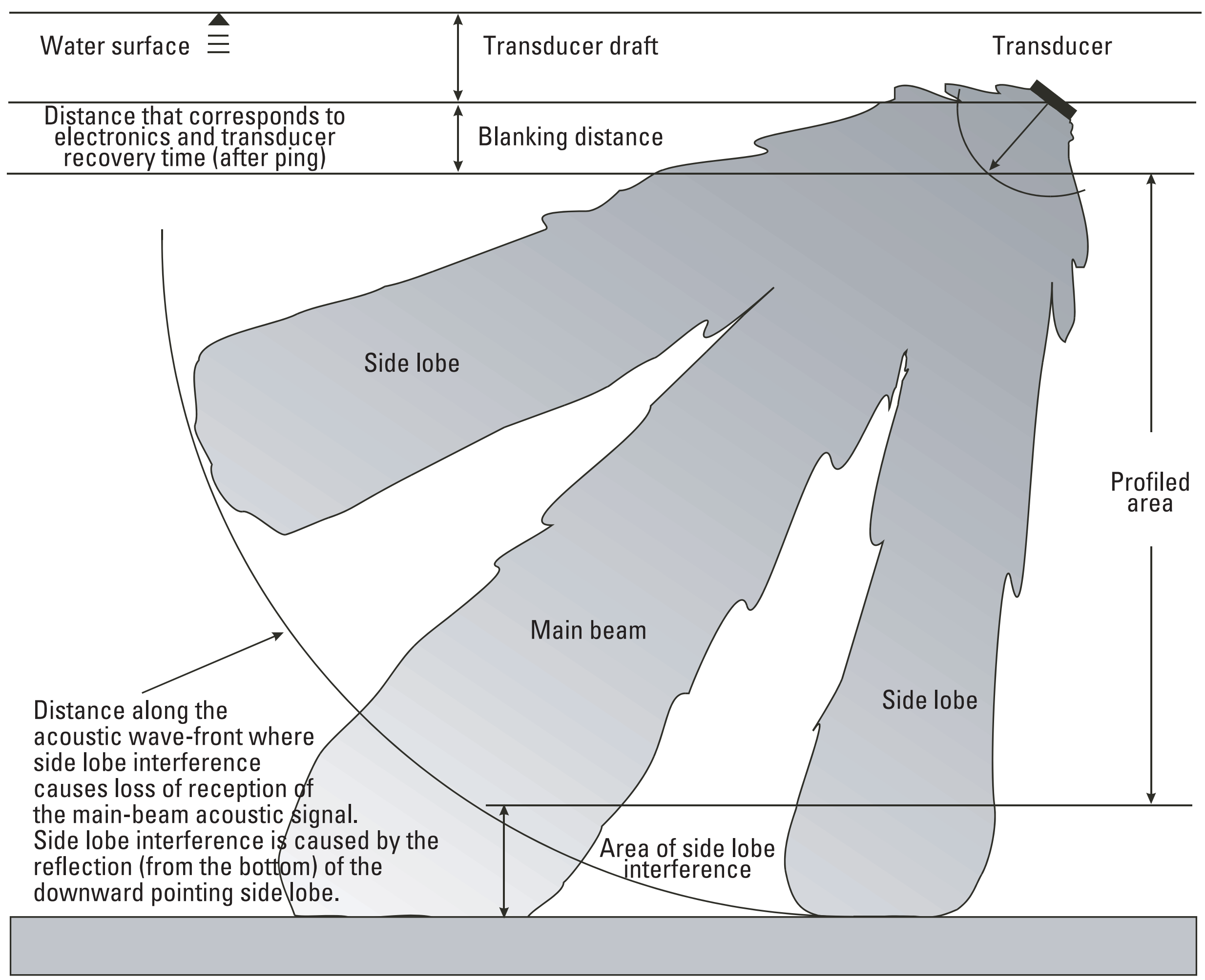


Figure 1.21. Acoustic Doppler current profiler transducer beam pattern.

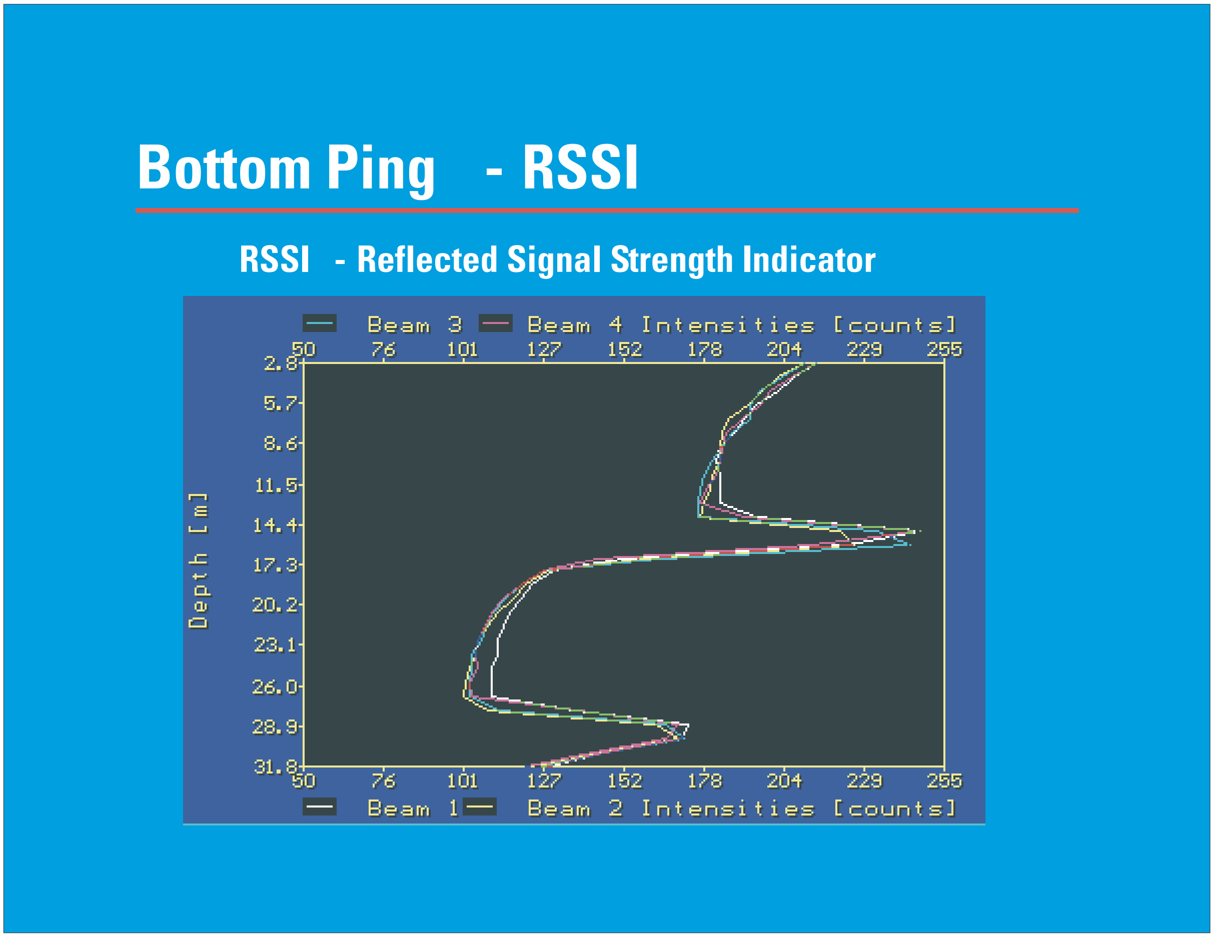


Figure 1.22. Reflected signal strength indicators (RSSI) for a four-beam acoustic Doppler current profiler.

strength indicator" (RSSI). Notice that the RSSI falls off logarithmically with depth until the side lobes strike the bottom. A sharp increase in the RSSI occurs when the side lobes hit the bottom because the bottom is such a strong reflector. Another reflection is seen below the first bottom reflection. This is called a multiple, and it occurs when the signal is reflected off the bottom, travels to the surface, and is reflected off the surface. Note that the multiple is twice the depth as the "original" bottom echo.

Effects of Different Beam Angles

Although using smaller beam angles increases the percentage of the profile that is measured, the precision of water-velocity measurements also is reduced because of decreased coupling with the horizontal. The formula for this calculation is shown in equation 1.4 (R.D. Instruments, Inc., 1989):

$$R_m = D\cos(A) \qquad (1.4)$$

where

R_m = maximum measurable range, in meters;

D = distance from the ADCP to the channel bottom, in meters; and

A = angle of the beam relative to the vertical, in degrees.

The standard deviation of single-ping water-velocity measurements decreases as a function of beam-pointing angle (angle between beam and the vertical). If standard-deviation values are known for a given beam angle, they can be predicted for other beam angles using the ratio of the sines of the angles (eq. 1.5).

$$\sigma_u = \frac{\sigma_a \sin(A)}{\sin(a)} \qquad (1.5)$$

where

σ_u = predicted single ping standard deviation of measured horizontal water velocity, in centimeters per second;

σ_a = single-ping standard deviation of measured horizontal water velocity, in centimeters per second, using beam angle *a*;

A = beam angle *a*, in degrees; and

a = beam angle of predicted measurement, in degrees.

Note that σ_u approaches infinity as the beam angle approaches zero (fig. 1.9).

Blanking Distance

After transmitting acoustic pulses, the transducers and associated electronics must rest a short time before receiving the reflected acoustic signals. A good analogy of this effect is a large gong. The vibrations from a gong take a long time to die out (sometimes several minutes). A transducer ceramic is similar to a miniature gong in that the pulse (ping) vibrations at the 1,200-kHz resonant frequency must be allowed to die out before the transducer is used as a listening device. These tiny vibrations last about 170 microseconds. During that time, the acoustic pulse has traveled about 0.3 m (0.98 ft) if sound velocity is assumed to be 1,500 meters per second (m/s) [4,921 feet per second (ft/s)], and velocity measurements cannot be made within that distance (fig. 1.21).

The actual distance to the first measured bin depends on several factors:

- Blanking distance
- Speed of sound
- Operating mode
- Bin size
- Transmit frequency
- Transducer beam angles

Instrument Development: Solving the Problem of Velocity-Measurement Uncertainty

Aside from the instrument errors discussed in the previous section, most early ADCP measurement systems suffered from “sloppiness,” or in more technical terms, “velocity-measurement uncertainty.” Single-ping velocity uncertainty for an RDI narrow-band 1,200-kHz ADCP purchased in 1986 (using default settings), for example, was 13 cm/s (0.43 ft/s). Luckily this “sloppiness” is, for the most part, random and can be reduced by data averaging. “Narrow-band” is defined later in this chapter. The following section discusses the reasons for velocity-measurement uncertainty and some techniques used to reduce it.

Random and Bias Error

When using an ADCP, two types of errors contribute to velocity uncertainty; random error and bias. Bias errors are sometimes called systematic errors. Random error can be reduced by data averaging; bias error cannot. A thorough understanding of these two types of errors is a crucial prerequisite to the assessment of ADCP velocity and discharge measurement accuracy.

Random Error

ADCP sources of random error are as follows:

- Pulse length—The shorter the pulse length for a given frequency in a narrow-band ADCP, the greater the random error
- Transmit frequency—the lower the frequency at a given pulse length (or lag distance), the greater the random error
- Signal-to-noise ratio—the lower the signal-to-noise ratio, the greater the random error
- Beam angle—As the beam angle approaches vertical, random error approaches infinity

A random velocity-vector error is composed of a random magnitude and a random direction. Figure 1.23 shows 1,920 pings (individual velocity measurements) taken on a lake near Sacramento, California, using a BB-ADCP. Velocities were taken in still water from depth cell number 10 (bin 10) and averaged into 10 ping groups that gave a total of 192 velocity averages. The north and east components were averaged for 10 pings each and the resultant averages were converted to polar coordinates, then plotted. Notice that the error pattern is similar to the pattern of a shotgun blast, with the errors evenly distributed around zero. A directional bias would show as a nonuniform pattern of data points distributed along one of the directional axes.

Random error is reduced by the square root of the number of samples. When data averaging reduces random error magnitudes below the value of bias errors, further averaging becomes superfluous. Figure 1.24 shows the same set of data as in figure 1.23 averaged for about 200 pings; the same set of data yields nine averages.

Bias Error

A velocity-vector bias has a fixed magnitude and direction that either is constant or proportional to the measured velocity. Bias error is nonrandom and, therefore, cannot be reduced by data averaging. Fortunately, in most cases, bias error in ADCP-measured velocities and discharge measurements is

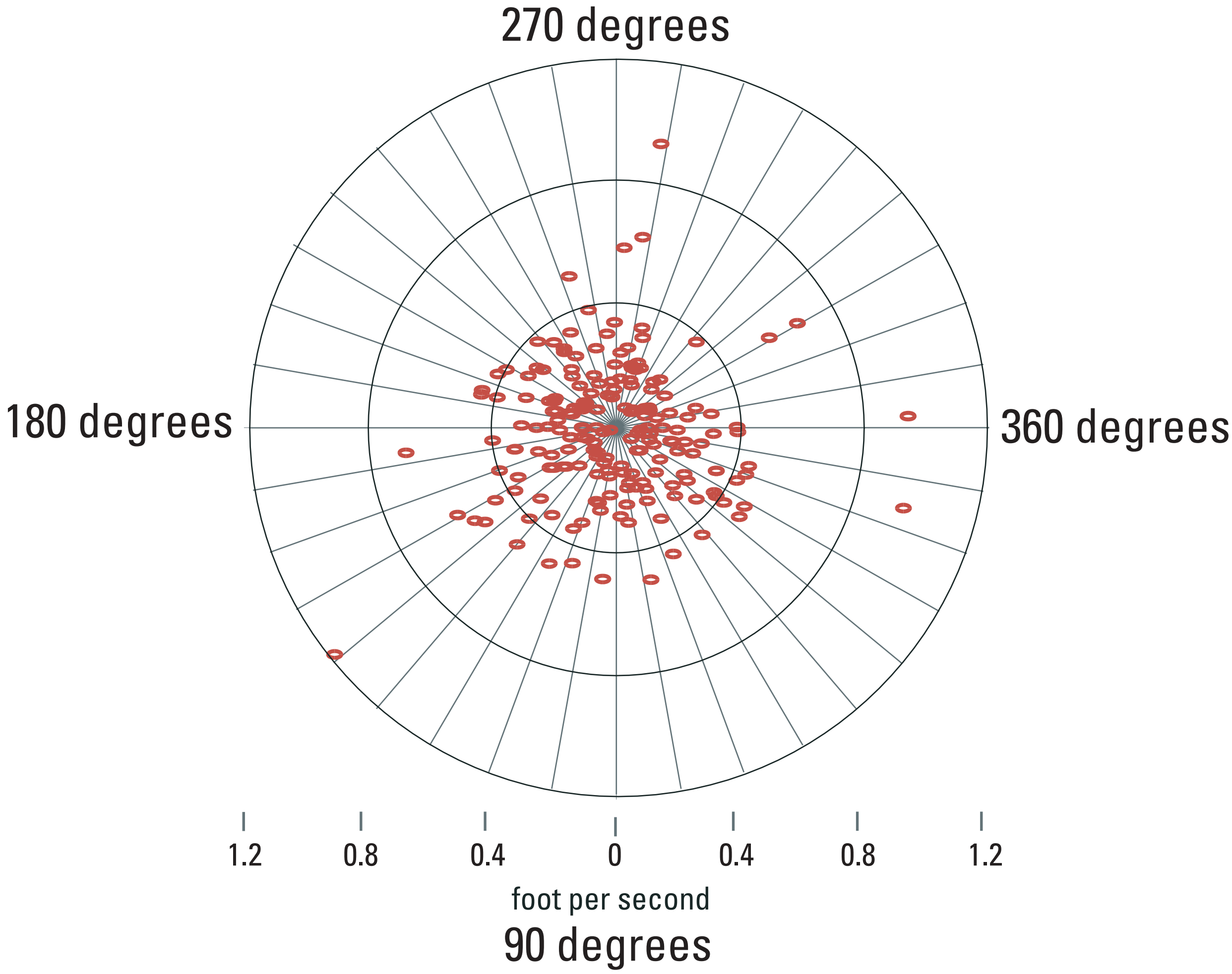


Figure 1.23. Polar plot of 10-ping broad-band acoustic Doppler current profiler velocity averages.

small. Examining figure 1.24 reveals that there may be a small bias error or an actual water velocity in the lake at a direction of 250º. Random and bias error are discussed in more detail in this report in the sections on velocity and discharge-measurement errors.

Pitch and Roll

Pitch is defined as rotation along the fore/aft axis of the ADCP, whereas roll is defined as rotation in the direction of the starboard/port axis of the ADCP. Most ADCP systems contain instruments that detect the magnitude of pitch and roll, as well as methods to correct ADCP-measured velocities for the effects of pitch and roll. Figure 1.25 shows the pitch and roll axes as they apply to a boat-mounted ADCP.

Corrections for pitch and roll of an ADCP must address velocity corrections and depth corrections. The velocity corrections are needed because the geometry of the beam angles change, with regard to the flow field (eq. 1.3, fig. 1.8), during instances of pitch and roll.

Changes in bin depths also are evident during pitch and roll occurrences (fig. 1.26). Bottom depths and bin depths must be “remapped” during an ADCP pitch and roll occurrence. For small angles of pitch and roll, these corrections are not significant unless velocity profiles in all three orthogonal coordinates are desired. Values of horizontal water velocity are a function of the cosine of the pitch and roll, which is insignificant for angles less than 5º. However, if accurate vertical velocities are desired, even small amounts of pitch and roll can significantly affect accuracies. ADCPs commonly are designed with pendulum-type pitch and roll sensors, which are affected by acceleration. However, if an ADCP is expected to be used primarily aboard a vessel in areas having large waves, then fast-responding gyroscope systems should be used to compensate for pitch and roll.

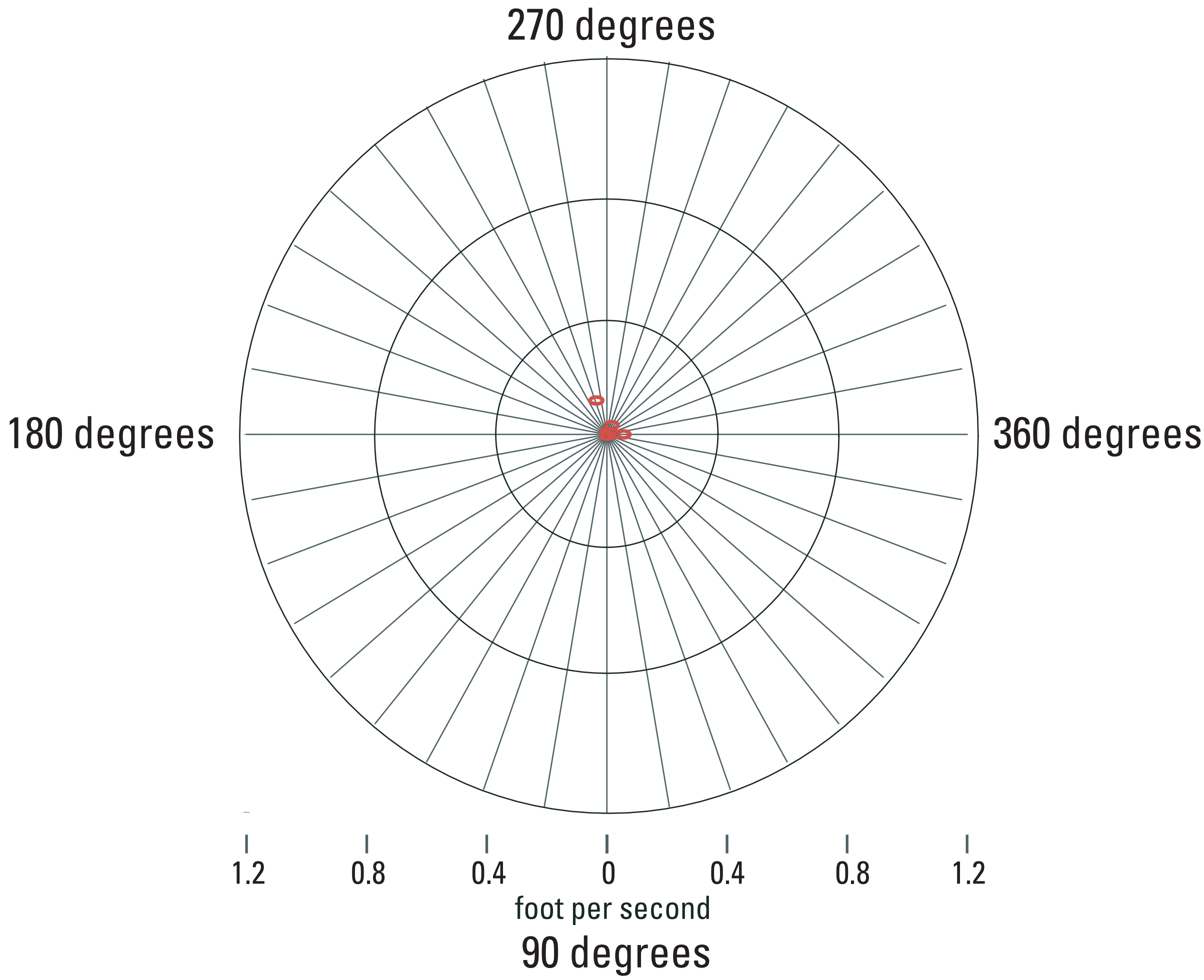


Figure 1.24. Polar plot of about 200-ping broad-band acoustic Doppler current profiler velocity averages.

Beam-Angle Error

Errors in the beam angles could have been a significant source of bias error with early ADCP systems before the manufacturer instituted quality-assurance procedures to minimize this type of error. Beam-angle errors are best detected on a fixed distance course. The manufacturer has developed a computer program that accurately calculates ADCP beam-angle errors, based on data that are collected on the fixed distance, lake, or bay course. Beam-angle errors also will show as biases during intercomparison tests with conventional discharge measurements or other discharge-measurement devices.

Beam-angle errors can be eliminated in recently developed (after 1993) ADCP firmware by introducing corrections into the ADCP system flash memory. This procedure should be done only by the manufacturer. Suspect systems should be sent to the manufacturer for beam-angle testing and recalibration.

Narrow-Band and Broad-Band Doppler Shift Measurements

"Narrow band" is not a very descriptive term and is used here only because the term is used in the industry to describe a certain type of ADCP instrument. The term is used to describe a pulse-to-pulse incoherent ADCP. This means that in a narrow-band ADCP, only one pulse is transmitted into the water, per beam per measurement (ping), and the resolution of Doppler shift must take place during the duration of the received pulse. In the case of RDI-manufactured narrow-band ADCPs, this is accomplished using an autocorrelation technique.

The broad-band (BB) ADCP was developed by RDI in an attempt to solve some of the measurement uncertainty problems seen with the narrow-band ADCP. In a BB-ADCP, the Doppler shift is resolved by transmitting two pulses of the same shape that are in phase with each other (pulse-to-pulse coherent). The following section describes, in detail, the operation of narrow-band ADCPs and BB-ADCPs.

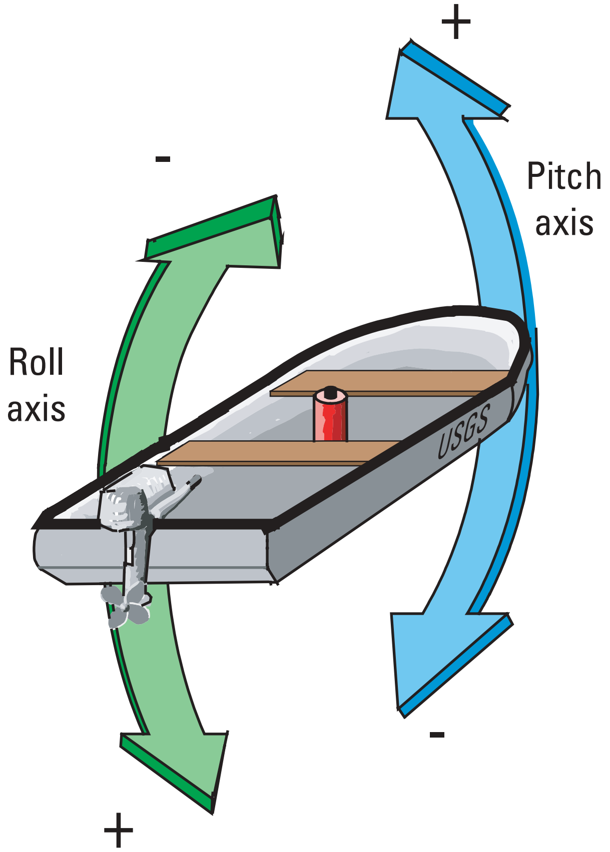


Figure 1.25. Pitch and roll axes for a boat-mounted acoustic Doppler current profiler.

Narrow-Band Doppler Shift Measurements

Doppler shift can be described as the perceived frequency shift of a transmitted (and then reflected) signal caused by the movement of the reflector. Doppler effect also can be described as the magnitude of the phase difference between two coherent (but independent) samples of a reflected signal. The following analogy provides an explanation of narrow-band Doppler shift velocity measurements.

Joel Gast (R.D. Instruments, Inc., oral commun., 1992) has likened a narrow-band Doppler shift measurement to the measurement of automobile speed on a freeway (at night) using a strobe light and a high-speed camera. Consider a freeway at night with traffic moving at a steady rate of speed. A camera has been placed near the freeway and posts have been installed at set distances within the camera's field of view. A strobe light is actuated and, while the freeway is illuminated by the single-strobe pulse, the camera takes two high-speed photographs. When the investigator examines the photographic negatives he finds that by lining up (synchronizing) the images of the cars on the two photographic negatives, the distance traveled by the cars can be determined by measuring the apparent shift in position of the reference posts (fig. 1.27). The auto speeds also can be calculated by multiplying intrapost distance by the lag time between the two photos. If the strobe flashes become acoustic pulses, the cars become reflective particles in the water column, and the negatives become the received

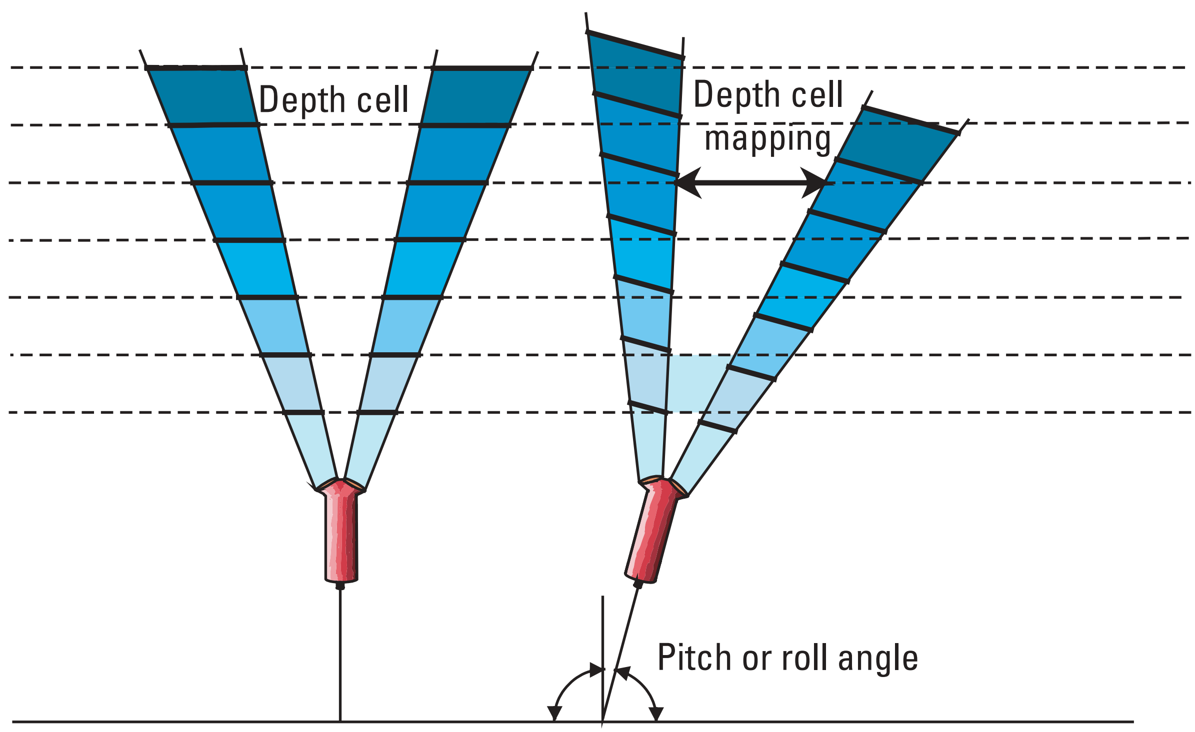


Figure 1.26. Bin positions during an acoustic Doppler current profiler roll occurrence.

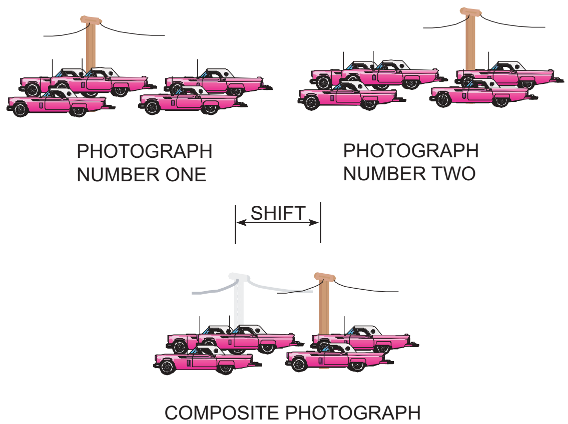


Figure 1.27. Freeway strobe-light system used to measure vehicle speed.

reflected signals, this scenario becomes roughly analogous to the workings of a narrow-band ADCP system.

The drawback to such a system is that the strobe pulse dissipates very quickly and the two photos must be taken while the same cars are still illuminated by the strobe. This means that time lags are very short and the distance traveled by the cars (reflectors) is very short; therefore, the car speeds cannot be measured precisely. Because of these limitations, velocity measurements made using the narrow-band technology are "noisy" (have a relatively high random error). Figure 1.28 shows a diagram of a narrow-band Doppler shift measurement. The signal is sampled twice during the reception of the reflected signal. The lag-time between each measurements is shown as T_L. Using an auto-correlation technique, the Doppler shift is then calculated. In the narrow-band ADCP, the pulse length depends on the lag (T_L) which is a function of bin size. A filter scheme that looks at the whole returned signal is used to resolve ambiguity.

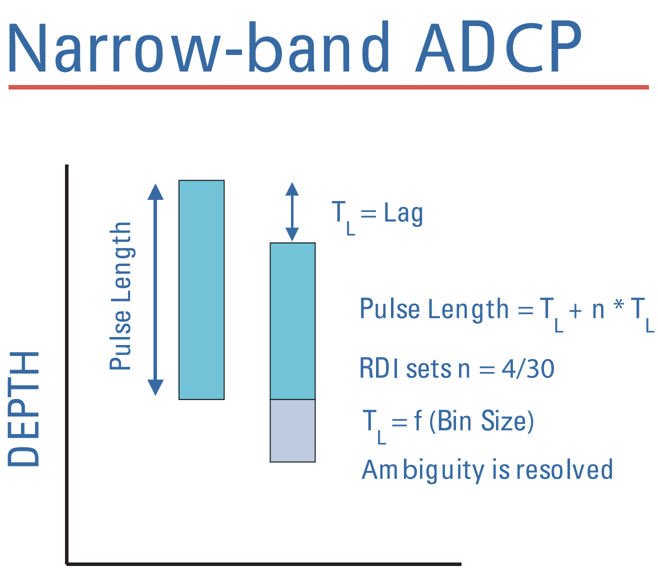


Figure 1.28. Narrow-band acoustic Doppler current profiler (ADCP) shift measurement. RDI, R.D. Instruments, Inc.

Broad-Band Doppler Shift Measurements

Using the freeway analogy, if the investigator decides to install another camera a distance of ten or more car lengths (parallel to the freeway) from the first camera, he could actuate a strobe, take a picture with the first camera, wait a short time, actuate another strobe, then take a picture with the second camera. If the strobes are timed correctly, the cars will travel from the field of view of the first camera into the field of view of the second camera during the time between photos. The investigator synchronizes the positions of the cars on the two negatives and finds that there is a much longer lag time (time between each strobe versus the time between two photos taken during the same strobe) and that the cars traveled a longer distance. The investigator then can calculate the speed of the cars with much greater precision than with the single-strobe system. The distance between the cameras and the time between each strobe must be chosen carefully. If the investigator waits too long between strobes, random movement between the cars (passing, slowing down, speeding up, and so forth) will render the two negatives "unmatchable" (uncorrelated). Transmitting a pair of pulses (strobes) into the water allows for much longer lag times (therefore, more precision) than the narrow-band system. The investigator finds, however, that there are some "costs" associated with this technique.

One of the most significant costs is self noise. The description of self noise again uses the freeway analogy. Suppose that, because of limitations in photographic technology, the freeway cameras have no shutters. Because the investigator must leave the camera shutters open, both cameras will "see" the traffic illuminated by the two strobes. However, only 50 percent of the "scenery" will be usable to both cameras for correlation purposes. For example, the film in camera one is exposed once during the first strobe. The cars then travel out of the field of view of camera one and into the field of view of camera two. However, the film in camera two already has been exposed by the flash of the first strobe and, thus, any cars photographed have left the field of vision. When the second strobe flashes, the film in both cameras is again exposed (double exposed) and the cars that were first photographed by camera one are now photographed by camera two. Because the film has been double exposed, only 50 percent of the scenery in each exposure contains cars that are common to both cameras.

As in the film of the freeway cameras, the reflected wave front from the first BB-ADCP pulse-pair is again "exposed" by the incident wave front of the second pulse and, therefore, is subject to the same "double exposure." The increased noise due to this 50-percent correlation is reduced by data averaging (very narrow pulses can be used, and, therefore, large amounts of data can be collected and averaged). Without a technique called phase coding (discussed later in this section) and a high signal-processing rate, BB-ADCP velocity measurements would be less precise (because of self noise) than measurements made by the narrow-band ADCP system.

The BB-ADCP cannot only measure the phase angle differences between pulse pairs, but can measure the change in lag spacing between transmitted and received pulse pairs (time dilation). This pulse-pair measurement concept can be visualized using a series of illustrations depicting a stationary particle, a moving particle, and the effects of these particles on lag times between reflected pulse pairs in a liquid medium. Figure 1.29 shows a transmitted pulse pair from a stationary source approaching a stationary particle.

Figure 1.30 shows the same pulse pair reflected from a stationary particle. In the case of a stationary particle, lag A (fig. 1.29) is equal to lag B (fig. 1.30). Now assume that the particle is moving away from the transducer. Figure 1.31 shows the aforementioned transmitted pulse pair approaching a moving particle. Figure 1.32 shows the pulse pair after their reflection from the moving particle.

Note that, in the case of a moving particle, the reflected pulse lag distance (lag B) has increased because the particle's movement delays the reflection of the second pulse, relative to the first. Although this

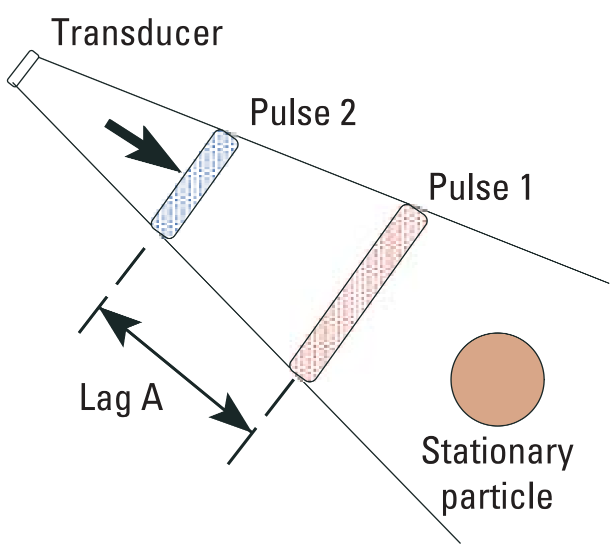


Figure 1.29. Acoustic pulse pair approaching a stationary particle.

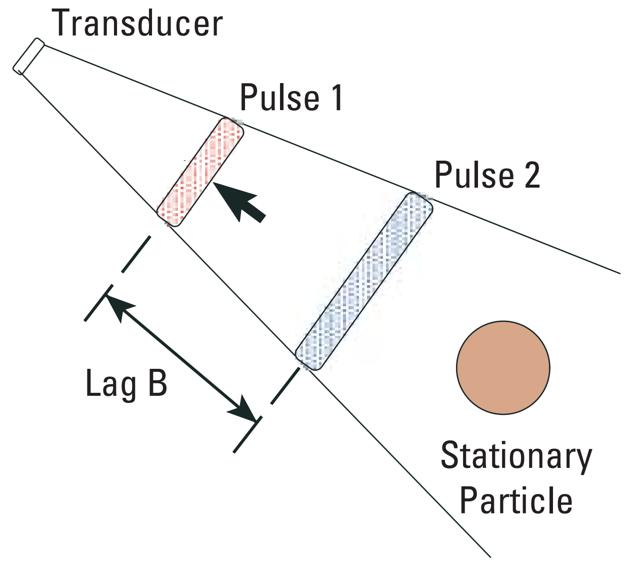


Figure 1.30. Acoustic pulse pair reflected from a stationary particle.

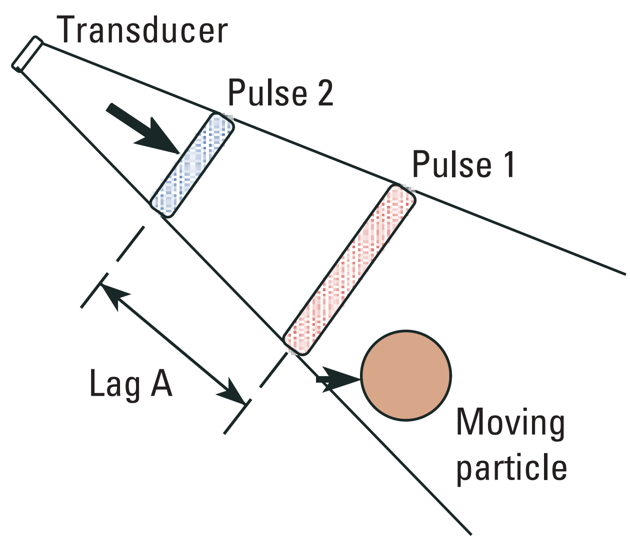


Figure 1.31. Acoustic pulse pair approaching a moving particle.

can be thought of as a time-domain phenomena, it is really a description of Doppler effect. The transmitted pulse repetition frequencies appear to vary in accordance with changes in the speed and direction of the transducer and (or) reflector.

Lag distance between the reflected pulses increases as the transducer and particle move apart. The opposite occurs if the particle and transducer move together. The difference between transmitted and received lag distance is proportional to the speed of the particle (relative to the transducer) or the transducer (relative to the particle). The difference in lag distance is exaggerated in these examples to aid comprehension. In reality, the ratio of the sound speed in water

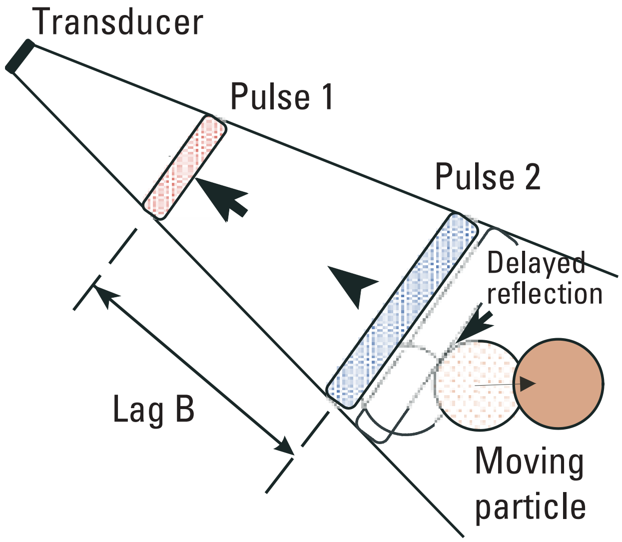


Figure 1.32. Acoustic pulse pair reflected from a moving particle.

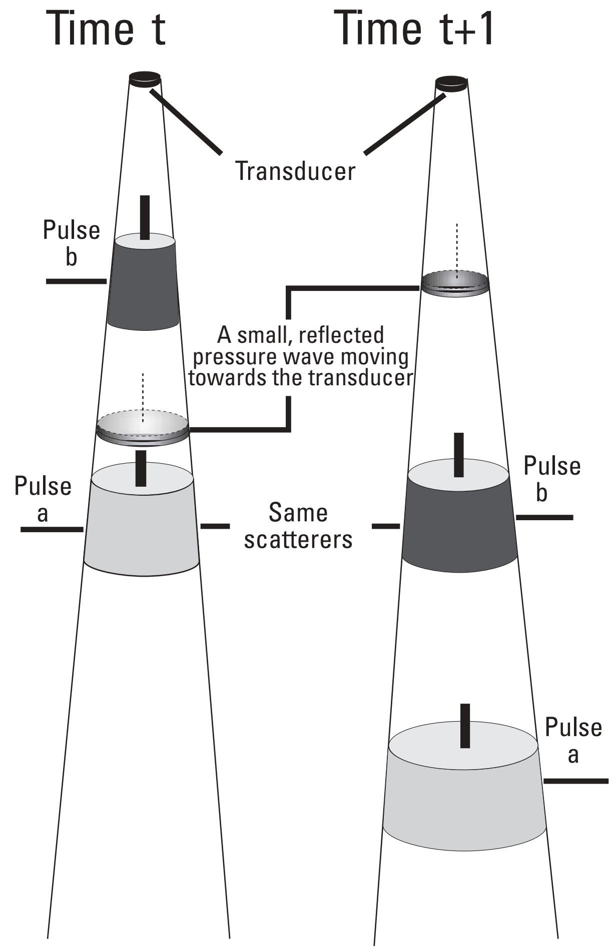


Figure 1.33. Acoustic pulse pair with a small reflected pressure wave.

[1,500 m/s (4,921 ft/s)] to the particle speed [0–2 m/s (0–6.6 ft/s)] results in very small lag differences. If a particle is moving slowly, the lag differences will be small and hard to measure. For that reason, discharge measurements of flows with low water velocities (0.05 m/s or less) are imprecise using the BB-ADCP discharge-measurement system unless special methods are employed. The accurate measurement of these lag differences is discussed in the next section.

Self noise can be visualized as shown in figure 1.33. When pulse "a" illuminates an object, a small pressure wave is reflected back toward the transducer. This pressure wave contains pure information about the speed of the object that caused the reflection. The passage of pulse "b" through the reflected pressure wave again illuminates scatterers in the vicinity of the pressure wave and contaminates the pure speed information of the pressure wave with unwanted noise. This contamination causes a dramatic increase in the single-ping random error of the velocity determination.

Another cost for using the increased lag spacing available with the BB-ADCP system is velocity ambiguity. The freeway analogy is not appropriate to explain the velocity ambiguity phenomenon, therefore, a circular racetrack analogy is used (figs. 1.34a, b). Suppose the investigator decides to mount cameras and strobe systems in a helicopter that hovers above a circular racetrack at night. Both cameras are mounted so that the racetrack is within their field of view. The circumference of the racetrack has been estimated and some reference poles (visible around the edge of the track) have been identified. The investigator tests the strobe and finds that just the outlines of the cars can be seen. The camera shutter is opened, and the first of two strobe flashes is actuated. After a short time, the other flash is actuated. The investigator rotates the developed negatives to synchronize the car outlines and estimates their speed by multiplying the distance between the poles by the time between strobe flashes.

This speed-measurement system works well until the car speeds increase substantially or the investigator decides to increase the time between strobe flashes (lag times) to improve measurement precision. After the first strobe flash, the cars complete one lap (past the spot where they were first photographed) before the second strobe flash. When the investigator attempts to synchronize the negatives, he becomes confused because he cannot determine how many (if any) laps the cars have completed or whether the cars have gone forward or backward.

The "ambiguity velocity" is the velocity the cars must achieve before this confusing circumstance happens. If the strobe flashes are temporally close, the ambiguity velocity is high (higher than the cars

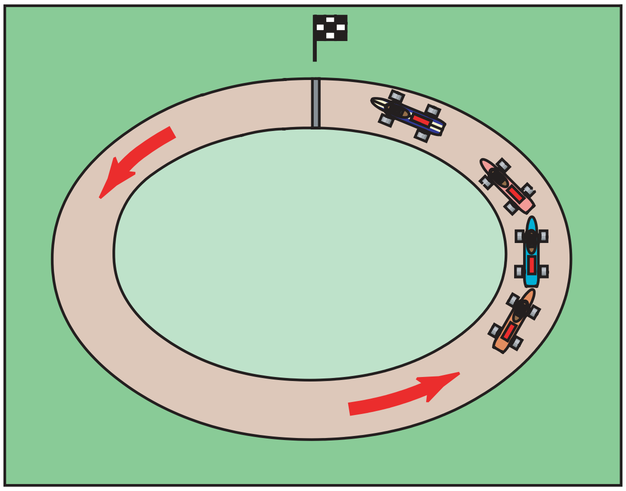


Figure 1.34a. Race track analogy during the first strobe flash.

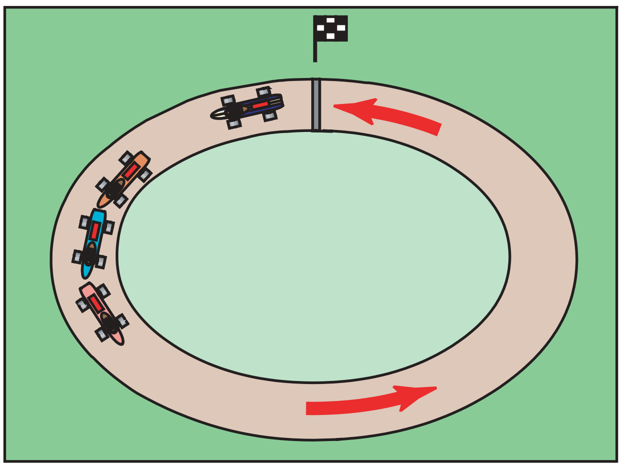


Figure 1.34b. Race track analogy during the second strobe flash.

normally travel) but measurement precision is lower because the cars have traveled a shorter distance between strobe flashes. If the investigator lengthens the time between strobe flashes (lag) to improve the measurement precision, the ambiguity velocity becomes lower and, therefore, more troublesome.

The primary method of measurement used by BB-ADCP systems is the measurement of phase-angle differences between the pulse pairs. This measurement is subject to ambiguity errors because the yardstick used to make these measurements actually is one-half of one cycle at the transmitted frequency. Figure 1.35 shows the error factor when the speed of the measured velocity exceeds the ambiguity velocity. The colored circle represents one cycle of transmitted energy with a possible phase measurement capability of 0–360°. In this example, we will let 1 millimeter per second (mm/s) equal 1° of phase change. We have no trouble measuring plus and minus 10 mm/s or even plus and minus 170 mm/s using our one-half cycle yardstick, but when the measured velocity is 190 mm/s, our yardstick reads a velocity of –170 mm/s. This is an error of 360 mm/s. Notice that this ambiguity velocity is 180 mm/s and is equivalent to 180° on our circular yardstick. The measurement error (when the ambiguity velocity is exceeded) is always equal to two times the ambiguity velocity.

The BB-ADCP (and even the narrow-band ADCP) may report an erroneous velocity caused by ambiguity when scatterer velocities are high enough that their movement between lags exceeds one-half of the transmitted frequency wavelength. Because a 1,200-kHz BB-ADCP uses the change in phase of a 1,200-kHz sinusoid for a Doppler shift “ruler,” it is impossible to identify which cycle of the reference signal to use when calculating the phase shift between the two returned reflections when the reflected signal phase shift is greater than one-half of one wave length. To solve this problem, the manufacturer has included a signal processing technique that corrects for ambiguity errors. This technique takes additional time, however, and somewhat slows the water ping rate. Shortening the lag distance increases the ambiguity velocity, causing it to be more noticeable and less bothersome, especially if water and bottom velocities are significantly lower than the ambiguity velocity. However, decreasing the lag distance also increases noise (standard deviation of measured velocities).

The ambiguity velocity of a 1,200-kHz BB-ADCP can be estimated by equation 1.6 (L.Gordon, R.D. Instruments, Inc., written commun., 1992):

$$U_a = \frac{47}{L} \tag{1.6}$$

where

U_a = the ambiguity velocity, in meters per second; and

L = the lag specified by the BB-ADCP “&L” command.

The maximum allowed ambiguity velocity is 5.2 m/s (17 ft/s) (L = 9) for a 1,200-kHz system. Contamination of the measured data shows up as velocity spikes at the ambiguity interval (twice the ambiguity velocity). This means that if ambiguity errors are suspected, the (unaveraged) data should be examined for velocity spikes of the opposite sign that, when compared with the last good measured velocity, have a difference of about twice the ambiguity velocity.

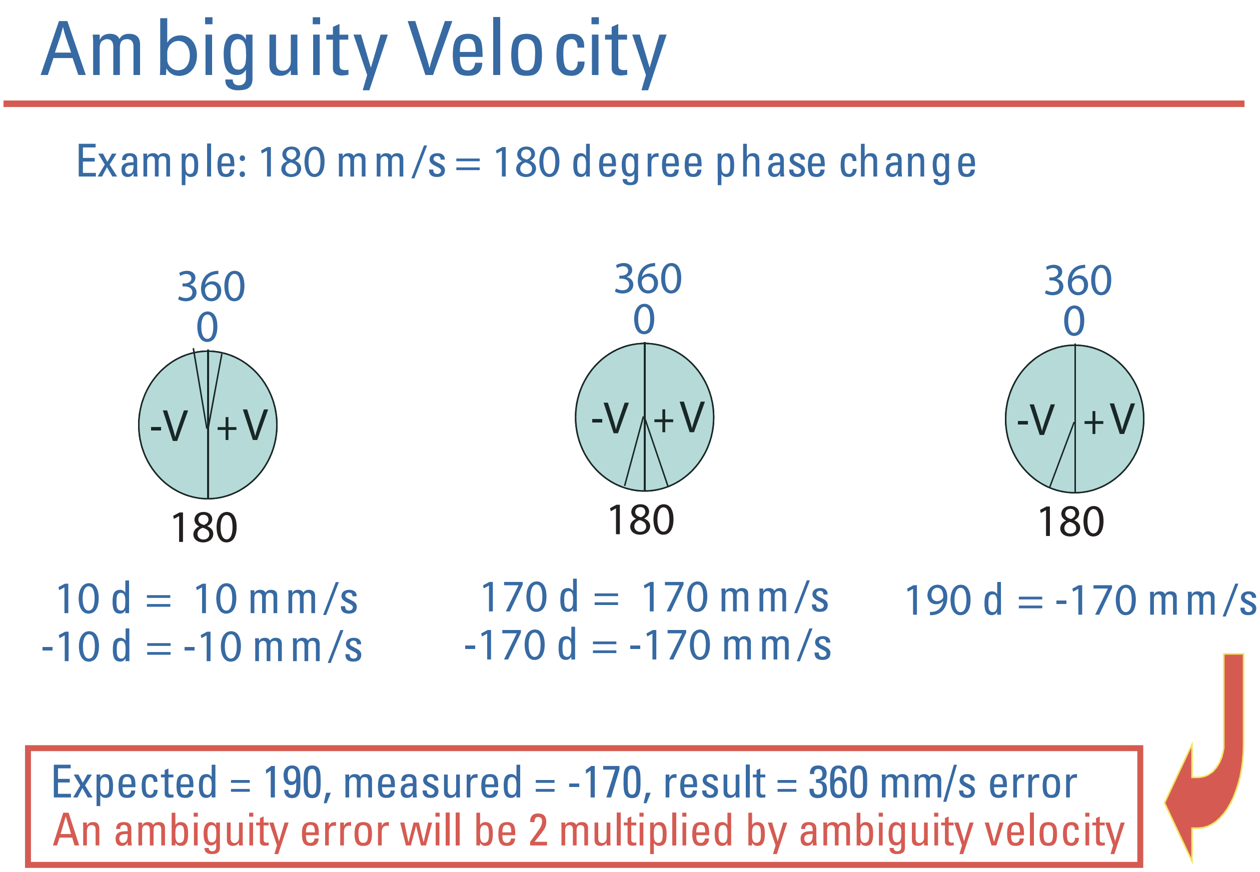


Figure 1.35. Explanation of ambiguity velocity. mm/s, millimeter per second; V, velocity; d, degree.

Differences Between Phase-Shift Measurements and Lag-Spacing Measurements (Time Dilation)

An unambiguous measurement can be obtained from the returned Doppler information by looking at the change in lag spacing (figs. 1.31, 1.32) but this method of measuring time dilation is much less precise than the measurement of phase-angle difference. Figure 1.36 shows the differences between phase angle and time dilation. Note that even though the ambiguity velocity has been exceeded in the last example, the time-dilation measurement still provides a “ball-park” measurement of velocity. The time-dilation method usually is used to resolve ambiguities.

Bottom-Tracking Limitations

To measure discharge, the ADCP must sense and measure the velocity of the ADCP, relative to the river bottom (bottom tracking). If the velocity of the water is known, relative to the ADCP, and the velocity of the ADCP is known, relative to the river bottom, then the water velocity, relative to the bottom, can be calculated. The bottom-track pulse must be somewhat longer than the water-track pulse to properly illuminate the bottom (fig. 1.17). In many cases, a group of water-velocity pings is averaged along with one or more bottom-track pings to form an averaged ensemble. To compute discharge, the ADCP must provide the horizontal water and boat velocity components, depth, and time between ensembles. The ADCP discharge-measurement software discussed in chapter 2 uses these data to calculate a vector cross product at each bin and then uses an extrapolation scheme to estimate the cross products in the unmeasured areas near the top and bottom of the profile (eq. 2.2, chap. 2).

The discharge-measurement software then integrates these cross products over the profile depth to obtain a mean, depth-weighted cross product for each ensemble. The depth-weighted cross products are summed during the cross-section traverse to produce the discharge measurement (eq. 2.2, chap. 2). Bottom tracking is required by the discharge-measurement software to compute discharge. If the river bed is moving, or if the bottom-track velocities are affected by material moving near the bottom, then the cross product will be biased. This problem sometimes can be

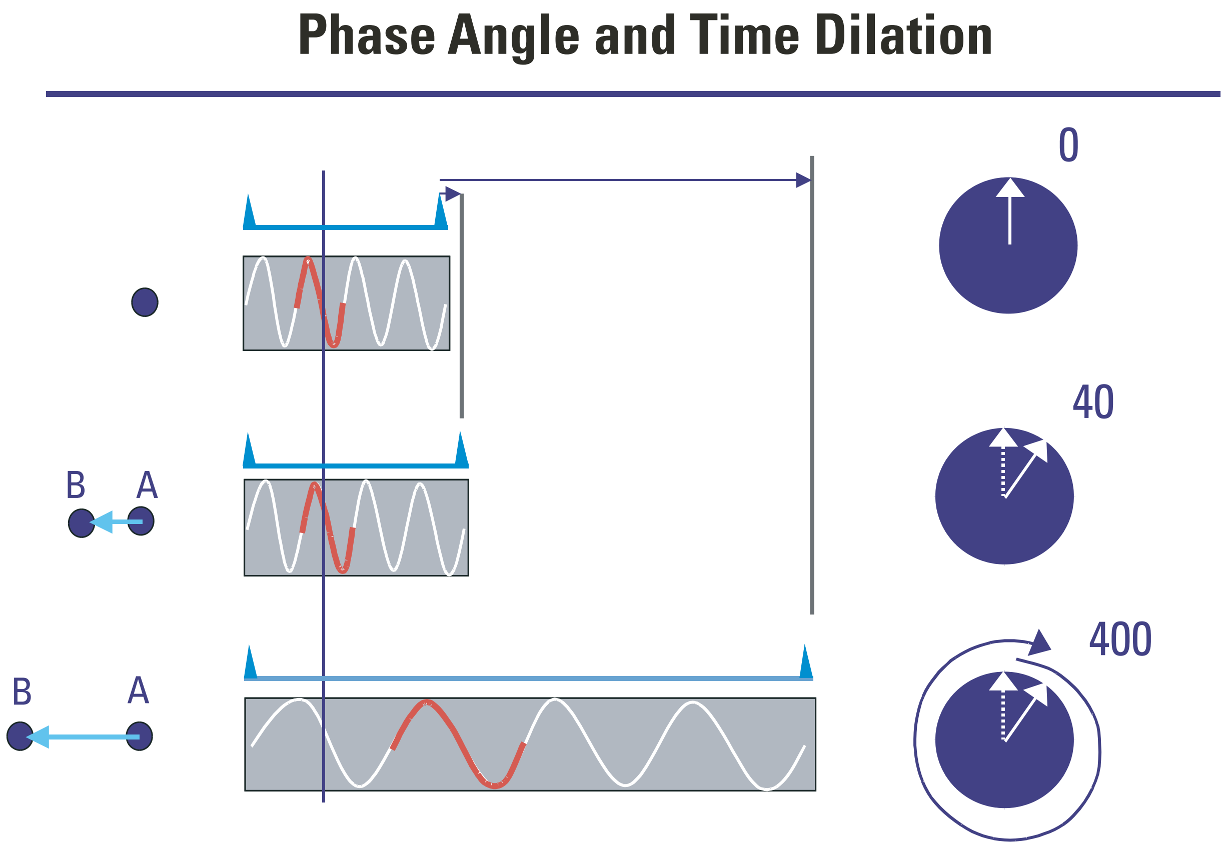


Figure 1.36. Description of time dilation compared with phase-angle difference.

alleviated by shortening the bottom-track pulse length (as shown in fig. 1.37) using the "&R" direct command as discussed in chapter 5. If shortening the pulse width does not work and if the river bed is moving at a speed of more than a few centimeters per minute, this bottom-track error cannot be eliminated and other means must be used to determine boat velocity (chap. 8).

The Broad-Band Acoustic Doppler Current Profiler: Overcoming the Self-Noise Problem

Error Sources Unique to Broad-Band Acoustic Doppler Current Profilers

In the previous section we discussed general ADCP errors. To enable a more complete understanding of the broad-band technology, we will touch upon those error sources again showing their effects on BB-ADCP systems. Although many sources of error for narrow-band ADCP systems have been discussed by Hansen (1986), Theriault (1986), Chereskin and others (1989), and Simpson and Oltmann (1993), few investigators have identified and itemized the error sources that can degrade accuracy and precision of the more recent BB-ADCP technology. Some of the known sources of error that affect the accuracy of velocity measurements (and, therefore, discharge measurements) and errors due to the physical limitations of the system are listed in this section. The signal processing technology required to accomplish water-velocity measurements with the BB-ADCP is extremely complex; the manufacturer and users will undoubtedly find new error sources during operational use of the BB-ADCP system. Major error sources in the narrow-band ADCP systems were identified over a period of 5 years (1986–91), and it is possible that the same length of time will be required to fully understand the sources of error in the BB-ADCP system, as well.

Errors that affect the performance of BB-ADCPs for velocity measurements (and, therefore, discharge measurements) can be either random or bias. As discussed earlier in this chapter, random errors can be reduced by data averaging; bias errors cannot. For purposes of this report, random errors are assumed to be Gaussian (normally distributed about the mean) and are expressed as standard deviations (in percent) of the measured mean quantity. Bias errors have sign and

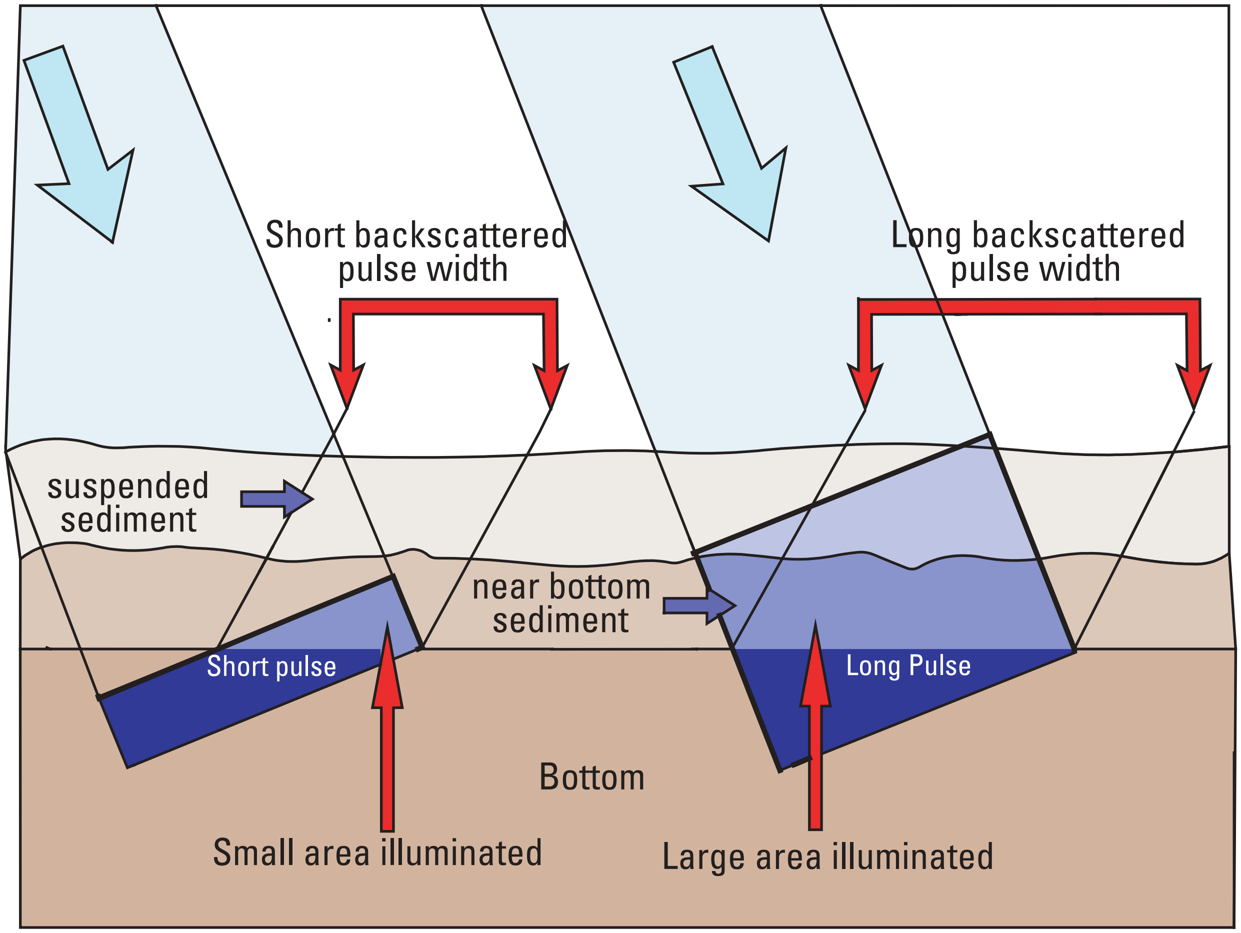


Figure 1.37. Effect of bottom-track pulse width on bias caused by bottom movement.

magnitude and are expressed as a percent of the "true" mean quantity, where "true" is defined as unbiased.

This report will not attempt a complete discussion of BB-ADCP bias error sources related to the physics of the acoustic signal (other than beam-angle errors and depth-measurement errors) because many of these sources are not yet documented and are beyond the scope of this report. Bias errors for the narrow-band ADCP system (with some application to the BB-ADCP system) are discussed in Simpson and Oltmann (1993). The most overwhelming source of velocity-measurement error in the BB-ADCP is random uncertainty due to self noise.

Random Uncertainty Caused by Self Noise

Whenever a pair of pulses is used to measure water velocity (using lag times associated with the BB-ADCP), only a 50-percent correlation can be obtained from the scenery illuminated by the pulse pair when attempts are made to synchronize (autocorrelate) the reflected signals (as discussed earlier in this chapter). Figure 1.33 shows an acoustic beam with a pair of long acoustic pulses being transmitted into the water (pulse "a" and pulse "b"). Directly after the transmission of the pulse pair, the receiver begins "listening" to the pressure waves that have been reflected from scatterers in the water column. At time t, the reflected signals from scatterers in the water mass, illuminated by pulse a, begin their return path toward the transducers in the form of a small pressure wave. The small pressure wave advances toward the transducer for a short time before it is illuminated by pulse b traveling in the opposite direction. The passage of pulse b causes instantaneous reflected signals to be superimposed on the original reflected signals in the small pressure wave, creating a "double exposure." This is the 50-percent decorrelation effect caused by self noise (discussed above). The reflected signals (actually a continuum of reflected signals) travel back to the transducer. These signals are received and shunted to a delay-line register (or scratch-pad memory) for a short time while the BB-ADCP signal processor applies an autocorrelation technique to the received signals in an attempt to synchronize (match) reflections obtained from the same water mass (data separated by the time between t and t + 1, as shown in fig. 1.33). If the lag is matched correctly, the autocorrelation function of the reflected signals will reach a peak. Because the two pulses were transmitted coherently (with the same phase), amplitude and phase information can be calculated from the function output. By using the phase information, the speed of the reflective particles can be determined, however, measurement precision is limited because of self noise.

Suppose very narrow (short) pulses are transmitted at a and b (fig. 1.38). These pulses are so narrow that 100 of them can be placed into the space occupied by the original long pulses. This modification will increase measurement precision by the square root of the number of samples (in the case of 100 samples, by a factor of 10). With this increased precision (even with the 50-percent level of self noise), the BB-ADCP capabilities surpass those of the narrow-band ADCP by almost one order of magnitude. This increased precision is gained at great cost because of the limited amount of energy the narrow pulses can deliver into the water. This energy loss caused by the narrow pulses is so great that it renders the system nearly unusable. To overcome this energy loss, the manufacturer developed a design innovation that incorporates most of the advantages of wide and narrow pulses. A wide pulse is transmitted (therefore, delivering more energy into the water than a narrow pulse), but is logically split into many small segments called code elements, each having a phase shift of either 0º or 180º (fig. 1.39).

The coding order of these phase shifts is pseudo random (behaves numerically like a random sequence). This technique has previously been applied to radar signals and some spread-spectrum communications signals (Minkoff, 1992), but the BB-ADCP manufacturer probably is the first to use this technique for water-velocity-measurement sonar.

The consequence of transmitting this phase-coded pulse-pair series into the water is that even though the pulses are long, the signal processor still must wait the full lag period (a to b) before achieving an autocorrelation peak of significant amplitude (fig. 1.40). In other words, because of the phase coding, it is difficult for the autocorrelation algorithm to realize a peak at the wrong interval.

The objective of the manufacturer is to achieve decorrelation of adjacent pulse pairs and, therefore, a

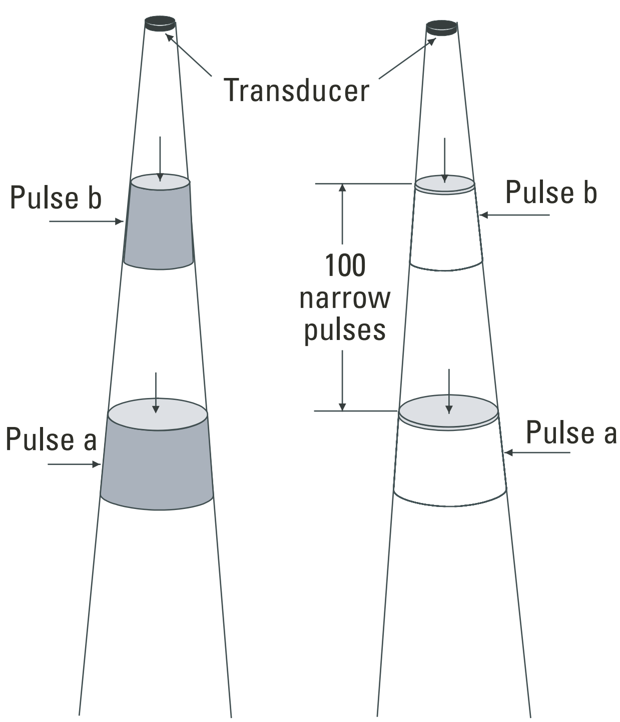


Figure 1.38. Narrow pulse pairs compared with wide pulse pairs.

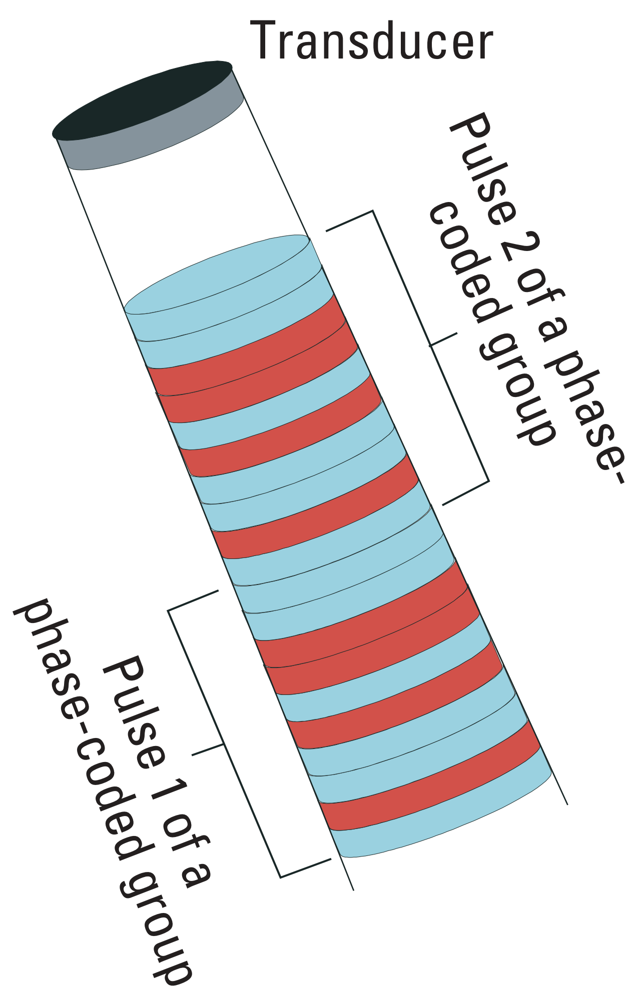


Figure 1.39. Phase-coded pulse pair.

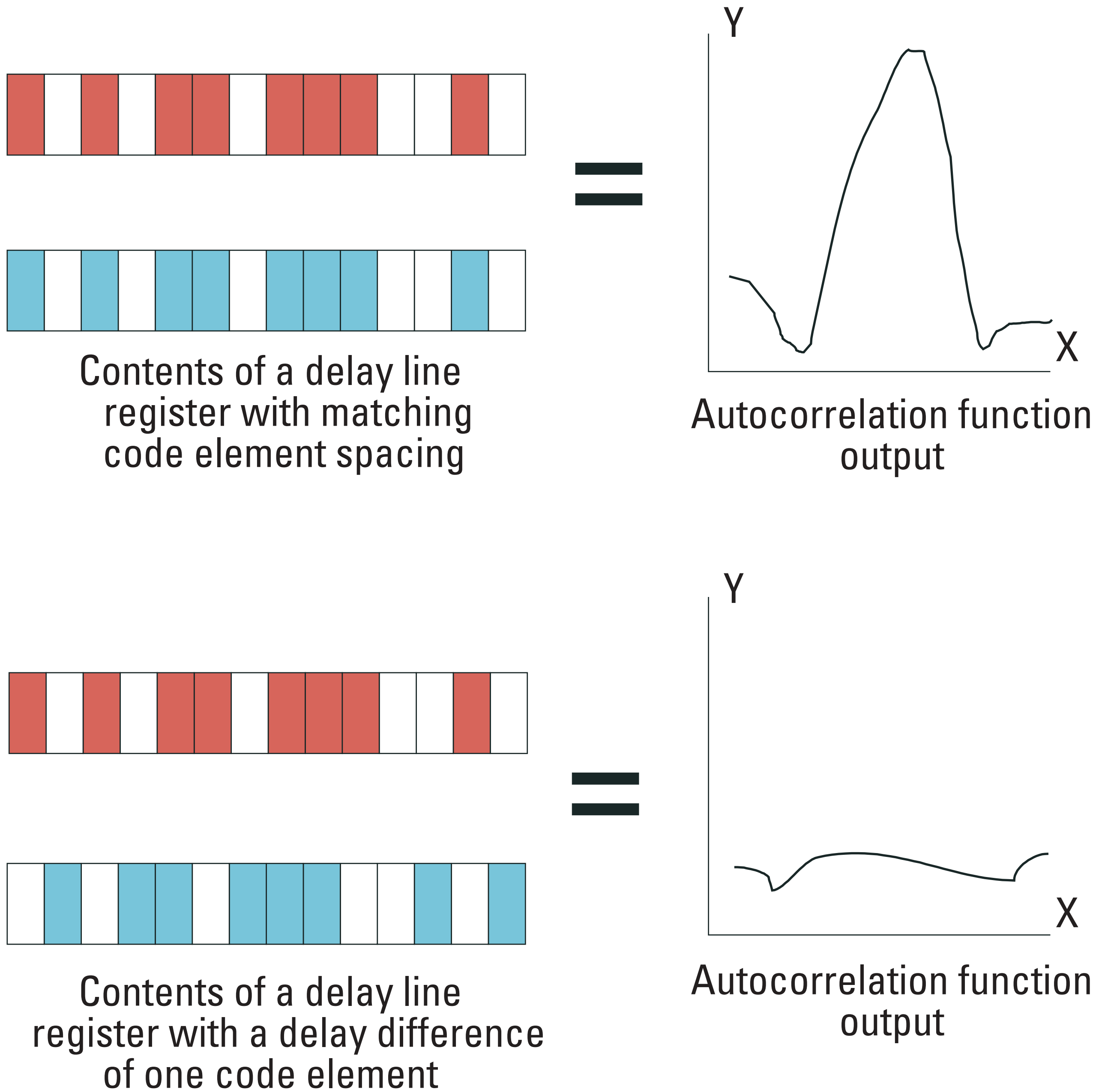


Figure 1.40. Effects of code element lag on correlation.

greater effective N (number of samples used for data averaging). Effective N as opposed to actual N is discussed in chapter 9. Obviously, there are times when accidental correlation occurs because currently there are only two phase choices, but, overall, a much greater precision is achieved using phase coding (because of improved signal-to-noise ratio) than by simply using a narrow pulse pair. The principle reason the manufacturers named the ADCP “broad-band” was that its bandwidth was increased to accommodate the signal processing of narrow-pulse pair (coded or not). The amount of random uncertainty in velocity measurements due to self noise has not been formally presented by the BB-ADCP manufacturer, but presumably is contained in the performance data for overall system random uncertainty (noise) values predicted by the manufacturer's error model and presented later in this chapter. When a phase coding method is used to reduce random uncertainty due to self noise, its effectiveness is greatly dependent on the order and number of the pseudo-random code elements used to construct the measurement pulse pair.

Table 1.1. Comparison of narrow-band and broad-band single-ping standard deviation
[m, meter; ft, foot; cm/s, centimeter per second; ft/s, foot per second]

Property	Narrow-band	Broad-band
Single-ping standard deviation	13.5 cm/s (0.44 ft/s)	6.4 cm/s (0.21 ft/s)
Minimum bin size	1. m (3.3 ft)	.25 m (.82 ft)
Pings per second	8	2
Standard deviation of a 5-second average	2.1 cm/s (.07 ft/s)	1.81 cm/s (.06 ft/s)

The single-ping random error of a narrow-band ADCP is significantly higher than a BB-ADCP for a given operating frequency and bin size. However, the signal processing requirements of the BB-ADCP system are much greater than those of the narrow-band ADCP, slowing the ping rate markedly. The ping rate of a narrow-band ADCP system can be as high as 10 pings per second (or higher, depending on depth and transducer frequency), whereas the maximum ping rate of a BB-ADCP system is less than three pings per second (using present technology). Table 1.1 is an example of the net result of these effects (for 30º beam-angle systems).

The narrow-band ADCP has a 5-second average standard deviation that is comparable to the BB-ADCP if the BB-ADCP bin size is one-fourth that of the narrow-band ADCP. This means that the BB-ADCP has a higher resolution and a smaller bin size, and can be used in shallower water than the narrow-band ADCP system for a given operating frequency.

Future systems using the narrow-band ADCP technology should not be ruled out. If an adaptive scheme were used to increase the narrow-band ADCP ping rate and reduce the narrow-band ADCP bin size in shallow water, discharge measurements using either system would have comparable accuracies. Because of larger, more energetic pulses, the narrow-band ADCP system also has a slightly greater range for a given frequency than the BB-ADCP system, as well as a more robust bottom-tracking ability.

Summary

Narrow-band acoustic Doppler current profilers (ADCPs) and broad-band acoustic Doppler current profilers (BB-ADCPs) use the Doppler principle to measure profiles of water velocity. To measure discharge, they also must measure velocity of the ADCP, relative to the river or estuary bottom.

Narrow-band ADCPs use a measurement method called pulse-to-pulse incoherent velocity measurement, which means that the ADCP transmits single, independent acoustic pulses from each beam and resolves the Doppler frequency shift during the duration of a single pulse. The frequency determination method usually is an autocorrelation technique.

BB-ADCPs use two or more coherent (synchronized) acoustic pulses in a scheme called the pulse-to-pulse coherent method. The frequency determination method usually is an autocorrelation technique that measures the phase angle difference and the time difference (spacing) between the transmitted and received pulse pairs to determine Doppler shift.

The single-ping random error of a narrow-band ADCP is significantly higher than a BB-ADCP for a given operating frequency and bin size, however, the signal processing requirements of the BB-ADCP system are much greater than those of the narrow-band ADCP, slowing the ping-rate markedly.

Increasing the lag distance between the pulse pairs in a BB-ADCP system lowers the single-ping standard deviation (to a point). Longer lag times increase the chances of ambiguity errors and should be used with caution, especially when averaging data.

CHAPTER 2: ACOUSTIC DOPPLER CURRENT PROFILER DISCHARGE-MEASUREMENT PRINCIPLES

In chapter 1, narrow-band ADCP and BB-ADCP velocity measurements were discussed in detail. In this chapter, we will discuss the methods used to calculate discharge from data collected using an ADCP. A basic knowledge of conventional river discharge-measurement techniques is necessary to understand how an ADCP measures discharge. Conventional ADCP discharge-measurement techniques are covered in Buchanan and Somers (1969).

Parts of an Acoustic Doppler Current Profiler Discharge Measurement

Just how is an ADCP used to measure discharge? The ADCP could be used as a conventional current meter. If an ADCP were mounted to a boat, the operator could position the boat at 30 or more stations (verticals) in the cross section. Velocities and depths could then be taken at each vertical, and the discharge calculated using the area/velocity method ($Q = AV$). Such a method would be only a slight improvement over the conventional boat-tagline discharge-measurement techniques.

The unique ability of the ADCP to continuously collect water-velocity profile data and ADCP-velocity (boat-velocity) data, relative to the bottom, lends itself to the use of a more sophisticated method of discharge-measurement integration. A velocity vector cross product at each depth bin in a vertical profile is calculated using ADCP-collected data. This cross product is first integrated over the water depth measured by the ADCP and then integrated, by time, over the width of the cross section. The following equations illustrate the integration method. The reader should try to envision them as descriptions of the discharge-measurement algorithm and mechanics.

Velocity Cross-Product Measurement Using an Acoustic Doppler Current Profiler

General Equation

The general equation (eq. 2.1) for determining river discharge through an arbitrary surface, s, is

$$Q_t = \int_s \bar{V}_f \cdot \bar{n} \, ds \qquad (2.1)$$

where

Q_t = total river discharge, in cubic meters per second;

$\bar{V}_f$ = mean water-velocity vector, in meters per second;

$\bar{n}$ = a unit vector normal to ds at a general point; and

ds = differential area; in meters.

The General Equation, as Applied to Acoustic Doppler Current Profiler Moving-Boat Measurements

The above is just a form of the familiar equation $Q = AV$ integrated over a cross section. For moving-boat discharge applications, the area s is defined by the vertical surface beneath the path along which the vessel travels. The dot product of $\bar{V}_f \cdot \bar{n}$ will equal zero when the vessel is moving directly upstream or downstream, and will equal $\bar{V}_f$ when the vessel is moving normal to $\bar{V}_f$; both vectors are in the horizontal plane.

Because the ADCP provides vessel-velocity and water-velocity data in the vessel's coordinate system, it is convenient to recast equation 2.1 in the following form (eq. 2.2) (Christensen and Herrick, 1982):

$$Q_t = \int_O^T \int_O^d ((\bar{V}_f \times \bar{V}_b) \cdot \bar{k}) \, dz \, dt \qquad (2.2)$$

where

T = total cross-section traverse time, in seconds;

d = total depth, in meters;

$\bar{V}_b$ = mean vessel-velocity vector, in meters per second;

$\bar{k}$ = a unit vector in the vertical direction;

dz = vertical differential depth, in meters; and

dt = differential time, in seconds.

The derivation of this equation by Christensen and Herrick (1982) is summarized in Simpson and Oltmann (1993). The equation originally was formulated by Kent Dienes (R.D. Instruments, Inc., oral commun., 1986).

The cross-product algorithm is well suited to ADCP discharge-measurement systems. Translated into nonmath terms, the above can be described as the cross product of the boat velocity and the water velocity first integrated over the cross-section depth and then integrated, by time, over the cross-section width (fig. 2.1).

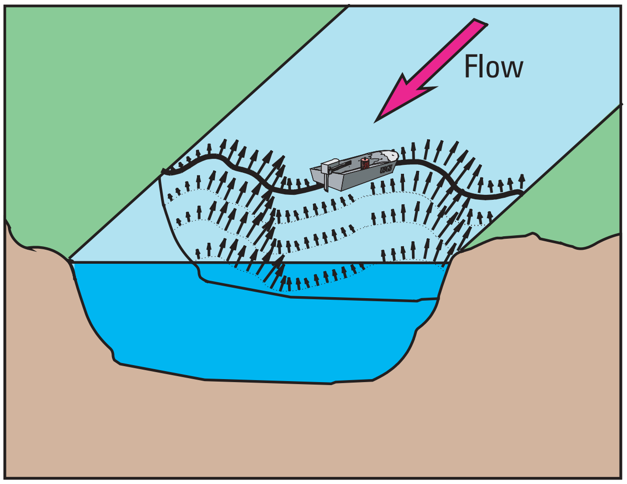


Figure 2.1. Cross-product vectors during a cross-section traverse.

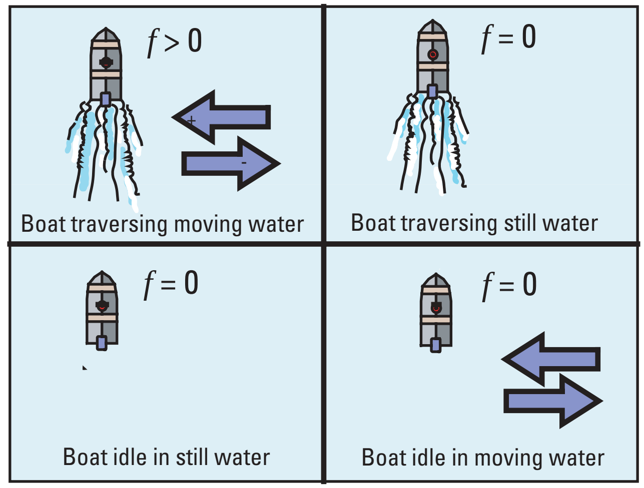


Figure 2.2. Properties of the water-velocity/boat-velocity cross product.

The cross product part of equation 2.2, $(\bar{V}_f \times \bar{V}_b) \cdot \bar{k}$, can be converted to rectangular coordinates to facilitate plugging in boat- and vessel-velocity vectors (eq. 2.3).

$$(\bar{V}_f \times \bar{V}_b) \cdot \bar{k} = a_1 b_2 - a_2 b_1 , \qquad (2.3)$$

where

a_1 = cross component of the mean water-velocity vector, in meters per second;

a_2 = fore/aft component of the mean water-velocity vector, in meters per second;

b_1 = cross component of the mean vessel-velocity vector, in meters per second; and

b_2 = fore/aft component of the mean vessel-velocity vector, in meters per second.

This is simply called the velocity cross product, which can be represented as shown in equation 2.4:

$$f = a_1 b_2 - a_2 b_1 , \qquad (2.4)$$

where

f = the cross product of the water-velocity and boat-velocity vectors.

Properties of the Acoustic Doppler Current Profiler Measured Cross Product

Figure 2.2 shows the properties of the cross product. Note that the boat must be traversing a velocity field before the cross product becomes greater than zero. In practice, several ADCP pings often are averaged to help reduce random error. This group of averaged water- and bottom-track velocity measurements is called an ensemble. The cross product is calculated from the averaged ensemble velocities and is expressed in units of square meters per second per second.

Integrating the Cross Product Over the Water Depth

When the cross product is integrated over depth, the resulting value is in cubic meters per second per second, and by substituting in the values for the beginning and ending times of each ensemble, a discharge value (cubic meters per second) is determined for each measured ensemble. The discharges for each ensemble then are summed to obtain total channel discharge (fig. 2.1). The mechanics of this operation require casting equation 2.2 into a form usable by the ADCP measurement software (eq. 2.5):

$$Q_m = \sum_{i=1}^{N_s} \left[\int_0^d f_z \, dz \right] t_i \qquad (2.5)$$

where

Q_m = measured channel discharge (doesn’t include the unmeasured near-shore discharge), in cubic meters per second;

N_s = number of measured discharge subsections;

i = index of a subsection;

d = depth of a subsection, in meters;

f_z = value of cross product at depth z;

dz = integrated vertical depth of subsection i, in meters; and

t_i = elapsed traveltime between the ends of subsections i and $i-1$, in seconds.

Estimating Cross Products in the Unmeasured Portions of the Profile

Problems arise when trying to implement the above summation for several reasons. To understand those reasons, the limitations of an ADCP water-velocity measurement are reexamined in the following sections.

Blanking Distance

Blanking distance was discussed in chapter 1, but is examined again here. Figure 2.3 is a modified version of figure 1.21 showing the unmeasured parts of a vertical-velocity profile. As discussed in chapter 1, the small ceramic element in the transducer is like a miniature gong. The large voltage spike of the transmit pulse bangs it like a hammer, and the vibrations, as well as the residual signal, must die off before the transducer can be used to receive incoming signals. This means that incoming signals are not used if they are received during a short period after the signal is transmitted. This time period is equivalent to a distance traveled by the signal known as the blanking distance. The blanking distance plus the transducer draft (depth of the transducer face below the water surface) compose a part of the near-surface profile that is not measured by the ADCP.

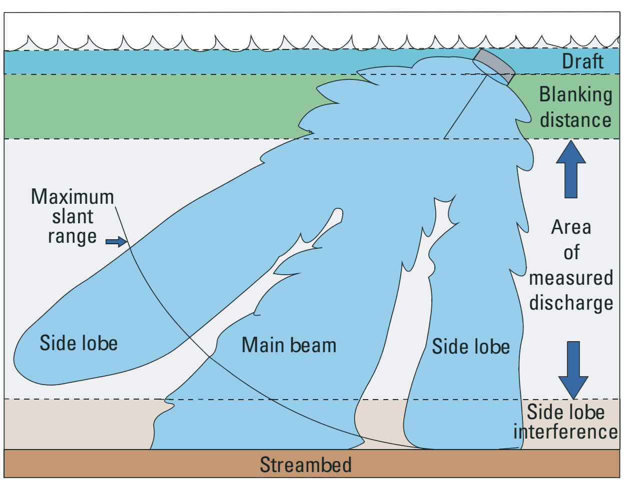


Figure 2.3. Acoustic Doppler current profiler-beam pattern showing side-lobe features.

Side-Lobe Interference

Most transducers emit unwanted (parasitic) side lobes of acoustic energy at 30–40º angles off the main beam. Figure 2.3 shows a slice of a typical transducer beam pattern. The side lobe probably is a single, hollow cone with its apex at the transducer (fig. 2.4). This is only the author's mental image of the three-dimensional side-lobe structure, but the image probably is a simplistic view of the true pattern. This three-dimensional structure should be kept in mind when profiling close to obstacles. Most acoustic beams have parasitic side lobes (including external depth sounders that may be mounted on the vessel). As discussed in detail in chapter 1, up to 15 percent (depending on the beam angle) of the water column near the bottom cannot be measured because of interference from these side lobes.

The combination of the effects of transducer draft, blanking distance, and side-lobe interference yields a profile that is incomplete. To properly compute discharge for each subsection, the cross-product values near the water surface and near the bottom must be estimated.

As shown in figure 2.5, f values are not provided at or near the water surface and below a point equal to 85–94 percent of the total depth. The percent of unmeasured profile area depends on the beam angle. The unknown f values are labeled $f1$ at the water surface and fn at the channel bottom. The simplest method of estimating these f values would be to let $f1$ at the surface equal $f2$ and to let fn at the bottom equal the last measured value ($fn-1$) and approximate the

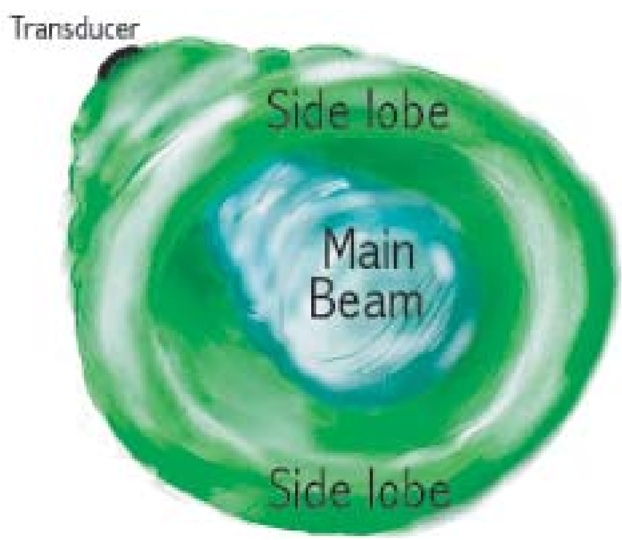


Figure 2.4. Hypothetical shape of a parasitic, side-lobe pattern.

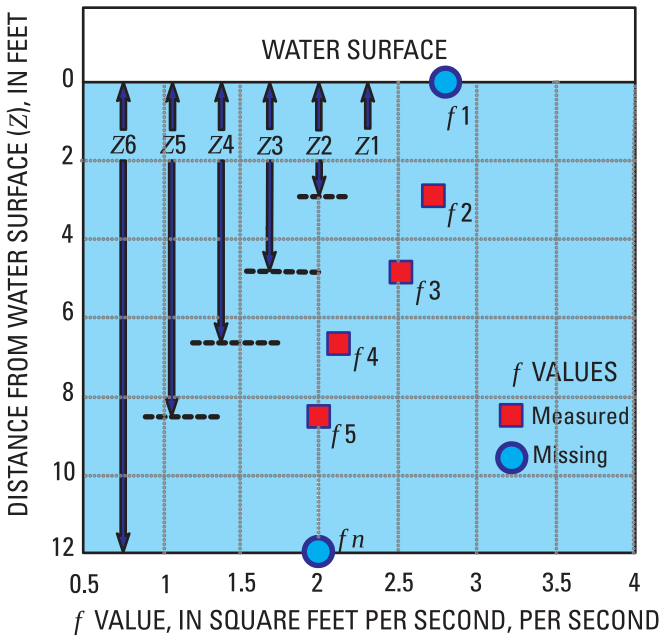


Figure 2.5. Example velocity profile showing measured and missing *f* values.

integral in equation 2.5 using a trapezoidal calculation (eq. 2.6):

$$g_i = \sum_{i=1}^{n-1} \left(\frac{f_j + f_{j+1}}{2} \right) (z_{j+1} - z_j) , \qquad (2.6)$$

where

g_i = depth-weighted mean f value in measurement subsection i, in square meters per second per second;

j = index of depths and respective f values;

n = number of measured and estimated f values; and

z_j = depth from water surface of respective measured and estimated f values.

Although equation 2.6 appears intimidating, it is nearly the same method as used on standard USGS discharge-measurement notes to sum discharge. In this case, however, it is used from surface to bottom rather than across the width of the river.

Evolution of the One-Sixth Power-Curve Estimation Technique

The above method might work, but, in most cases, water at the surface is moving faster than water deeper in the profile, and the water near the bottom of the profile slows to zero velocity as it nears the channel bed (assuming a stationary bed). There are exceptions to this rule, especially in an estuary, but for general use, the top-most and bottom-most values in an ADCP-measured profile must be estimated to calculate an accurate ADCP discharge measurement.

The author attempted to calculate discharge using several different methods for profile estimation (Logarithmic and general power law), but found that because of “noisiness” of the ADCP-profile data, the resulting least-squares-derived estimates were unrealistic, especially near the upper part of the profile. A method using a one-sixth power law (Chen, 1989) eventually was chosen because of its robust noise rejection capability during most streamflow conditions. A full discussion of the one-sixth power law and its derivation can be found in Simpson and Oltmann (1993). The power law estimation scheme is an approximation only and emulates a Manning-like vertical distribution of horizontal water velocities. Different power coefficients can be used (one-half to one-tenth) to adjust the shape of the curve fit to emulate profiles measured in an estuarine environment or in areas that have bedforms that produce nonstandard hydrologic conditions and provide alternate estimation schemes under those circumstances. Figure 2.6 shows a one-sixth power curve drawn through the same set of f values that were illustrated in figure 2.5.

In cases where bidirectional flow exists (water is moving one direction at the surface and is moving the opposite direction near the channel bottom), the power-curve estimation scheme will not work. In these cases, the unmeasured areas must be estimated using other methods.

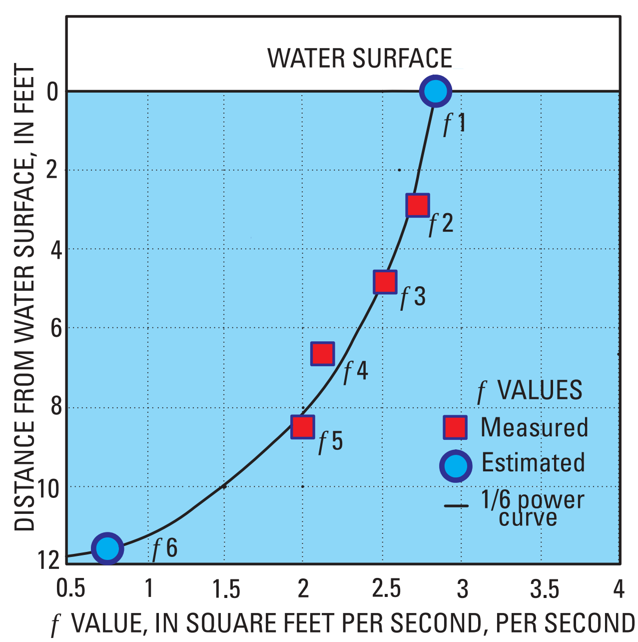


Figure 2.6. Example velocity profile of one-sixth power-curve fit and typical *f* values.

In most cases, points at the top and the bottom of the profile can be estimated using the one-sixth power-curve estimation scheme. The estimated points then are used with the actual measured points, to calculate a depth-weighted mean cross product for each ensemble. Discharge then can be calculated for each ensemble pair because the time between each ensemble is known.

Integration, By Time, Over the Width of the Cross Section

The summation in equation 2.5 is accomplished by equation 2.7

$$q_i = g_i t_i \qquad (2.7)$$

where

q_i = midsection discharge between measurement subsection i and subsection $l - 1$, in cubic meters per second;

g_i = depth-weighted mean f value in measurement subsection i, in square meters per second per second; and

t_i = vessel traveltime between measurement subsection i and $i - 1$, in seconds.

Equation 2.5 is used to calculate the main channel discharge by summing all Q values (eq. 2.7) collected during the cross-section traverse. Unfortunately, before the total channel discharge can be calculated, two other areas need estimation schemes (fig. 2.7).

Estimating Discharge Near the Channel Banks

The power-curve fitting scheme estimates values in the areas at the top and bottom of the profile (blanking/draft distance and side-lobe interference area), but, because of these and other ADCP depth limitations, shallow areas near the edges of the riverbank cannot be measured. The near-shore areas are estimated using a ratio interpolation method presented by Fulford and Sauer (1986), which can be used to estimate a velocity at an unmeasured location between the riverbank and the first or last measured velocity in a cross section. The equation for the estimate is equation 2.8

$$\frac{V_e}{\sqrt{d_e}} = \frac{V_m}{\sqrt{d_m}} \qquad (2.8)$$

where

e = a location midway between the riverbank and first or last ADCP-measured subsection;

V_e = estimated mean velocity at location e, in meters per second;

V_m = measured mean velocity at the first or last ADCP-measured subsection, in meters per second;

d_e = depth at subsection e, in meters; and

d_m = depth at the first or last ADCP-measured subsection, in meters.

Fulford and Sauer (1986) defined d_m and V_m as depth and velocity at the center of the first or last measured subsection and not the near-shore edge of the subsection, as presented in equation 2.8. However, because the ADCP subsections purposely are kept very narrow at the start and finish of each measurement, the differences between the two applications are not significant (Simpson and Oltmann, 1993). Figure 2.8 illustrates the estimation method used for near-shore discharge. With this method, discharge can be estimated by assuming a triangular discharge area between subsection m and the riverbank, which reduces equation 2.6 to equation 2.9

$$V_e = 0.707 V_m \qquad (2.9)$$

Remembering that $Q = AV$, discharge in the estimated area can be calculated by equation 2.10.

$$Q_e = \frac{0.707 V_m L d_m}{2} \qquad (2.10)$$

where

Q_e = estimated edge discharge, in cubic meters per second; and

L = distance to the riverbank from the first or last ADCP-measured subsection, in meters.

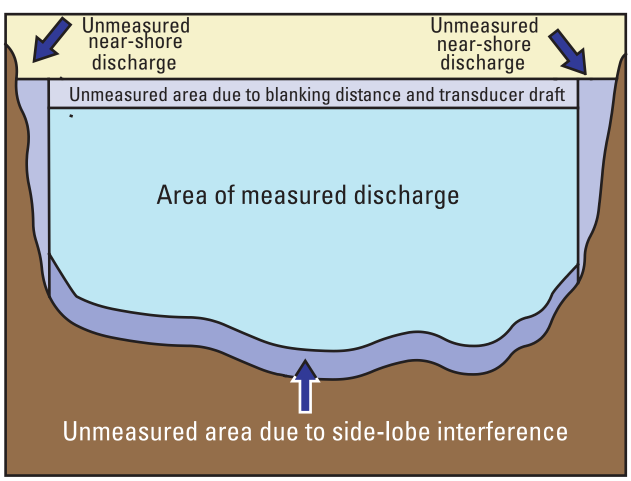


Figure 2.7. Unmeasured areas in a typical acoustic Doppler current profiler discharge-measurement cross section.

The discharge-measurement software calculates depth (d_m) from the average of the depths measured on all four beams. The distance (L) to the riverbank from the first or last discharge measurement subsection is provided by the system operator using estimation

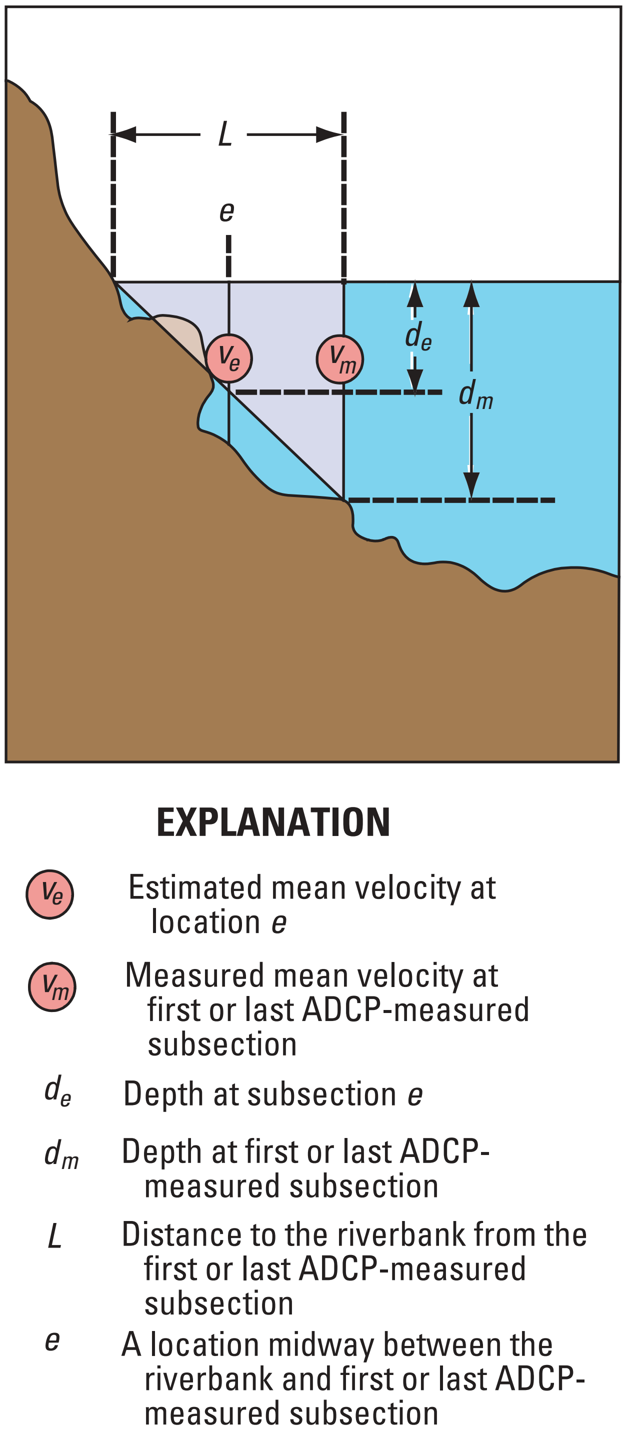


Figure 2.8. Edge-value estimation scheme described by equations 2.8, 2.9, and 2.10. ADCP, acoustic Doppler current profiler.

techniques described in the chapter on discharge-measurement techniques.

The triangular ratio-interpolation method works well in parabolic-shaped natural channels, however, it does not work well in rectangular concrete channels or natural channels with nonstandard slopes near the banks. In these cases, a bank-slope coefficient can be used to properly depict the channel-bank geometry (see chapter 5.)

Determination of Total River Discharge—Putting it All Together

Using all the methods and equations described in this chapter, total river discharge (Q_t) can be calculated by equation 2.11

$$Q_t = Q_m + Q_{e_l} + Q_{e_r} \tag{2.11}$$

where

Q_m = total channel discharge [the sum of all q_i values collected during the discharge measurement traverse (eq. 2.7)], in cubic meters per second;

Q_{e_l} = near-shore discharge estimate on the left side of the channel, in cubic meters per second; and

Q_{e_r} = near-shore discharge estimate on the right side of the channel, in cubic meters per second.

Discharge-Measurement Software

Based on the above principles, the USGS, as well as the manufacturers of ADCPs, have written computer programs designed to collate ADCP data collected during a cross-section traverse and compute discharge in real time. Because of the difficulty in maintaining and updating such a program, the USGS has elected to use manufacturers' proprietary programs for this capability, provided the proper algorithms are used and quality assurance (QA) criteria are met. The current QA plan (Lipscomb, 1995) requires that the whole system (ADCP and discharge-measurement software) meet certain standards.

The USGS has an archtype computer program written in Pascal that can be used as a basis for a vendor-created software package. Because the archtype computer program has not been translated into machine code that will run on IBM personal computers and compatibles, most ADCP system operators utilize "Transect," a suite of proprietary software modules developed by RDI for use with their ADCPs. The

Transect software includes the estimation methods used by the USGS in the archtype program and has proven to be a useful, accurate discharge-measurement tool. Other manufacturers currently are developing similar software.

Summary

Unlike conventional discharge-measurement methods, acoustic Doppler current profiler (ADCP) discharge-measurement software does not calculate discharge directly from area and velocity data. The ADCP discharge-measurement software calculates a water/boat velocity vector cross product in each bin before integrating the cross products over the subsection depth. The resulting subsection discharges then are summed over the width of the cross section.

Discharge cannot be measured near the water surface because of the draft required by the transducer (depth below water surface) and transducer blanking distance. Discharge cannot be measured near the channel bed primarily due to side-lobe interference. Cross products in these unmeasured portions of the channel cross-section usually are estimated using a one-sixth power-curve estimation scheme (unless the profile shape dictates other methods). Discharges in the unmeasured portions of the cross-section near the edges of the riverbank are estimated using a ratio-interpolation method.

The U.S. Geological Survey (USGS) has developed a discharge-measurement archtype program; however, most ADCP system operators are using a proprietary suite of software modules called “Transect” developed by R.D. Instruments, Inc., for use with their ADCPs. Transect includes the estimation methods used by USGS in the archtype program and has proven to be a usable, accurate discharge-measurement tool. Other manufacturers also are developing discharge-measurement software.

This page left blank intentionally.

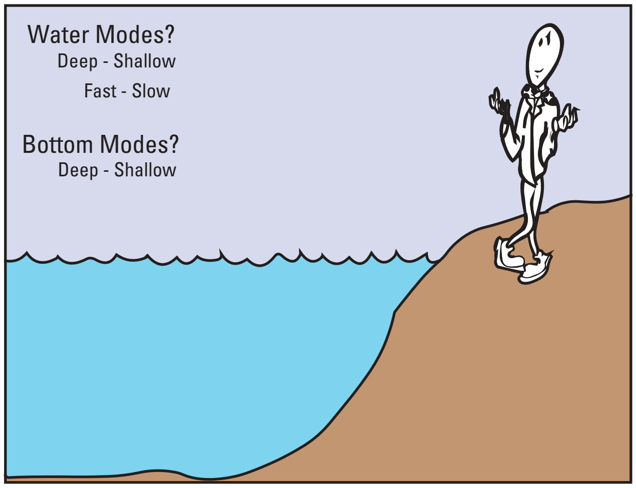


Figure 3.1. Choosing the proper measurement mode is difficult.

CHAPTER 3: R.D. INSTRUMENTS, INC., BROAD-BAND ACOUSTIC DOPPLER CURRENT PROFILER MEASUREMENT MODES

Measurement Modes—Why?

One of the most compelling features of ADCP systems is their versatility. Versatility comes with a cost, however, and the cost is added complexity. Most ADCPs have several water-measurement modes (fig. 3.1) and bottom-measurement modes. These modes are chosen based on environmental conditions (fast/slow or shallow/deep water and current shear). A simple matrix of mode choices for different measurement conditions would be desirable for this chapter, but, unfortunately, it's not that easy! Several environmental factors may play a part in the choice of measurement modes.

In an ADCP manufactured by RDI, these modes are set using direct commands placed in a configuration file (chap. 5). The BB-ADCP commands W (water mode) and B (bottom mode) can be set to different values depending upon the flow and bottom conditions expected at the discharge measurement site. Mistakes in setting these values may cause unrecoverable errors in the measurement of discharge. This chapter, therefore, is devoted to the explanation of the different operational modes available for ADCPs manufactured by RDI. It is quite likely that when this report is published, operational modes for ADCPs manufactured by RDI will be available that are not covered in this chapter. The manufacturer releases technical notes and bulletins when such changes are developed, which are available on the manufacturer's web site (www.rdinstruments.com).

Parameters that dictate the operation of water- and bottom-track measurement modes are set by direct commands sent to the profiler from the Transect configuration file (chap. 5). These direct commands take the form of W$nnn, or B$nnn, where W = water mode and B = bottom mode. The "$" signifies the water- or bottom-mode parameter that receives the numeric value, nnn. These direct commands are discussed in detail in this chapter.

Water Modes

The water-measurement modes juggle different lag distances, pulse lengths, code element combinations, and adaptive schemes to measure water velocity under many hydrologic conditions. Some of these modes should be used with caution because errors can result if they are misapplied. Direct commands for these modes take the form of WMn, where n is 0, 1, 4, 5, 7, or 8, depending on the mode used.

Water Mode Zero (WM0)

Water mode zero (direct command WM0) is referred to as the "expert" mode because it allows the user to set virtually all aspects of the water-measurement ping structure. Water mode zero will not be addressed further in this report because it is almost never used under routine measurement conditions. When this mode is used, it is used in connection with instructions from the manufacturer and usually is used for special circumstances where other modes are inadequate.

Water Mode 1 (WM1)

Water mode 1 (direct command WM1) is called the "dynamic" mode. This is a general purpose mode that should be used (in preference to mode 4) for most routine measurement conditions—with one caveat; the ambiguity velocity must be set correctly for stream conditions. Operators can modify the ambiguity velocity (and, thereby, the lag spacing of the mode 1 ping structure) using the WV command. Proper adjustment of the WV value allows mode 1 to be used in shallow and deep water and in current shear where other modes fail. Ambiguities in the measurement of velocity are not automatically resolved in water mode and the maximum expected velocity of the boat (relative to the water) must be estimated before setting the WV command. If the value is set too low, an ambiguity error could be introduced into the velocity measurement (see chap. 1).

The default WV value (lag spacing) for mode 1 allows a high ambiguity velocity [480 centimeters per second (cm/s), 16 ft/s]. The single-ping standard deviation of a velocity measurement using this default setting is about 19 cm/s (0.62 ft/s). This magnitude of uncertainty usually produces an unacceptable precision for the resulting discharge measurement, unless the measurement vessel is slowed to less than one-third of the speed of the absolute water velocity (water velocity relative to the Earth) during the cross-section traverse. Fortunately, the mode 1 default lag spacing can be changed by altering the WV command. Note: Most of the ambiguity-velocity directives expect radial (along-beam) ambiguity velocity, not horizontal ambiguity velocity. Radial ambiguity velocity can be determined using the following formula (eq. 3.1) if the desired horizontal ambiguity velocity is estimated

$$V_{radial} = 1.5(V_{horizontal})\sin\theta \qquad (3.1)$$

where

V_{radial} = radial ambiguity velocity, in centimeters per second;

$V_{horizontal}$ = horizontal ambiguity velocity, in centimeters per second; and

θ = transducer beam angle, in degrees.

The horizontal ambiguity velocity can be estimated by adding the highest expected ADCP speed (relative to the water) and the highest expected absolute water velocity. This value is $V_{horizontal}$ and is plugged into equation 3.1 to arrive at a reasonable value for the WV command. It is multiplied by 1.5 in the equation for safety reasons. Usually, it is better to have a bit of extra noise (standard deviation of velocities) in the measurement than to inadvertently average in an ambiguity error. Table 3.1 shows the single-ping standard deviation for three different ambiguity-velocity values.

Mode 1 can be used in slightly more shallow water than mode 4 [1 m (3.3 ft)], but modes 5 or 8 are preferred for medium-to-slow velocities [below 10 cm/s (0.33 ft/s)] because of the increased resolution available with these modes. Mode 1 sometimes can be used in shallow water where modes 5 and 8 do not work because of high velocities and shear. Figure 3.2 shows the depth and velocity range windows wherein each mode is designed to function properly. Notice that mode 1 encompasses a much larger range of depths and velocities than do the other modes.

To increase the range of mode 1 in water depths near the edge of the ADCP measurement capability (depends on frequency), the operator can toggle the WB command from 0 to 1. According to the manufacturer, setting the WB command to 1 enables greater ADCP range by narrowing the received

Table 3.1. Mode 1 single-ping standard deviation using three different values for the WV command

[ADCP, acoustic Doppler current profiler; kHz, kilohertz; cm/s, centimeter per second; ft/s, foot per second]

ADCP frequency (kHz)	Ambiguity velocity (WV command)	Single-ping standard deviation
300	480 cm/s (15.78 ft/s)	19.35 cm/s (0.63 ft/s)
300	190 cm/s (6.23 ft/s)	14.07 cm/s (.46 ft/s)
300	60 cm/s (1.99 ft/s)	6.87 cm/s (.23 ft/s)
600	480 cm/s (15.78 ft/s)	19.35 cm/s (.63 ft/s)
600	190 cm/s (6.23 ft/s)	14.08 cm/s (.46 ft/s)
600	60 cm/s (1.99 ft/s)	6.87 cm/s (.23 ft/s)
1200	480 cm/s (15.78 ft/s)	19.37 cm/s (.64 ft/s)
1200	190 cm/s (6.23 ft/s)	14.08 cm/s (.46 ft/s)
1200	60 cm/s (1.99 ft/s)	6.87 cm/s (.23 ft/s)

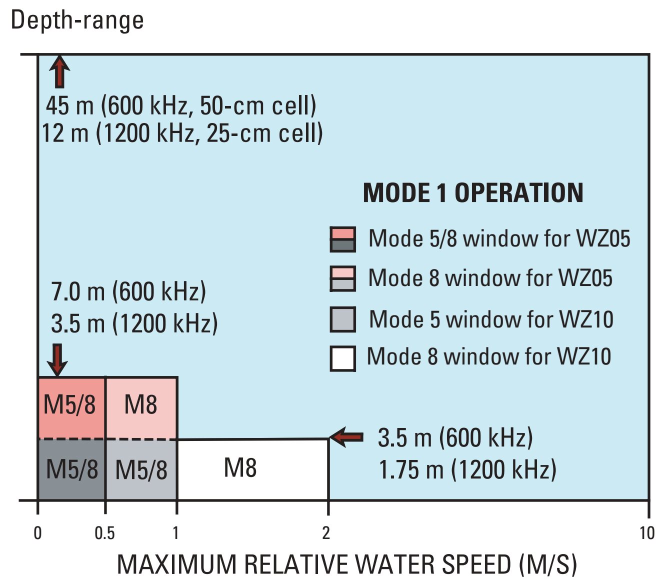


Figure 3.2. Depth/range/speed-operational "windows" for water modes 1, 5, and 8. m, meter; kHz, kilohertz; cm, centimeter; M/S, meter per second.

bandwidth (which improves the signal-to-noise ratio). Unfortunately this also increases the velocity measurement standard deviation by a factor of 2. See chapter 9 (table 9.1) for the maximum recommended ranges for ADCPs of different frequencies. The WB command only can be used for mode 1 operation. Setting WB to anything other than zero in other water modes will cause unpredictable results.

For routine discharge measurements in swift-flowing waters with depths greater than 2 m (6.5 ft), mode 1 is the mode of choice. The operator must set the WV command for the proper ambiguity velocity. Water modes 2 and 3 are obsolete and are no longer used for riverine measurements.

Water Mode 4 (WM4)

Until recently, water mode 4 (default for the BB-ADCP) was used as the general production mode for water-discharge measurement. This mode is no longer recommended by RDI for discharge measurement because of hard-to-detect errors that can be introduced with automatic mode switching. Mode 4 uses a single set of pulses with a long lag that is dependent on depth cell length. The lag is either one-half the depth cell length or has a horizontal ambiguity velocity of 160 cm/s (5 ft/s), whichever is greater. The value of 160 cm/s (5 ft/s) is used for most depth cell sizes. Using the minimum depth cell size for a given operational frequency [25 centimeters (cm), 10 inches (in.)] for a 1,200-kHz BB-ADCP, for example, will decrease the lag, raise the ambiguity velocity slightly, and increase the measured water-velocity standard deviation. The ambiguity is resolved on this single set of pings by a proprietary signal-processing algorithm developed by the manufacturer (R.D. Instruments, Inc., 1996).

If necessary, mode 4 can be used in high- and low-velocity conditions. When depths become too shallow [2 meters (m) and below], or if the signal return is too weak, the ADCP will shift automatically to mode 1 operation. The operator is not notified when automatic mode switching occurs and it is recommended that an appropriate WV command be inserted into every configuration file that uses mode 4 operation. The WV command value can be estimated using equation 3.1 (see Water Mode 1 discussion).

Again, mode 4 is no longer recommended for discharge measurement use. It is only available on BB-ADCP systems and should be used only if directed by the manufacturer, or if mode 1 will not work.

Water Mode 5 (WM5)

Water mode 5 (“low and slow” mode) uses a true version of pulse-to-pulse coherent signal processing. The two transmitted pulses are completely independent of each other, but are synchronized in phase. To eliminate self noise in mode 5, the second pulse is not sent until the first pulse dies out. This procedure creates a long lag with low standard deviation of the measured water velocity.

Ambiguity Velocity Revisited

One problem with extra long lags is a low ambiguity velocity. Using the racetrack analogy from chapter 1, the first strobe flash (analogous to an acoustic pulse) shows the car with the racing stripe leading the pack of racers (fig. 1.34a). The second strobe flash reveals that the pack of racers apparently has passed the racing-striped car and won the race (fig. 1.34b). Or does it? If the racing-striped car was actually moving three or four times faster than the other racers, it not only won the race but has almost “lapped” the rest of the racers. In this case, the racing-striped car has exceeded the velocity at which the timekeeper could determine its speed without ambiguity. In the case of mode 5 operation, this ambiguity velocity is relatively low [50 cm/s (1.7 ft/s) ADCP speed, relative to the water].

A long lag time increases the possibility of decorrelation between pulses. Using the above racetrack analogy, the photographer could overlay the negative of the first strobe flash on the negative of the second strobe flash and then rotate the negatives until the “pack” of cars are aligned. When the pack of cars are aligned, the checkered flag on the first negative will be a certain distance from the checkered flag on the second negative. By using this distance and the time between strobes, the speed of the pack of cars can be computed. This method of speed computation works unless the time between strobes becomes so long that the cars in the pack change position, lanes, or speeds. If this happens, the cars will not “match up” when the negatives are rotated. The two negatives are then said to be uncorrelated. This effect can occur using mode 5 if there is shear and turbulence in the water column.

Because of the above two effects, mode 5 is not usable in water with substantial velocity, shear, or turbulence. However, in slow-moving water with little current shear, mode 5 can be used to obtain highly precise discharge measurements. Because of the high precision of mode 5, smaller bin lengths can be used, which enables mode 5 to be used in shallow water. Direct command changes must be made for mode 5 operation. The WZ command sets the starting length of the mode 5 and mode 8 lags and it is recommended that a command of WZ05 be used as a starting point for mode 5 and mode 8 operation. Table 3.2 describes water mode 5 performance for the specified setup.

Water Mode 7 (WM7)

Water mode 7 (extended range mode) is used to obtain water profiling at ranges 10–15 percent greater than profiling ranges available in other modes. Mode 7 converts the BB-ADCP system to a system similar to a narrow-band ADCP, thereby increasing the signal-to-noise ratio and range. This mode is practical only for 75-, 150-, and 300-kHz BB-ADCPs and is intended for open-ocean use where extended depth range is needed. Mode 7 water-velocity measurements have

Table 3.2. Setup and performance values for water mode 5 operation (WZ05)

[kHz, kilohertz; cm, centimeter; cm/s, centimeter per second; m, meter; ft/s, foot per second; ft, foot. WF, WS, keyboard commands]

Acoustic Doppler current profiler operating frequency (kHz)	Blanking distance WF, (cm)	Depth cell size, WS (cm)	Single-ping standard deviation (cm/s) (ft/s)	Range to first depth cell (m) (ft)	Minimum profiling range (m) (ft)	Maximum profiling range (m) (ft)
600	25 (WF25)	10 (WS10)	0.5 cm/s (0.16 ft/s)	0.35 m (1.15 ft)	0. 9 m (2.95 ft)	7.0 m (23.0 ft)
600	25 (WF25)	25 (WS25)	.3 cm/s (.010 ft/s)	.50 m (1.64 ft)	1.6 m (5.25 ft)	7.0 m (23.0 ft)
600	25 (WF25)	50 (WS50)	.2 cm/s (.007 ft/s)	.75 m (2.46 ft)	2.2 m (7.18 ft)	7.0 m (23.0 ft)
1200	25 (WF25)	5 (WS05)	.6 cm/s (.020 ft/s)	.30 m (.98 ft)	.8 m (2.63 ft)	3.5 m (11.5 ft)
1200	25 (WF25)	10 (WS10)	.4 cm/s (.013 ft/s)	.35 m (1.15 ft)	.9 m (2.95 ft)	3.5 m (11.5 ft)
1200	25 (WF25)	25 (WS25)	.3 cm/s (.010 ft/s)	.50 m (1.64 ft)	1.6 m (5.25 ft)	3.5 m (11.5 ft)

approximately 2.5 times the standard deviation of velocities measured with a mode 4 ping using the same depth cell size.

Water Mode 8 (WM8)

Water mode 8 is for shallow water and will sometimes work in conditions where mode 5 will not. This mode uses a pulse-to-pulse coherent configuration much like mode 5 to calculate velocity, but employs sophisticated signal processing techniques to reduce lag times. A mode 8 ping has a single-ping standard deviation 10 times greater than a mode 5 ping of the same bin size, but can be used in shallow water in much the same manner as mode 5. Setups for mode 8 are the same as the setups for mode 5. Table 3.3 gives the conservative values provided by the manufacturer for mode 8 performance (R.D. Instruments, Inc., 1995). Under certain circumstances, the operator may see up to a 30 percent improvement over the maximum depth range and maximum velocities listed in table 3.3; however, it is best not to expect optimum performance under field conditions.

Range/Speed “Windows” for Water Modes 1, 5, and 8

Figure 3.2 shows a graphic rendition of the depth-range/speed operational “windows” for water modes 1, 5, and 8. Notice that mode 1 is, by far, the most robust operational mode, with the largest operational range of depth and relative water speed. For slow velocities with shallow depths, mode 5 is the mode-of-choice, especially with 600-kHz ADCPs. Mode 8 sometimes will work in shallow water where relative water velocities are too high for mode 5 operation. The higher standard deviation of the mode 8 measurements usually requires some data averaging, or a slow cross-section traverse (at speeds below that of the water speed, relative to the Earth).

Bottom-Track Modes

Bottom-track modes are implemented independently of the water-velocity measurement modes and sometimes are set differently. There are two bottom-track modes currently used by the BB-ADCP: modes 4 and 5. Bottom-track modes 1–3 are obsolete. Other bottom-track modes may be available by the time this report is published.

Bottom tracking is done by proprietary firmware schemes built into the ADCP by the manufacturer; however, all such schemes must rely on the assumption that the bottom reflection obeys basic laws of physics. These principles of bottom tracking should be known by the ADCP operator to properly evaluate bottom tracking under variable field conditions.

The Bottom Reflection

When an acoustic signal strikes the river bottom, the reflected signal normally is much stronger (by orders of magnitude) than the reflected signal from scatterers in the water mass. It is no surprise, therefore, that the standard deviation of the bottom-track velocity measurement is about 10 times less than the water-mass

Table 3.3. Setup and performance values for water mode 8 operation (WZ05)

[kHz, kilohertz; cm, centimeter; cm/s, centimeter per second; m, meter; ft/s, foot per second; ft, foot. WF, WS, keyboard commands]

Frequency (kHz)	Blanking distance WF (cm)	Depth cell size, WS (cm)	Single-ping standard deviation (cm/s) (ft/s)	Range to first depth cell (m) (ft)	Minimum profiling range (m) (ft)	Maximum profiling range (m) (ft)
600	25 (WF25)	10 (WS10)	8.2 cm/s (.27 ft/s)	0.35 m (1.15 ft)	0.6 m (1.97 ft)	7.0 m (23.0 ft)
600	25 (WF25)	25 (WS25)	5.2 cm/s (.17 ft/s)	.50 m (1.64 ft)	.9 m (2.95 ft)	7.0 m (23.0 ft)
600	25 (WF25)	50 (WS50)	3.7 cm/s (.12 ft/s)	.75 m (2.46 ft)	1.4 m (4.59 ft)	7.0 m (23.0 ft)
1200	25 (WF25)	5 (WS05)	11.0 cm/s (.36 ft/s)	.30 m (.98 ft)	.5 m (1.64 ft)	3.5 m (11.5 ft)
1200	25 (WF25)	10 (WS10)	7.8 cm/s (.26 ft/s)	.35 m (1.15 ft)	.6 m (1.97 ft)	3.5 m (11.5 ft)
1200	25 (WF25)	25 (WS25)	5.0 cm/s (.164 ft/s)	.50 m (1.64 ft)	.9 m (2.95 ft)	3.5 m (11.5 ft)

velocity measurement. Figure 3.3 shows a 1,200-kHz ADCP backscattered intensity (measured in counts) that decreases with depth until the acoustic beam strikes the river bottom at a depth of approximately 7 m (23 ft). Data averaged from a series of water-track pulses were used to construct figure 3.3, but a single bottom-track pulse backscattered-intensity plot would look much the same.

Modern bottom-track schemes are self adaptive to stream conditions and use factors such as correlation magnitude, correlation side peak location, and (or) spectral width to determine the presence of the bottom echo. Still, bottom-track failures can occur when one or more of the parameter identification criteria are not met by the output signal or, for some reason, are met at the wrong time.

In the case of heavy sediment load, which causes high absorption and scattering of the acoustic signal, the weakened bottom reflection (from deep water) cannot activate a detection threshold. In some cases, when this happens, the ADCP firmware is programmed to try other (more robust) bottom-tracking modes before flagging the data as "bad."

Another problem occurs during periods of high flow when heavy sediment loads are moving on or near the channel bed; the bottom-track velocities become biased. The physical process that causes this phenomenon is theorized only at this time. Attempts have been made to overcome this bias problem by using lower frequency systems and special bottom-track schemes. A separate method of measuring vessel velocity that eliminates the need for bottom tracking can be used; the input from a differential global positioning systems (GPS) receiver and depth sounder is used to replace the data from the ADCP bottom-track pulse. Because this method requires that the operator have an indepth understanding of GPS systems, as well

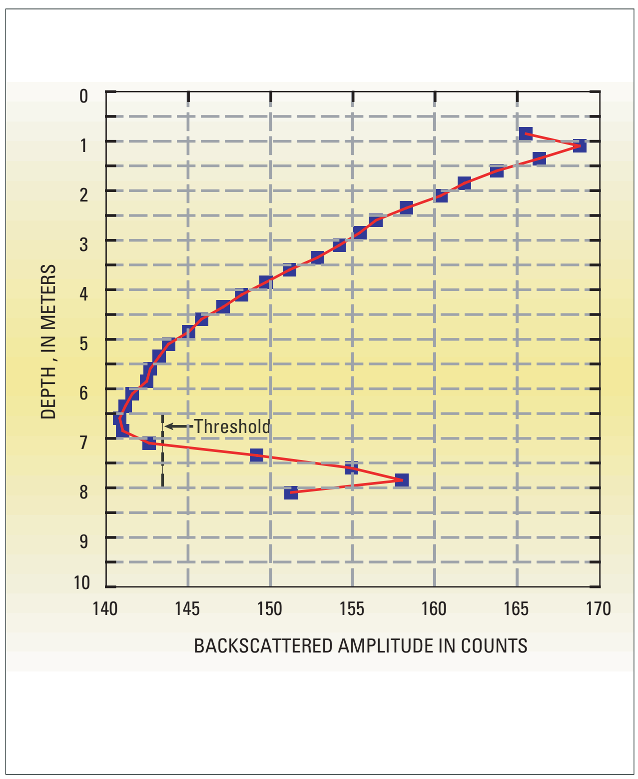


Figure 3.3. Acoustic Doppler current profiler-backscattered intensity with depth showing the bottom reflection.

as significant investment in additional GPS and depth sounding equipment, it will not be discussed in this report. For more information on using this method for discharge measurements during conditions of bottom-sediment movement, contact the ADCP manufacturer.

Bottom-Track Mode 4 (BM4)

Bottom-track mode 4 is a general-purpose bottom-track mode. This mode can unambiguously determine the speed of the ADCP, relative to the channel bottom, under most conditions. The detailed detection scheme used is proprietary and copyrighted by RDI, but mode 4 uses the correlation side-peak position to resolve velocity ambiguities and it lengthens the lag at predetermined depths to improve variance. Bottom-track mode 4 can be used with water-track modes 1, 4, 5, 7, and 8; however, because of processing limitations, the standard deviation of bottom-track velocity data (using mode 4) increases as depth decreases.

Bottom-Track Mode 5 (BM5)

Bottom-track mode 5 is the default mode for most discharge-measurement and velocity-profiling use. This mode uses a pulse-to-pulse coherent technique that has a lower variance in shallow water than bottom-track mode 4 by a factor of up to four. In very shallow water at slow speeds, mode 5 variance is lower than mode 4 by a factor of 100. Although mode 5 has a very precise measurement capability, it has a slightly slower ping rate than mode 4. Bottom-track mode 5 will automatically switch to bottom-track mode 4 when water is too deep (or too fast) for mode 5 operation. Because of this adaptive capability, mode 5 is the mode of choice for small rivers and estuaries (table 3.4). Table 3.4 lists the minimum bottom-tracking depths for bottom-track modes 4 and 5.

Table 3.4. Minimum depth ranges for bottom-track modes 4 and 5

[kHz, kilohertz; m, meter; ft, foot]

Frequency (kHz)	Depth (m) (ft)
1200	0.8 m (2.6 ft)
600	.8 m (2.6 ft)
300	1.5 m (5 ft)

At least one other ADCP manufacturer has developed the software and system firmware (bottom-tracking algorithms) for the measurement of river discharge; however, at the time this report was written, no detailed information was available for analysis and publication.

Summary

Water-track modes and bottom-track modes are independent of each other and must be carefully chosen, depending upon the stream conditions. In general, a good starting point for measurements at an unfamiliar site is water mode 1 (WM1) and bottom-track mode 5 (BM5). In cases of slow-moving, shallow flow, water mode 5 should be tried first, followed by water mode 8, followed by modified versions of mode 1 (use bottom-track mode 5 in all cases). In cases of high velocities, high shear, abrupt boat movements, or dynamic depth conditions, default and modified versions of mode 1 can be tried with a slow cross-section traverse to reduce random error. In such cases, bottom-track mode 4 probably should be used.

The theory of ADCP discharge measurement has been discussed in chapters 1–3. Chapters 4–9 introduce “practical” techniques and equipment.

CHAPTER 4: ACOUSTIC DOPPLER CURRENT PROFILER HARDWARE AND ANCILLARY EQUIPMENT

In this chapter we discuss the equipment needed to measure river discharge with an ADCP (fig. 4.1). Although a generic discussion of ADCPs is provided in this report, the following three sections cover the ADCP manufactured by RDI. The reason for this is twofold:

- Until recently, RDI was the only manufacturer of ADCP systems that could be utilized for discharge measurements (bottom-track algorithms). Another vendor (Sontek) has developed a bottom-tracking ADCP that can be used for discharge measurements, but the system is not yet widely used by the USGS
- As discussed in chapter 2, RDI has written discharge-measurement software that is integrated with the ADCP to calculate discharge and to store data (Transect software). Knowledge of the details of this software is required for the collection of accurate discharge measurements.

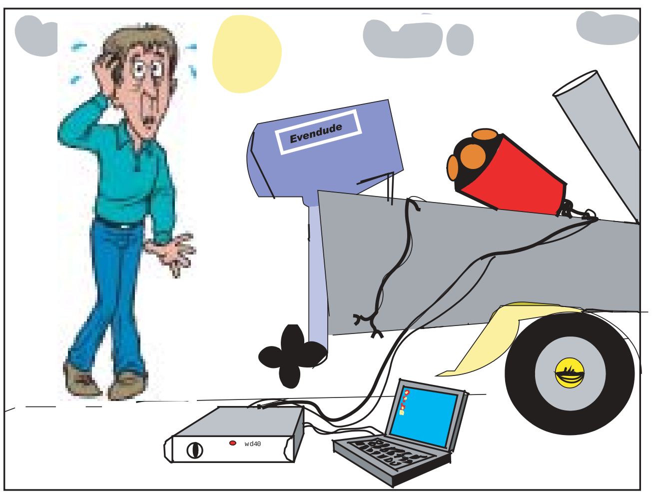


Figure 4.1. "Which equipment do we need?"

When another ADCP manufacturer produces a capable system that is used by a significant number of USGS offices, a description of that system (and its associated software) will be included in a follow up to this report.

Where Do We Start?

The following equipment is needed to measure river discharge with an ADCP:

<u>ADCP system</u>

- Pressure case and transducer assembly
- Power supply and communications interface
- Discharge-measurement software
- Manufacturer's documentation

<u>Ancillary equipment</u>

- Measurement platform or vessel
- ADCP mounting assembly
- Laptop computer
- Range finder or method for estimating distance to shore

Of course, the measurement equipment is worthless unless used by a competent, well-trained ADCP operator. If a boat is used, the skipper must be experienced in boat-maneuvering techniques required for ADCP discharge measurement and must have attended a U.S. Department of Interior (DOI) boat safety course.

Acoustic Doppler Current Profiler Equipment

Acoustic Doppler Current Profiler Pressure Case and Transducer Assembly

The direct-reading BB-ADCP is configured much like the narrow-band ADCP (Simpson and Oltmann, 1993); however, the transducer and electronics are contained in the same cylindrical enclosure (pressure case). The diameter of the enclosure is approximately 150–220 millimeters (mm), depending on the configuration. A convex or concave transducer assembly on one end of the cylindrical canister employs an orthogonal (Janus) beam aiming

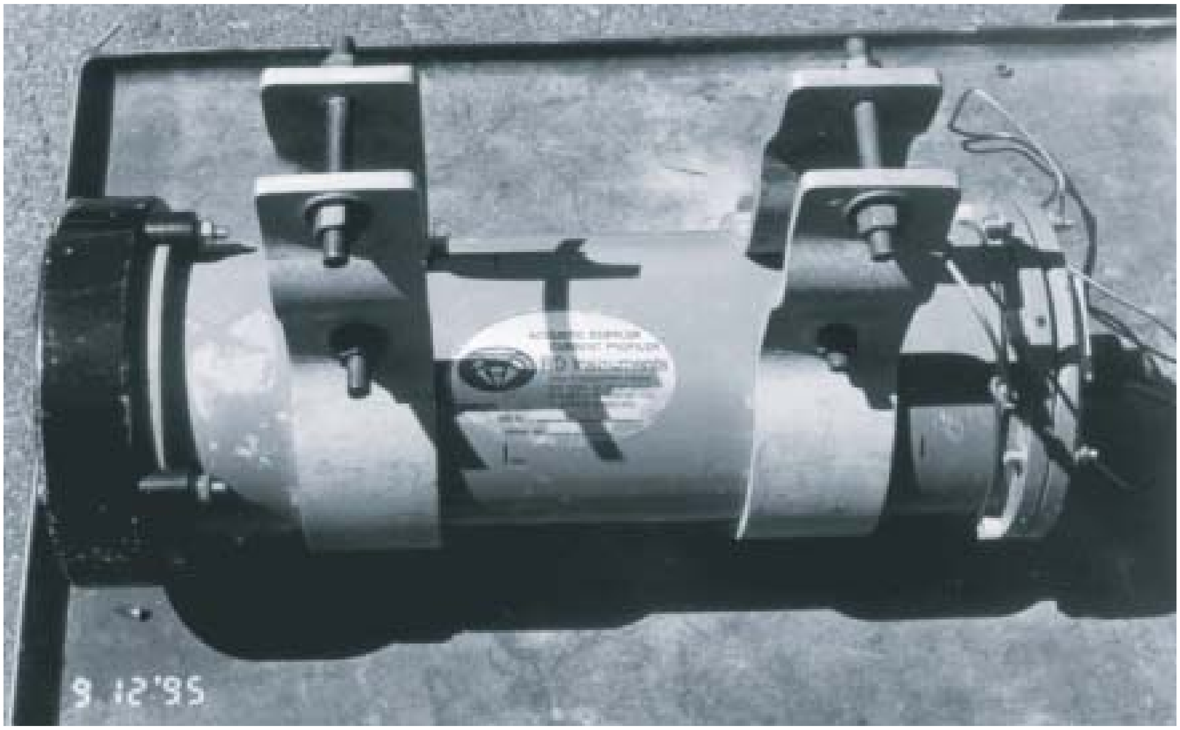


Figure 4.2. A 1,200-kilohertz broad-band acoustic Doppler current profiler with attached pipe brackets.

pattern with the three or four transducer beams angled 20º (or optionally 30º) outward from the center axis of the assembly. The transducer assembly diameter depends on the frequency of operation and configuration. For most work, the concave transducer head has proven to be more durable because it is protected somewhat from floating debris and direct contact with the river bottom. Figure 4.2 shows a BB-ADCP with a 1,200-kHz concave transducer assembly with pipe brackets attached.

RDI has introduced another version of the BB-ADCP into its product line called the “Workhorse.” The Workhorse line of ADCPs can be purchased with or without bottom-tracking capability. A river version of the Workhorse (the Rio Grande, fig. 4.3) is available with bottom-tracking and operational modes suited to river-discharge measurements.

Power Supply and Communications Interface

For BB-ADCP direct-reading units, the manufacturer supplies a deck unit with the BB-ADCP that can convert several power sources to voltages required by the BB-ADCP. The deck unit can accept 120-volt (V) alternating current (AC), 20- to 60-volt

Figure 4.3. An R.D. Instruments, Inc., 600-kilohertz Workhorse "Rio Grande" acoustic Doppler current profiler.

direct current (DC), or 12-volt DC (fig. 4.4). The deck unit has a power switch on the front panel as well as two luminescent electronic display (LED) indicators. One LED indicator lights up when power is applied to the deck unit, and the other LED indicator lights up when data are being transmitted to and from the ADCP.

A 13-mm (0.5-inch) diameter cable connects the BB-ADCP to the deck unit assembly. At the ADCP end, the cable is potted to an underwater connector (fig. 4.5). The shell connector at the deck unit end of the cable has

Figure 4.4. Front and rear view of an R.D. Instruments, Inc., acoustic Doppler current profiler deck unit.

24 pins and uses a bayonet-style connector. The overhang on the back of the deck unit can hinder the ability to easily disengage this connector and many users do not fully engage the bayonet mechanism. Connectors for RS-232 serial communications, power connections, and fuse holders also are on the back panel of the deck unit. The fuses protect the ADCP and deck unit in the event of short circuits and incorrect (reverse) battery polarity.

The manufacturer also markets an ADCP product known as the “Workhorse Rio Grande” (fig. 4.3) that does not require a separate deck unit. The Workhorse is powered directly from a DC source, or optionally from a 120-volt AC to a 12-volt DC converter. The Workhorse communications cable and the power supply cable are attached to the pressure case by way of a submersible connector.

Figure 4.5. Connector cable for attachment of R.D. Instruments, Inc., broad-band acoustic Doppler current profiler to accompanying deck unit.

Acoustic Doppler Current Profiler Discharge-Measurement Software

To measure river discharge, the ADCP system is controlled by discharge-measurement software (chaps. 2, 3). The configuration of this software is discussed in detail in chapter 5.

Documentation

The manufacturer provides several pieces of documentation that are essential for the proper operation and setup of the BB-ADCP including "The Direct Reading and Self-Contained BB-ADCP Technical Manual" (R.D. Instruments, Inc., 1995). For those using the Workhorse Rio Grande, RDI provides "Workhorse Rio Grande Technical Manual P/N 957-6101-00," November 1999. Also needed is the Transect Program users manual for the broad-band acoustic Doppler current profilers (R.D. Instruments, Inc., 1994). The technical manual is shipped with each ADCP; however, the Transect computer software and manual must be purchased separately. The Transect software and users manual are shipped as computer diskettes. Both manuals are updated periodically and hard copies of these updates can be obtained from the manufacturer for a fee. The manufacturer also maintains an internet web site that provides downloadable copies of the latest ADCP documentation updates, technical bulletins, and complete manuals (www.rdinstruments.com). The operator also should become familiar with the "Quality assurance plan for discharge measurements using broad-band acoustic Doppler current profilers" (Lipscomb, 1995).

Ancillary Equipment

Measurement Platform or Vessel Requirements

Discharge measurement platform or vessel requirements will vary, depending on the size and flow rates of the rivers and streams. For example, if measurements are in large rivers or estuaries, the BB-ADCP may be mounted on a 9- to 15-m (30- to 50-foot) vessel with an enclosed cabin. If, on the other hand, discharge measurements are on small, slow-moving rivers, the vessel of choice may be a 5- to 6-m (16- to 20-foot) skiff. For very small streams or rivers with minimal wave action, the BB-ADCP may be mounted on an inflatable boat, such as a Zodiac.

For improved safety while taking measurements that would be hazardous using manned platforms or to avoid traffic hazards, the USGS Indiana District has developed a tethered platform (fig. 4.6). For flood work and bridge scour measurements, the USGS Office of Surface Water has developed a prototype radio-controlled platform (fig. 4.7).

Figure 4.6. Tethered acoustic Doppler current profiler discharge measurement platform.

Figure 4.7. Radio-controlled, 12-foot, broad-band acoustic Doppler current profiler platform.

The proper boat choice will depend on the topography and hydrology of the area of interest; however, it is best to have several alternative vessels for discharge measurement use. In the USGS California District, three boats are used for ADCP discharge measurements. Figure 4.8 shows a 30-m (95-foot) vessel with a side-swing mount. Using this configuration, measurements in the estuary can be obtained under all but the worst of conditions.

Figure 4.9 shows a similar mount on a 6-m (20-foot) Boston Whaler. This vessel can be used in estuaries, rivers, and in river tributaries. A large 150-horsepower (hp) engine is used to get from place to place quickly when making discharge measurements in an estuary or river delta. A smaller engine is used when making discharge measurements in small rivers and

Figure 4.8. Two views of an acoustic Doppler current profiler side-swing mount on a 30-meter (95-foot) vessel.

slow-moving water. This vessel can be rigged with canvas for inclement weather.

Figure 4.10 shows a side-swing mount on a 4.5-m (15-foot) Boston whaler. This vessel is easily trailerable and is used when measuring small rivers. The main engine has a four-cycle, 45-horsepower engine that can be idled at low speeds for discharge measurement. This configuration is used mainly in fair weather; however, canvass also can be rigged to make the vessel usable in inclement weather.

When making discharge measurements in narrow rivers, a trolling plate can be used on the main engine or an electric trolling motor can be used to slow the vessel. For accurate measurements in very slow-velocity water, this vessel can be pulled on a tagline.

In Sweden, BB-ADCP operators have used a small, inflatable dinghy when making discharge measurements (fig. 4.11). The advantage of this type of vessel is that launch ramps are not needed. The dinghy can be inflated on the riverbank and the equipment set up for use in less than 30 minutes.

It is imperative that not only the correct boat be used for any given set of river and weather conditions, but also that boat operators be properly trained. Correct

Figure 4.9. Side-swing mount on a 6-meter (20-foot) Boston Whaler for an acoustic Doppler current profiler.

operation of the boat is vital to obtaining high-quality discharge and velocity measurements. The DOI requires that boat operators attend a DOI motor boat operators training course before operating a USGS boat or vessel. All passengers on USGS vessels should wear life jackets (type V or better) and observe all U.S. Coast Guard and USGS water safety regulations.

Laptop Computer

The computer selection for running the BB-ADCP software is very important. Because of the amount of data processing required, the computer must have an i286 central processing unit (CPU) or equivalent (an i386, i486, or Pentium CPU is desirable), and also must be IBM compatible. The computer at least must be capable of displaying extended graphics array (EGA) compatible graphics. Because of the amount of data storage required, a hard drive (nonvolatile ram drive) should be used with at least 20 megabytes (Mb) of available storage space.

The computer screen display should be visible in direct and diffuse sunlight (fig. 4.12). Those computers that do not rely on backlighting for display illumination

Figure 4.10. Side-swing mount on a 4.5-meter (15-foot) Boston Whaler for an acoustic Doppler current profiler.

seem to have the most visible display in direct sunlight. Standard monochrome liquid crystal display (LCD) and LEDs have the best visibility. Active matrix color displays have fair-to-poor visibility, and dual scan color LCD displays have poor-to-no visibility in direct sunlight. The computer purchase should be based on the computer's ability to run the Transect software and on the visibility of the screen display in direct sunlight.

For routine collection of streamflow data, a rugged laptop computer is desirable. Several manufacturers now produce laptops with antiglare screen coatings, shock-mounted hard drives, and water-resistant keyboards and access panels. Standard laptops have minimal protection from the elements; rain and dust protection are not provided and many have flimsy plastic doors covering the port connections. These plastic doors fall off or are easily broken (fig. 4.13).

Do not rely on the internal laptop battery to provide power for an all-day measurement session because most laptop batteries will not last beyond about 3 hours and many will not last 1 hour before requiring recharge. Most of these rechargeable batteries tend to

Figure 4.11. Acoustic Doppler current profiler mount for an inflatable dinghy.

Figure 4.12. Laptop computer screen in diffuse sunlight.

gradually lose capacity with age. The measurement system operator should attempt to power the computer from an external battery with a large capacity, such as an external 12-volt automobile or deep-cycle marine battery. Many of the newer laptops do not directly accept 12-volt power and require special adapters for power conversion. These adapters should be purchased with the computer, if possible, because they may be unavailable with ensuing computer model changes. Most adapters have a cigarette lighter plug at the 12-volt end of the adaptor. The cigarette lighter plug can be replaced with two alligator clips that can be attached directly to battery terminals. Another alternative for laptop power is to purchase a 200-watt (W) inverter. There are several small efficient inverters on the market today that do not draw excessive power under idle conditions. The inverter is connected to the 12-volt batteries and the computer AC adaptor is plugged into the inverter.

The data-processing computer is connected to the BB-ADCP through a serial connection on the back of the deck unit. Normally, this serial connection is RS-232c; however, for long cables (longer than 200 ft), RS-422 protocol should be used. RS-422 protocol requires the use of a separate converter box as well as changes in the internal BB-ADCP switch settings (R.D. Instruments, Inc., 1995). The RS-232c serial connection is provided by way of a standard IBM personal computer (PC) 9-pin female to 25-pin male adaptor cable, which is available in most computer shops. A null-modem adaptor is not needed.

The computer must be protected from direct sunlight and heat during data collection. The LCD screen turns dark and unusable if it remains in direct sunlight too long. The computer also can be damaged by the heat of direct exposure to the sun. One solution is to place the computer inside an empty cooler that is turned on its side. The cooler shades the computer and

Figure 4.13. Laptop computer with missing plastic doors and port covers.

LCD from direct sunlight and also protects the computer from splashing water.

Acoustic Doppler Current Profiler Mounts

For discharge measurement or profiling, the BB-ADCP is positioned with the transducer assembly facing downward into the water column with beam three oriented forward. The BB-ADCP can be mounted in many different ways, but two methods have been used for most deployments; the side-swing mount and the “sea chest” mount.

Figures 4.14 and 4.15 show two types of side-swing mounts that have been used successfully. An inexpensive mount made from 51-mm (2-inch) aluminum pipe and 51-mm by 305-mm (2-inch by 12-inch) lumber is shown in fig. 4.14, and a more expensive mount fabricated from 6061-T aluminum is shown in fig. 4.15. These types of mounts have been used on boats that range in length from 4–30 m

Figure 4.14. Inexpensive acoustic Doppler current profiler mount.

(14–95 ft) and on streams 3.5 m (10 ft) wide and on rivers as wide as 1.6 km (1 mi). These mounts have the disadvantage of being far from the boat keel and, therefore, are subject to altitude changes caused by pitch and roll. However, for most applications, these mounts produce acceptable results.

Figure 4.16 shows a “sea-chest” mount that has been used successfully for narrow-band ADCPs and can be modified for use with BB-ADCPs. The “sea-chest” mount has the advantage of being close to the

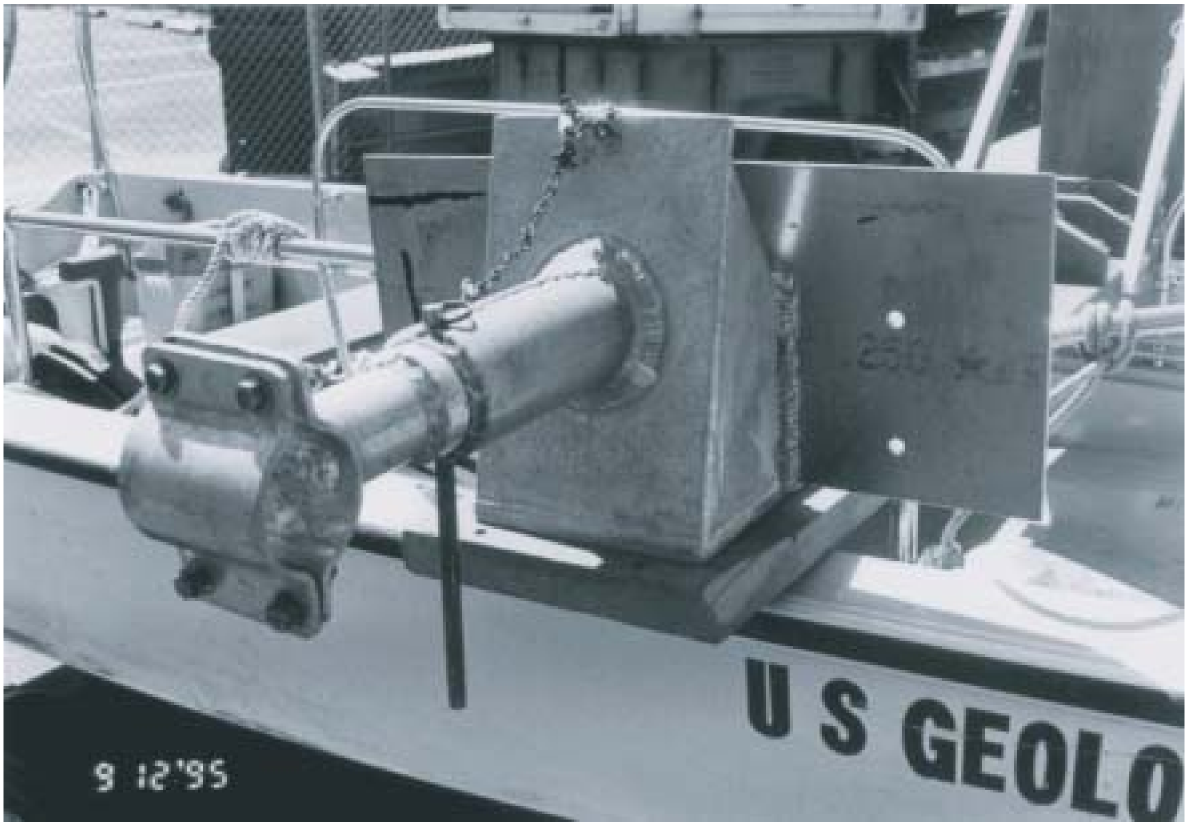


Figure 4.15. Aluminum acoustic Doppler current profiler mount.

boat keel and, therefore, less subject to altitude changes due to pitch and roll. The position also places the BB-ADCP away from edges of the boat wake where entrained air is present. Entrained air can cause loss of bottom track.

ADCP operators at Tampa, Florida, have developed a variant of the swing mount (fig. 4.17) that allows the BB-ADCP to be easily swung aboard the measurement vessel. A hydraulic mount was designed and installed on a "john boat" in the USGS Indiana District (fig. 4.18). A unique variant of the transom mount was designed by Harry Hitchcock of the USGS Kentucky District (fig. 4.19). An inboard variation on the transom swing mount is being used by the USGS Illinois District (fig. 4.20). An easily detachable swing mount was designed and used by the USGS Idaho District (fig. 4.21).

Range Finder or Method for Estimating Distance to Shore

Edge discharges are estimated in the Transect software using a technique similar to that used when making conventional discharge measurements. The unmeasured area between the boat and the river edge is estimated using the last measured mean velocity, the last measured depth, and the distance from the boat to shore. The algorithm assumes a triangular-shaped area

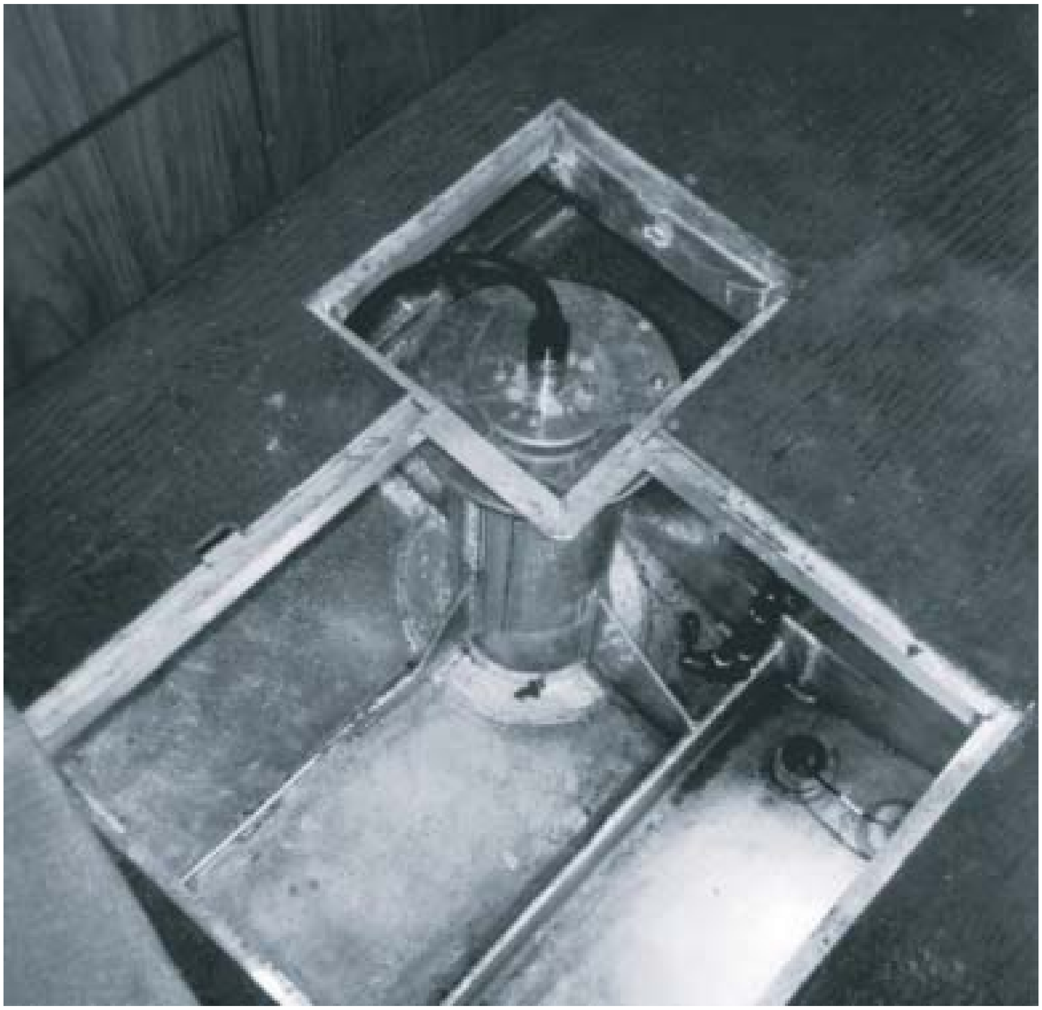


Figure 4.16. Sea-chest mount for a narrow-band acoustic Doppler current profiler.

for this estimate. If the river channel is rectangular, these edge estimates can be doubled and an adjustment made for the roughness of the edges.

Estimating the distance to shore can be done with the naked eye; however, such distance estimates are almost always short of the true distance (underestimated). The reason for this is unclear, but is possibly due to lack of visual clues between the boat and shore. The most reliable way of ensuring accurate edge estimates is to set buoys out from the shore at known distances (measured with a tape or distance meter). The Transect software is then started and stopped at these buoys. This method is not always possible when large numbers of discharge measurements are needed at different locations within a short time period.

Figure 4.17. Mount used by the U.S. Geological Survey Tampa, Florida, Subdistrict.

There are several types of distance-measurement devices on the market that have been used to increase the accuracy of the edge estimates without the need to set buoys or onshore devices. The devices can be placed into three categories:

•Optical

•Sonic

•Infrared laser

Good results have been obtained with inexpensive, optical range finders (fig. 4.22) that use parallax and a focusing device to estimate distance. The operator identifies a rock or object at the stream edge and then rotates a knob to converge two images of the object. The distance is then read from a scale on the device. This method requires a little practice but, with properly calibrated range finders, acceptable accuracy can be obtained up to about 180 m (600 ft).

Sonic devices that have been tried, require a vertical wall for a signal return. Riverbank edges generally do not have topographies that enhance acoustic reflections. To be usable, these devices need special sonic targets (corner reflectors) placed on the riverbanks. These devices can be useful if the operator

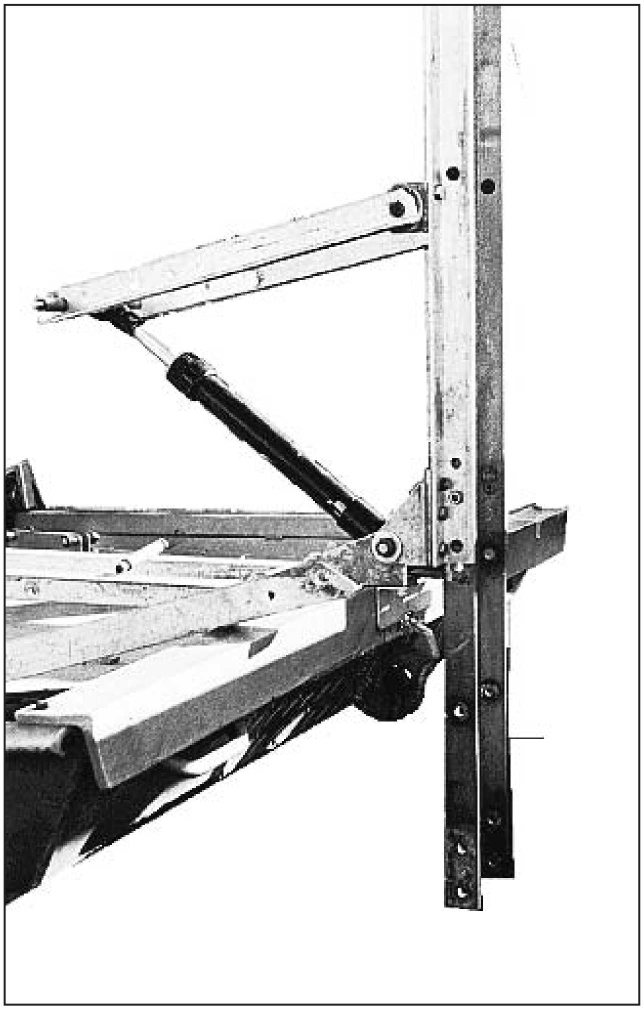


Figure 4.18. Hydraulic mount used by the U.S. Geological Survey Indiana District.

is able to deploy the sonic targets at the cross-section edges.

Laser devices are cumbersome and more delicate than the other range finders, but can be more accurate over longer distances. They can be used without targets (corner reflectors) up to about 75 m (250 ft) and up to hundreds of meters (thousands of feet) with targets. The major drawback to these devices are their cost and durability. They require precision optics, which are delicate and easily damaged.

Trolling Motors/Plates

Discharge measurements typically require the use of slow boat speeds, especially in low water-velocity conditions. The main boat engine usually is too large for use when making discharge measurements. A battery-operated trolling motor (fig. 4.23) with variable speeds or a small gasoline-driven marine engine may be used to maneuver the boat at the slow speeds required for making a discharge measurement.

If an electric trolling motor is used, extra deep-cycle marine batteries should be included in the discharge-measurement equipment inventory. When using a trolling motor, a full day of discharge measurements may require two or more fully charged, deep-cycle marine batteries. If a gasoline-powered trolling motor is used, the operator may wish to purchase a four-cycle marine engine. A four-cycle engine is quieter than a two-cycle engine, does not smoke as much, idles for longer times at low speeds without spark plug fouling, and does not require an oil/gas mixture for operation.

Inexpensive steering adapters (fig. 4.24) can link smaller trolling motors to the main engine steering, and remote throttles and gearshifts also can be console mounted. Electric trolling motor steering even can be done with a foot pedal.

Miscellaneous Measurement Equipment

Miscellaneous discharge-measurement equipment may include the following:

- Buoys with attached anchors for marking cross-section edges
- Tag-line systems for measuring very slow velocities

Figure 4.19. “Toggle” mount used by the U.S. Geological Survey Kentucky District.

- External depth sounders and navigation equipment
- Rain/sun canopy and computer-protection gear

Installation of the Broad-Band Acoustic Doppler Current Profiler

Mounting the Acoustic Doppler Current Profiler on the Vessel

The ADCP is mounted on the measurement vessel using the mounting systems described previously. In most cases, beam three is oriented toward the bow of the vessel, however, if the vessel will be measuring discharge next to bridge piers or vertical walls, the ADCP should be oriented such that the beams are at 45º angles to the axis of the vessel. This orientation allows the closest approach to the vertical wall.

Care must be taken to eliminate magnetic fields or ferrous materials from the vicinity of the pressure case. Not only the ADCP mounts, but all nuts, bolts, and other fasteners must be made from nonferrous materials.

Figure 4.20. Swing mount variation used by the U.S. Geological Survey Illinois District.

Deck-Unit and Power-Supply Connections

The other components of the BB-ADCP system also must be mounted or placed in safe (splash-free) areas on the measurement vessel. There are some precautions to be observed when installing the system components. The deck unit (if used) should be positioned out of direct sunlight (excessive heat) and away from exposure to moisture (the housing for the deck unit electronics is not waterproof). The deck unit should be opened and examined to ensure that all components (especially the DC-to-DC convertor block) are firmly attached to the board socket by some means other than electrical connector pins. The manufacturer has corrected this problem, but several of the early deck units had no mechanical attachments on the DC-to-DC converter block. The block would become dislodged during transportation and the deck unit would not function when connected to 12-volt DC power.

The connections on the back of the deck unit are shown in figure 4.25. Using the deck unit, the BB-ADCP may be powered with 110- to 120-volt AC power, 12-volt DC power, or 20- to 60-volt DC power. The AC power is supplied to the deck unit using a standard IBM personal computer-style pigtail

Figure 4.21. Detachable swing mount used by the U.S. Geological Survey Idaho District.

connection. The 12-volt DC power is supplied using a user-designed cable connected to the labeled terminal block on the back of the deck unit. Polarity is important when connecting to this terminal block using this cable connector. Early versions of the deck unit did not have input diode protection and could be damaged by improper DC polarity. The input polarity should be double checked before applying power. Most experienced BB-ADCP users begin a daily measuring session with two fully charged marine deep-cycle batteries. One fully charged 12-volt battery should

Figure 4.22. Optical range finders used to estimate near-shore distances.

power the BB-ADCP and computer for the whole day. The second battery is for backup.

A range of 20–60 V DC can be supplied to the deck unit through the bayonet style coaxial (BNC) connector (fig. 4.25). This voltage also must have proper polarity, as it is delivered directly to the BB-ADCP. The voltage must be supplied using a properly insulated (center positive) female BNC connector. IMPORTANT!!! These voltage magnitudes can be lethal, especially around water. Make sure all connections are insulated properly.

The voltage entering the 20- to 60-volt connector does not go through the DC-to-DC convertor before being sent to the BB-ADCP; therefore, it is not “stepped up” to the nominal BB-ADCP transmit voltage of 50. Voltages less than 30 may not supply the BB-ADCP with enough transmit power to enable profiling in the deeper depth ranges, especially if the water has few scatterers. Voltages greater than 60 may damage BB-ADCP power regulation components.

Acoustic Doppler Current Profiler Cables and Connectors

Broad-Band Acoustic Doppler Current Profiler

A multi-pin shell connector on the BB-ADCP cable connects to a 24-pin bayonet socket on the back of the deck unit. This connector assembly is not very

Figure 4.23. Typical battery-operated trolling motor used when making acoustic Doppler current profiler discharge measurements.

sturdy and should be protected from undue twisting and mechanical pressure. The overhang at the back of the deck unit prevents easy disengagement of the bayonet mechanism, and many operators only partially engage the mechanism to facilitate easy removal. A right-angle shell connector can be ordered (when specifying the cable length) that may provide greater protection than the standard shell connector.

The molded underwater connector on the BB-ADCP end of the cable has a plastic alignment key that can become worn. Slight misalignment caused by wear of the alignment key can cause connector pins to bend when mating the connectors and tightening the locking ring. The O rings on both connector ends should be lubricated regularly with silicone grease and the connector rocked slightly to enable proper connector mating. If the alignment key or keyway is worn excessively, the connectors should be replaced.

It is possible that a long, coiled BB-ADCP cable can cause improper BB-ADCP operation. Noise or interference can be introduced (induced) into the coiled cable. Excess BB-ADCP cable should not be coiled, but flaked (using a non-overlapping S-shaped pattern) along the deck. It is best to order a short cable for use when the deck unit is mounted close to the BB-ADCP.

Workhorse Rio Grande

There is no deck unit for the Workhorse Rio Grande ADCP. Power is supplied to the electronics in the pressure case through a combination power and communications cable. The communications cable is terminated with a standard DB-9 RS-232 connector that mates with most laptop communication ports. The power cable is terminated with alligator clips that can be attached to a 12-volt battery. A users guide (R.D. Instruments, Inc., 1999) for connecting and configuring the Rio Grande is provided with the instrument or can be obtained from the RDI web site (www.rdinstruments.com).

Undoubtedly, other equipment will be needed that is unique to each operator or measurement site. Most operators build a “kit” containing ADCP measurement equipment, manuals, and field forms to be loaded before each deployment, thereby reducing the chances of forgetting to pack a vital piece of measurement gear.

Figure 4.24. Two views of a steering adaptor that connects the trolling motor to the main engine.

Summary

The acoustic Doppler current profiler (ADCP) discharge-measurement system consists of the following items:

An ADCP system with bottom-tracking capability

•Pressure case and transducer assembly

•Power supply and communications interface

•Discharge-measurement software

•Manufacturers' documentation

Ancillary equipment

•Safe measurement platform or vessel

•ADCP mounting assemblies

•Laptop computer

•Range finder or method for estimating distance to shore

•A knowledgeable ADCP operator and well-trained vessel operator.

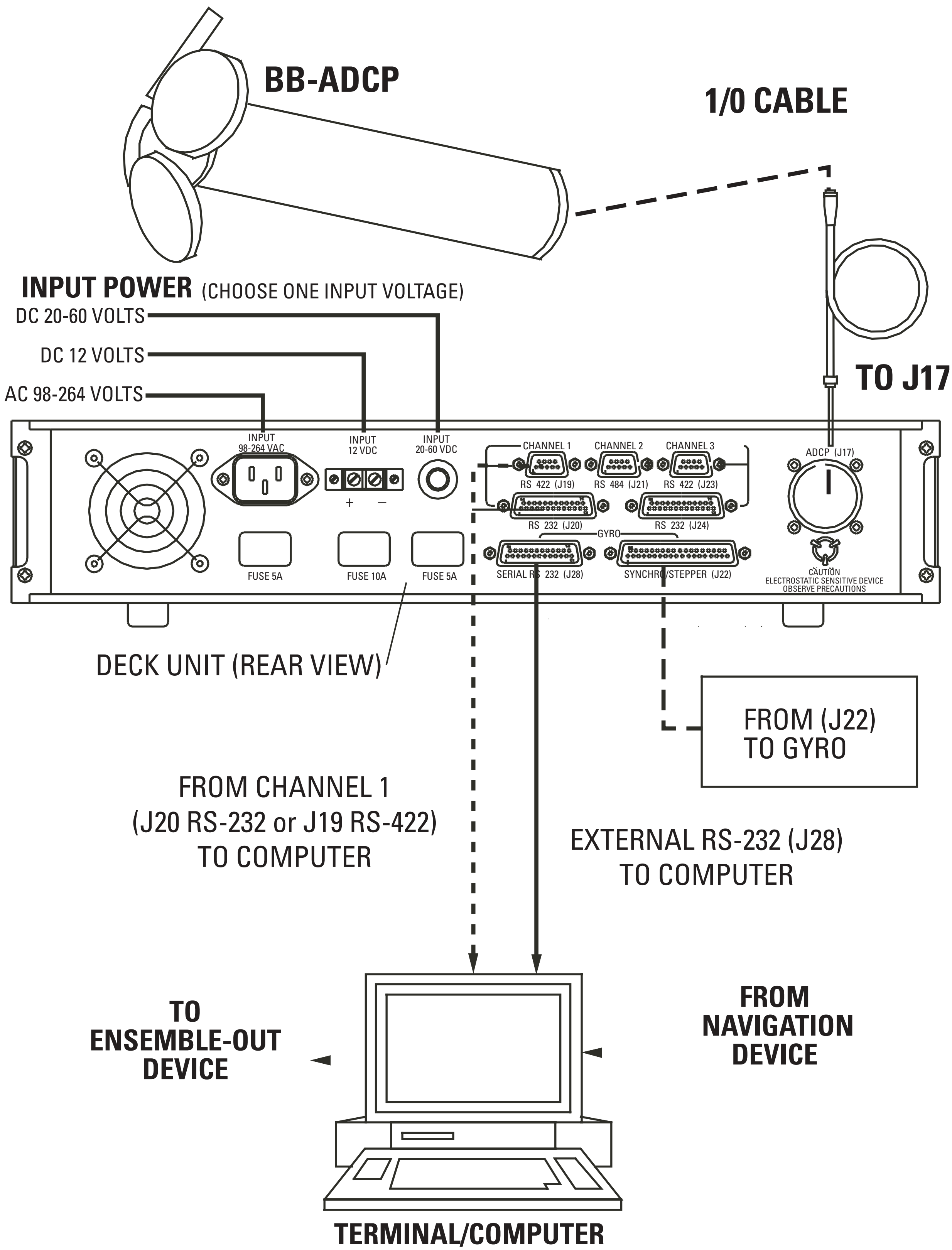


Figure 4.25. Interconnections of the broad-band acoustic Doppler current profiler (BB-ADCP) deck unit with other components of the acoustic Doppler current profiler discharge-measurement system. Adapted from R.D. Instruments, Inc., (1995). DC, direct current; AC, alternating current; V, volt.

This page left blank intentionally.

CHAPTER 5: BROAD-BAND ACOUSTIC DOPPLER DISCHARGE-MEASUREMENT SYSTEM CONFIGURATION

Discharge-Measurement Software—"Transect"

Although the BB-ADCP can be used as a velocity-profiling instrument, this report primarily addresses its usefulness as part of a discharge-measurement system. The purpose of this chapter is to discuss proprietary software used to configure the BB-ADCP or Workhorse Rio Grande and to acquire data from these ADCPs to measure discharge. This software is called "Transect." Most of the information covered in this chapter also can be found in the Transect Users Manual for the BB-ADCP (R.D. Instruments, Inc., 1995). This chapter will not dwell on the small details of configuring the BB-ADCP or Rio Grande, but will attempt to touch on the important issues and provide tips to the neophyte ADCP operator.

Transect is composed of a series of stand-alone software modules that incorporate the discharge-measurement algorithms discussed in chapter 2 and also include the following features:

- A graphical user interface
- Graphical output of ADCP velocity and discharge-measurement data
- Tabular output of ADCP velocity and discharge-measurement data
- Command and control interface to the ADCP
- Raw and processed data storage and playback

Transect also includes algorithms for estimating unmeasured parts of the water column and cross section. The Transect software has the ability to accept and record (along with the velocity data) external navigation and depth inputs.

Transect Configuration

The configuration file is at the heart of the Transect software. The configuration file can be thought of as the interface between the ADCP and the Transect software modules. Commands in the configuration file tell the Transect software how to communicate with the ADCP, how to configure the ADCP, and how to modify the ADCP data-collection parameters for proper discharge measurement. It is possible to use the communication, calibration, and planning modules of the Transect software to build a trial configuration file on the basis of rough stream parameters. Although this method is used below to illustrate some of the modules in the Transect software, it is recommended that neophyte operators obtain preliminary configuration files from ADCP training classes or the USGS Office of Surface Water ADCP users' group Web site (http://il.water.usgs.gov/adcp/). Experienced users usually bypass the Transect communication, calibration, and planning modules and directly modify preexisting configuration files using a text editor to fit the desired stream conditions.

To familiarize the reader with the Transect communication, calibration, and planning modules, we will first discuss a method for creating a preliminary configuration file, and then discuss each section of the configuration file, in detail.

Creation of a Preliminary Configuration File Using Transect Modules

Communications Setup

The Transect software provides a communication test and setup whereby the user can establish communication with the BB-ADCP processor. The user also can use any terminal-emulation software or the software supplied by the manufacturer called "BBTALK" to establish communication with the BB-ADCP. BBTALK is a simple terminal emulator with file-capture capability that can be used to initially check the BB-ADCP communication parameters if the Transect software cannot establish communication.

Instructions for using the emulator are in a disk file called 'BBTALK.DOC' that is shipped with the Transect software utilities. If the operator cannot establish communication with the BB-ADCP, then the BB-ADCP technical manual should be consulted and the communications and power connections should be double checked. Different baud rates and bit combinations can be tried on a trial-and-error basis in the event that the BB-ADCP was setup on a nondefault baud-rate/bit combination. This will be practical only for semistandard parity bit and stop bit combinations (for example, no parity bit, eight data bits, one stop bit). It is possible to set the BB-ADCP to a nonstandard baud rate with a combination of stop bits and parity that is difficult (if not impossible) to determine by trial and error. If all standard methods produce "garbage" output to the BBTALK screen, the ADCP should be disassembled and the master reset button on the CPU board should be pushed (R.D. Instruments, Inc., 1995–1999). This will reset the BB-ADCP to factory default communication values. This should, however, be done only after the failure of all other attempts to establish communication with the ADCP.

By using the BB-TALK terminal emulator (fig. 5.1), the operator can invoke the BB-ADCP diagnostics menu with the PT command. PT0 displays

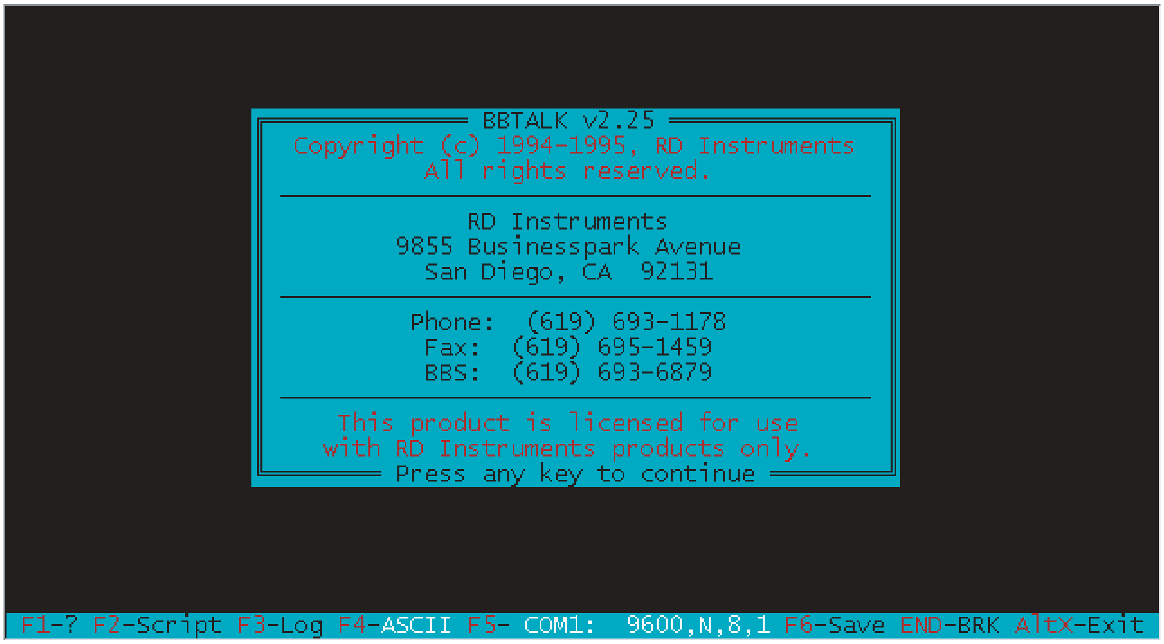


Figure 5.1. BB-TALK terminal emulator help screen.

the test menu. PT200 performs an entire suite of diagnostic tests. The BB-ADCP technical manual provides a detailed description of the diagnostic tests. Parts of the PT200 diagnostic test often will indicate failure if the ADCP transducer assembly is not immersed in water. In fact, certain parts of the PT200 diagnostic test may fail (with a healthy ADCP) if the transducers are immersed in a shallow bucket of water that is placed on a hard surface.

For best results, the diagnostic tests should be performed at the river cross section with the ADCP immersed in water. If the tests must be done in the office or lab, the transducer surfaces should be cleaned with soap and water (to remove grease), and then immersed in a plastic pail of water sitting on a foam pad. The manufacturer should be called if the BB-ADCP fails any of the PT200 suite of diagnostic tests using this scenario. Discharge measurements should not be done if the diagnostic tests indicate a failed subsystem. A PT200 test should be done before every discharge-measurement series, and the test output should be captured to a file and archived.

The communications menu selection of the Transect software main menu (fig. 5.2) allows the operator to establish communication with the BB-ADCP, provides the proper communication parameters for the construction of the configuration file, and provides access to direct (terminal emulation) communication with the BB-ADCP for checkout, configuration, and debugging of configuration problems. The communications parameters established in a session using the communication submenu are added to the communication section of the configuration file.

The communications ADCP submenu (fig. 5.3) provides for the setup and checkout of initial BB-ADCP communication parameters. Once these parameters have been determined, the trial configuration file can be saved with these parameters included. The communication menu also provides for the setup of communications between navigational devices, external readouts, and the external sensors (if any are required). The setup of these devices is covered in detail in the Transect software documentation (R.D. Instruments, Inc., 1999) and is not covered in this report.

Calibration Setup

After establishing communication with the BB-ADCP (and, thereby, setting up communication parameters in the configuration), the operator then should go to the calibration submenu for the next level of configuration file construction. In the calibration menu within the main menu (fig. 5.4), two submenus (offsets and scaling) will help create a “trial” configuration file when saved.

The calibration offsets submenu (fig. 5.5) provides the operator with the opportunity to set the BB-ADCP time and to enter compass alignment offsets (if the compass is separate from the BB-ADCP) or to enter compass magnetic corrections.

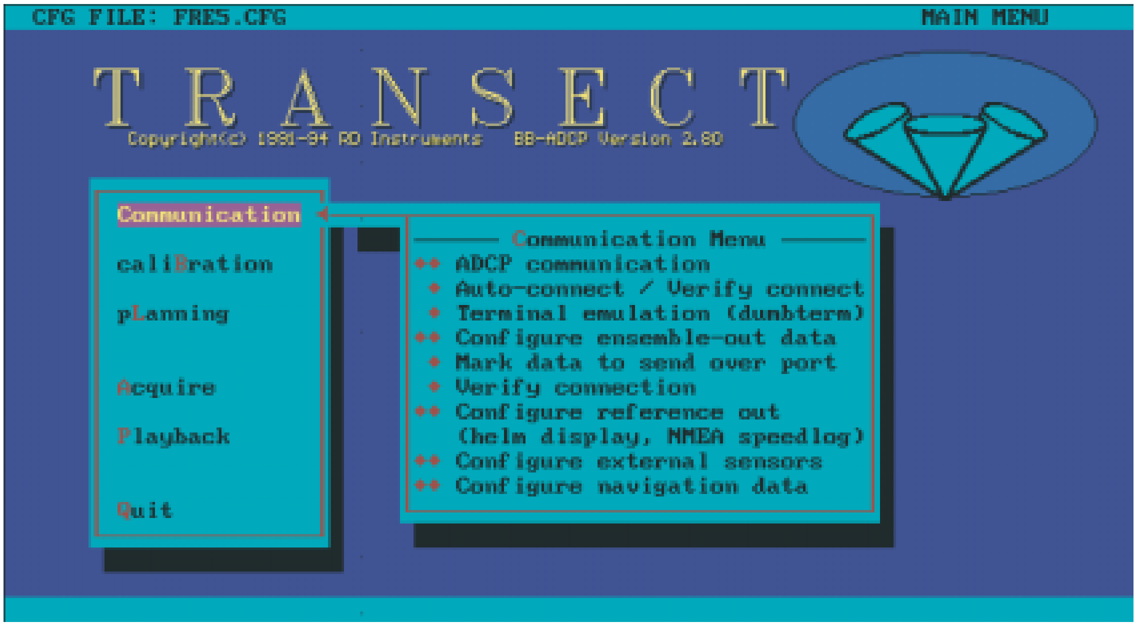


Figure 5.2. Transect main menu showing menu choices. BB-ADCP, broad-band acoustic Doppler current profiler.

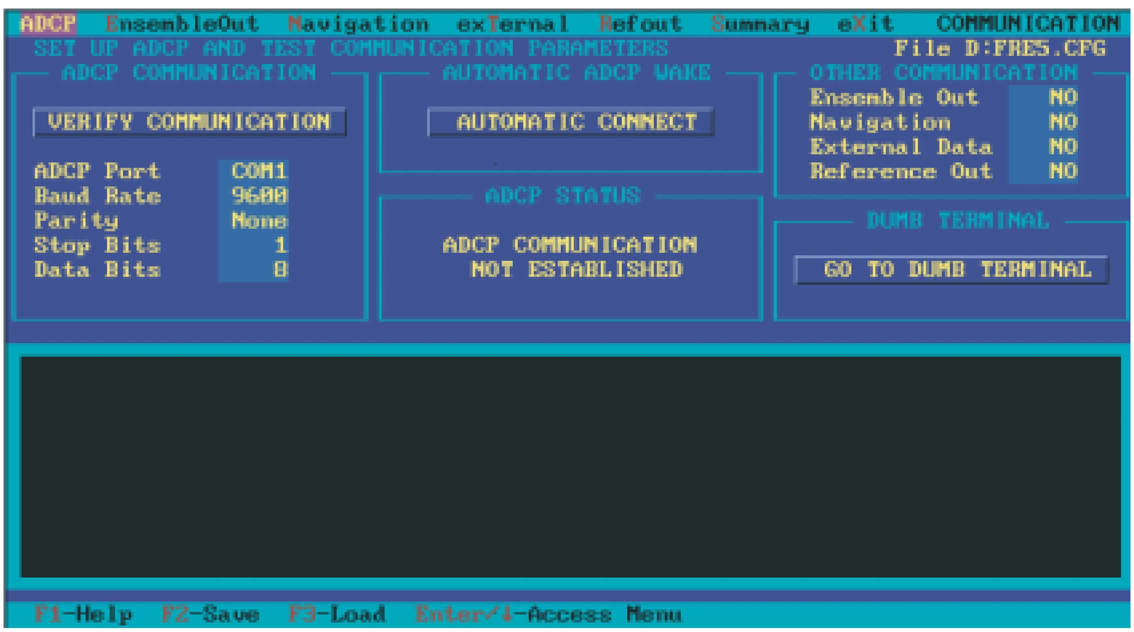


Figure 5.3. Communication acoustic Doppler current profiler (ADCP) submenu.

The next menu entered should be the calibration scaling submenu (fig. 5.6). The calibration scaling submenu provides the operator with the option to change several important velocity-profile scaling and estimation parameters. If salinity at the measurement site is known, or can be accurately estimated, it can be entered in this menu. Speed of sound can be entered manually if it is known, but, in almost all cases, should be computed for each ensemble. The discharge extrapolation scheme should be left at “power” for the top estimation method, and “power” for the bottom estimation method, unless examination of the profiles indicates that these values should be changed or bidirectional flow exists in the measurement cross section. The power-curve exponent also should be left at 0.16670, unless otherwise indicated (chap. 8). Pitch and roll compensation should be left at the default setting of YES, which allows the Transect software to automatically compensate for vessel pitch and roll during the discharge measurement. The absorption coefficient and echo intensity scale also should be left at default values, unless otherwise indicated. The value of these parameters has no effect on discharge- or velocity-measurement results. The configuration file should be saved with the appropriate name upon exiting the calibration menu.

Planning Setup

The next main menu is the planning menu (fig. 5.7). The planning menu, has two submenus (set and ADCP) that, when used properly, will complete the initial creation of the configuration file.

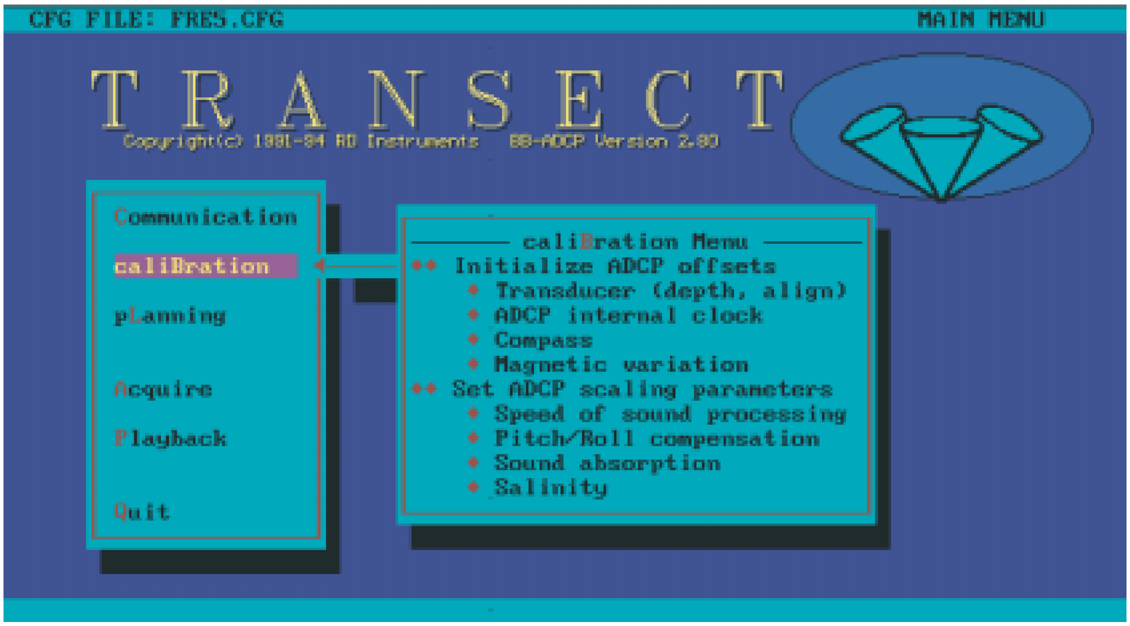


Figure 5.4. Transect main menu showing calibration menu choices. BB-ADCP, broad-band acoustic Doppler current profiler.

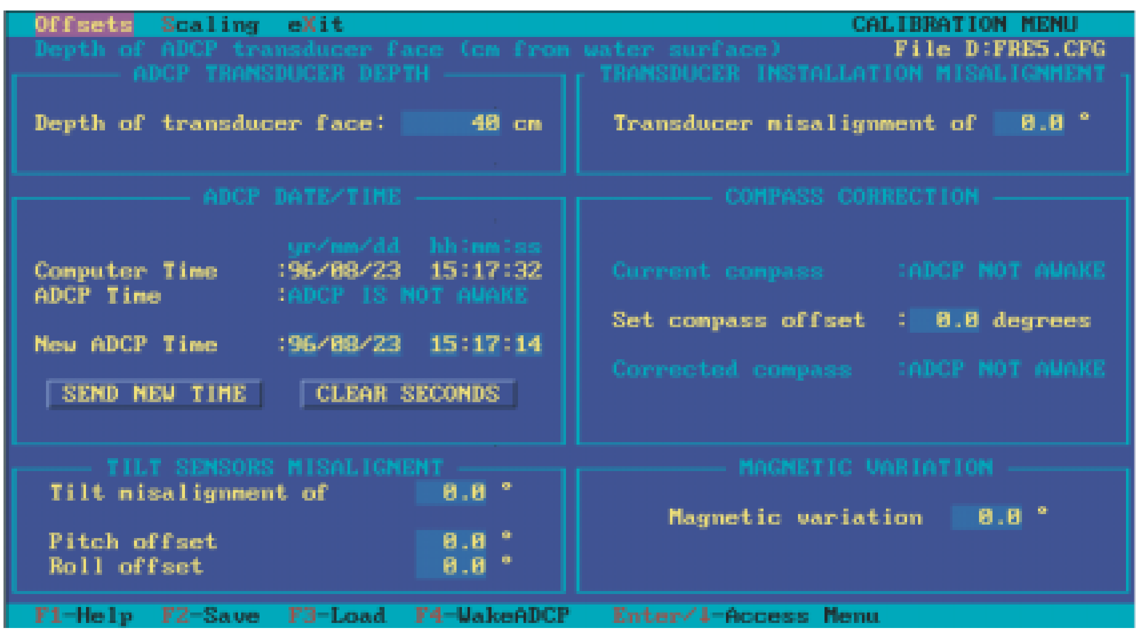


Figure 5.5. Calibration offsets submenu screen. ADCP, acoustic Doppler current profiler

The planning setup submenu (fig. 5.8) prompts the operator for the deployment name, primary drive, secondary drive, recorded data types, measurement processing, and engineering units used for tabular and graphics output. If an operating frequency for the ADCP has not been specified, the setup menu will prompt the operator to provide an entry.

The deployment name should be a unique, four-letter identifier for the measurement site. For example, the identifier FRE5 could be used for Sacramento River at Freeport, California, session 5 (fig. 5.8). Future releases of Transect may support the use of a longer identifier. The deployment name has two functions; it becomes the name of a MS DOS root-level directory

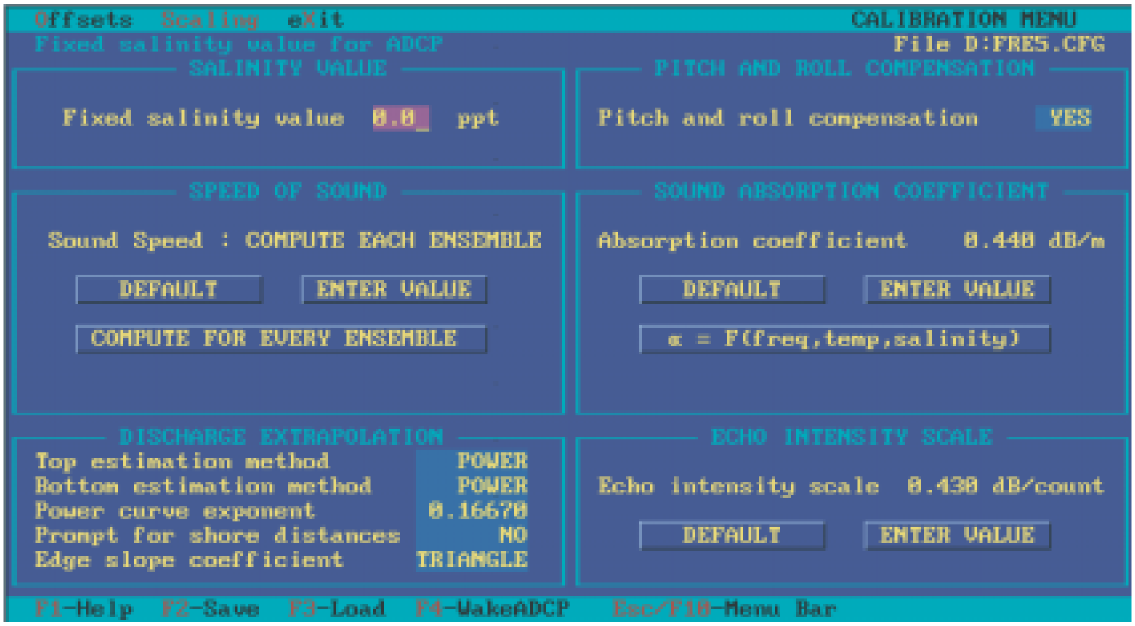


Figure 5.6. Calibration scaling submenu screen. ADCP, acoustic Doppler current profiler.

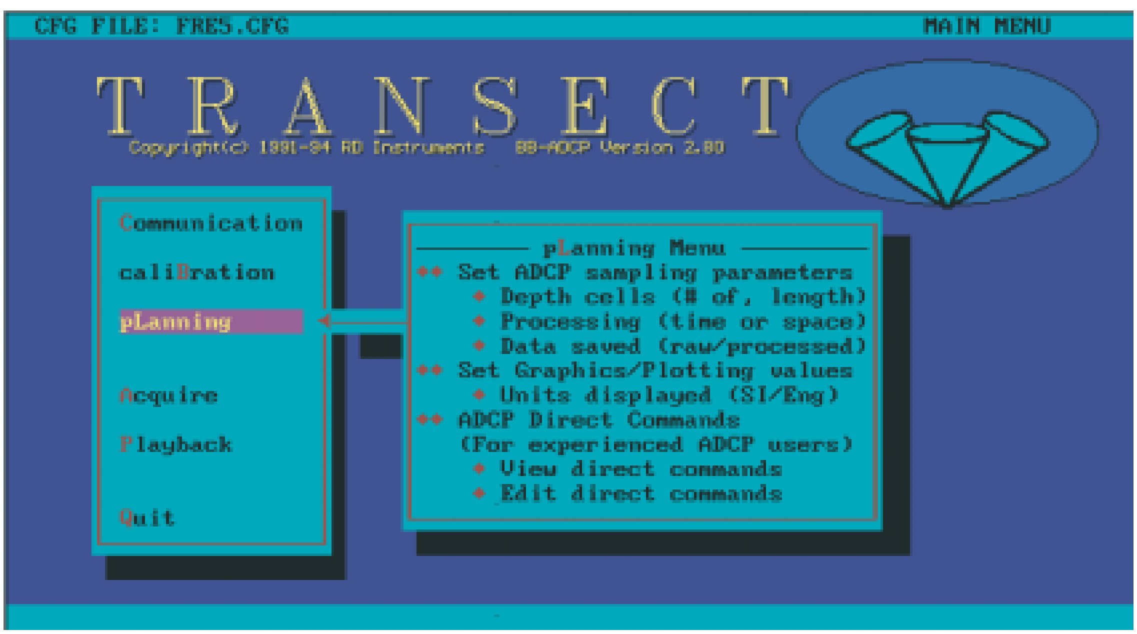


Figure 5.7. Transect main menu showing planning menu choices. BB-ADCP, broad-band acoustic Doppler current profiler.

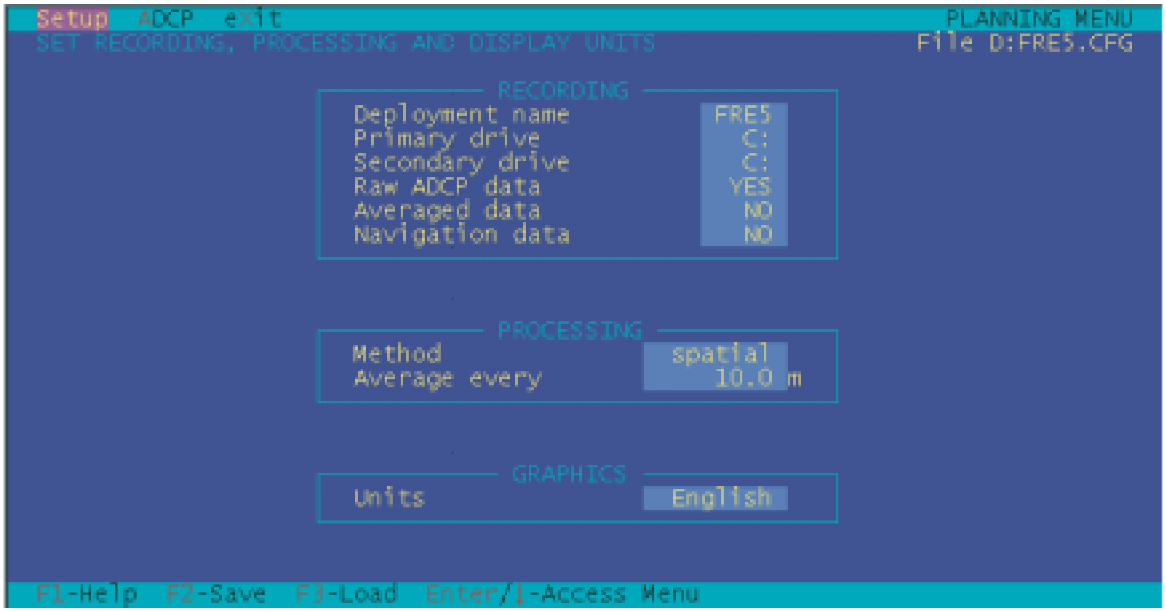


Figure 5.8. Planning setup submenu screen. ADCP, acoustic Doppler current profiler.

where all ADCP data collected with this configuration will be stored and it also forms the first four characters of each filename of ADCP data.

The primary and secondary drives in the setup submenu are usually the same and are used to construct the data storage path name. For example, data from the above example would be stored in the FRE5 directory on the C drive (C:\FRE5). The secondary drive is used in cases where the Transect software runs out of storage space on the primary drive. When hard disk space is limited, the secondary drive can be changed to indicate another hard disk or a floppy drive.

Data recorded with Transect may be stored in three different types of files: raw, processed (averaged), and navigation. Raw data always should be recorded for USGS discharge measurements. These data provide the operator with the ability to "play back" any discharge measurements that were recorded from unprocessed BB-ADCP data-output files. Processed data can be recorded if additional information needs to be stored during the discharge-measurement series. Raw data files contain unmodified data recorded directly from the ADCP. Processed data files typically contain averaged ADCP data, but also may contain data from an external navigation device, configuration-file data, and estimates of edge discharges.

Navigation data should not be recorded unless the BB-ADCP is connected to external navigation devices such as GPS or Loran C systems. The recording and processing of navigation data requires a recent version of the Transect software (4.00 or later) to execute properly. This report will not cover the operation of external navigation interfaces.

The processing selection (fig. 5.8) controls data averaging done by the Transect software (not in the BB-ADCP) and is used for processed data output. The raw ensemble data can be averaged with time (traverse time) or space (cross-section distance). This setting will affect the number of ensembles that are displayed during a cross-section traverse but will not affect the recording of raw ADCP data. The averaging of raw data is affected by the number of measurement pings averaged by the ADCP firmware (discussed in chap. 6).

The graphics and tabular displays can be annotated in either standard or metric units. This setting does not affect the raw data.

The planning ADCP submenu (fig. 5.9) allows the operator to input ship speed and the length of transect, and then provides the operator with a display of estimated transect time, first and last depth-cell positions, time between ensembles, and standard deviation of individual ensemble velocity averages. The operator also is informed of the amount of available disk space and disk space required for the transect.

If the operator has saved the configuration file at each of the above described menu steps, a configuration file has been created, much like the one in figure 5.10.

The Configuration File, in Detail

As explained in the previous section, the ADCP configuration file is used by the Transect software to communicate with, configure, and control an ADCP.

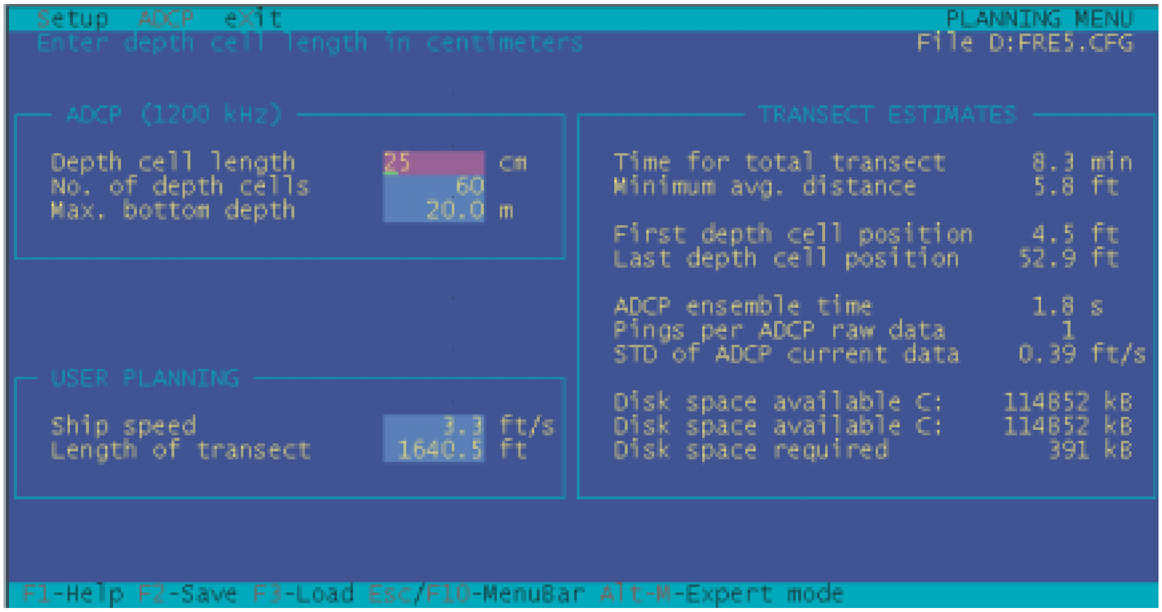


Figure 5.9. Planning acoustic Doppler current profiler submenu screen. ADCP, acoustic Doppler current profiler.

The configuration file also controls the type of data collected and where the data are stored on the host computer. Configuration files are standard text files that can be opened with a generic text editor.

The first line of a configuration file verifies that this is an official RDI configuration file and must be present for proper loading. If the line becomes altered or corrupted, the operator will get a message that reads "the file is not a Transect configuration file." If the above described error occurs, the line can be corrected (with the exact text shown in fig. 5.10) using a text editor.

The configuration file consists of the following sections:

- The communications section
- The calibration section
- The recording section
- The ADCP hardware section
- The direct command section
- The processing section
- The graphics section
- The history section

Each section of the configuration file addresses different aspects of ADCP command and control, as well as Transect software data storage and visualization. We will discuss each section of the configuration file in detail in the following paragraphs. Sections within the configuration file are enclosed in braces.

The Communications Section

The first section is the communication section, which sets up the Transect software to "talk" with the ADCP. The section contains directives in the form

```
Device 5sp (Switch sp Port sp Baud-rate sp
Paritybits sp Databits sp Stopbits) [port baud
parity databits stopbits]
```

where

sp = space.

Items in parentheses should be edited to match the device configuration. Items in brackets are reminders or comments and should not be changed. For example, if an ADCP were setup to communicate at 38,400 bauds per second with no parity, eight stop bits, and one data bit through the COM1 port of a computer, the first directive line would read: ADCP (ON COM1 38400 N 8 1) [Port Baud Parity Databits Stopbits].

There are directives for all allowed devices that might communicate with the Transect software through the various computer ports. The ADCP directive line is mandatory; however, the other directive switches should be turned off unless needed (fig. 5.10). These directives also can be set from the communication menu in the Transect software.

Ensemble Out Section

The ensemble out section (fig. 5.10) contains a series of toggles that enable or disable output of the various ensemble data. If the ENSOUT directive in the communication section is ON, then information from

```
BEGIN RDI CONFIGURATION FILE — This line must be first in all RDI configuration files

COMMUNICATIONS — Begin communication section
{
                  Switch  Port    Baud   Parity  Databits  Stopbits
ADCP — A Must      ON     COM1    9600    N        8         1      — Must be set to ADCP rate
ENSOUT             OFF    COM2    9600    N        8         1

NAV — This is for  OFF    COM3    9600    N        8         1    ┐
      GPS or Loran                                                │
REFOUT             OFF    COM4    9600    N        8         1    ├ Optional...see
                                                                  │ explanation in text.
EXTERNAL           OFF    COM5    9600    N        8         1    ┘
UseSoftwareBreak (NO) — This is set to yes when using a radio modem.
}

ADCP HARDWARE
{
Firmware     (5.57) ┐
Angle          (20) │
Frequency    (1200) │  This section (ADCP hardware) will fill with pertinent information
System       (SHIP) ├  when you start the acquire program (see text).  If you have set these
Mode            (1) │  values incorrectly, you will receive a warning message after the ADCP
Orientation (DOWN)  │  responds.
Pattern    (CONVEX) ┘
}
```

Figure 5.10. Communication, ensemble out, and acoustic Doppler current profiler (ADCP) hardware sections of the configuration file. RDI, R.D. Instruments, Inc.; GPS, global positioning system.

each ensemble is transmitted from the selected computer port. This section normally is not used for ADCP discharge measurements. Details for obtaining real-time ensemble data are available in the Transect software manual (R.D. Instruments, Inc., 1995). The ensemble out section also can be set up from the communications menu in the Transect software.

Acoustic Doppler Current Profiler Hardware Section

The ADCP hardware section (fig. 5.10) is a list of parameters that describe the ADCP hardware configuration. These parameters are not actually transmitted to the ADCP but are checked against actual ADCP hardware parameters upon ADCP "wake up." Missing parameters are filled in to match ADCP hardware. If the Transect software discovers a discrepancy between parameters in the configuration file ADCP hardware section and configuration data transmitted by the ADCP, a warning is displayed. Additional information regarding this check is given later in this chapter.

Direct Commands Section

Direct commands are commands interpreted by the ADCP, much like a computer operating system interprets commands issued by a user. Direct commands can affect the outcome of a discharge measurement, therefore, it is imperative that the ADCP operator fully understand the purpose and outcome of the basic direct command set. The direct commands section is the most important part of the configuration file (fig. 5.11). Some direct commands are mandatory for proper discharge measurement. Erroneous commands can cause improper operation of the ADCP. The most important of the direct commands are the water- and bottom-mode commands (WM, WV, and BM). These commands were discussed in chapter 3, and are not discussed here.

Some direct commands may be controlled from menus within the Transect software. Direct commands are discussed in detail in the technical manuals for the BB-ADCP, Rio Grande, and narrow-band ADCP (R.D. Instruments, Inc., 1995–1999) and many of them are not referenced in this report. However, an understanding of the most important commands is required for proper creation of configuration files.

Direct commands, like all other BB-ADCP parameters, can be edited into the configuration files without using the Transect software menus. However, the expert mode (alt-M) in the ADCP planning sub-menu provides an easy way to enter direct commands into the configuration file. This mode allows the operator to specify the direct commands that will be sent to the BB-ADCP during Transect initialization (fig. 5.12).

```
DIRECT COMMANDS — Direct command section:  These commands are very important
                  and are covered in detail later in chapter 5 of this report.
{
WS25 — Bin size
BX300 — Bottom-track depth
WNXXX — Number of water-measurement bins
WF50 — Blanking distance
WV170 — Mode 1 ambiguity velocity
WZ5 — Mode 5 lag
WD111100000 — Output data types
WM1 — Water mode 1 — Number of bottom pings
WP5 — Number of water pings
BP4 — Number of bottom pings
BM5 — Bottom-track mode
TP000006 — Time between pings
EX10111 — Coordinate transformation flags
ES0 — Salinity
}

RECORDING — Beginning of the ADCP recording setup section
{
Deployment  (FRE5) — Unique four-letter deployment name
Drive 1  (C) — Primary data storage drive
Drive 2  (C) — Secondary (or emergency) data drive
ADCP  (YES) — Set YES to record ADCP data (a MUST)
Average  (NO) — Averaged data are not usually recorded
Navigation  (NO) — Set to No external GPS data are recorded
StartRecording (NO) — Set to yes to turn recording on by default
                      when Transect is first started.
}
```

Figure 5.11. Direct command and recording sections of the configuration file. ADCP, acoustic Doppler current profiler; GPS, Global Positioning System.

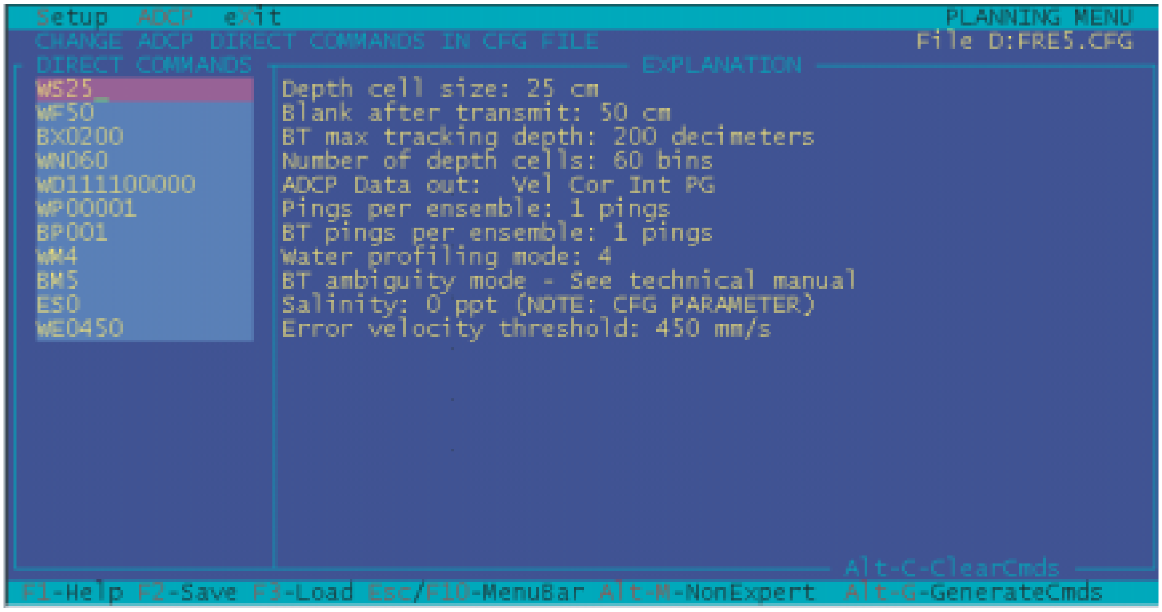


Figure 5.12. Planning acoustic Doppler current profiler (ADCP) menu in expert mode (Alt-M).

The direct command numeric arguments are set by the manufacturer and are in metric units. To avoid confusion, standard-unit conversions will not be presented in the following discussion. All direct commands listed in the technical manual are important; however, some are set by default and almost never change, some are not changed except under rare conditions, and some are changed dynamically by the instrument. Some direct commands must be changed by the operator for optimum BB-ADCP operation in changing environments and are discussed below.

When discussing the direct commands, the syntax for each command will be shown as CCnnnn, where CC is a two-letter command; and nnnn is an integer parameter. For example, the water ping command will be referred to as WPnnnn, where nnnn is the number of water pings averaged for a data ensemble.

Water-Track Commands

WSnnn

WSnnn is the command used to set the length, in centimeters, of the depth cell used for water-velocity measurement (0–999), and controls the vertical resolution of the measured-velocity profile. In most cases, this value of WS can be determined using table 5.1

These settings provide the best resolution in the event that velocity profile information must be extracted from the discharge measurement. By default, these values are placed in the direct command section when a new configuration file is created with the ADCP frequency specified. In some cases, these values may have to be changed (in very deep or very shallow water, for example). Consult the BB-ADCP technical manual before doing so. The WS parameter also may be set in the planning menu of the Transect software.

WNnnn

WNnnn is the command used to set the number of water-velocity measurements (depth cells) in the vertical profile, and can have a numeric range of 1–128. This value should be set so that WS multiplied by WN exceeds the maximum expected depth in the cross section by a safe margin. CAUTION! Failure to properly set this parameter can cause loss of discharge-measurement accuracy, loss of vertical resolution, and incomplete velocity profiles. This parameter also can be set using the planning menu in the Transect software.

WPnnnn

WPnnnn is the command that sets the number of water-velocity measurements (pings) that are averaged together to form a data ensemble (range from 0 to

Table 5.1. Optimum bin size (WSnnn) for acoustic Doppler current profiler (ADCP) discharge-measurement applications

[kHz, kilohertz]

ADCP water mode	WSnnn for 1,200-kHz ADCP	WSnnn for 600-kHz ADCP	WSnnn for 300-kHz ADCP
Mode 1	25	50	100
Mode 5	5	10	20
Mode 8	5	10	20

6384). As a general rule it is recommended that this value be set to 1 because if an ambiguity error occurs, it will not be averaged with other pings and therefore can be readily identified. If data are averaged by using a WP command greater than 1 and an ambiguity error occurs in one of the ensembles, it will be averaged along with the good pings and will cause a bias error that may not be recognized when the data are played back. In situations where many ambiguity errors occur, the discharge measurement will be biased. This bias can occur using water modes 5 and 8 and sometimes is seen using mode 1 during dynamic conditions.

In some cases during low-flow measurements, when using mode 1, a modest number of pings can be averaged to help reduce the standard deviation of the discharge measurement. Averaging pings in the ADCP by using a non-zero WP command can increase the total number of pings collected during a discharge measurement because the ADCP firmware processes data faster than the Transect software. However, using a non-zero WP command is dangerous (because of the possibility of disguised velocity ambiguities) and should be used with caution.

WFnnnn

WFnnnn is a command used to set transducer blanking distance (range 0–9999 cm); the blanking-distance command defines the regions near the transducer faces where no velocity data should be collected. Depth cells close to the transducer faces may be corrupted because transmitted energy has not completely dissipated from the electronics or transducer ceramics. If this command is set too low, it may cause corruption of the first measured velocity bin. This corruption can be very hard to detect. For 1,200- and 600-kHz BB-ADCP units, the recommended minimum setting for this value is 50 for mode 1 and 30 for modes 5 and 8 operation. For Rio Grande units, the recommended setting for this value is 25 for all modes. Minimum recommended values for this parameter also depend upon operating frequency.

WDnnn nnn nnn

WDnnn nnn nnn is the water-data output from the BB-ADCP. The toggles for these parameters are set to 1 or 0 (1 = enabled, 0 = disabled) for the following data: velocity, correlation, intensity, percent good, status, and P0, P1, P2, and P3 (Px = external parameter data 0–3). For example, WD111100000 outputs velocity, correlation, intensity, and percent good.

Bottom-Track Commands

BAnnn

BAnnn is the bottom-track evaluation amplitude minimum (1–255 counts). This command defaults to 30, but can be changed to 25 when bottom movement is suspected. Values lower than 25 should not be used because of the possibility of velocity-measurement contamination by sediment moving above the bottom. When bottom-sediment movement is present, using lower frequency ADCPs (300- or 600-kHz) may sometimes help eliminate bottom-movement bias (chap. 3) (example BA25).

BCnnn

BCnnn is the bottom-track correlation magnitude minimum (1–255 counts). The BB-ADCP flags any data having a correlation magnitude less than this value as bad data—perfect correlation (solid target) is 255 counts and the default value is 220 counts. This value can be set slightly lower when bottom tracking is difficult to acquire (example BC210).

BPnnn

BPnnn is the number of bottom pings that are averaged for each data ensemble (1–999 pings). This value should be set to the same value as that of the WP command, or one less than the WP command if more than one water ping is averaged for each data ensemble (example BP01).

BXnnnn

BXnnnn is the maximum bottom-track search depth, in decimeters [80–9999 decimeters (dm)]. This value should be set to match the deepest expected depth plus a safety factor. CAUTION! Error in this parameter in water deeper than 8 m can cause loss of bottom track and invalid discharge measurements because of missing ensembles. This parameter is set in decimeters, rather than centimeters, and, therefore, is more prone to operator setup errors (example BX100).

&Rnn

The &Rnn command, while not a standard bottom-track command, must be set properly in the BB-ADCP because the default setting is not optimized for river discharge measurement. The value nn is the length of the bottom-track pulse, in percent of total depth. In BB-ADCP firmware, the default for this is 30 (30 percent). The manufacturer suggests that a value of 20 (20 percent) is more applicable to riverine environments. The recommended setting for this command is &R20, and it should be included in the direct commands section of the configuration file so that the default value is overwritten.

General Commands

ESnn

ESnn is the estimated salinity, in parts per thousand (0–40). It is important to set this parameter properly because the BB-ADCP default setting is for open ocean (ES35), which can cause discharge-measurement errors in freshwater if undetected. An ES0 command is necessary in the configuration file if measuring freshwater. Salinity in brackish or oceanic waters should be measured with a salinimeter. Unless the salinity is known, this command always should be set for zero salinity (ES0) because the value can be changed after the fact in the Transect calibration section (if it is discovered that brackish water was present, for example). If the value is set to the wrong salinity (other than 0) in the direct command section, it is much harder to correct the resulting discharge values.

EXnnnnn

EXnnnnn is the set of coordinate transformation flags, where each n in the command is set to a 1 or a 0, according to the following encoding scheme:

- •EX00nnn = no transformation (beam coordinates)
- •EX01nnn = instrument coordinates
- •EX10nnn= ship coordinates
- •EX11nnn = Earth coordinates
- •EXnn1nn = uses tilts (pitch and roll) in transformation
- •EXnnn1n = allows three-beam solutions if one beam is below WC threshold
- •EXnnnn1 = allows bin mapping

This command allows the BB-ADCP to transform beam coordinates into other coordinate systems. The Transect software can do the above transformations if radial-beam velocities (beam coordinates) are recorded (the default mode). For robust operation, the BB-ADCP probably should be set for ship coordinate transformation because the data are transformed in the Transect software rather than adjustments made to the raw recorded data.

If velocity profiles are required, it is preferable to collect raw data in beam coordinates because of the difficulty in changing coordinate systems after conversion to Earth coordinates. (It is difficult to “back out” raw-beam coordinates if there is no ping-by-ping record of the corrections for pitch, roll, and heading.)

When recording in ship or beam coordinates while averaging ensemble data in the profiler, pitch, roll, and sharp boat movements and heading changes should be kept to a minimum. Corrections for these events are calculated by the Transect software at the end of the ensemble (not for each ping). For example, if averaging is set to five water pings and five bottom-track pings per ensemble and beam coordinate transformation is selected, coordinate transformation and pitch and roll correction will not occur until the averaged ensemble is transmitted to the computer from the ADCP. In the above case, the transformation and correction occurs at the end of a 4- to 5-second interval. If the boat has pitched or rolled significantly during the 5-second period, the correction may be applied incorrectly or not applied at all. For velocity coordinates, the Transect software calculation is not affected by the coordinate system being used, however the software does require exact synchronization between the bottom-track vector and the water-track vector. If both coordinates are Earth transformed at the end of a 5-second interval and there are abrupt heading changes during the interval, the synchronization of these vectors may not be achieved because of time/phase lag in the onboard flux-gate compass. For these reasons, despite the lower ADCP ping-rate performance, the WP and BP commands probably should be set to average 1 ping for each data ensemble (WP01 and BP01) in windy conditions or conditions with a significant amount of pitch and roll.

Another reason for setting WP and BP to 1 is so ambiguity errors (chap. 3) will be more apparent. If data are averaged along with an ambiguity error, the error could be masked because of the averaging. This can be especially devastating in mode 5 because ambiguity errors are more likely to occur.

Pitch and roll corrections should be applied, unless the tilt sensors are defective. If tilt sensors are transmitting invalid data, they can be disabled to collect discharge data.

In most cases, three-beam solutions always should be enabled so that velocities can be calculated in the event that data are lost from one beam, however, there is some controversy as to the proper setting for three-beam solutions. Please check the USGS ADCP users web site (http://il.water.usgs.gov/adcp/) for late-breaking instructions.

Bin-depth mapping should be enabled so that the measurement bins are kept at the same depth for each beam during a pitch and roll event.

For example, an EX00111 command does no coordinate conversion (beam coordinates, uses pitch and roll in the transformation, allows three-beam solutions for missing beams, and allows bin-depth mapping for pitch and roll).

Recording Section

The recording section of the configuration file (fig. 5.11) contains information that is used by the

Transect software to set up the data recording paths, as well as specifications for drive priority, averaged data recording, and navigational data recording. Required sections are as follows:

- Deployment (cccc), where cccc is a four-character file name to be used as a prefix for the data file. For example, if the operator picks deployment (TUFA), resulting file names will be TUFA001r.000, TUFA002r.000, and so forth. The deployment name and configuration file name should be the same to keep the correct configuration file synchronized with the correct data set (version 2.72 and earlier). Version 2.80 (and later) of the Transect software stores a configuration file with each transect, thereby eliminating the synchronization problem.
- Drive 1 (d) where d is the path name for the primary data-storage drive. For example, if drive C:\ is the primary data drive, then the proper directive is drive 1 (C).
- Drive 2 (d) where d is the path name for the secondary data-storage drive. For example, if drive C is nearly full and is the primary data-storage drive, the Transect software will automatically switch to the secondary storage drive upon filling C drive with data. If a formatted floppy disk is placed in drive A for such an emergency, then the proper directive would be drive 2 (A).
- ADCP (YES/NO) specifies that the Transect software record (or not record) ADCP raw (unaveraged) data. This always should be set to YES.
- Average (YES/NO) specifies that the Transect software record (or not record) averaged data. This directive usually is set to NO, unless the operator wishes to record averaged data. Because raw data can be averaged on playback, this directive usually is not needed, even if averaged data are desired.
- Navigation (YES/NO) specifies that the Transect software record (or not record) external-navigation data. This is set to YES if external-navigation data from Loran C or GPS systems are to be recorded with each ensemble. Any external RS-232 data can be recorded in this manner and synchronized with the ADCP data.

Calibration Section

The calibration section of the configuration file (fig. 5.13) contains important information that supplies the Transect software with data that are vital to proper coordinate transformation and discharge calculation. Note that these data can be changed upon playback and are not part of the raw data file.

- ADCP depth, in meters, is the draft (depth below water surface) of the ADCP transducer faces. This parameter is used by the Transect software to calculate the depths at the bin centers and is vital to the proper calculation of the curve fit estimation data as well as subsection depth.
- Heading/magnetic offsets are values that are primarily used to correct the internal flux gate compass of an ADCP to true north. One parameter adjusts for magnetic anomalies (such as metal objects), whereas the other adjusts for magnetic declination obtained from navigational charts or maps.
- Transducer misalignment is a value that is nonzero only when the compass is separate from the transducer assembly. This value is used to correct the azimuth of the transducer assembly to the azimuth of the compass (in degrees), and is primarily used with gyroscopic-based heading systems.
- The intensity and absorption values are scale factors used to correct the raw, backscattered intensity counts from the ADCP into decibel values corrected for receiver gain and range. The intensity scale factor is used to convert raw counts to decibels and should be left at the default value unless other values are indicated. From the calibration menu, the absorption value can be set to a default value, set to a known value, or calculated by the Transect software as a function of frequency, water temperature, and salinity. All three choices can be made from the Transect calibration software by tabbing to the appropriate selection in the sound absorption coefficient part of the scaling submenu.
- Salinity should be set to the measured or estimated salinity at the measurement site.
- Speed-of-sound correction and pitch-and-roll compensation normally should be set to YES, unless the temperature or tilt sensors are providing erroneous data.
- Tilt misalignment, pitch offset, and roll offset normally are set to zero unless the tilt sensors are mounted external to the ADCP case.
- Top discharge estimate can be set to POWER or CONSTANT. If it is set to POWER, then the Transect software uses the power-curve coefficient to estimate velocities in the unmeasured area near the water surface. If it is set to CONSTANT, then the Transect software

```
CALIBRATION — ADCP calibration section (discussed in detail in chapter 5 of this report ).
{
ADCP depth (0.16 m) — ADCP draft (distance below water surface).
DBTDraft (0.00 m) — Depth sounder draft (if an external depth sounder is used).
Heading / Magnetic offset (0.00 10.00 deg) — For setting compass alignment to true north.
Transducer misalignment (0.00 deg) — For aligning compass to ADCP (if compass is separate).
Intensity scale (0.43 dB/cts)
Absorption (0.278 dB/m)
    } Normally left at default values.
Salinity (0.0 ppt) — Set to correct salinity value here (or zero if in doubt).
Speed of sound correction (YES)
Pitch & roll compensation (YES)
    } Normally set to YES.
Tilt Misalignment (0.00 deg)
Pitch_Offset  (0.000 deg)
Roll_Offset (0.000 deg)
    } Normally set to 0.00 unless the tilt sensors are mounted external to the ADCP case.
Top discharge estimate (POWER)
Bottom discharge estimate (POWER)
    } Normally set to POWER.
Power curve exponent (0.1667) — Normally set to 0.1667 unless the velocity profiles appear to be nonstandard.
}
```

Figure 5.13. Calibration section of the configuration file. ADCP, acoustic Doppler current profiler.

uses the same cross product as is used for the uppermost measured bin to estimate near-surface, unmeasured discharge. Chapter 8 contains a discussion on how to examine the measured profiles to determine the proper estimation technique.

- Bottom discharge estimate can be set to POWER or CONSTANT. If it is set to POWER, then the Transect software uses the power-curve coefficient to estimate velocities in the unmeasured area near the channel bed. If it is set to CONSTANT, then the Transect software uses the same cross product as is used for the bottom-most measured bin to estimate near-bottom, unmeasured discharge. Chapter 8 contains a discussion on how to examine the measured profiles to determine the proper estimation technique.

- Power-curve exponent usually is set to 0.1667 for a “Manning-like” water-velocity profile. Under most conditions, this value should be set to the one-sixth power setting (0.1667), even in the estuary. A good test of this value is to pick a transect and average a series of ensembles in the deeper, faster part of the cross section. The averaged profile then should be then viewed from the discharge profile plot in the Transect software playback menu. If the plotted power curve fits the data points, the one-sixth exponent value can be used. If the plotted power curve does not fit the data, other exponent values can be tried until a good fit is obtained. If the velocity profile is distinctly nonstandard, or crosses zero (bidirectional) then a power-curve fit should not be used (use CONSTANT for top and bottom velocity estimates). This technique will be discussed in more detail in chapter 8.

Processing Section

The processing section of the configuration file (fig. 5.14) contains directives to the Transect software that control ensemble averaging, profiled depth, and internal depth-sounder data, as well as directives that control the output of an external velocity monitor (refout):

- Average every () directive can be set to a time value or a spatial value. For example, if the value is set to "average every [5.00 seconds (s)]," then the Transect software will display an averaged output to the console every 5 s. This parameter also can be set to a metric distance value. "Average every (5.00 m)" will send an averaged output to the console every 5 m (16 ft). During data acquisition (acquire) it usually is best to set this value to zero for faster updates to the computer screen. The setting of this value will not affect the raw-data file.
- Depth-sounder value must be set [(YES) or (NO).] If the ADCP has an internal fifth-beam depth sounder, this value should be set to YES; otherwise, it should be set to NO. (This normally should be set to NO, unless you have a special system.)
- BTM layer percent () is a value that overrides the normal maximum bottom profile range percentage (85 percent with 30º transducer angle and 94 percent with 20º transducer angles). This directive need not be used unless the operator wishes to change the default profiling range for the ADCP. This change must be made for old firmware versions for mode 5 operation and for other special circumstances. The accuracy of the Transect software output data can be seriously degraded if this value is set incorrectly. Inclusion of this command is not recommended unless you are trying to use water mode 5 with an older BB-ADCP with phase 2 firmware.

The remainder of the values in the processing section are not discussed in this report, and are used only if data are being sent to an external reference via an RS-232 port. Information on these settings is in the BB-ADCP or Rio Grande technical manual (R.D. Instruments, Inc., 1995–1999).

Graphics Section

The graphics section of the configuration file controls the Transect software display scaling factors. This section is best changed from within the Transect software in either the Acquire or playback software using the F6 special function key. These settings are discussed in chapters 6 and 8.

History Section

The history section of the configuration file is modified by the Transect software. This section gives the version number of the Transect software used with the configuration file and should not be changed by the operator.

Finishing the Preliminary Configuration File: Required Commands

Before the preliminary configuration file that we created in the first part of this chapter can be used for data collection, some additional commands must be added, either by using an editor or by using the expert mode in the Transect software calibration menu. The sections must be checked, changed, or modified (figs. 5.15–5.18).

Entries in the ADCP hardware section that are added by the Transect software during the first run of the Acquire module are shown in figure 5.15. These entries also can be added using a text editor such as Microsoft Disk Operating System (MS DOS) Edit. The Transect software will check the values against values returned from the ADCP and will deliver a warning to the operator if they do not match.

Entries in the direct command sections that must be checked and entered manually, if necessary, also are shown in figure 5.15. The command syntax and purpose are discussed in the Direct Commands Section earlier in this chapter. The critical entries to check are as follows:

- WPnnn is the water pings per ensemble. This value normally should be set to 1 (example WP001).
- BPnnn is bottom pings per ensemble. This value normally should be set to the same value as the WP value (example BP001).
- ESnn is estimated salinity, in parts per thousand. This value should be set to zero, unless the operator is sure of the actual salinity value (example ES0). The Transect software can calculate speed-of-sound using salinity values after-the-fact.
- EXnnnnn is for coordinate transformation. If beam coordinates are selected, then EX00111 should be used.
- BXnnnn is bottom-track maximum search depth, in decimeters. This value should be set slightly deeper than the expected maximum depth at the measurement site. Loss of bottom track can result if this value is too shallow, and

```
PROCESSING — Beginning of the ADCP processing parameter section.
{
Average every (0.00 s) — Normally set to 0.00 unless you are data averaging
Use Depth Sounder (NO) — Set to NO unless the ADCP has a depth-sounder beam.
MaxFileSize (1200)
External_formats (N N N N N) [HDT HDG RDID RDIE]
External_decode (N N N N) [heading pitch roll temp]
Start_Shore_distance (-1) [cm]
End_Shore_distance (-1) [cm]
Edge_distance_prompt (NO)
Use GPS For Btm (0)
}
```

These data should be left alone unless the ADCP output is being sent to an external monitor or device other than the computer running the Transect software.

```
GRAPHICS — Graphics parameter section.
Units (English)
Velocity Reference (BOTTOM)
East_Velocity (-1.0  1.0  ft/s)
North_Velocity (-1.0  1.0 ft/s)
Vert_Velocity (-0.5  0.5 ft/s)
Error_Velocity (-0.5  0.5 ft/s)
Depth (1   35 bin)
Intensity (50  200 counts)
Discharge (-1  1 ft3/s)
East_Track (-211  211 ft)
North_Track (-190  231 ft)
Ship track (1 bin  0.5 ft/s)
Proj_Velocity (-1.0  1.0 ft/s)
Proj_Angle (250.0 deg from N)
Bad_Below_Bottom (YES)
Line1 ('Standard' Config file for 1200 kHz)
Line2 (Mode 1 -- 25cm bins -- 5 WP 4 BP -- Ship)
}
```

These values are set in the Transect program and should not be changed directly by editing the configuration file.

Information stored in these lines is displayed on Transect's output data plots.

```
HISTORY
{
SOFTWARE (BB-TRANSECT)
Version (4.05)
}
END RDI CONFIGURATION FILE — This is a required end-of-file statement.
```

This section should not be modified. Transect stores the version number here that was used to collect discharge data.

Figure 5.14. Processing, graphics, and history sections of the configuration file. ADCP, acoustic Doppler current profiler; GPS, Global Positioning System; RDI, R.D. Instruments, Inc.

```
BEGIN RDI CONFIGURATION FILE
COMMUNICATIONS
{
ADCP  (ON COM1 9600 N 8 1) [Port Baud Parity Databits Stopbits]
ENSOUT(OFF COM2 9600 N 8 1) [Port Baud Parity Databits Stopbits]
NAV  (OFF COM3 9600 N 8 1) [Port Baud Parity Databits Stopbits]
REFOUT(OFF COM4 9600 N 8 1) [Port Baud Parity Databits Stopbits]
EXTERNAL (OFF COM5 9600 N 8 1) [Port Baud Parity Databits Stopbits]
UseSoftwareBreak (NO)
}
ENSEMBLE OUT
{
ENS CHOICE (NNNNNNNN)[Vel Corr Int %Gd Status Leader BTrack Nav]
ENS OPTIONS (Bottom 1 8 18) [Ref First Last Start End]
ENS TYPE (RAW) [RAW (default) or AVERAGED data transmitted]
}
ADCP HARDWARE
{
Firmware (5.57)
Angle (20)
Frequency (1200)
System (SHIP)
Mode (1)
Orientation (DOWN)
Pattern (CONVEX)
}
```

This section now has information that should correspond to the current ADCP hardware on your system.

```
DIRECT COMMANDS
{
BX200 — The maximum bottom-track depth is 200 decimeters (20 meters).
WS50 — Water bin size is 50 centimeters.
WN060 — Set for 60 depth bins.
WF50 — Blanking distance is 50 centimeters.
WV170 — Mode 1 ambiguity velocity is set for 170 centimeters per second.
WD111100000  — Data collected are velocity, correlation, intensity, and percent good.
WM1 — Water-measurement mode 1.
WP1 — One water ping averaged per ensemble.
BP1 — One bottom ping averaged per ensemble.
BM5 —Bottom-measurement mode 5.
EX10111 — Coordinates are ship, with pitch and roll correction and bin mapping enabled.
ES0  — Salinity is set to zero.
&R20 — Bottom-track bin size is set to 20 percent of the measured depth.
}
```

Figure 5.15. Hardware and direct command sections of the configuration file. RDI, R.D. Instruments, Inc.; ADCP, acoustic Doppler current profiler.

```
RECORDING
{
Deployment (FRE5) — Make sure to update this deployment name when
                    using the CFG file in another area.
Drive 1  (C)
Drive 2 (C)
ADCP (YES)
Average (NO)
Navigation (NO)
StartRecording (NO)
}
```

Figure 5.16. Recording section of the configuration file. ADCP, acoustic Doppler current profiler; CFG, configuration (file).

excessive ensemble times can result if it is too deep. For example, a BX0250 command sets the bottom-track maximum search depth at 25 m.

- WMnn, BMnn, and WVnnnn are water and bottom mode commands. These commands should be added per instructions in chapter 3.

The recording and calibration sections of the completed configuration file are shown in figures 5.16 and 5.17, respectively. If the configuration file is renamed for use at another measurement site, the four-character deployment name must be changed to one matching the new site. If the configuration file is reused at another site, the proper transducer draft must be entered. Failure to do so can cause significant errors when measuring shallow/wide rivers. The two-line comment in the graphics section (fig. 5.18) also should be updated when reusing the configuration file.

Transect Release Enhancements (2.80 and Later)

For purposes of brevity, Transect software releases 2.80 and later hereafter will be referred to as Transect 2.80+. The following enhancements are included in Transect software release 2.80+:

- A copy of the configuration file is saved with each discharge data file with the letter C imbedded in the file name. Example—If the raw data file name is JUNK001R.000, then the configuration file is JUNK001C.000.
- The user is prompted for starting and ending edge distances. These values are stored in the configuration file and in the processed data file, if one has been generated.
- The unique configuration file can be loaded automatically and used during the Transect software playback.
- The Transect module “Acquire” starts with recording turned off. This feature eliminates two keystrokes at the start of each measurement. Percent good is redefined by the user in processed data files.
- The Transect software will extrapolate discharge in missing bins.
- Default data file size is changed from 300 kilobytes (K) to 1,200 K.
- Other enhancements are included as detailed in the Transect version 2.80 software documentation.

Transect 2.80+ operation requires some additional commands within the configuration file and at the DOS prompt (or in the Autoexec.bat file).

Earlier versions of the Transect software allowed only for a triangular-shaped edge slope. Transect 2.80+ allows the operator to select an edge slope that can vary from square to no slope at all (fig. 5.19). Entering a -1 directs the Transect software to use a triangular-shaped edge slope (default). Entering a -2 directs the Transect software to use a square-edged slope, and entering a value between 1 and 0 directs the software to use that value as a slope coefficient where 0.91 is nearly square, 0.35 is almost triangular, and 0.05 is nearly flat (fig. 5.19).

In the processing section of the configuration file, there are three new items used by Transect 2.80+. If Edge_distance_prompt is set to YES, then the software will prompt the operator for edge-distance estimates during data acquisition (acquire). The values that are entered by the operator are saved in the configuration file in the Start_Shore_distance and the End_Shore_distance variables (fig. 5.20).

Several DOS environmental variables also must be set before running Transect 2.80+. DOS environmental variables can be compared to memory “mail boxes.” The system operator puts a directive into a mail box, and when the Transect starts, it checks the mail box, reads the mail, and takes appropriate action. In the case of Transect 2.80+, four environmental variables (mail boxes) are used to send directives to the Transect software. The first environmental variable is typed at the DOS prompt, or in the Autoexec.bat file; (set AUTOSAVECFG = Y). This environmental variable tells the Transect software to save a configuration file with each save of a raw- (or processed-) data file. The file names have the following form. If the deployment name in the RECORDING section of the configuration file is, ARKN, for example, then the files saved are

- •ARKN001R.000 for the raw-data file;
- •ARKN001P.000 for the processed-data file (if requested);
- •ARKN001C.000 for the configuration file (this is the new one!);
- •ARKN001N.000 for the navigation file (if requested).

```
CALIBRATION
{
ADCP depth (0.16 m)
DBTDraft (0.00 m)
Heading / Magnetic offset (0.00  0.00 deg)
Transducer misalignment (0.00 deg)
Intensity scale (0.43 dB/cts)
Absorption (0.278 dB/m)
Salinity (0.0 ppt)
Speed of sound correction  (YES)
Pitch & roll compensation (YES)
Tilt Misalignment (0.00 deg)
Pitch_Offset (0.000 deg)
Roll_Offset (0.000 deg)
Top discharge estimate (POWER)
Bottom discharge estimate (POWER)
Power curve exponent (0.1667)
Edge_slope coefficient (-1.00000) [-1=Trianglar(0.3535):-2=Square(0.91):User]
OneCycleK (0.0000000)
OneCycleOffset (0.0000000)
TwoCycleK (0.0000000)
TwoCycleOffset (0.0000000)
DBTOffset (0.00 m)
DBTScaleFactor (NO)
GPSLead (0.00 s)
}
```

— This value must be updated when copying the CFG file for use in a new deployment.

Figure 5.17. Calibration section of the configuration file. ADCP, acoustic Doppler current profiler; GPS, Global Positioning System.

(Graphics section in part)

```
Proj_Angle (250.0 deg from N)
Bad_Below_Bottom (YES)
Line 1 (Sacramento River at Freeport)
Line 2 (Mode 1 -- 25cm bins -- 5 WP 4 BP -- Ship)
}
HISTORY
{
SOFTWARE (BB-TRANSECT)
Version (4.05)
}
END RDI CONFIGURATION FILE
```

Remember to update this two-line message when redeploying the ADCP in a new area

Figure 5.18. Graphics and history sections of the configuration file. ADCP, acoustic Doppler current profiler; RDI, R.D. Instruments, Inc.

If AUTOSAVECFG = N or is missing, the Transect software will not save a configuration file when it saves a data file.

The second environmental variable is AUTOLOADCFG. Transect 2.80+ will autoload the matching configuration file when a data file is loaded for playback if the environmental variable AUTOLOADCFG is set to Y; (set AUTOLOADCFG = Y). These first two directives greatly enhance the post-processing of the Transect software data files. Although still necessary, the operator is not dependent only upon the log sheets for the recording of edge distance estimates. The operator also will be assured that changes to the transducer draft and other configuration directives will not be inadvertently applied to the wrong data files during playback.

The third environmental variable is STARTRECORDOFF, which can effectively eliminate one minor annoyance that is present in earlier versions of the Transect software; (set STARTRECORDOFF = Y).

This variable tells the Transect software to start the Acquire software with the data recording toggled OFF. Many operators prefer to start the cross-section traverse with the recording turned off because discharge should not be collected with zero good bins or only one good discharge bin. Recording can begin when the operator observes that velocities are being properly measured (chap. 7). Older versions of the Transect software started with recording turned on and the operator was required to toggle recording off before starting ADCP data collection.

The fourth and final environmental variable relates to the collection of processed-data files. Older versions of the Transect software used an unusual definition of percent good to describe the data in each averaged bin (number of good four-beam and three-beam Earth transformations). In Transect 2.80, the operator can define the meaning of percent good in a processed-data file by setting the following environmental variables; (set USEPERCVEL = Y).

If this variable is set to Y, percent good will equal the number of good velocity values in each bin, averaged together by the Transect software; (set USEPERCQ=Y).

If this variable is set to Y, percent good will equal the number of good discharges in each bin averaged together by the Transect software. Note: the "redefined" percent good will be saved to the processed-data files, but nothing is saved to indicate which of the above two definitions were used.

To ensure that the above environmental variables are set each time the Transect software is run, the operator should edit them into the Autoexec.bat file in the boot drive root directory.

The additions to the Transect configuration file, discussed above, can be entered with a text editor or added from the Transect software calibration menu. In the Transect software calibration menu, the

```
CALIBRATION
{
ADCP depth (0.16 m)
DBTDraft (0.00 m)
Heading / Magnetic offset (0.00  0.00 deg)
Transducer misalignment (0.00 deg)
Intensity scale (0.43 dB/cts)
Absorption (0.278 dB/m)
Salinity (0.0 ppt)
Speed of sound correction (YES)
Pitch & roll compensation (YES)
Tilt Misalignment (0.00 deg)
Pitch_Offset (0.000 deg)
Roll_Offset (0.000 deg)
Top discharge estimate (POWER)
Bottom discharge estimate (POWER)
Power curve exponent (0.1667)
Edge_slope coefficient (-1.00000) [-1=Trianglar(0.3535):2 =
    Square(0.91):User]
}
```

- Enter "-1" for a Trianglar edge slope (0.3535) (default)
- Enter "-2" for a Square edge slope (0.91)
- Enter a coefficient between 0 and 1 (see diagram)

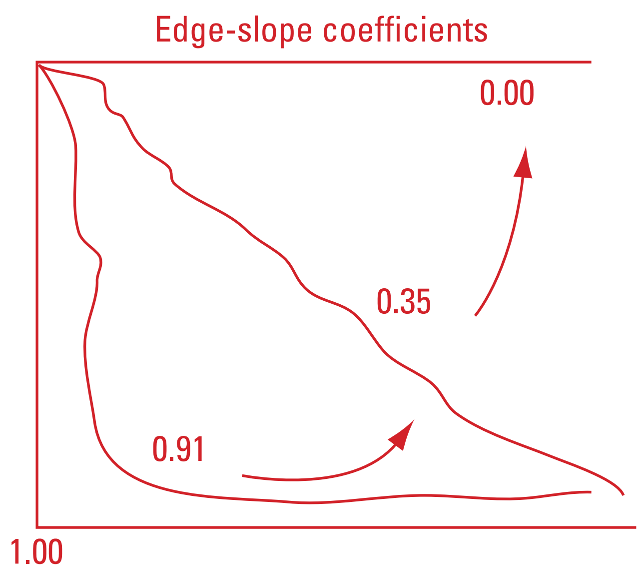


Figure 5.19. Edge-slope coefficient in the Transect 2.80+ configuration file. ADCP, acoustic Doppler current profiler.

```
PROCESSING
{
Average every (0.00 s)
Use Depth Sounder (NO)
MaxFileSize  (1200) — This value defaults to 1200 kilobytes. When the file size reaches
                      1200 kilobytes, it is saved and the file extension is incremented
                      by 001 and a new file is started.
External_formats  (N N N N N)  [ HDT HDG RDID RDIE ]
External_decode   (N N N N) [ heading pitch roll temp ]
Start_Shore_distance  (-1) [ cm ] ⎤ These values will be added by the operator during
End_Shore_distance    (-1) [ cm ] ⎦   transect if ...
Edge_distance_prompt  (YES) — ... THIS value is set to YES (prompts the operator for edge
}                                 values).
```

Figure 5.20. Transect 2.80+ directives in the processing section of the configuration file.

configuration file must be loaded before the operator moves to the scaling screen. In the DISCHARGE EXTRAPOLATION box, the “Prompt for Edge Shore Distances” should be set to YES with the spacebar. The “Edge Shore Coefficient” for the channel should be selected. If the “Edge Shore Coefficient” is unknown, TRANGLE should be selected.

Summary

The Transect software requires a companion configuration file for each measurement session. The configuration file contains instrument and recording setup data that enable the Transect software to properly measure the cross-section discharge and to store the resulting data. This configuration file can be created from within the Transect software or can be modified from a preexisting configuration file using a text editor. The configuration file should be checked before use with an American standard code for information interchange (ASCII) text editor to verify that the correct direct commands and recording parameters have been included and that unwanted commands are not present.

CHAPTER 6: DATA ACQUISITION

Operation of Transect Software

As described in chapter 5, Transect is a series of stand-alone software modules that are run from an executable menu program named Transect.exe. Transect.exe is an MS DOS-based computer program that can be run from an MS DOS prompt or from a batch file. There are several command line switches that can be used when running Transect, but we will discuss only the "/m" switch. The /m switch runs the Transect software in monochrome mode. It can be used when running Transect on a laptop with a monochrome liquid crystal display or on a laptop with a color screen if increased contrast is desired. For example, if the operator wishes to start Transect in monochrome mode, he would simply invoke Transect by typing TRANSECT /M at the command prompt. The default (color) mode is invoked by simply typing TRANSECT at the command prompt. Unlike unix, MS DOS commands can by typed in upper or lower case.

In chapter 5 we discussed the communication, calibration, and planning modules of the Transect software. In this chapter we will discuss the operation of the Acquire module.

Loading the Configuration File

During Transect initialization, the Transect software must obtain a valid configuration file. The proper configuration file can be loaded manually into the Transect software from any of the menus by pressing F3 and supplying a configuration file name (for example, by typing SACU.CFG). The Transect software stores the name of the last configuration file used in a small file called TRANSECT.PTR. TRANSECT.PTR may be edited and modified prior to entering the Transect software. For example, the TRANSECT.PTR file contains the following command: C:\SACU.CFG. When the Transect software starts, it will look for a file named SACU.CFG for its initial configuration. Any valid file path name can be entered into TRANSECT.PTR. For example, when TRANSECT.PTR is edited and C:\SACU.CFG is replaced with C:\BBTRAN26\SACU.CFG, the Transect program will find and load SACU.CFG from the C:\BBTRAN26 directory.

Starting the Transect Acquire Module

Entry into the Acquire menu (fig. 6.1) causes the Transect software to load a configuration file using the path name in the TRANSECT.PTR file. If a valid file name is not present in TRANSECT.PTR or if

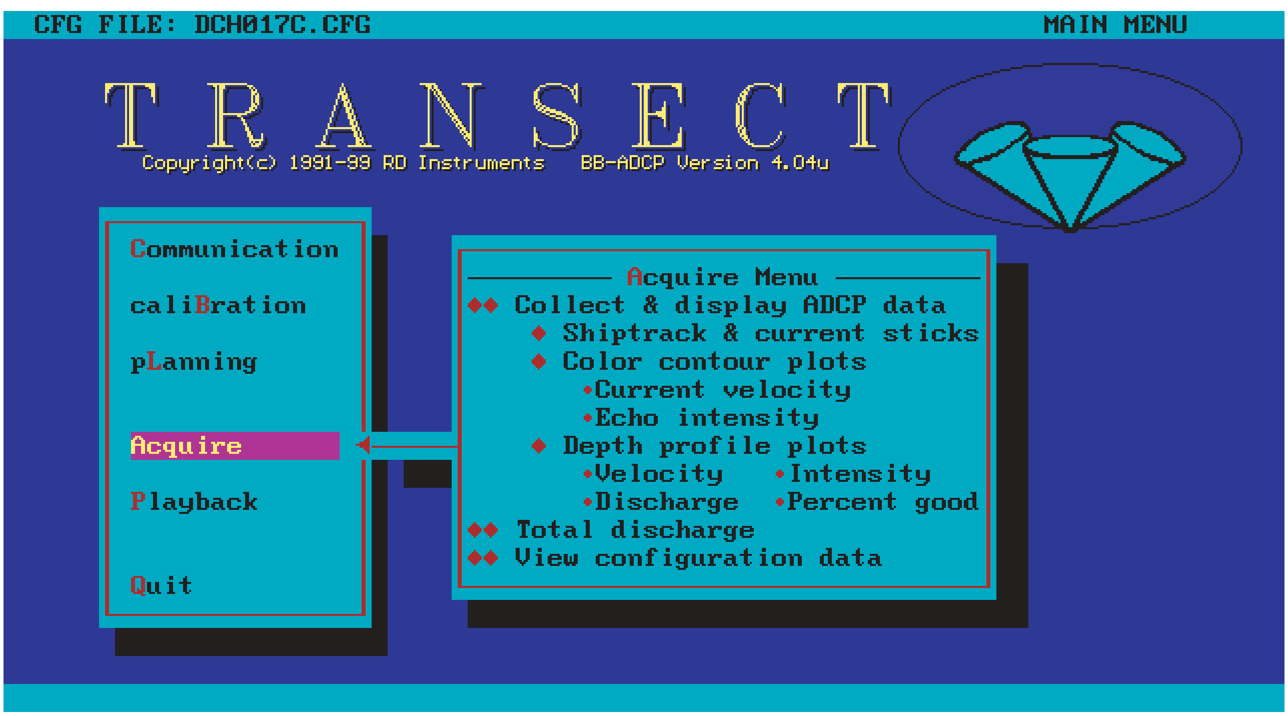


Figure 6.1. Transect software main menu. BB-ADCP, broad-band acoustic Doppler current profiler.

TRANSECT.PTR is not present, Transect will prompt the operator for a configuration file name. After loading the configuration file, Transect sends a “break” signal to the ADCP and waits a short time for a response. This is termed “waking up” the ADCP. If the ADCP does not wake up, usually it is because the operator has failed to turn on the power from the deck unit or that a communications or power cable has not been connected. If all attempts to communicate with the BB-ADCP from the Acquire menu meet with failure, the operator can do one of two things: exit the Transect software and try to establish communication with the ADCP using BBTALK or another terminal-emulator program, or enter the Transect software communication ADCP submenu and select auto connect. The Transect software will cycle through all combinations of baud rates and configuration combinations until it successfully establishes communications or it makes so many failed passes that the operator finally looses patience and calls for help. The BB-ADCP technical manual contains trouble-shooting procedures in cases of BB-ADCP failure or apparent faulty operation.

Once the ADCP is communicating properly, the introductory screen for the Acquire menu will appear on the monitor. This screen (fig. 6.2) contains helpful information on the setup and configuration of the ADCP:

- •ADCP communication parameters;
- •ADCP firmware parameters—firmware-release version, beam angle, operating frequency, coordinate system, operating mode, orientation system, and head configuration (pattern);
- •Recording selections;
- •ADCP operating variables: depth cell length, number of depth cells, pings per ensemble, time between pings, and blanking distance;
- •Configuration file processing parameters.

The BB-ADCP operator should inspect the data for accuracy before continuing with the Transect software session.

Transect-Data Displays

The F10 or escape key then can be pressed to invoke the Transect software profile menu.

The Acquire menu provides many different ways to view ADCP data as they are being collected. Typically, most users will view incoming data using the Tabular display. Some of the available data displays are described below:

- •Profiles of water velocity, echo intensity, and discharge cross product may be displayed (fig. 6.3).

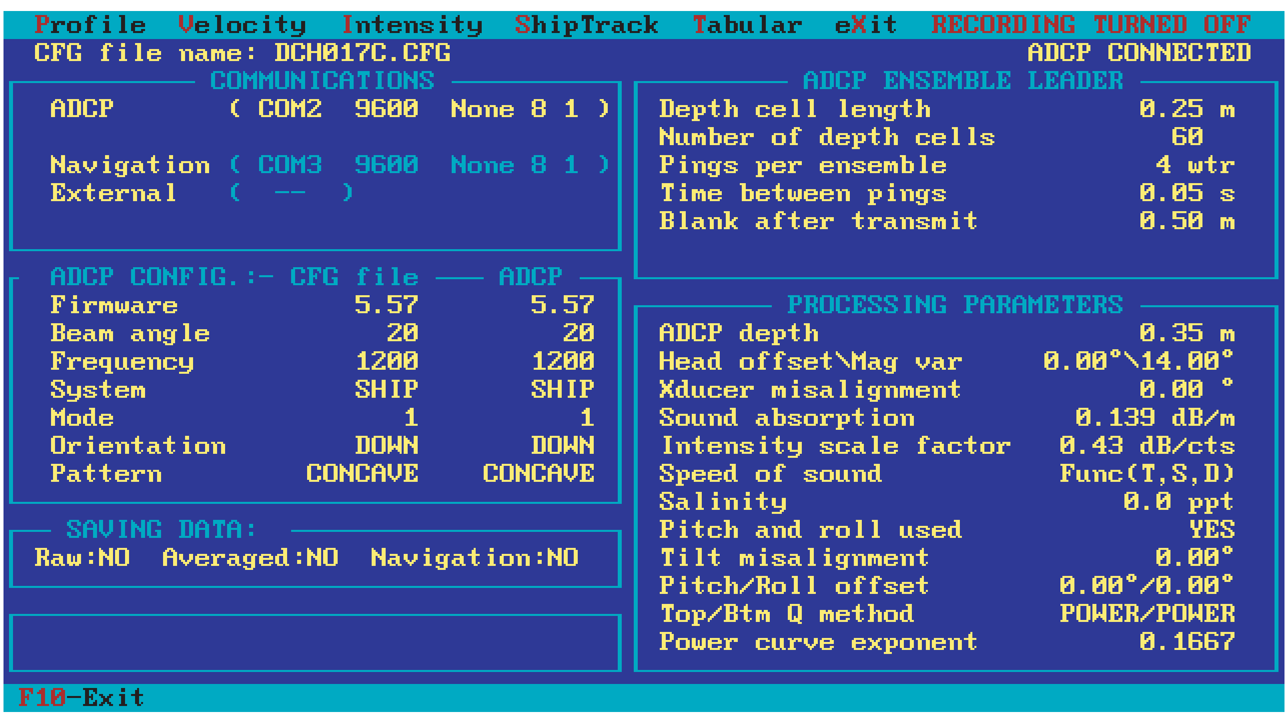


Figure 6.2. Transect software Acquire introductory screen. ADCP, acoustic Doppler current profiler.

•Color or monochrome plots of north velocity, east velocity, vertical velocity, error velocity, and velocity along a user set azimuth may be displayed (fig. 6.4).

•Backscattered intensities (fig. 6.5) also may be contour plotted. This can be useful for providing the operator with a relative indication of

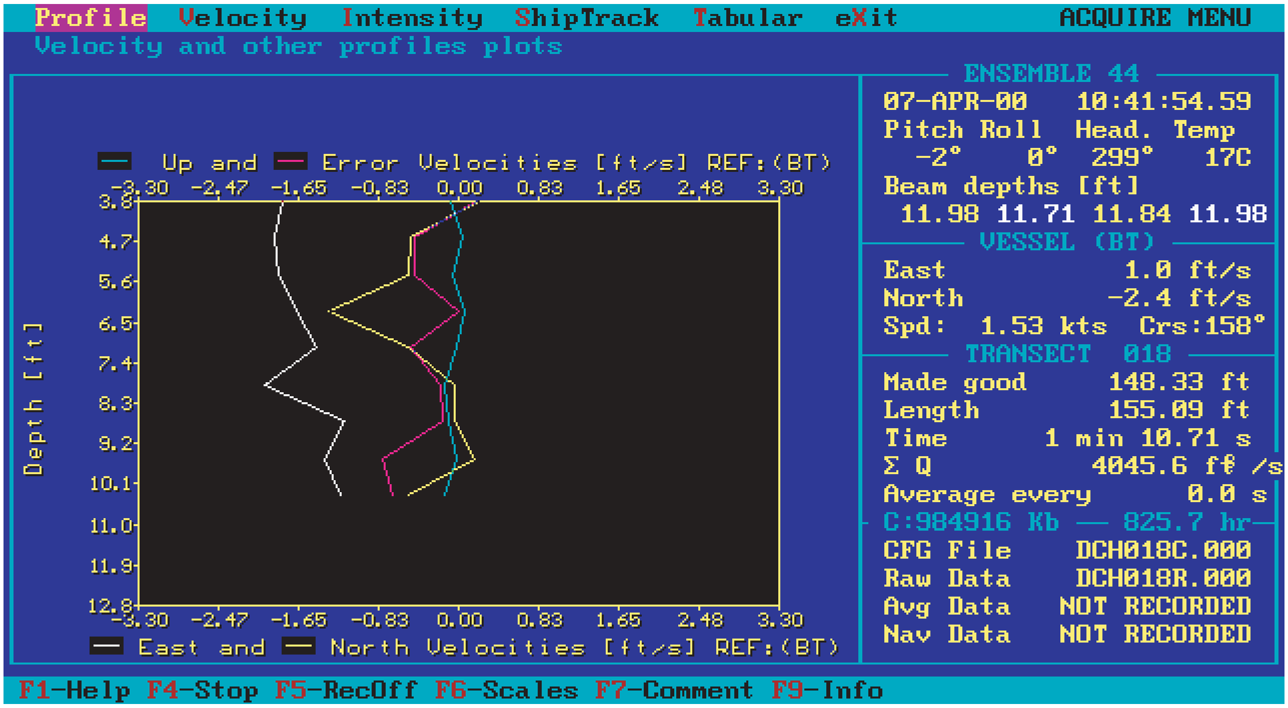


Figure 6.3. Transect software Acquire profile menu screen.

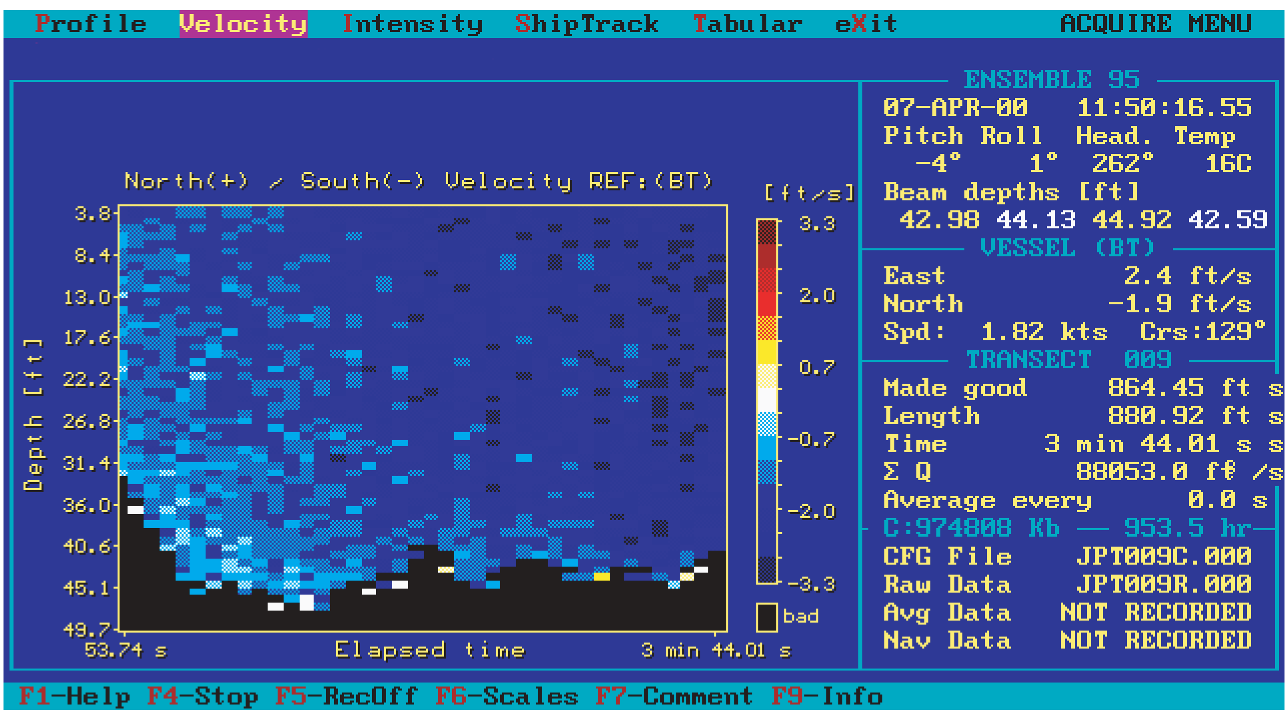


Figure 6.4. Transect software Acquire velocity contour plot screen.

suspended-sediment concentration in the measured cross section.

•The movement of the boat can be displayed in the so-called shiptrack plot (fig. 6.6). The operator also can display velocity vector "stick" plots at specified depths.

•Measured velocities, intensities, and correlations may be displayed in tabular form

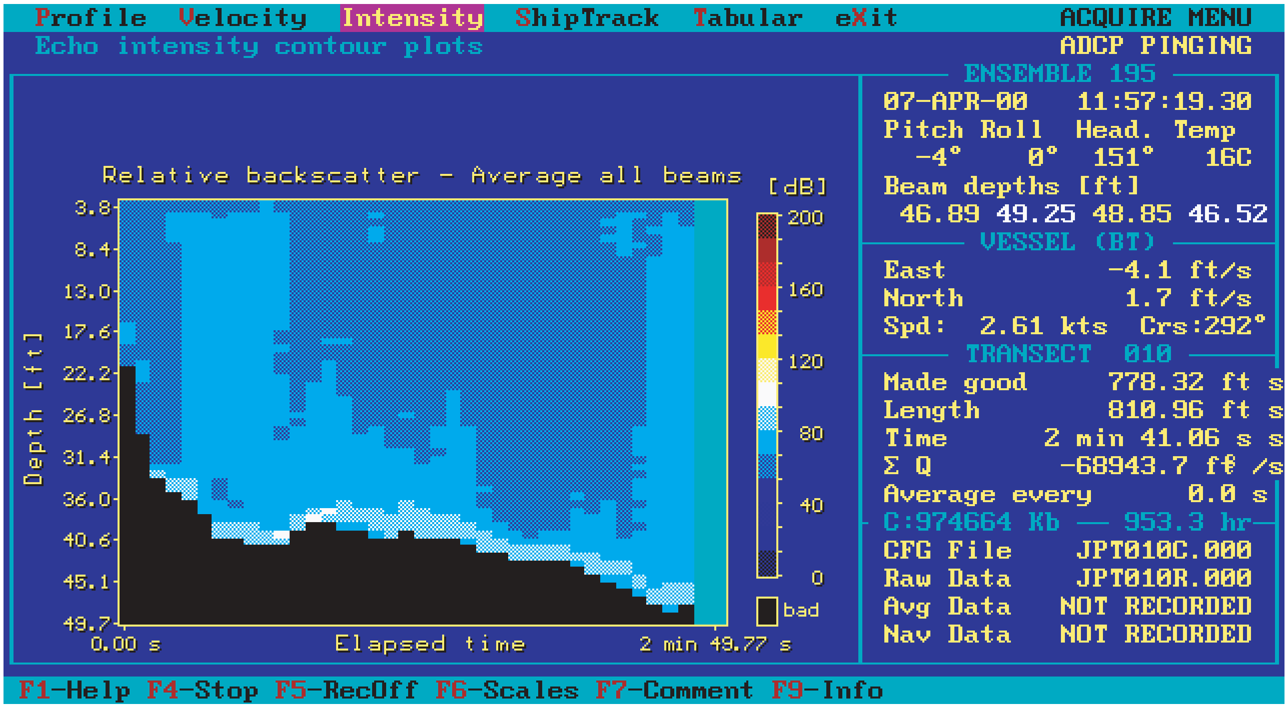


Figure 6.5. Transect software Acquire intensity contour plot. ADCP, acoustic Doppler current profiler.

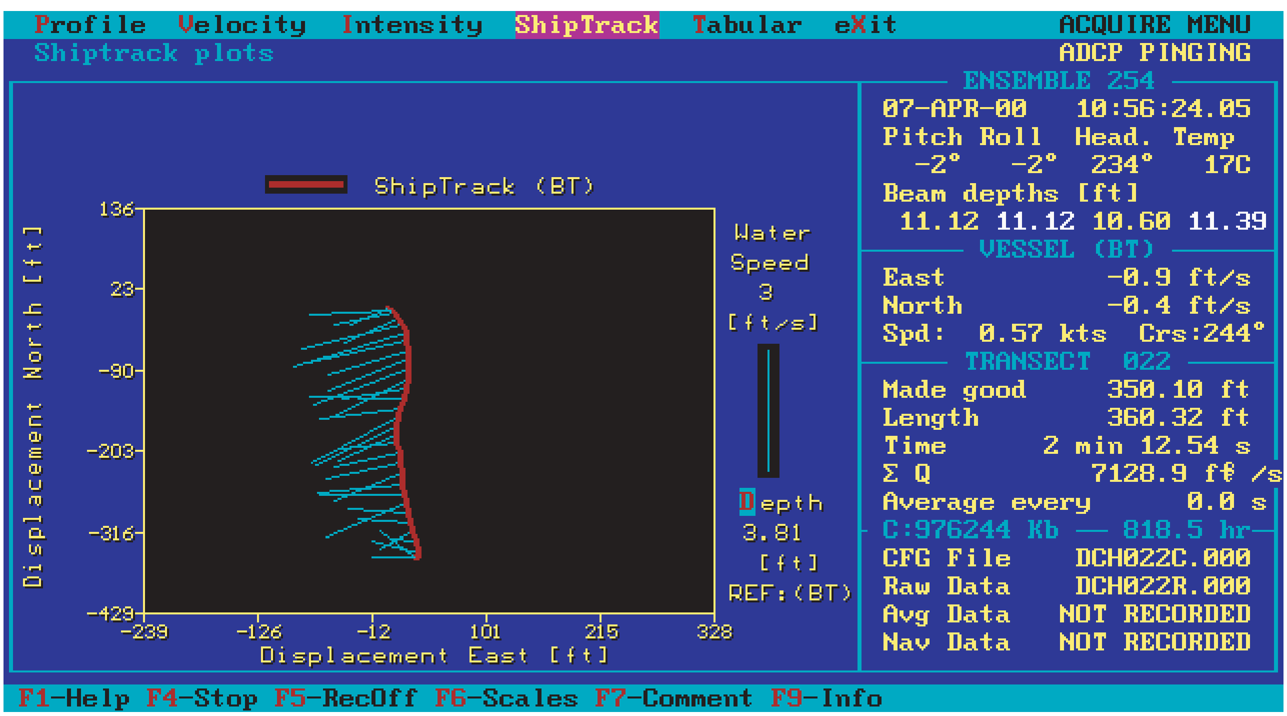


Figure 6.6. Transect software Acquire shiptrack plot. ADCP, acoustic Doppler current profiler.

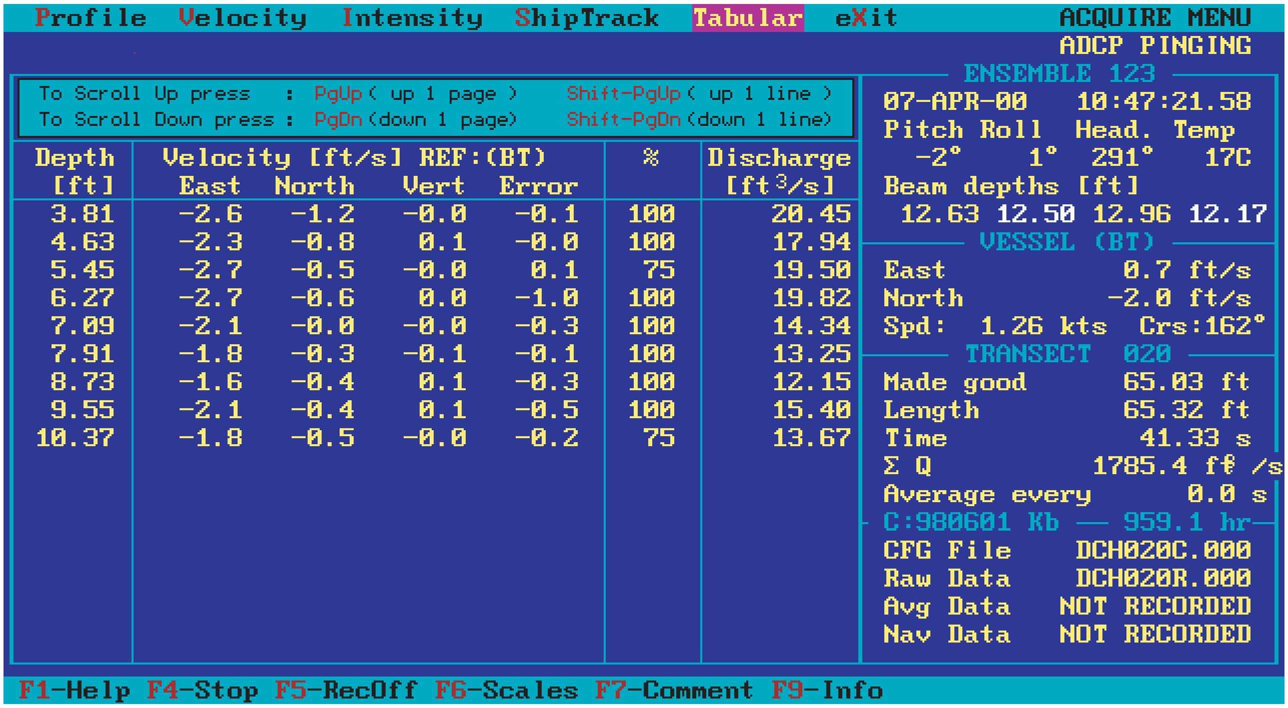


Figure 6.7. Transect software Acquire tabular display screen. ADCP, acoustic Doppler current profiler.

(fig. 6.7). The tabular screen is the most useful of the many displays available because of the information it imparts. The operator can tell quickly if error velocities are high, or if beam measurements or bottom tracking are bad, and scale factors need not be preset.

Transect-Data Recording

Data are recorded under the file name given in the RECORDING section (figs. 5.11 or 5.16) of the configuration file. Recording of the data to a data file is controlled by toggling the F5 key. When the Transect software is instructed to start recording (by toggling the F5 key), the discharge-measurement registers (but not the ensemble counter) are set to zero. The F4 key, on the other hand, wakes up the ADCP, starts the ADCP pinging, and resets the discharge-measurement registers and ensemble counter. Chapter 7 presents a detailed description of the use of the F4 and F5 keys.

Summary

Transect software data acquisition is invoked using the Acquire menu. The Transect software always loads the last used configuration file. There are two ways to load a new configuration file. The first is to edit the TRANSECT.PTR file and insert the path name of the configuration file before starting the Transect software. The second is to use the F3 key when starting the Transect software. The software then will prompt the operator for a configuration file name.

Actuating the F4 function key starts the data collection by the acoustic Doppler current profiler (ADCP). Recording can be toggled on and off with the F5 key.

Data displays during data acquisition can be selected by the operator. The tabular view is one of the more useful displays available during data collection. Some operators prefer to collect data while displaying profile plots of velocity magnitude and direction.

This page left blank intentionally.

Figure 7.1. Improper discharge-measurement technique.

Figure 7.2. Discharge-measurement cross section on Dutch Slough near Oakely, California.

CHAPTER 7: DISCHARGE-MEASUREMENT PROCEDURE

In this chapter we will discuss procedures for making discharge measurements (fig. 1) utilizing the ADCP and the Transect software. The following topics will be discussed in detail:

- Cross-section reconnaissance
- Premeasurement checkout
- Boat-maneuvering techniques
- Transect software tips and tricks during the discharge measurement
- Alternate discharge-measurement techniques for low-flow conditions
- What constitutes a “good” discharge measurement
- Recent Transect software enhancements

Cross-Section Reconnaissance

Figure 7.2 shows a 91-m- (300-ft-) wide stream with tidally affected flows having a roughly trapezoidal cross section with average depths of 4.5–6 m (15–20 ft). This cross section on Dutch Slough near Oakley, California, is typical of rivers in the northern California Sacramento/San Joaquin River Delta. Proper cross-section reconnaissance is vital to the precision and accuracy of ADCP discharge measurements. The measurement vessel depth sounder or the ADCP depth-range measurements are useful tools in determining the usability of the cross section for ADCP discharge measurements.

In general, the ADCP operator should look for a cross section with a roughly parabolic, trapezoidal, or rectangular shape, having an average depth of at least 1.5 m (5 ft). The measurement sometimes can be made at locations having less depth, if water modes 5 or 8 are employed (chap. 3).

Cross sections with asymmetrical bottom topographies should be avoided, if possible. For example, the operator should avoid a measurement cross section that is very shallow on one side and deep on the other.

Average water velocity also is an important factor in choosing a measurement cross section. Cross sections exhibiting slow [less than 10 cm/s (0.30 ft/s)] average velocities should be avoided. Although measurements can be made under these conditions, special techniques must be employed (discussed later in this chapter).

Premeasurement Checkout

After the boat is launched and the ADCP equipment is set up, care should be taken to obtain an accurate transducer depth measurement.

If a side-swing mount is used, the weight of the operator(s) can cause an unwanted pitch of the ADCP vessel (fig. 7.3). This pitch angle may cause an erroneous reading of the ADCP depth. For example, when the operator moves to the side of the vessel to measure transducer depth, the vessel pitches to that side because of the operator’s shifted weight. The operator notes the depth of the ADCP below water surface, and then returns to his normal position in the vessel causing the vessels pitch to return to the original value. This

Figure 7.3. Broad-band acoustic Doppler current profiler mount being deployed vertically.

Figure 7.4. Discharge-measurement log sheet/note.

recorded depth measurement will be incorrect. Because the transducer depth measurement is used in the Transect software to compute discharge, the error in ADCP depth sometimes can cause a significant bias of the ADCP discharge measurement. This is true especially for wide, shallow rivers.

Before the discharge measurement begins, the operator should note any conditions relevant to the discharge measurement on the discharge-measurement log sheet (fig. 7.4). Wind, bidirectional flow, eddies, standing waves, passing boats, and sediment conditions are just some of the things that should be noted for later analysis of the discharge measurements.

Before a discharge measurement begins, the operator should complete the following tasks:

- Meet all DOI boat-safety requirements and make sure all required life jackets, throwable devices, fire extinguishers, and horns are in good working condition aboard the ADCP vessel.
- Determine the "unpitched" transducer depth and enter it on the log sheet and in the configuration file.
- Perform a PT200 diagnostic test using BB-TALK or other terminal emulator software. Save the test results to an ASCII file placed in the deployment directory.
- Synchronize the computer, ADCP, and operator watch times.
- Perform a short reconnaissance of the cross section to determine shallow areas and the shape of the cross section so that unmeasured areas near the bank can be characterized. If the cross section is unsuitable for any reason (too shallow in places, for example), select another measurement cross section.
- If buoys are used to aid the estimation of edge distances, they should be deployed and the distance to shore from each buoy should be measured and noted on the discharge-measurement log sheet.
- If range finders are used to determine edge distances, they should be checked for proper calibration.
- Record weather, hydrological, and other physical phenomena pertinent to the discharge measurement on the discharge-measurement note.
- Make sure that the right configuration file has been loaded properly into the Transect software.
- Make sure that the power supply has been turned on and the ADCP has been "awoken."

Boat-Maneuvering Techniques

Boat-maneuvering techniques for discharge measurements when using the ADCP and the Transect software do not require the precision once needed for conventional moving-boat discharge measurements. However, there are some basic maneuvers that improve accuracy and allow smooth transitions between measurements.

Starting the Cross-Section Traverse

For a typical measurement, the operator must maneuver the boat close to, and parallel with, the riverbank (fig. 7.5). The boat should be maneuvered in as close as possible to the bank without grounding (bottoming out) the boat motor propeller or the

Figure 7.5. Acoustic Doppler current profiler vessel at the beginning of a discharge measurement.

Figure 7.6. Acoustic Doppler current profiler vessel near center channel.

BB-ADCP transducer assembly. Performing this maneuver takes practice.

While the boat is somewhat stationary, the operator should start the Transect software and set the Acquire display to tabular velocity mode (initial setting). The tabular mode setting is optional as the Transect software will collect data in any display mode. However, the tabular mode enables the operator to determine if there is an adequate number of depth cells (having good discharge) before starting the measurement traverse. This capability provides the greatest advantage over the other display modes, especially when starting and ending the discharge measurement.

At this point, the operator is beginning the discharge measurement and must accomplish several tasks quickly:

- The distance to shore must be estimated by some means and recorded.
- The operator must turn the ADCP data recording off by pressing the F5 key and must start the ADCP pinging by pressing the F4 key.
- While looking at the tabular display, the operator must verify that the ADCP is collecting at least two good bins of velocity data.
- When the operator is satisfied that accurate data are being collected and the boat is in the correct position to start the discharge measurement, he must press the F5 key to begin recording and wait until two good ensembles have been collected. During this period (about 5 s), the boat should be barely moving toward center channel.

During the Cross-Section Traverse (Transect Tips and Tricks)

When the Transect software begins collecting data, the operator should verify that there is an "ADCP PINGING" message near the upper right of the monitor display and that a transect recording file is opened (file name visible at the lower right of the Transect software screen). At this time the boat should have just begun traversing the river cross section. The operator must quickly scan the initial ensemble display to determine if everything is operating correctly. Signs of improper operation are flagged "bad" in all columns and rows or "bad" in all rows of an individual column. The display columns correspond to north velocity, east velocity, vertical velocity, error velocity, and percent good. If the incoming data appear correct, the operator should continue the transect with the same course and a slightly increased speed (approximately that of the water or slightly less). As the boat enters faster flow, engine revolutions per minute (rpm) and boat heading may have to be adjusted slightly to enable a smooth traverse (fig. 7.6).

Uniform boat speed during a transect is more important than steering a straight course. The course may be allowed to change slightly and slowly, if necessary, during the traverse. However, rapid course and boat heading changes can introduce errors into the measurement. The key element here is to DO EVERYTHING SLOWLY, including course changes, the speed of the vessel itself, and even the speed of persons moving around onboard the measurement vessel. Sharp accelerations of the measurement vessel in any direction should be minimized or eliminated.

Ending the Cross-Section Traverse

As the vessel approaches the opposite edge of the measuring section, the boat should be slowed by slowly changing the heading to a more upstream direction and slowing the boat motor. The boat then can creep (crab) toward the bank. When the operator decides that the approach cannot be continued further, an edge value is determined, and the F5 key is pressed to end the transect.

At the end of a cross-section traverse (fig. 7.7), the boat heading is changed just enough so that the boat stops its bankward movement and begins to slowly creep in the direction of center channel. At this point, the operator may press the F5 key again to begin another transect and obtain a starting distance value. Slow “crabbing” at the start and finish of each cross section works better than nosing the boat into the bank and then backing away. The ADCP should not be allowed to pass over the boat propeller vortex during the discharge measurement. Entrained air in the vortex will cause failure of the BB-ADCP bottom track and result in lost ensembles.

The operator should practice the above described technique a few times before an actual transect session is begun so that you (and the boat operator) can become accustomed to the flow conditions at this location. The more practice you have in making these measurements, the more uniform will be the measurement results. When maneuvering near the riverbank, you must remember that making a large heading adjustment away from the bank (swinging the bow away from the bank) will bring the stern (and, therefore, the engine prop and shaft) into contact with the bank or bottom. This maneuver can produce highly undesirable results.

Figure 7.7. Acoustic Doppler current profiler vessel at the end of a cross-section traverse.

The boat will crab slowly away from the bank with only minor adjustments needed in the boat steering.

Alternate Techniques Used During Low-Flow Conditions

The above described technique works only when there is sufficient stream velocity to allow the boat to crab. At very low stream velocities [less than 10 cm/s (0.33 ft/s)], the boat must be turned VERY SLOWLY to enable a direct crossing of the stream. In some cases, the best approach is to raise the engine and pull the boat slowly (at the stream velocity or less) across the stream with ropes or a tag-line (fig. 7.8).

The winching system shown in figure 7.8 was used to measure leakage through control structures in the USGS Illinois District (Oberg and Schmidt, 1994). Because the velocities measured were very slow

Figure 7.8. Winching system used to move an acoustic Doppler current profiler vessel at slow speeds.

[around 10 cm/s (0.3 ft/s)], the ADCP was winched slowly across the control structure opening to reduce the random error in the discharge measurement (chap. 9).

To gain reasonably accurate measurements in very slow moving water, special setup commands must be used to increase the measurement pulse lag times (chap. 5). The use of these long lag times causes the ambiguity velocity to be very low. Therefore, the boat must be moved across the stream ever so slowly (as if rows of dominoes were balanced on the gunnels).

What Constitutes a "Good" Discharge Measurement?

The ADCP operator should consult Lipscomb (1995) for guidelines on discharge-measurement requirements and documentation procedures. However, because these instruments are relatively new and sometimes used for special purposes, common sense also will dictate the procedures in some cases. General procedures conforming to the quality-assurance plan are presented here, but the ADCP operator is cautioned to observe conditions and to document as much information as possible during the transect session. With the advent of electronic instruments used for data recording, valuable information can sometimes "fall through the cracks" and may not be missed until the ADCP operator reviews the data back at the office.

Because a BB-ADCP transect may be made much faster than a conventional discharge measurement, multiple transects usually are averaged to increase discharge-measurement accuracy. During fairly uniform conditions, a group of four or more transects usually are averaged for a final discharge-measurement value. If one transect differs significantly (±5 percent) from the rest, and there is no rationale to discard it, at least four additional transects should be obtained and the average recomputed. The average of these transects can be reported as an individual discharge measurement and logged on a USGS ADCP discharge-measurement note (fig. 7.9). The back of the USGS measurement note has space for 14 transects, their edge-value estimates, and other pertinent data (fig. 7.10).

In figure 7.10, the values labeled standard error (range) and standard error (percent) near the bottom of the note are critical for measurement results in steady-flow conditions. For fairly uniform flow conditions, at least four ADCP discharge measurements should be made to determine mean and standard-deviation values. From these data, the standard error, in percent of mean discharge, should be calculated. The standard error, in percent of mean discharge, also is known as the coefficient of variation (CV). The CV is calculated by dividing the standard deviation (in discharge units) of the four transect discharges by the mean discharge. If the CV is larger than 5 percent, additional measurements should be made. A large CV can be an indication that the ADCP ping rate is too slow, or that the boat should be slowed during the cross-section traverse to collect more pings. Outliers or single, bad, transects can cause a large CV, however, they should not be simply thrown out without an attempt to discover the reason for their imprecision. When in doubt, it is always advisable to collect additional transects.

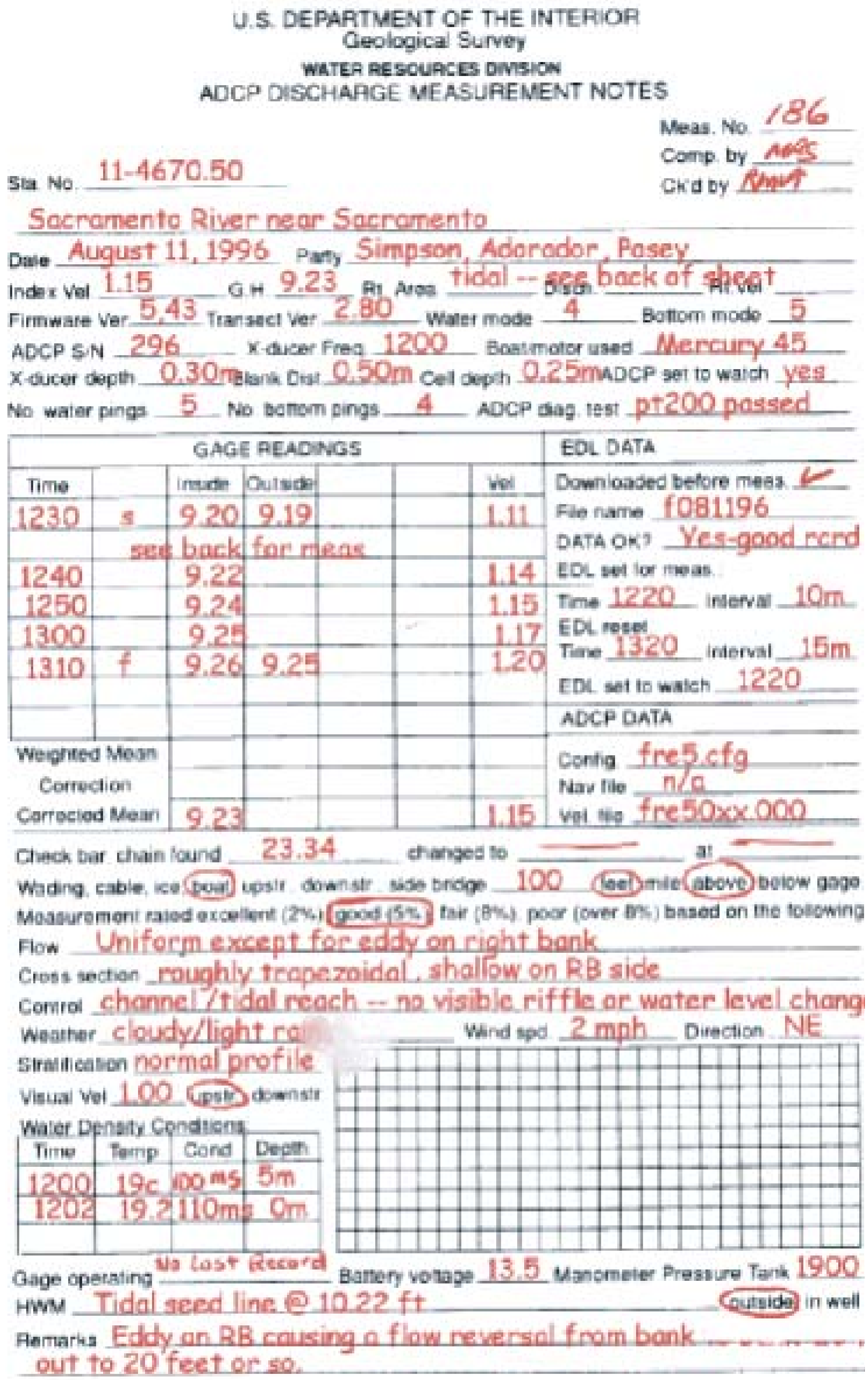
For measurements of net flow in tidally affected estuaries and rivers, many discharge measurements may have to be made (more than can be logged on the example ADCP discharge-measurement form). Figure 7.11 shows a series of transects made at a tidally affected gaging station on a tributary of the San Joaquin River.

In these cases, a discharge-measurement log sheet (fig. 7.12) may be used with pertinent data logged on a discharge-measurement note (fig. 7.9) that is attached to the log sheet. This log sheet is used by the USGS California District. Standard-deviation calculations for tidally effected discharge measurements are meaningless unless the "true mean" discharge can be calculated. Because of the difficulty in calculating the coefficient of variation for tidally effected discharge (or any dynamically changing discharge), its inclusion on the discharge-measurement note example (fig. 7.9) is of questionable significance.

Where tides or discharge conditions are changing rapidly, the operator may not wish to average transects and, in these cases, a single transect constitutes a discharge measurement. In most cases, many measurements will be required to have as much coverage as possible of the dynamic flow time series. Single measurements should be logged on a BB-ADCP discharge-measurement note (fig. 7.9) and if many are made, they should be logged on a discharge-measurement log sheet (fig. 7.12) with an attached USGS discharge-measurement note. Again, standard-deviation calculations or coefficient of variation calculations, in these cases, are of questionable value.

Archival of Acoustic Doppler Current Profiler Discharge-Measurement Data

Transect software data files should be placed on archival media in the following form:



U.S. DEPARTMENT OF THE INTERIOR
Geological Survey
WATER RESOURCES DIVISION
ADCP DISCHARGE MEASUREMENT NOTES

Meas. No. 186
Comp. by AMS
Ck'd by RMVT

Sta. No. 11-4670.50

Sacramento River near Sacramento

Date August 11, 1996 Party Simpson, Adorador, Posey

Index Vel 1.15 G.H. 9.23 Rt. Area tidal -- see back of sheet Disch. ____ Rt. Vel ____

Firmware Ver. 5.43 Transect Ver. 2.80 Water mode 4 Bottom mode 5

ADCP S/N 296 X-ducer Freq. 1200 Boat/motor used Mercury 45

X-ducer depth 0.30m Blank Dist. 0.50m Cell depth 0.25m ADCP set to watch yes

No. water pings 5 No. bottom pings 4 ADCP diag. test pt200 passed

GAGE READINGS						
Time		Inside	Outside			Vel
1230	s	9.20	9.19			1.11
	see back for meas					
1240		9.22				1.14
1250		9.24				1.15
1300		9.25				1.17
1310	f	9.26	9.25			1.20
Weighted Mean						
Correction						
Corrected Mean		9.23				1.15

EDL DATA
Downloaded before meas. ✓
File name f081196
DATA OK? Yes-good rcrd
EDL set for meas.
Time 1220 Interval 10m
EDL reset
Time 1320 Interval 15m
EDL set to watch 1220

ADCP DATA
Config fre5.cfg
Nav file n/a
Vel. file fre50xx.000

Check bar, chain found 23.34 changed to ____ at ____

Wading, cable, ice, (boat), upstr., downstr., side bridge 100 (feet), mile, (above), below gage

Measurement rated excellent (2%), (good (5%)), fair (8%), poor (over 8%) based on the following

Flow Uniform except for eddy on right bank

Cross section roughly trapezoidal, shallow on RB side

Control channel/tidal reach -- no visible riffle or water level chang

Weather cloudy/light ra Wind spd. 2 mph Direction NE

Stratification normal profile

Visual Vel 1.00 (upstr) downstr

Water Density Conditions

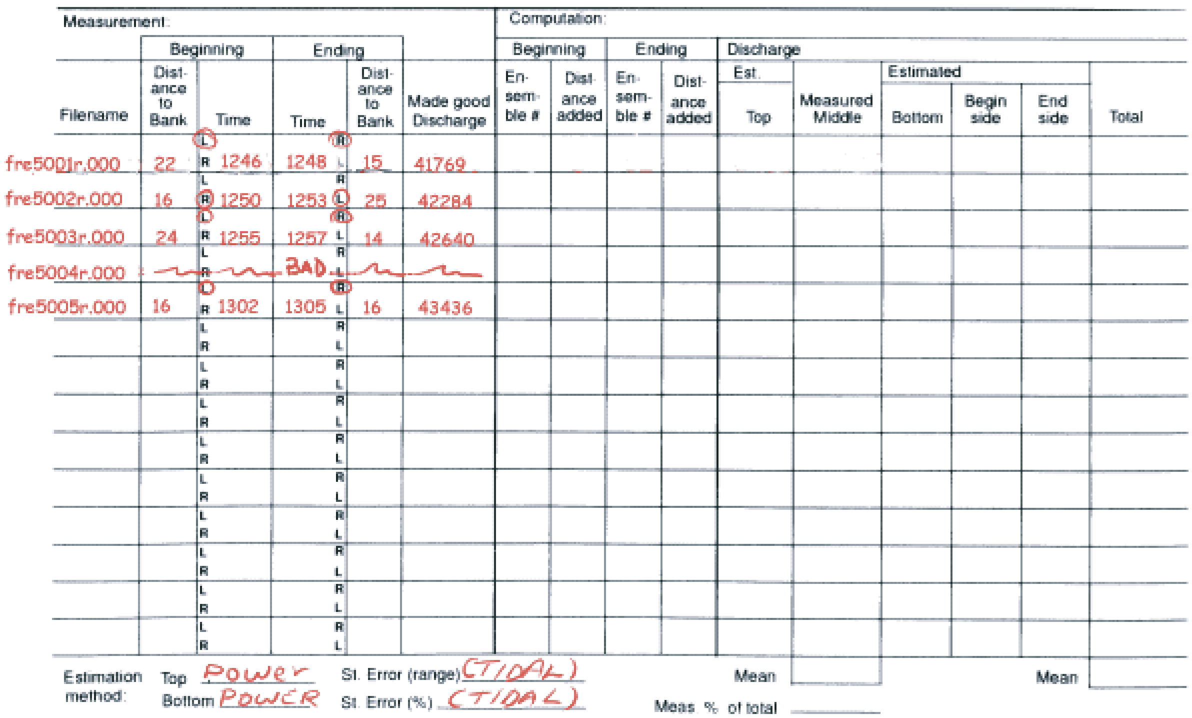
Time	Temp	Cond	Depth
1200	19c	100 ms	5m
1202	19.2	110ms	0m

Gage operating No Lost Record Battery voltage 13.5 Manometer Pressure Tank 1900

HWM Tidal seed line @ 10.22 ft (outside) in well

Remarks Eddy on RB causing a flow reversal from bank out to 20 feet or so.

Figure 7.9. Example of an acoustic Doppler current profiler (ADCP) discharge-measurement note (front).



Measurement:						Computation:									
	Beginning		Ending			Beginning		Ending		Discharge					
										Est.		Estimated			
Filename	Distance to Bank	Time	Time	Distance to Bank	Made good Discharge	Ensemble #	Distance added	Ensemble #	Distance added	Top	Measured Middle	Bottom	Begin side	End side	Total
fre5001r.000	22	(L) R 1246	1248 L (R)	15	41769										
fre5002r.000	16	L (R) 1250	1253 R (L)	25	42284										
fre5003r.000	24	(L) R 1255	1257 (R) L	14	42640										
fre5004r.000		L R	BAD R L												
fre5005r.000	16	(L) R 1302	1305 (R) L	16	43436										
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												
		L R	R L												

Estimation method: Top POWER; Bottom POWER; St. Error (range) (TIDAL); St. Error (%) (TIDAL); Mean; Meas % of total; Mean

Figure 7.10. Example of an acoustic Doppler current profiler discharge-measurement note (back).

- •Site deployment directory name NNNN (where NNNN is the four-letter site designator)
- •Set of transect raw data files

```
{NNNN001R.00
 |
 |
\/
 NNNN0XXR.00
}
```

where XX is the last transect number in the series,

- •Transect session *.CFG file NNNN.CFG
- •Transect session documentation file NNNN.DOC

The operator must create an ASCII file, using a text editor, to be archived with each set of Transect data. This electronic NNNN.DOC file is needed to preserve Transect edge-value estimates and other site-specific information in the event that hard copies of log sheets are lost or misplaced. This DOC file must be drafted as soon as possible after the completion of the Transect session and stored in the Transect session directory. At a minimum, the file should contain the following information:

- •Site location
- •Date, start time, and end time
- •Names of measurement staff
- •Description of measurement vessel and equipment
- •Transducer depth (depth from water surface to the center of the transducer assembly faces)
- •BB-ADCP serial number and firmware-revision number
- •An electronic copy of the measurement log, which is helpful for reconstituting ADCP discharge measurements. The log copy should include: start time; Transect file name; start-edge estimate; end-edge estimate; discharge; and remarks about site conditions, including indication of eddies or reverse flow at bank edges; and remarks about passing boat traffic and wind conditions (pitch and roll)
- •Any pertinent information about instrument setup or changes to the setup during the Transect session

These data should be archived to safe media as soon as possible following a Transect session. Safe

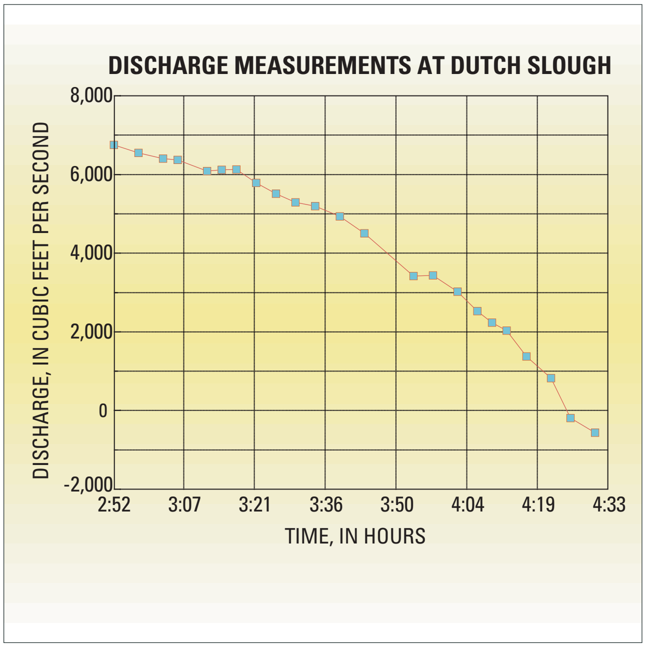


Figure 7.11. Discharge-measurement data from a tidally affected gaging station on a tributary of the San Joaquin River.

media may consist of a compact disk, read-only-memory (CD-ROM), optical media (30-year), or a disk drive on a computer system that is backed up regularly. The computer hard disk of the laptop used for data collection is not considered "safe media."

Summary

A smooth bank-to-bank transect technique is essential for accurate discharge measurements. The operator always should remember that slow, smooth boat movements are desirable.

For steady-state flows, at least four transects should be made and the results averaged to calculate a "discharge measurement." If one measurement is more than 5 percent from the mean, four additional transects should be collected and averaged. A CV should be calculated from the discharge-measurement series by dividing the standard deviation, in units of discharge, by the mean of the series. If the CV is greater than 5 percent, the ping rate should be increased or the boat slowed during the transect to collect more pings per transect. Additional transects should be made until a series of four is obtained having a CV of less than 5 percent.

For discharge measurements made in tidally affected rivers and estuaries, the CV value and standard deviations cannot be computed easily and, therefore, are not used. However, comparison and common sense sometimes can detect inaccurate transect discharges. In these cases, a single transect can be used as a discharge measurement, although many measurements usually are made during a discharge-measurement session to define the dynamic flow conditions.

Suitable log sheets and discharge-measurement notes must accompany the discharge-measurement series. The operator should store a copy of the configuration file that is used for the series in the Transect software deployment directory with a documentation file containing edge values and other pertinent information (described above). A documentation file should be stored with the Transect software data files describing stream conditions and pertinent information not collected by the Transect software.

All Transect data files and accompanying configuration and documentation files should be archived to "safe" media as soon as possible after the measurements are made. Although paper-copy records can be kept for records computation, acoustic Doppler current profiler discharge-measurement archives should be such that the discharge measurements could be wholly recreated from data stored on electronic media.

United States Department of the Interior
Geological Survey
Water Resources Division

ADCP Discharge Measurement Notes

Sta. No.: 11-4670.50 Name: Sacramento River @ Freeport, CA.

Date: Aug 31, 1996 Party: Simpson, Aborador, Posey

Width: 530 Area: 1019 Vel. ≈ 1.40 G.H. 1.20 - 1.40 Discharge Tidal

ADCP Information

Ser. No. 296 Firmware 5.43 Software 2.72 Diagnostic Test Pass

ADCP draft: 0.34 m Depth Cell Size: 0.25 m

	Hour	Minute	Second	Circle	
Recorder	12	45	05	(CST)	CDT
ADCP	12	45	20	CST	CDT
Watch	12	46	10	CST	CDT

Transducer Frequency: 1200

Beam Angle: (20)

Shore Description: Left: (Sloping) / Vertical; Right: (Sloping) / Vertical

Transect Number	Watch Time	Distance to Shore Start	Distance to Shore End	Start Bank	Sum Q	Edge Estimate	Total Discharge	Config File	Remarks
001	1220	50	40	(L) R	12433	320		FREG.CFG	file fre600IR.000
002	1225	42	60	L (R)	12524	298		"	Passing Boat (wake)
003	1228	38	43	(L) R	12632	265		"	Wind picking UP 5.0 mph
004	1232	49	60	L (R)	12722	300		"	
005	1235	58	37	(L) R	12845	305		"	
——BAD——				L R					
006	1239	42	50	(L) R	12963	285		"	Small white Caps
007	1243	53	39	L (R)	13005	242		"	
008	1247	36	62	(L) R	13107	303		"	Large Ship Passed (wake)
009	1252	64	37	L (R)	13152	312		"	
010	1256	56	63	(L) R	13098	320		"	
011	1301	66	39	L (R)	13005	301		"	Getting More Windy 10 mph
012	1305	42	54	(L) R	12970	259		"	
013	1310	57	39	L (R)	12920	288		"	
014	1314	43	62	(L) R	12860	276		"	Meas not too good (WAKE)
015	1319	60	39	L (R)	12740	300		"	
016	1323	32	57	(L) R	12610	296		"	
017	1328	56	37	L (R)	12500	299		"	really windy ≈20MPH
018	1342	39	62	(L) R	12320	276		"	
019	1346	61	38	L (R)	12200	300		"	Went to Dutch Slough
				L R					

Page 1 of 1

Figure 7.12. Discharge-measurement log sheet. ADCP, acoustic Doppler current profiler.

This page left blank intentionally.

CHAPTER 8: DISCHARGE-MEASUREMENT REVIEW AND ASSESSMENT

Individual transects should be checked for discharge-measurement errors and inconsistencies as soon as possible after collecting the discharge-measurement series. In most cases, this examination is done at the office or in a motel suite, but it can be done at the measurement site. The data are examined by using the Transect software to reconstruct the measurement from the stored raw data and configuration files. This is termed “playing back” the discharge measurement. During playback, the edge discharges also can be estimated, and the power-curve (or other) estimation scheme used near the top and bottom of the profile can be examined for correctness and changed, if necessary.

Proper review and assessment of ADCP discharge measurements is almost as important as the techniques and instrument setup used to collect the original data. Improper instrument setup and faulty measurement techniques can be revealed during post processing and, in some cases, corrections can be made to improve discharge-measurement accuracy.

Review of ADCP discharge measurements should include the following steps.

- Configuration file review with focus on the applicability of the following sections to river conditions:
  - ADCP hardware setup
  - ADCP direct commands
  - ADCP calibration constants
- Transect software playback with focus on the following subjects:
  - Missing data ensembles
  - Possible bottom-sediment movement
  - Magnitudes of discharge in the unmeasured (estimated) parts of the cross-section near the top and bottom of the profile
  - Technique used for low-velocity [< 10 cm/s (0.33 ft/s)] measurements
  - Power-curve-fit applicability
  - Reasonableness of edge values
  - Shiptrack examination

These assessment procedures are discussed in the following paragraphs.

Configuration-File Review

The first thing that should be checked is the applicability of the configuration file to the data file and to river conditions. The ADCP discharge-measurement notes should indicate the location of the configuration file used for the discharge-measurement series or contain a listing of the file.

River Conditions

The configuration file should be examined in a text editor to determine if the proper setup and configuration commands were used for the stream or river being measured. All sections should be checked, but the most important are the ADCP hardware, the direct command, and the calibration sections:

Acoustic Doppler Current Profiler Hardware

- First examine the ADCP Hardware section of the configuration file.

(example)

```
ADCP HARDWARE
{
Firmware        (5.45)
Angle (20)
Frequency (1200)
System (BEAM)
Mode (4)
Orientation (DOWN)
Pattern (CONCAVE)
}
```

Are these entries compatible with the ADCP used to make the discharge measurements? Is the proper mode being used for the river or stream in question?

Acoustic Doppler Current Profiler Direct Commands

- Next examine the Direct Commands section of the configuration file.

(example)

```
DIRECT COMMANDS
{
WS25
WF50
BX200
WN060
WD111100000
WP00001
BP001
WM1
BM5
ES0
WE0450
}
```

Is the blanking distance (WF) adequate for the transducer frequency? Is the bin size (WS) proper for the transducer frequency? Are enough depth bins specified (WN) to cover the range of depth measured? A few playback profiles may have to be examined before this question is answered. Is the bottom track maximum depth (BX) greater than the maximum stream depth? If BX is less than the maximum depth, there will be missing ensembles. Are the bottom and water modes (BM,WM) specified correct for the measurement application? Is an ES0 (salinity of zero) command present?

Calibration Section

•Finally, examine the calibration section.

(example)

```
CALIBRATION
{
ADCP depth (.40 m)
Heading/Magnetic offset (0.00
        0.00°)
Transducer misalignment (0.00°)
Intensity scale [0.43 decibels (
 dB) per count)]
Absorption (0.440 dB/m)
Salinity [0.0 parts per thousand
  (ppt)]
Speed of sound correction (YES)
Pitch and roll compensation (YES)
Tilt Misalignment (0.00°)
Pitch_Offset (0.000°)
Roll_Offset (0.000°)
Top discharge estimate (POWER)
Bottom discharge estimate
 (POWER)
Power curve exponent (0.16670)
```

Does the transducer draft correspond to the draft entered on the ADCP discharge-measurement notes? Have the proper offsets (if any) been entered? Is the proper estimation scheme being used for the bottom and the surface, and is the proper power-curve exponent being used?

Transect Software Playback

When the configuration file has been verified, the Transect software data files should be loaded and replayed using the Transect software playback menu. When the playback section is first entered, the software looks for the last loaded configuration file (in TRANSECT.PTR) for information about file locations. The operator either can load a new configuration file or load an individual data file by pressing the F3 key. The operator can load a list of files from a deployment by pressing the F8 key. During playback, the data should be examined with a critical eye for the anomalies discussed in the sections below. Common sense also should be used when reviewing Transect software data files.

Missing Ensembles

A velocity contour plot of the ADCP discharge measurement should first be examined for missing ensembles. Missing ensembles show as vertical black lines in the contour plot, as shown in figure 8.1. Figure 8.1 shows a transect containing missing

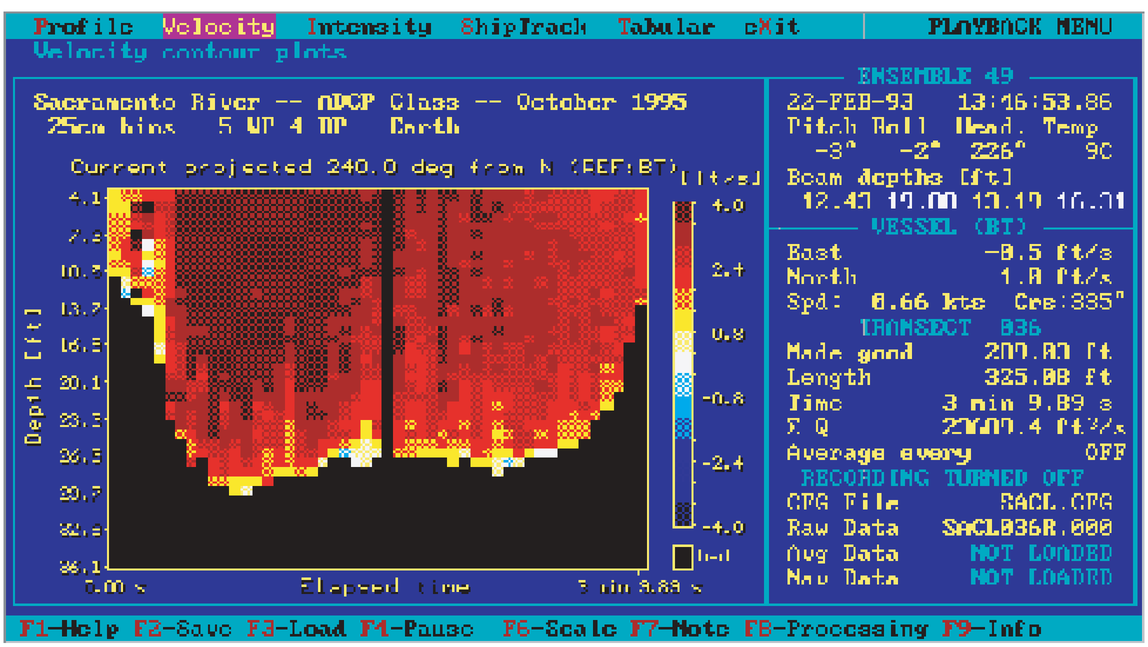


Figure 8.1. Transect containing missing ensembles caused by a loss of bottom tracking.

ensembles caused by a loss of bottom tracking. Note that, in this case, the missing ensembles would contain a significant amount of flow if they were present. The discharge calculated from the transect described above will be underestimated unless the missing data are estimated.

The following procedure can be used (using one of Transect's hidden commands) to correct transects containing bad bottom-track velocities:

- In the playback section of Transect, load the file to be used in the normal way.
- Put playback into single-step mode by toggling the F4 key, and rewind the file using the ALT W command.
- Type F6 to open the 'scale menu' and enter 7 m/s (20 ft/s) for the water-speed (current sticks) value. Type F10 to return to the main menu.
- Hit the space bar to single step through the data. Write down the ensemble number for any ensemble that has anomalously long current sticks, or high or bad speed indicated in the bottom-track portion (near the right side of the screen). After stepping through the entire file, type ALT W to rewind the file. Let's assume ensemble 40 was bad.
- Set caps lock, scroll lock, and num lock on.
- Single step through the file to the ensemble preceding the bad ensemble (39). Type CTRL-END (simultaneously). A small window will open in the upper left corner of the screen with the message ENTER ACCESS CODE:. Type 3200 then ENTER (on a laptop computer, the zero key may be remapped to another location on the keyboard as a result of pressing num lock). The bottom-track velocity now is locked into its present value. Single step to the next ensemble (40). The bottom-track velocity should be the same as the preceding ensemble (39). If the next ensemble (40) is good, open the access code window again and type 3200 to release the lock. If the next ensemble (41) is bad, continue stepping through the file until the ensemble preceding the last bad ensemble is reached and then release the lock. The locking procedure described above is then repeated until all bad ensembles have been corrected and the end of the file is reached. The total discharge will then include estimates for missing ensembles, based on extrapolated bottom-track velocities.
- Edge estimates should be done in the usual way.

The method described above should be used with caution. It only should be used to "fill in" one or two missing ensembles, at most. When the method is used, it should be so noted on the discharge-measurement log sheet and the discharge measurement should be rated accordingly. If most of the measurements collected during a measurement session contain missing ensembles, the discharges should be remeasured at a more favorable cross section (usually with slower velocities) or should be remeasured when conditions become favorable.

Error Caused By Sediment Movement Near the Bottom

Errors caused by bottom movement generally show as negatively biased discharge measurements. These errors are introduced into the discharge-measurement cross product as apparent upstream boat movement. Sometimes the quantity of sediment moving near the bottom is enough to completely attenuate the bottom echo, causing catastrophic loss of bottom track, which shows as missing ensembles in the playback data. Figure 8.1 shows a velocity contour plot with missing ensembles caused by loss of bottom track.

When the ADCP is affected by bottom-sediment movement but has not lost bottom track, one might expect the resulting shiptrack plot to be curved in the upstream direction, even though the vessel is moving normal to the flow. In reality, the boat usually is pushed downstream by the current and, therefore, the information from the shiptrack plot can be misleading.

If bottom movement is suspected, the vessel should be anchored near the highest flow area in the cross section and data collected for at least 10 minutes. Examination of the resulting shiptrack plot will reveal the magnitude of the bottom-track error as a upstream-going shiptrack. The length of the track, in meters, multiplied by the elapsed time can be used to calculate the speed of the apparent upstream boat movement.

Figure 8.2 shows a shiptrack plot taken with the boat at anchor. The plot shows an apparent upstream boat movement of 18.7 m (61.5 ft) and an elapsed time of 612 s. This indicates an apparent velocity measurement error of 0.03 m/s (0.10 ft/s). It would be tempting to use this value to correct discharge measurements, however, the bottom probably is moving at different speeds in the cross section (slower near the edges and faster near the center, for example). A correction based on a single bottom-movement measurement would be questionable. Again, ADCP measurements sometimes can be made during conditions of bottom-sediment movement by substituting differential GPS-positioning inputs for

ADCP bottom-tracking data. See the manufacturers' web sites for information on using GPS systems for bottom tracking (www.rdinstruments.com) and (www.sontek.com).

Large Magnitudes of the Unmeasured Layers

Figure 8.3 shows the ending edge estimate (ALT E) screen with the show unmeasured discharge (ALT U) switch invoked. The unmeasured discharge magnitudes near the top and bottom of the channel are summed with the measured discharge (circled area in fig. 8.3). If the magnitude of the discharge in these unmeasured areas is greater than 30 percent of the measured discharge, special attention must be paid to the applicability of the power-curve estimation scheme used. A deeper cross section should be located and used, if possible.

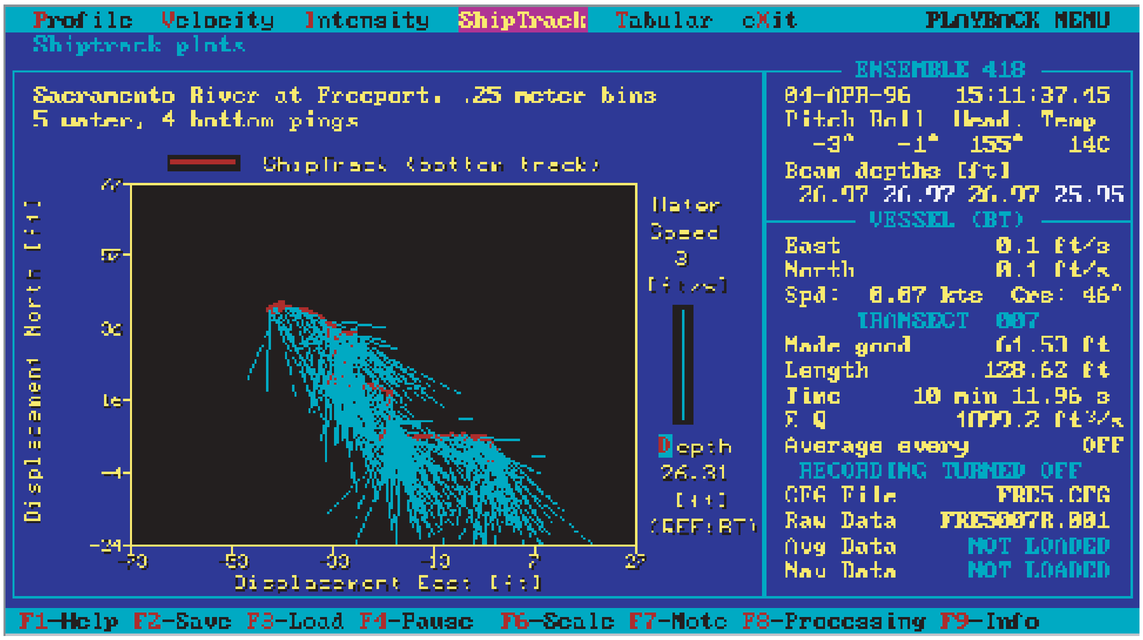


Figure 8.2. Transect software shiptrack plot of an anchored vessel.

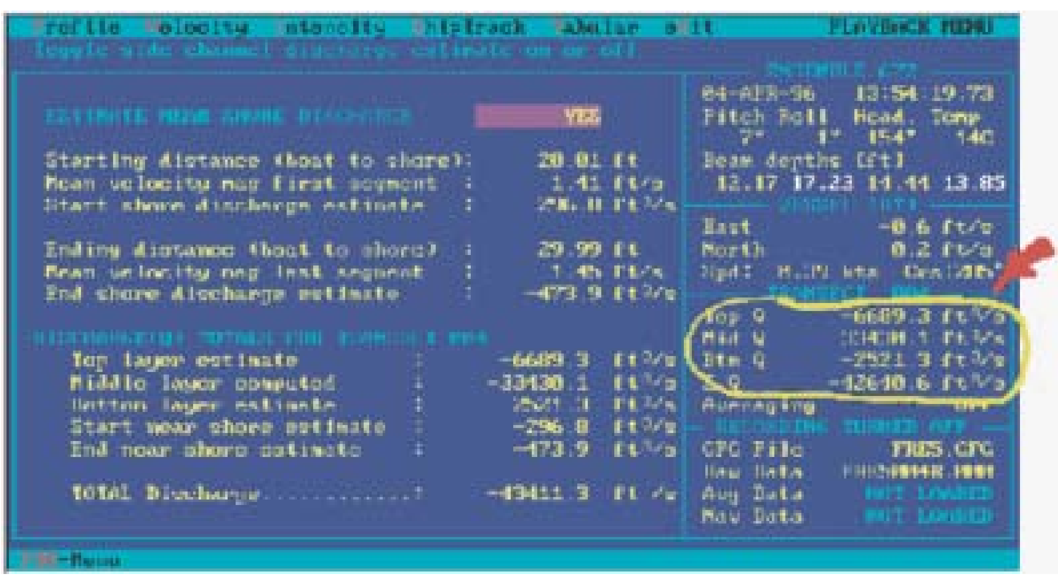


Figure 8.3. Transect software edge-value screen showing unmeasured layers.

Low-Velocity Measurements

Most of the errors seen during Transect software playback are caused by too few ensembles being collected for a given river velocity. Even seasoned ADCP operators sometimes fall prey to this error. It cannot be over emphasized that SLOWER river traverses are BETTER when it comes to the measurement of discharge in rivers having slow mean velocities. Slow traverses allow more ensembles to be collected, thereby reducing the amount of random error in the discharge measurement. In general, the boat should traverse the river at about the same velocity as the water. In large, wide rivers, this often is not possible (or feasible), and in such cases, equation 9.1 in chapter 9 should be used to estimate the proper boat velocity. The large standard deviation of ADCP-measured (slow) velocities can be seen in the shiptrack plot of figure 8.4.

The boat speed for the traverse (fig. 8.4) was close to that of the water. Even though there was a large single-ping standard deviation, the standard deviation of the resulting group of discharge measurements was small. If any single discharge measurement has a coefficient of variation larger than 5 percent, the ADCP and boat operator should be cautioned to decrease vessel speeds during discharge measurements at the site in question for similar or lower velocities.

Power-Curve-Fit Applicability

Figure 8.5 shows a discharge profile with measured data, cross-product curve fit, and the resulting discharge profile.

As can be seen from figure 8.5, the actual measured profile differs significantly from the one-sixth power-curve fit. In this profile, velocity near the surface is less than the velocity in the middle of the profile (as shown by the arrow). This may be caused by such things as wind shear or a flow reversal near the surface. If many or all of the measured profiles differ in this manner, then the TOP estimation scheme should be changed from POWER to CONSTANT in the configuration file, and the data replayed. The circled area indicates the profiled area where measurement bias can occur because of incorrect top layer discharge estimates. Generally, the bottom estimation scheme should be left at POWER. The exception to this rule is when significant numbers of profiles are bidirectional. A bidirectional profile is one wherein the velocities are stratified with the top-most velocities moving in a different direction than the bottom-most velocities. In cases of stratified flow, the estimation scheme should be set to CONSTANT at the top and CONSTANT at the bottom. This method will introduce some errors but the errors will pnot be as great as those caused by setting the estimation scheme to POWER.

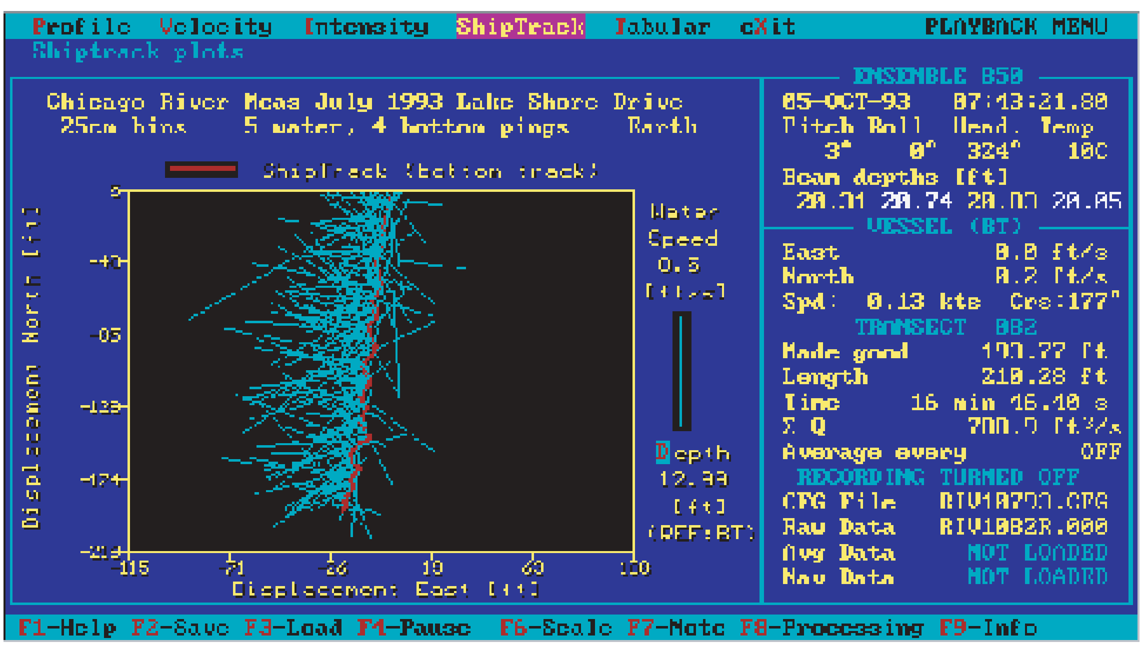


Figure 8.4. Transect shiptrack plot of acoustic Doppler current profiler-measured velocities on a slow-moving river.

Edge Values

Figure 8.6 shows the Transect software playback edge-value estimate screen, which is accessible by pressing ALT-E after Transect playback. Note! This feature is available only during playback at this time. This menu allows the operator to insert start and end edge distance estimates. The software then calculates an estimated discharge for each edge and adds it to the total discharge. Transect software version 2.80 (and later versions) allows the operator to enter edge values while acquiring the discharge measurement. These edge values are saved in the configuration file and can be loaded during playback.

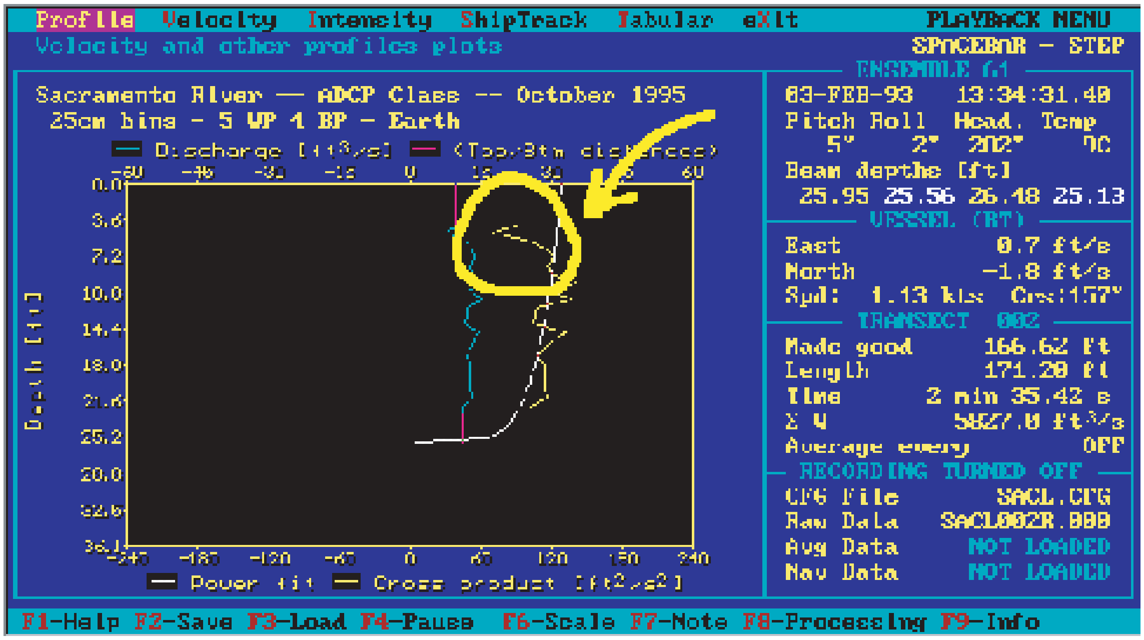


Figure 8.5. Transect software discharge profile plot. ADCP, acoustic Doppler current profiler.

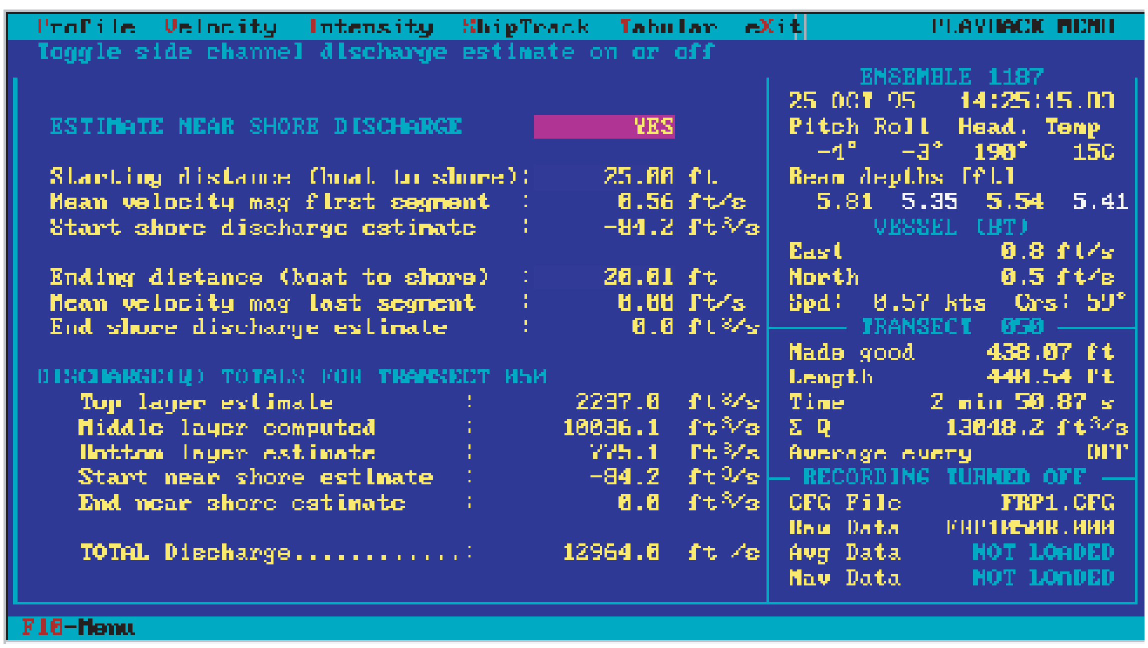


Figure 8.6. Transect software edge-value screen.

Note that in figure 8.6, the start edge-discharge estimate is negative, the main body of discharge is positive, and the end edge discharge is positive. This phenomena can be caused by two things:

- •The start-edge discharge is moving in the opposite direction from the main body of discharge and the end-edge discharge [this can occur because of eddies or momentum effects (fig. 8.7)].
- •Initial boat movement was toward the starting shore rather than away from it.

The sign (+ or –) assigned to the cross-product calculation is based on the boat course, in relation to the flow direction. If the water is flowing uniformly in one direction and the boat is traversing the flow uniformly without changing course, the sign of the cross product should remain constant. If the boat reverses course (or the flow changes direction during the traverse), the sign of the cross product will change. If this occurs at either or both edges, the edge velocities will have a sign that differs from that of the main flow body (fig. 8.6). In recent versions of the Transect software (version 4.00 and later), corrections have been made to eliminate incorrect signs (+ or –) near the riverbank edges, however, the operator still should carefully examine the edge-value water velocities.

Shiptrack

The operator should take care to start the Transect software only after the boat begins the cross-section traverse and to stop the Transect software before making the course reversal at the end of the traverse. During the discharge measurement, the ADCP operator also should note any observed longitudinal-flow reversals on the discharge-measurement log sheet. Longitudinal-flow reversals can take place at high flow (due to eddies) and near slack tide (due to momentum effects). Longitudinal-flow reversals should be noted during the review of shiptrack plots. Then the reviewer should determine whether the reversal is actual or caused by initial boat movement toward shore.

The shiptrack plot shown in figure 8.7 also should be examined for discrepancies in the motion of the discharge-measurement vessel. In general, a good discharge measurement occurs when the measurement vessel makes a smooth traverse from bank to bank. An extreme example of irregularities in the shiptrack is illustrated in figure 8.8. Examination of the velocity-profile data in figure 8.9 does not reveal these irregularities. If the shiptrack plot of this measurement had not been examined, it may have been erroneously labeled as a good measurement.

The shiptrack plot should be examined for "hooks" (fig. 8.10) near the edges that indicate that the F5 key was either pressed too early in the transect (before the vessel had started its move toward the far bank) or too late (after the boat operator has reversed course at the end of the transect). Such "hooks" can be edited out of the data using the F8 subsectioning menu (fig. 8.11).

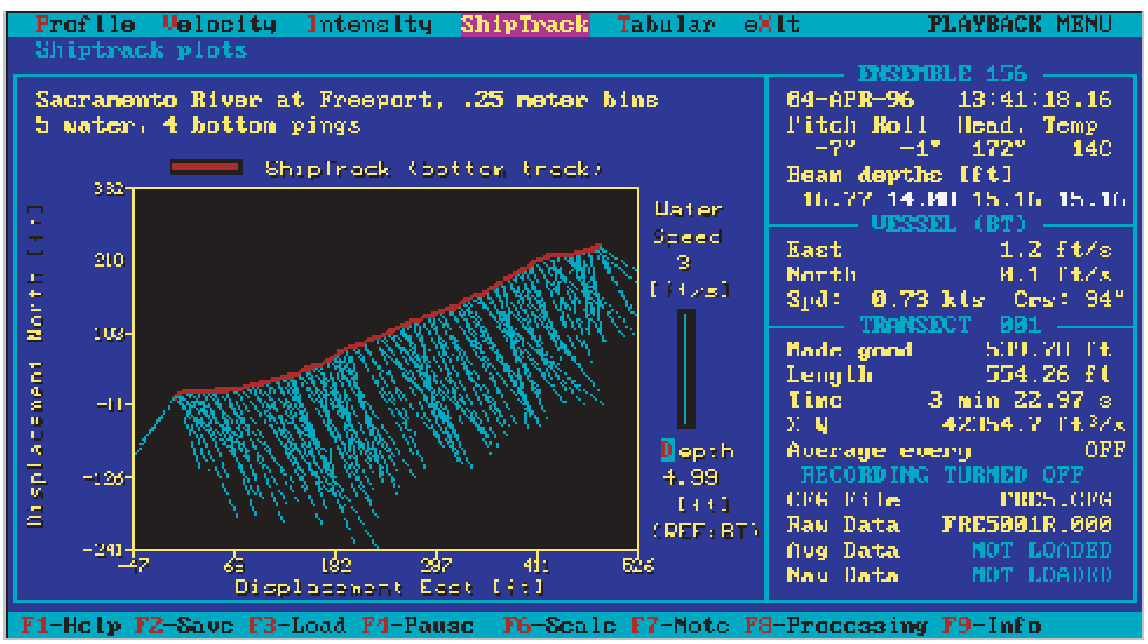


Figure 8.7. Transect software shiptrack plot.

Summary

Transects should be replayed as soon as possible after being collected to check for possible errors in acoustic Doppler current profiler (ADCP) setup and discharge-measurement technique. Configuration files should be examined to see if proper ADCP setup parameters were used for the measurement. The power-curve estimation scheme should be checked for correctness and the edge-value estimates should be checked.

Discharge-measurement technique should be checked for correctness. In particular, the boat speed should be slow enough to reduce the discharge-measurement standard deviation to a value under 5 percent (of mean discharge). In tidally affected areas or large shallow, slow-moving rivers, equation 9.1

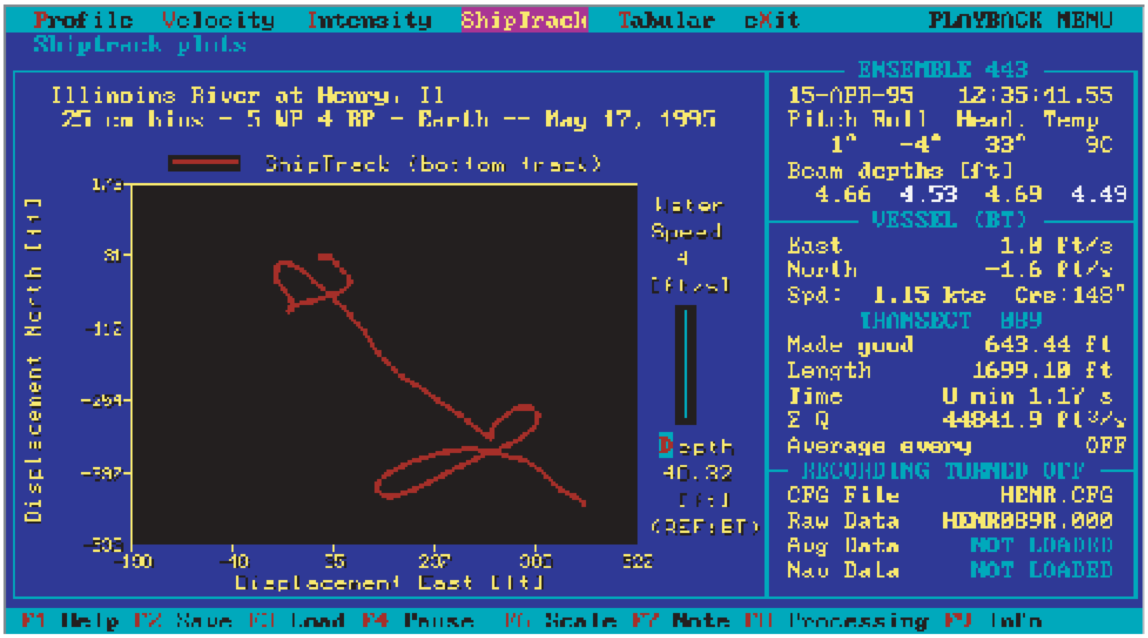


Figure 8.8. Transect software shiptrack plot with operator's initials.

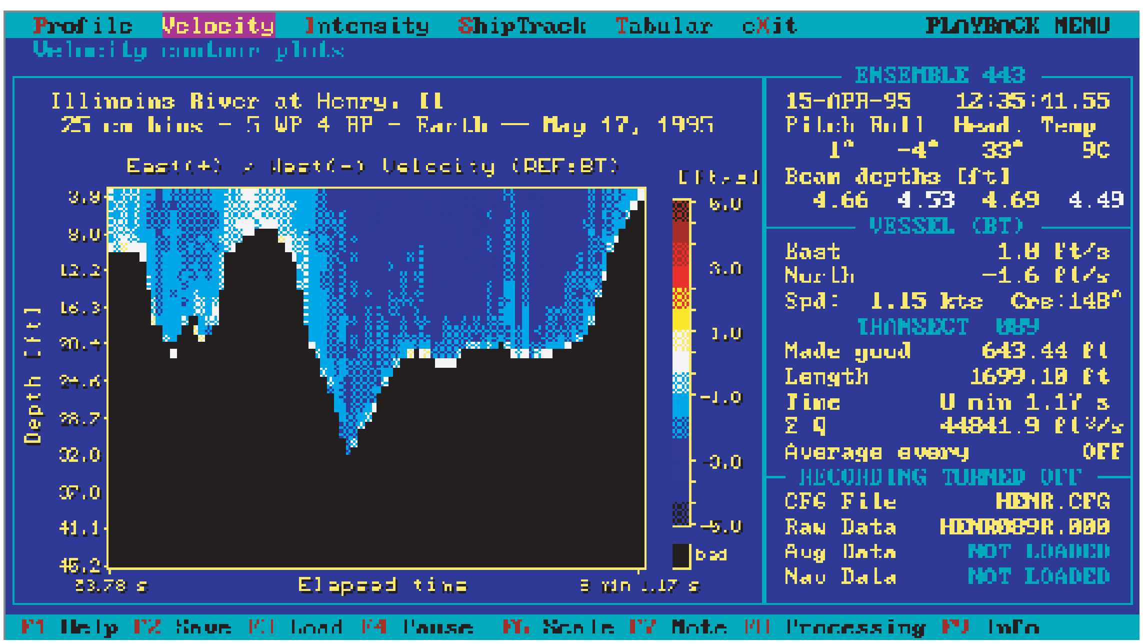


Figure 8.9. Transect software profile plot of "initials".

(chap. 9) can be used to assess discharge-measurement standard deviation.

If bottom movement is suspected, the boat should be anchored in an area of the highest channel flow and transects should be collected for at least 10 minutes. The resulting shiptrack plot should be examined for apparent upstream boat movement.

If a few missing ensembles are discovered during playback, they can be estimated using the technique described in this chapter. If there are many missing ensembles present in the transect data, the discharges should be remeasured at a different cross section or when conditions become more favorable.

Magnitudes of the discharges in the unmeasured layers should be examined and, if they comprise a significant portion of the total discharge, the operator should attempt to locate a deeper cross section for future measurements.

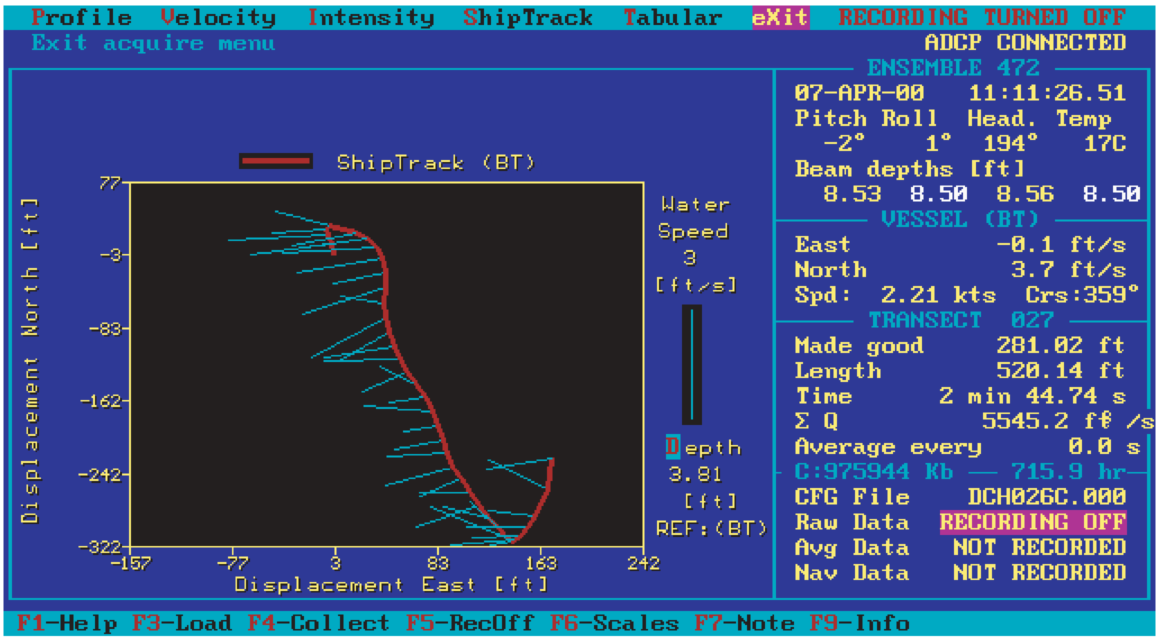


Figure 8.10. Transect shiptrack screen. ADCP, acoustic Doppler current profiler.

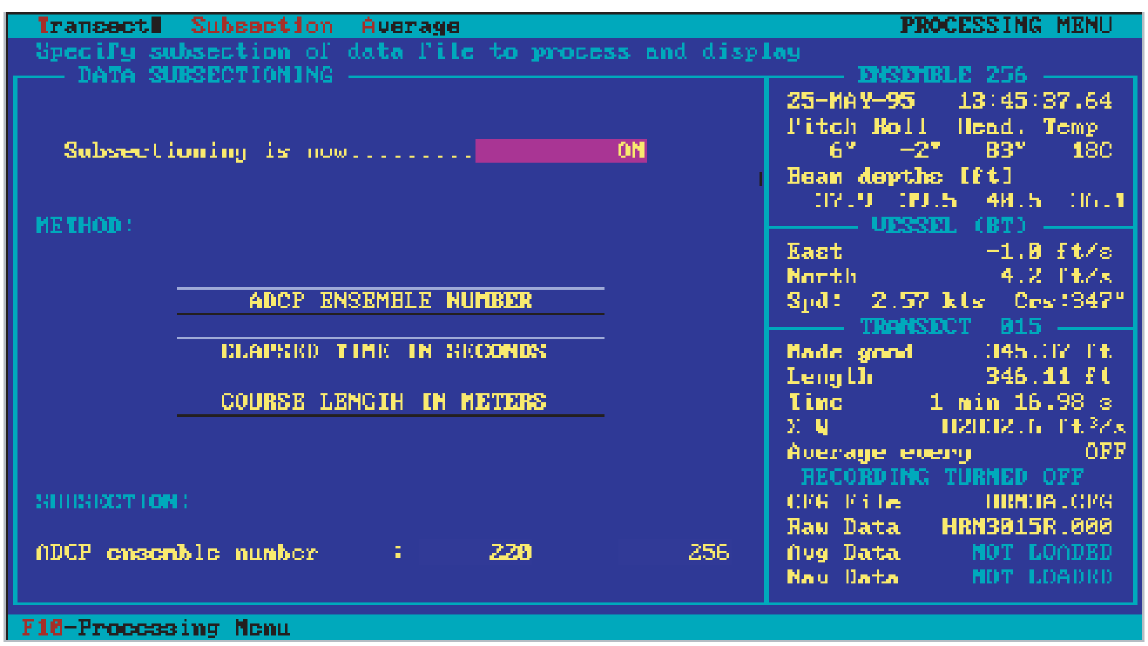


Figure 8.11. Transect subsectioning menu screen.

This page left blank intentionally.

CHAPTER 9: DISCHARGE-MEASUREMENT ERROR

In this chapter we will discuss the major sources of error in ADCP discharge measurements. We will first review velocity-measurement uncertainty (chap. 1) and then discuss random and systematic ADCP discharge-measurement errors. A simple discharge-measurement error model is presented to aid the operator in premeasurement planning and error assessment.

A Review of Major Acoustic Doppler Current Profiler Velocity-Measurement Limitations and Uncertainties

A short review of ADCP velocity-measurement uncertainty and measurement limitations will help in understanding discharge-measurement errors. Detailed explanations and examples of these uncertainties are discussed in chapter 1.

Limitations

Range Limitations

The signal strength of an acoustic pulse decreases logarithmically with distance from the transducer face (range). As the signal strength and signal-to-noise ratio decreases, the spectral width of the returned signal increases. This increase in spectral width with range causes an increased standard deviation of the measured velocity with range. At some range the return echo is unusable. This limiting range is largely dependent on transducer frequency and, to a much lesser extent, on transmit pulse length and beam angle for any given ADCP. The usable range of an ADCP also is affected by the number of scatterers in the water column. Below is a conservative estimate of ADCP maximum range for several transducer frequencies (table 9.1).

Table 9.1. Approximate maximum depth range for 300-, 600-, and 1,200-kilohertz acoustic Doppler current profiler (ADCP) systems

[kHz, kilohertz; m, meter; ft, foot]

ADCP frequency (kHz)	Range (m) (ft)
300	20 m (390 ft)
600	48 m (157 ft)
1,200	15.4 m (50.5 ft)

Side-Lobe Interference

When a parasitic side lobe strikes the bottom, the returning echo drowns out the reception of the echo from the main beam. In an ADCP with 20º-beam angles, this loss of reception occurs at a point equal to about 94 percent of the total depth. This area of side-lobe interference near the bottom (equal to 6 percent of total depth) can be calculated using equation 1.4. Using this equation, the Transect program “throws out” discharge data in the area of side-lobe interference and then estimates the velocities near the bottom using power-curve fits or other estimation techniques. However, if the operator is collecting velocity profiles, the velocities may not be flagged “bad” by the Transect software. To determine the depth at which the side-lobe interference will affect the data, the operator must examine backscattered intensities. In a normal profile, the backscattered intensities start at around 140 counts (or higher) and “drop off” with depth. Velocity measurements become questionable at the point where intensities increase (or stop decreasing). Looking at beam 1 in the tabular plot in figure 9.1, we see that the intensities start at 145 and increase to 147 in the following bin because of ringing (mechanical and electronic resonance). This error in the top-most bin occurs if the blanking distance is set too short (see the next section on Blanking Distance). The intensities decrease until about 123 counts where they “flatten” and then begin to increase. The depth at which the counts flatten and do not decrease is the depth at which the velocities may become affected by side-lobe interference. The area between the last good bin center and the bottom must be estimated by some means to obtain mean velocity in the vertical profile.

Unmeasured Velocity Due to Blanking Distance and Transducer Draft

After transmitting the acoustic signal, the ADCP transducers and electronics must “recuperate” briefly before they can receive the incoming echoes. During recuperation, the acoustic signal travels a short distance (blanking distance). Acoustic reflections cannot be received within the area between the transducer face and the blanking distance.

The transducer assembly must be submerged adequately so that it does not break the water surface during pitch and roll events. The depth of the transducer faces below water surface is called transducer draft.

To calculate the distance to the center of the first bin, it is necessary to use the BB-SETUP software module, available from RDI, as part of the Transect software package. From the screen capture shown in figure 9.2 it can be seen that if you are using a

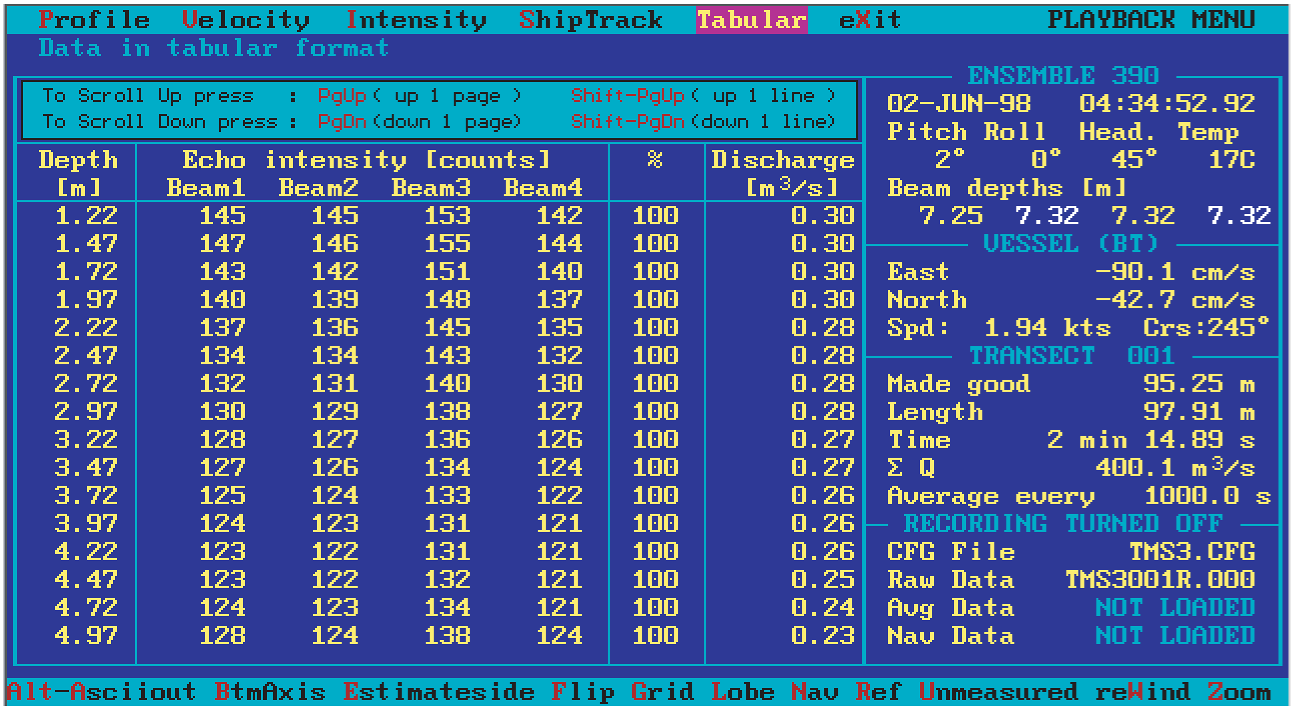


Figure 9.1. Screen shot of Transect software showing tabular output.

1,200-kHz BB-ADCP with 0.25-m (0.82-foot) bins, a blanking distance of 0.5 m (1.64 ft) and an ambiguity velocity (WV) of 190 cm/s (6.2 ft/s), the center of bin 1 will be at a range of 0.85 m (0.28 ft) from the face of the transducers. If the transducer draft is 0.25 m (0.82 ft), the center of the first bin is 0.85 + 0.25 = 1.10 m (3.6 ft) below water surface. Water velocity in the area between the water surface and the first bin center must be estimated to calculate mean water velocity in the vertical profile.

Random and Systematic Uncertainty

In chapter 1, we discussed ADCP velocity-measurement uncertainty in detail. In the following paragraphs we will touch on each of the major sources of ADCP velocity-measurement uncertainty so that we can more readily grasp the causes of discharge-measurement error.

ADCP velocity-measurement uncertainty can take two forms:

- •Random uncertainty
- •Systematic uncertainty (bias)

Random uncertainty can be reduced by data averaging, but systematic uncertainty cannot. If the magnitude of systematic uncertainty is known, it can sometimes be corrected using adjustment factors or coefficients.

Random Uncertainty Due to Self Noise and Lag Distance

The most significant source of random uncertainty in a BB-ADCP water-velocity measurement is caused by self noise (freeway analogy in chap. 1). The magnitude of this uncertainty is affected by ADCP transducer frequency, transmit pulse width, lag distance, and many other factors. This uncertainty directly affects ADCP water-velocity measurement precision. Techniques such as pseudo random phase encoding, data averaging, and increasing the lag distance are used to help reduce the effects of this uncertainty. The magnitude of this uncertainty can be predicted using the BB-SETUP program that is shipped with the Transect software files. Figure 9.2 shows a screen shot of a typical 1,200-kHz broad-band ADCP setup scenario.

In mode 1 operation, the operator can control the lag distance by changing the value of the ambiguity velocity (WV command). Notice that for an ambiguity velocity of 190 cm/s the single-ping standard deviation (an indicator of velocity-measurement random uncertainty) is 14.08 cm/s (0.46 ft/s). If the operator lowers the ambiguity velocity to 90 cm/s (2.95 ft/s) for example, the single ping standard deviation drops to 10.3 cm/s (0.34 ft/s). There are practical upper and lower limits to the ambiguity-velocity setting; setting the ambiguity velocity too high will produce unacceptable random uncertainty in the velocity measurement and setting the ambiguity velocity too low may introduce ambiguity uncertainty (chap. 1). In

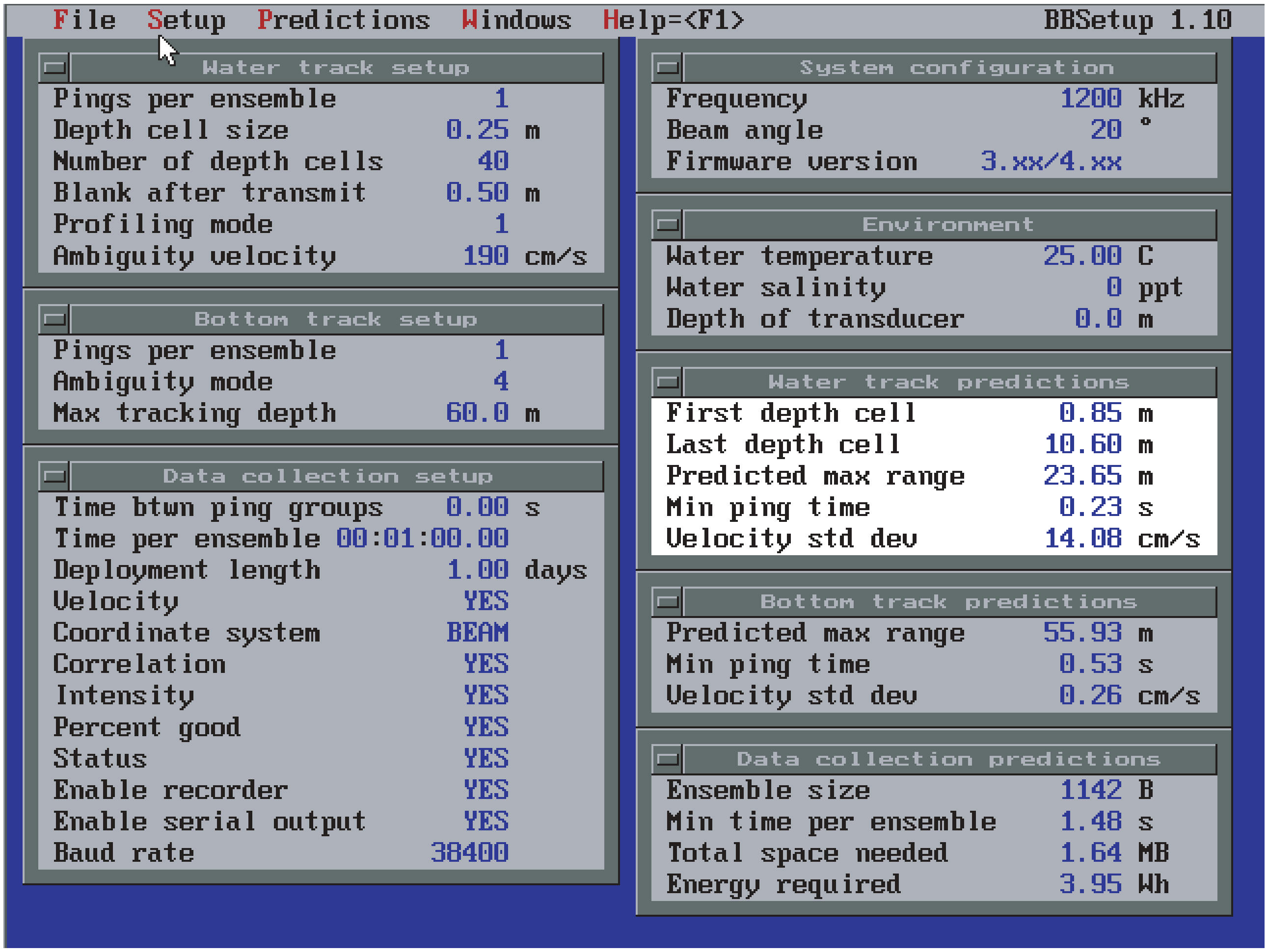


Figure 9.2. Screen shot of BB-SETUP software showing a typical setup for a 1,200-kilohertz broad-band acoustic Doppler current profiler.

mode 5 operation, the velocity-measurement uncertainty is greatly reduced (by about a factor of 10) because of the large lag spacing. However, because this large lag spacing lowers the ambiguity velocity, mode 5 only can be used in conditions where the bottom and water velocities are low [less than 50 cm/s (1.64 ft/s)], relative to the ADCP.

Systematic Uncertainty Due to Velocity Ambiguity

If the operator is recording single-ping ensembles, velocity-ambiguity uncertainties show as “spikes” in the data that are the opposite sign of the “true” velocity. The difference between the “true” velocity and the erroneous velocity is twice the magnitude of the ambiguity velocity (WV command in mode 1). A detailed explanation of this uncertainty is in chapter 1. For mode 1 operation, the operator can raise the value of the ambiguity velocity to eliminate these uncertainties, but the single-ping velocity-measurement standard deviation will increase, causing decreased measurement precision. The ambiguity-velocity setting is a trade off and usually can be set to a “safe” value using equation 3.1 in chapter 3. If the ambiguity-velocity values are set to a high value because of possible ambiguity uncertainties, the operator may have to slow the boat during the cross-section traverse to improve the discharge-measurement standard deviation (discussed later in this chapter).

For mode 5 operation, the ambiguity velocity (WZ command) is set automatically by the ADCP, depending on water depth and depth-cell length. If, during mode 5 operation, ambiguity uncertainties are encountered, the operator either must switch measurement modes or look for a cross section having lower velocities and (or) current shear.

Systematic Uncertainty in Speed of Sound Due to Temperature

Speed-of-sound calculations that are not corrected for temperature can cause velocity-measurement errors and depth errors as great as 7 percent. Fortunately the Transect software uses data from a thermistor in the transducer assembly to correct speed-of-sound calculations for temperature variations in the water near the transducer. Under normal stream conditions, this correction reduces speed-of-sound errors to insignificant levels. Sometimes, however, the water column becomes temperature stratified. Unlike horizontal water-velocity errors, depth-measurement errors can be introduced by temperature gradients in a stratified water column. Figure 9.3 shows depth errors, in percent, due to improper temperature compensation for speed of sound. Fortunately temperature gradients must be extremely high (10ºC or more) to cause a significant error in a BB-ADCP depth measurement. Gradients of this magnitude sometimes can occur during the summer in slow-moving water.

Speed-of-sound errors also can be caused by a faulty thermistor in the transducer assembly. An error in temperature causes an erroneous calculation of water density, which results in a speed-of-sound uncertainty.

Systematic Uncertainty in Speed of Sound Due to Salinity

The speed-of-sound equation in the Transect program (R.D. Instruments, Inc., 1995) depends on a user-supplied salinity value to calculate speed-of-sound corrections (as discussed in the velocity-measurement error section in the first part of this chapter). This value is specified in the Transect software configuration file. If the operator has entered an incorrect value or has forgotten to enter the proper value, depths (as well as velocities) are calculated incorrectly. Depth errors as high as 3 percent can be caused by speed-of-sound calculations that are not corrected for salinity (fig. 9.4). Fortunately "ball park" salinity values usually will reduce this error to less than 1 percent.

Velocity errors due to salinity-caused speed-of-sound variations can be at least as serious, therefore, many boat operators carry a salinimeter (or conductivity meter) with them to the discharge-measurement site. Salinity can be calculated and entered into the configuration file prior to the discharge measurement, however, a better approach is to enter zero salinity into the configuration file (ES0). The correct salinity can be plugged into the configuration file during playback. An incorrectly entered salinity using the ES direct command can be very hard to correct after the fact.

Systematic Uncertainty Due to Incorrect Beam Geometry

The largest source of systematic uncertainty in an ADCP is caused by uncorrected errors in the measurement of the beam-pointing angles. These uncertainties usually are in older BB-ADCP units that were sold before the manufacturer instituted stringent quality-control procedures. Late model BB-ADCPs and Workhorse Rio Grandes have transducer assemblies that meet more exacting beam-angle tolerance requirements. Each ADCP is tested on a distance course and corrections are saved in the ADCP firmware for any measured beam-angle discrepancies. Older ADCPs can be upgraded by the manufacturer and then tested in a lake to identify and correct beam-angle uncertainties.

Minimizing Uncertainty in Velocity Profiles

Many scientific studies require accurate water-velocity profile measurements and discharge measurements. Many of the velocity-measurement errors described above can be minimized or eliminated by using the following common sense rules:

- Use the proper water mode for the job. If the velocities are dynamically changing, or the vessel is affected by pitch and roll, use water mode 1. In shallow water that is placidly moving, mode 5 may be used. In shallow, fast-moving water, mode 8 may be used.

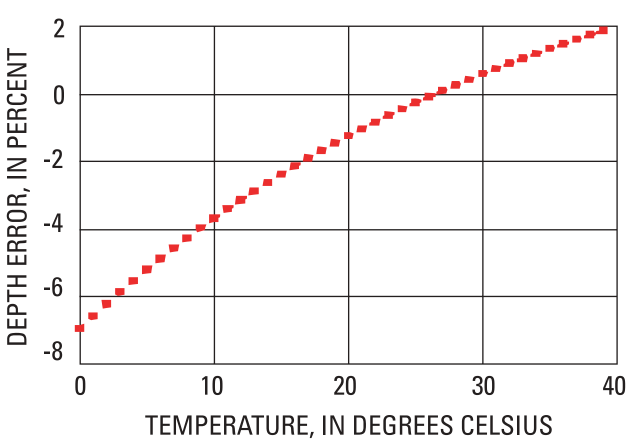


Figure 9.3. Depth error due to speed of sound that is uncorrected for temperature.

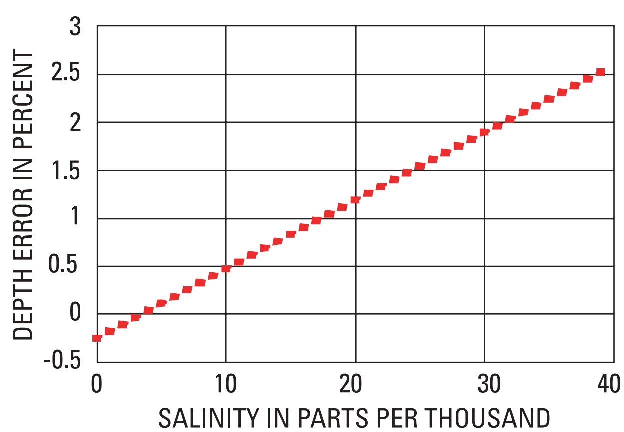


Figure 9.4. Depth error due to speed of sound that is uncorrected for salinity.

- •Collect enough data at the profile location to ensure that the measured water-velocity standard deviation is within usable limits (after the data are averaged).
- •If the unmeasured bottom and top velocities are to be estimated, ensure that the measured portion of the profile (after averaging) is congruent with the estimation scheme used. For example, if the measured part of the profile is bidirectional, a one-sixth power-curve estimation scheme is improper.

Errors Affecting the Accuracy of Discharge Measurements

If heavy sediment loads are not present and a moving river bed problem does not exist, errors in ADCP discharge measurements usually are caused by improper river traverse rates or erratic movements of the discharge-measurement vessel. These random errors usually cause imprecision in the discharge measurement (scatter). Reducing the traverse rate and eliminating erratic vessel movements can reduce random error.

The next most common error types are depth errors caused by incorrect transducer draft, depth errors due to speed-of-sound variations, and cross-product errors due to improper application of the power-curve fitting scheme. These sources of error are biases that cannot be improved by slowing the traverse rate or averaging the data (see bias error section later in this chapter). Random errors in discharge measurements made with the BB-ADCP system roughly can be predicted if the following values are known:

- •ADCP water-velocity measurement precision
- •ADCP bottom-track velocity measurement precision
- •The standard deviation of naturally occurring water-velocity pulsations (at the ADCP-measurement time scale)
- •Approximate average cross-sectional water depth
- •Approximate average water speed
- •BB-ADCP bin size
- •BB-ADCP ping rate

Table 9.2 gives the approximate depth-averaged, water-velocity standard deviation for 1,200-, 600-, and 300-kHz BB-ADCPs with 20º beam angles using mode 1 operation with an ambiguity velocity of 190 cm/s (6.23 ft/s).

Mode 5 bottom-track standard deviation is much less than the water-velocity standard deviation for all ADCP frequencies [0.2–0.3 cm/s (0.006–0.009 ft/s)].

Table 9.2. Approximate depth-averaged single-ping precision for 1,200-, 600-, and 300-kilohertz broad-band acoustic Doppler current profiler-measured water velocities using mode 1 operation, 20° beams, and WV190

[kHz, kilohertz; m, meter; ft, foot; cm/s, centimeter per second; ft/s, foot per second]

Frequency (kHz)	Depth cell size	Average standard deviation for depth range
1,200	0.25 m (0.8 ft)	14.1 cm/s (0.46 ft/s)
600	.50 m (1.64 ft)	14.1 cm/s (.46 ft/s)
300		14.1 cm/s (.46 ft/s)

Simplified Random-Error Model

The precision of a discharge measurement may be computed using the following algorithm in equation 9.1:

$$\sigma_q = \frac{\sqrt{\left[\left(100\frac{X_w}{V_m}\right)^2 + \left(100\frac{X_b}{V_m}\right)^2 + \sigma_p^2 + \sigma_z^2\right]}}{\sqrt{0.75 N_b N_s}} \qquad (9.1)$$

where

σ_q = standard deviation of discharge measurement, in percent;

V_m = estimated approximate mean stream velocity, in centimeters per second;

X_w = BB-ADCP water-velocity precision, in centimeters per second (table 9.2.);

X_b = BB-ADCP bottom-track precision, in centimeters per second (table 9.2.);

σ_p = estimated standard deviation of natural pulsations, in percent of mean velocity; a value of usually 8–12 percent (at the time interval used for an ensemble by the BB-ADCP);

σ_z = depth error due to round off and resolution limitations;

N_b = average number of bins in the vertical; and

N_s = total number of subsection measurements.

Equation 9.1 is derived using the following assumptions:

- •A 15-percent bin-to-bin correlation
- •A 0-percent subsection-to-subsection correlation
- •A smooth rectangular channel

The 0.75 constant in equation 9.1 is a rough approximation of the Markov model output when there is a sample (bin-to-bin) correlation of 15 percent (Matalas and Langbein, 1962). Matalas and Langbein (1962) present an equation for the calculation of effective N for any correlation coefficient, and this equation should be used in error models that are developed for the estimation or prediction of BB-ADCP (or narrow-band ADCP system) discharge-measurement error.

Depth error due to BB-ADCP round off and resolution limitations (σ_z) is estimated by the manufacturer to be 4 percent of the measured vertical depth range on an individual beam (Joel Gast, R.D. Instruments, Inc., oral commun., 1997). Because four beams are averaged for the depth measurement, the error becomes $\frac{4}{\sqrt{4}} = 2$ percent for each ping averaged during the discharge measurement.

Figure 9.3 shows graphs of mode 1, 1,200-kHz, error model output for a 61-m- (200-foot-) wide river, with boat speeds of about 0.3 and 0.9 m/s (1.0 and 3.0 ft/s). Figure 9.3 reveals that a boat operator traversing a 61-m- (200-foot-) wide, 4.6-m- (15-foot-) deep river could use a boat speed of about 0.3 m/s (1 ft/s) for the measurement of all mean river velocities above 0.15 m/s (0.5 ft/s). Figure 9.5 also shows that discharge-measurement error increases with the boat speed. This increase occurs because the BB-ADCP is collecting fewer pings during the cross-section traverse, with a resultant increase in random error (because fewer data are averaged). The boat operator must remember that the precision of a discharge measurement can change dramatically with changes in the total number of pings and the total number of bins sampled during the traverse. The total number of depth bins depends on the water depth. Figure 9.6 shows the same scenario as in figure 9.5, but with an average cross-section depth of 9 m (30 ft) rather than 4.3 m (15 ft). Note that the discharge-measurement error decreases to magnitudes similar to those shown in figure 9.5. This decrease occurs because there are twice as many bins averaged in the vertical profile.

Although equation 9.1 can be programmed into a spreadsheet and used to predict discharge-measurement uncertainty, a small executable software application (QERROR) has been developed (for mode 1 use) that is more easily used in the field. Figures 9.7–9.9 show screen shots from the QERROR application. Figure 9.7 shows the input screen. The measurement units are in mixed systems on the input screen for two reasons:

- USGS field office personnel are more adept at estimating widths and depths in the standard-measurement system.

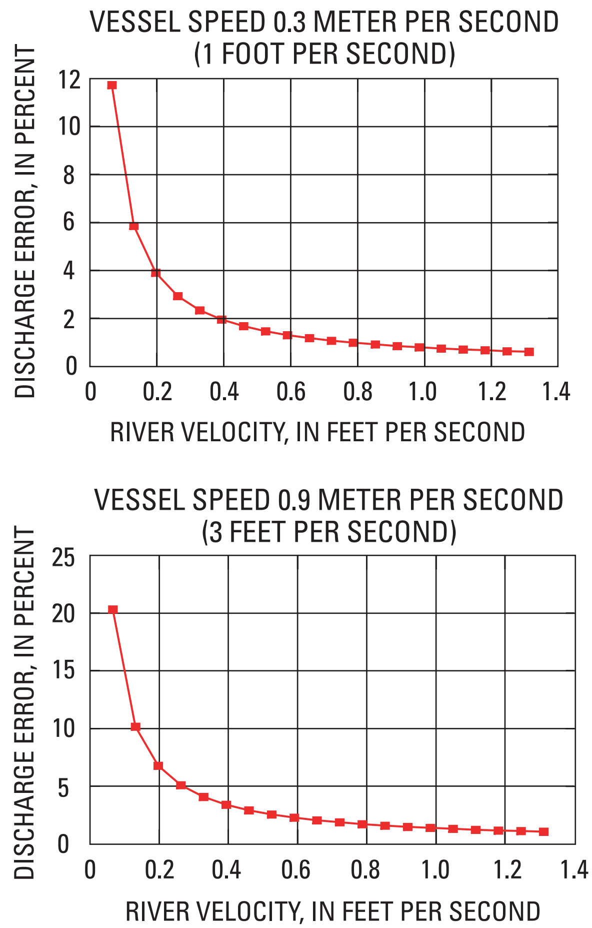


Figure 9.5. Discharge error using a boat speed of about 0.3 meter per second (1 foot per second) and about 0.9 meter per second (3 feet per second).

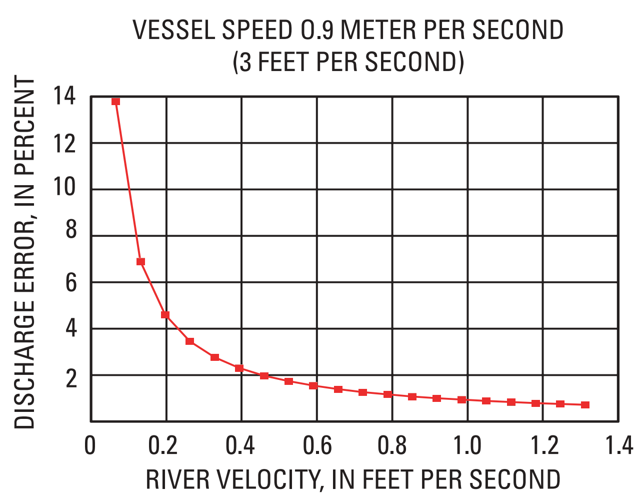


Figure 9.6. Discharge error using a boat speed of about 0.9 meter per second (3 feet per second) in 9 meters (30 feet) of depth.

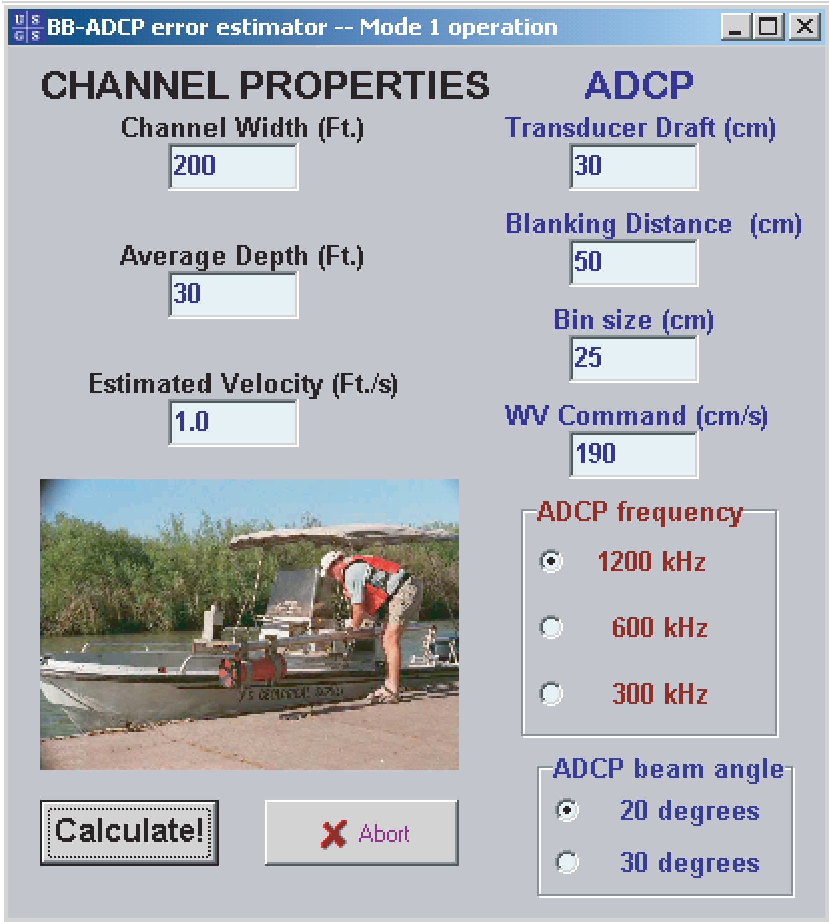


Figure 9.7. QERROR setup screen. ADCP, acoustic Doppler current profiler.

•ADCP input parameters always are requested in SIS units.

Figure 9.8 is the output screen from the QERROR application and it illustrates the importance of slow-vessel traverse rates when measuring rivers with slow mean velocities. Note that the error is reasonable when the boat is moving at speeds less than, or equal to, the water velocity. A good rule of thumb is to traverse the river at about the same speed as the mean water velocity. However, this rule becomes inapplicable when measuring wide, deep rivers, with slow water velocities. The operator would not be able to complete such a measurement within a reasonable time frame. In cases of wide, deep rivers, the operator can use equation 9.1 or the QERROR application to estimate discharge-measurement error based on boat speed, average water depth, and estimated mean water velocity.

Figure 9.9 shows the same measurement scenario as used for figure 9.8 with a mean river velocity of 0.15 m/s (0.5 ft/s). Notice that boat speeds as high as 0.6 m/s (2 ft/s) could be used for accurate measurement of the above described river, partly because the river (figs. 9.6 and 9.7) is 9 m (30 ft) deep. If the river depth were shallow [3 m (10 ft) or less], the boat would have to be slowed to the mean water velocity to maintain a reasonable precision (a CV of less than 5 percent) (fig. 9.10).

Examination of fig. 9.6 reveals that the length of time required for the river traverse increases exponentially as mean river velocities approach 0. The requirement for this extended averaging period begins to defeat the purpose of the BB-ADCP measurement system at very shallow depths and low velocities. Water mode 5 should be used, if possible, in these cases because it will reduce the above described discharge-measurement errors by almost an order of magnitude, however, its use is limited to rivers having little shear or turbulence. For 600-kHz BB-ADCPs, water mode 8 can be useful in shallow water if the vessel is slowed to reduce the higher random error of mode 8 operation.

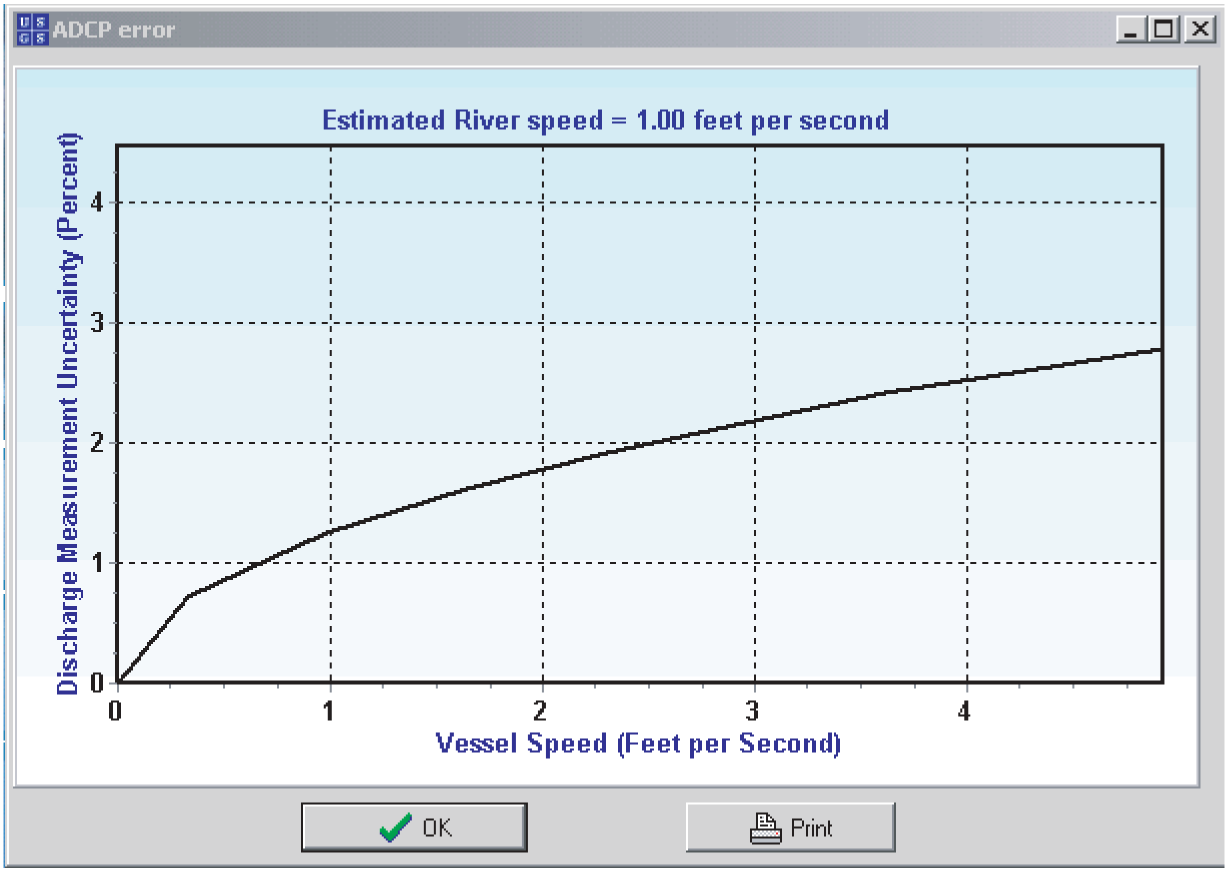


Figure 9.8. Discharge error with a mean water velocity of about 0.3 meter per second (1.0 foot per second). ADCP, acoustic Doppler current profiler.

Bias Error

Discharge-measurement random error can be reduced by data averaging (slowing the vessel speed for the measurement transect), as discussed above. Bias (systematic) errors cannot be reduced by data averaging.

Bias error can be separated into two classes: instrument error and operator error. Instrument error is due to physical, electrical, or acoustical limitations of the BB-ADCP instrument (or defects in the BB-ADCP hardware and firmware). Operator error is caused by improper BB-ADCP installation, setup, and, in some cases, application.

Instrument-Caused Bias Error

There are many sources of instrument bias error. Some are more significant than others. This report will not attempt a discussion of ADCP systematic error sources related to the physics of the acoustic signal (other than beam-pointing angles and depth measurements) because many of these sources are not yet documented and are beyond the scope of this report.

The manufacturer is aware of many of these types of errors and reports that the two most important of these are water-velocity measurement errors, due to selective absorption (nonuniform signal absorption in the water mass over the transmitted signal spectrum), and bottom-track errors due to terrain effect (the leading edge of the acoustic beam is far20ther away from the transducer than is the trailing edge when it impinges the channel bottom). These and other errors are thought by the manufacturer to be small and insignificant for most applications (Joel Gast, R.D. Instruments, Inc., oral commun., 1992). The following paragraphs will discuss or revisit instrument errors that significantly can affect the accuracy of an ADCP discharge measurement. These errors are as follows:

- Beam-angle errors.
- Depth-measurement errors.
- Speed-of-sound errors due to temperature and salinity.
- Bias errors caused by improperly estimating the unmeasured portions of the cross section.
- Operator-caused bias errors.

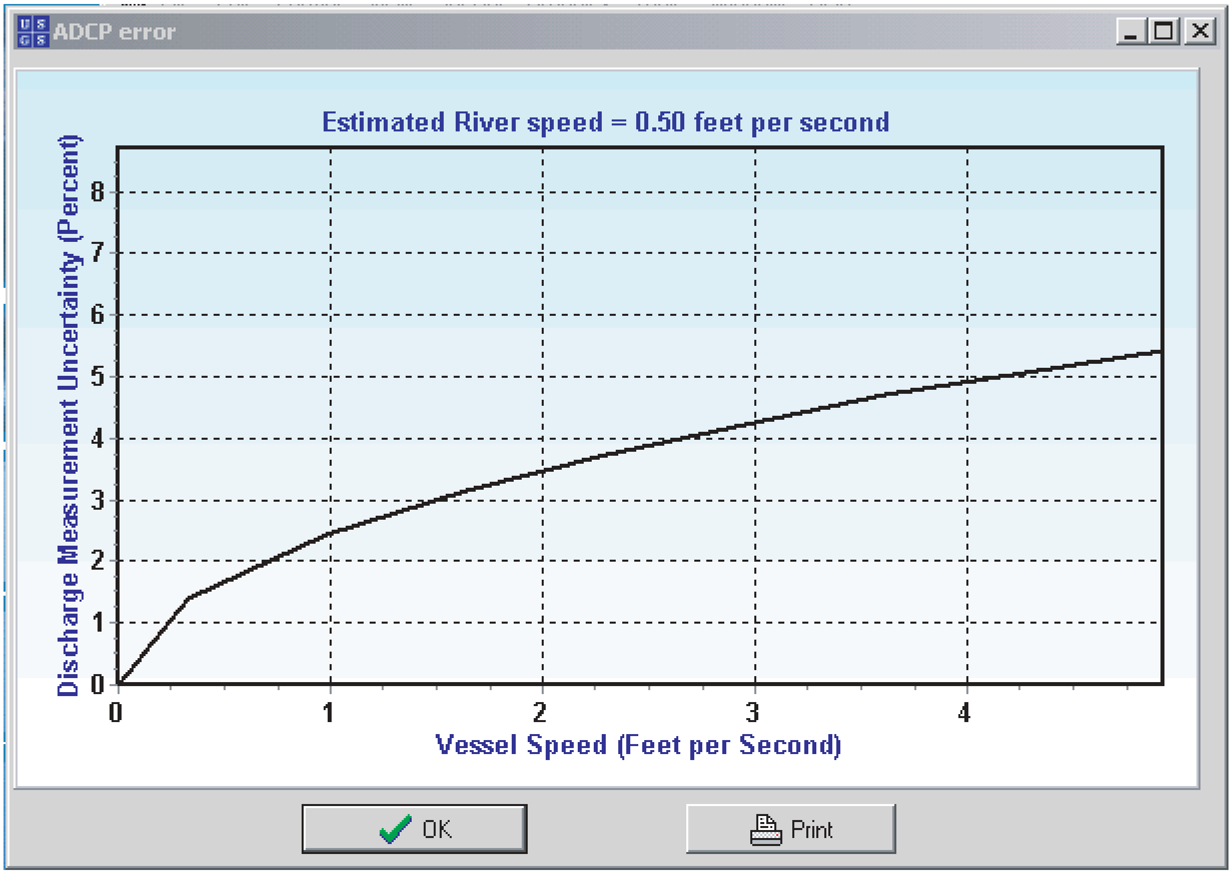


Figure 9.9. Discharge error in deep water [9 meters (30 feet)] with a mean river velocity of about 0.15 meter per second (0.5 foot per second). ADCP, acoustic Doppler current profiler.

Beam-Angle Errors

Errors in the beam-pointing angles (discussed in the velocity-error section) have an equivalent affect on the accuracy of discharge measurements.

Depth-Measurement Errors

The Transect software uses depth measured from the four acoustic beams to calculate mean depth for each discharge-measurement subsection. These depth-measurement errors can come from two sources:

- Depth sampling errors due to limitations of the acoustic beams and bin sizes.
- Depth errors due to improper estimation of speed of sound.

Figure 9.11 shows an exaggerated instance of depth error due to limitations of the acoustic beams. If only a few depth measurements were taken, per cross-section traverse, this type of error would be significant. However, the averaged depth is calculated using all four beam depths for each ensemble and, if the ensembles are kept short enough, the mound (fig. 9.8) will be integrated into the total cross-section averaged depth. A typical BB-ADCP discharge measurement collects many more depth measurements during the cross-section traverse than are collected using conventional methods.

Near the bank edges, the BB-ADCP beams oriented toward shore will show shallow depths, whereas the beams oriented toward the channel will show greater depths. An average of all four beams will approximate the vertical depth from the center of the BB-ADCP transducer assembly to the bottom. In pitch and roll conditions, averaged depth measurements from all four acoustic beams will be more accurate than depths measured by a single, vertically placed, depth sounder because of the large beam "footprint" or pattern.

Speed-of-Sound Errors Due to Temperature and Salinity Gradients

Speed-of-sound errors (discussed in the ADCP Velocity-Measurement Limitations and Uncertainties section of this chapter) affect the accuracy of discharge measurements in the same way that they affect the accuracy of velocity measurements. These uncertainties

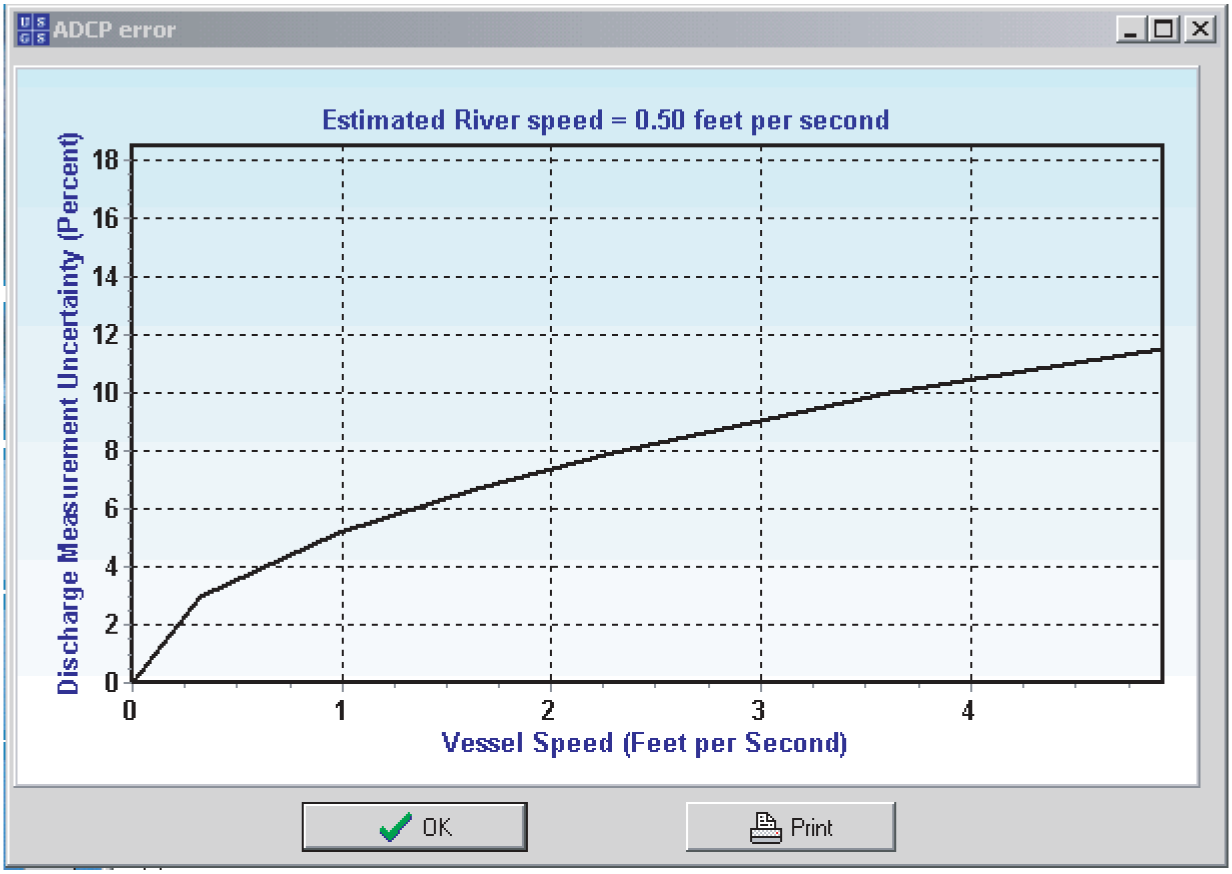


Figure 9.10. Discharge error in shallow water [3 meters (10 feet)] with a mean river velocity of about 0.15 meter per second (0.5 foot per second). ADCP, acoustic Doppler current profiler.

are subtle and hard to spot in the collected data. Close attention to detail is required by the ADCP operator to eliminate speed-of-sound uncertainties.

Bias Error Due to Incorrect Estimation of Unmeasured Velocities Near the Water Surface and Channel Bottom

Errors of this type are called extrapolation errors. An example of a nonstandard velocity profile is shown in chapter 8 to illustrate this error. The extrapolation scheme used to estimate cross products near the water surface and channel bed assumes a “Manning-like” velocity profile. The unmeasured area near the bottom usually is not a problem because the velocity must go to zero at some point close to the bed. However, the unmeasured area near the water surface is problematic, particularly in wind-affected cross sections and in estuaries. Wind effects can cause nonstandard profiles that are significantly biased (near the water surface). In these cases, the POWER estimation scheme (used in the Transect program) can be changed to CONSTANT.

In the estuaries and other backwater-affected sites, gravitational circulation sometimes can cause nonstandard profiles as well as bidirectional flow. Examination of the Transect program playback files can sometimes reveal nonstandard profiles and can provide the basis for a revised power-fit coefficient (chap. 8). In cases of bidirectional flow, the estimation scheme should be changed to CONSTANT on the bottom and CONSTANT at the surface because a power function extrapolation mathematically cannot cross zero. In bidirectional flows, the velocities may be positive (flowing downstream) in the upper portion of the water column and be negative (flowing upstream) in the lower portion of the water column.

Fortunately, extrapolation errors can be corrected during data playback. The raw recorded data are not affected by changing the extrapolation scheme, and the operator and office analyst can use trial-and-error techniques to reduce bias error that is due to incorrect estimation of unmeasured cross products.

Operator-Caused Bias Error

Operators can introduce a number of bias errors affecting a discharge measurement. Many of these

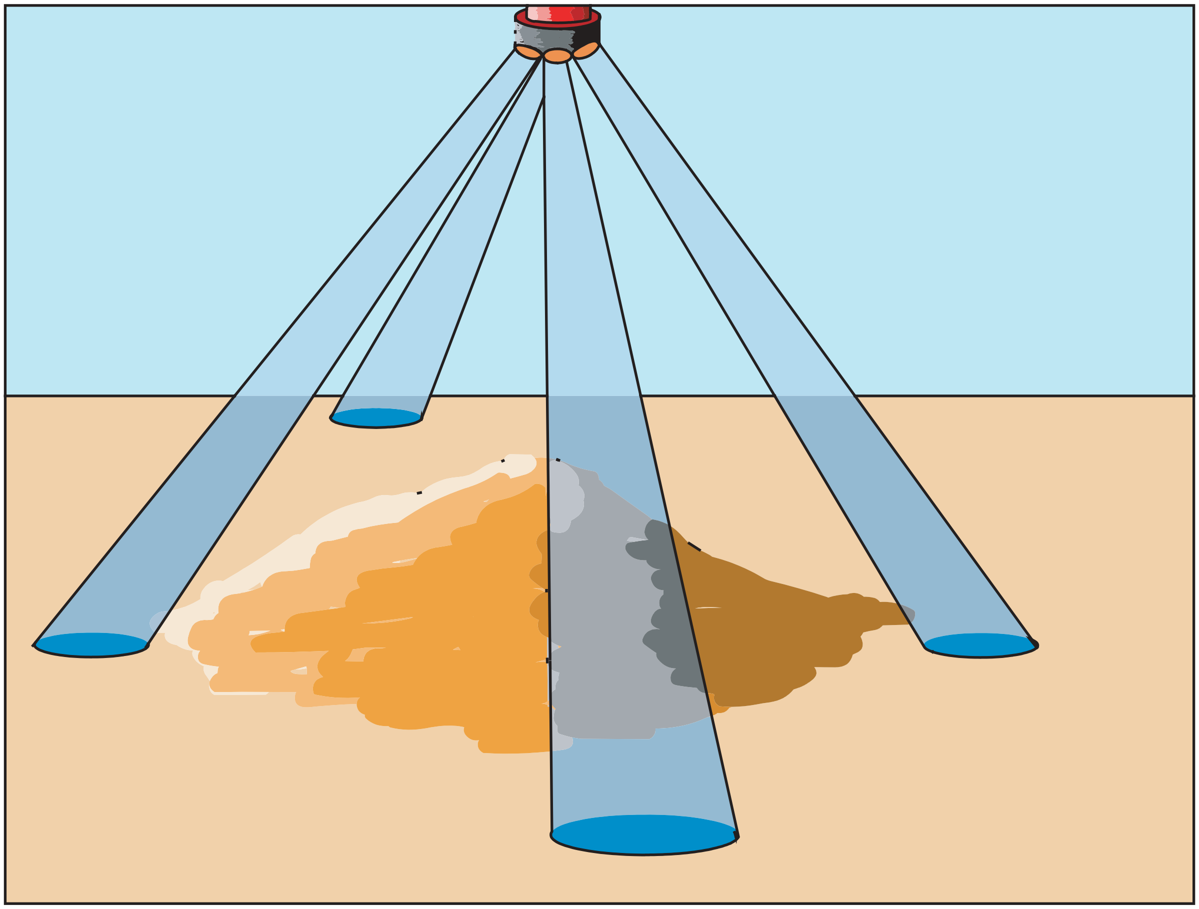


Figure 9.11. Exaggerated instance of depth error due to limitations of the acoustic beams.

errors have been covered in previous chapters, but are summarized here.

Incorrect Transducer Draft

This error probably is the most common operator-caused bias error. Missetting the transducer draft can cause significant discharge-measurement errors, particularly in wide, shallow channels.

Improper Broad-Band Acoustic Doppler Current Profiler Mounting

If the BB-ADCP is mounted to the side of the boat keel and in the boat wake, entrained air can cause occlusion of one or more BB-ADCP beams. A BB-ADCP that is mounted too high near the boat hull can suffer from the “good side/bad side” effect. The “good side/bad side” effect manifests itself in a series of discharge measurements that seem to be directionally biased. For example, discharges measured from right to left bank seem to be significantly different from discharges measured from left to right bank. Victor Levesque (U.S. Geological Survey, oral commun., 1996) has quantified this error and has associated it with the venturi effect of the boat hull on flowing water: water passing under the boat hull is slowed on the streamward side of the boat, and accelerated on the downstream side of the boat. This effect causes bias in the uppermost bins. Averaging even numbers of transects can help reduce this error.

Incorrect Edge-Distance Estimates

Distances to the riverbank are almost always underestimated unless the operator is very close to the riverbank when the distance is estimated. This underestimation can cause a significant bias error, if undetected.

Incorrect Estimated Edge Shapes

In narrow channels, significant bias errors can result from incorrectly characterizing the near-bank geometry. Rectangular-shaped edge-discharge areas can contain significant amounts of unmeasured discharge if the triangular edge algorithm is used for edge-discharge estimation.

Bottom Movement

As a general rule of thumb, all discharge measurement series taken where velocities are greater than 1 ft/s or where bottom movement is suspected should be followed or preceded by a bottom movement check (chap. 8).

Configuration-File Error

Every BB-ADCP operator undoubtedly has collected transects with the wrong configuration file or has inserted incorrect direct commands in the configuration file (at least once). Attention to detail will help eliminate this error.

Poor Choice of Cross Sections

Because the BB-ADCP is such a versatile instrument, it is easy to measure discharge in a cross section that normally would be rejected for use with conventional methods. “Pan-handle”-shaped cross sections with deep channels near one side of the river are examples of poor cross sections. The beam “foot-print” (with accompanying side lobes) becomes larger as depths increase. Discharge in a submerged canyon may be unmeasurable because the beams and side lobes impinge the canyon walls. Proper reconnaissance and experience will help in choosing a cross section that eliminates bias problems due to this effect.

Common Sense Rules

By following the common sense rules listed below, errors in discharge measurements can be reduced or eliminated:

- Be a smooth operator! The BB-ADCP discharge-measurement system will give more consistent results if rapid movements and course changes are kept to a minimum. Smooth boat motion is more important than a straight-line course
- Be observant! Are the edge flows moving in the same direction as the main body of flow? Did the wind come up? Did a motorboat pass the bow of the measurement vessel during the transect? This information may be needed during playback to properly evaluate the discharge measurement
- Is the discharge-measurement vessel moving slowly enough? The more pings collected during a discharge measurement, the more precise the measurement
- Examine discharge data on site, if possible. Problems with improper setup may not appear until the measurements are replayed
- Don’t trust an “eyeball” edge estimate. Most people tend to underestimate the distance to shore unless the vessel is very close to shore when the estimation is attempted
- Don't be afraid to ask for help! Experienced BB-ADCP operators carry a cellular phone, a long list of phone numbers, and are not afraid to ask, “What gives here?” Only novice operators are too proud to ask for help.

Summary

If high sediment loads are not present, errors in acoustic Doppler current profiler (ADCP) discharge measurements usually are caused by traversing the river too fast during the discharge measurement. As a rule, the vessel should traverse the river at the approximate speed of the mean water velocity to obtain consistently precise discharge measurements. When measuring wide, deep rivers or estuaries, the operator should use equation 9.1 to estimate correct vessel traverse rates, if possible. If the operator checks the standard deviation of the discharge measurements at the measurement site he or she can easily determine if the discharge measurements have too much scatter (5 percent or greater). If such is the case, the boat traverse rate can be slowed and the measurements can be redone. Most bias errors can be eliminated with proper attention to detail.

REFERENCES CITED

Buchanan, T.J., and Somers, W.P., 1969, Discharge measurements at gaging stations: Techniques of water resources investigations of the United States Geological Survey, book 3, chap. A8, 68 p.

Chen, Cheng-Lung, 1989, Power law of flow resistance in open channels. Manning's formula revisited: International Conference on Channel Flow and Catchment Runoff. Centennial of Manning's Formula and Kuichling's Rational Formula, May 22–26, 1989, Charlottesville, Virginia, (Proc.), v. 8, p. 17–48.

Chereskin, T.K., Firing, Eric, and Gast, J.A., 1989, On identifying and screening filter skew and noise bias in acoustic Doppler current profiler instruments: Journal of atmospheric and Oceanic Technology, v. 6, p. 1040–1054.

Christensen, J.L., and Herrick, L.E., 1982, Mississippi River Test, Volume 1. Final report DCP4400/300, prepared for the U.S. Geological Survey by AMETEK/Straza Division, El Cajon, California, under contract No. 14–08–001–19003, p. A5–A10.

Doppler, J.C., 1842, Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels: Abn.königl.böhm.Ges.Wiss, v. 2, p. 465–482.

Fulford, J.M., and Sauer, V.B., 1986, Comparison of velocity interpolation methods for computing open-channel discharge *in* S.Y. Subitsky (ed.) Selected papers in the hydrologic sciences: U.S. Geological Survey Water-Supply Paper 2290, 154 p.

Hansen, S.D., 1986, Design and calibration issues for current profiling systems. High-frequency volumetric backscattering in an oceanic environment: IEEE Third Working Conference on Current Measurement, January 22–24, 1986, Airlie, Virginia, (Proc.), p. 191–202.

Lipscomb, S.W., 1995, Quality assurance plan for discharge measurements using broad band acoustic Doppler current profilers: U.S. Geological Survey Open-File Report 95–701, 7 p.

Matalas, N.C., and Langbein, W.B., 1962, Information content of the mean: Journal of Geophysical Research, v. 67, no. 9, p. 3,441–3,448.

Morlock, S.E., 1996, Evaluation of acoustic Doppler current profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95-4218, 37 p.

Minkoff, John, 1992, Signals, noise, and active sensors. Radar, sonar, laser radar: John Wiley and Sons, Inc., New York, 249 p.

Oberg, K.A., U.S. Geological Survey acoustic Doppler current profiler Office of Surface Water support pages. http://il.water.usgs.gov/adcp. Accessed July 1998.

Oberg, K.A., and Schmidt, A.R., 1994, Measurements of leakage from Lake Michigan through three structures near Chicago, Illinois, April–October 1993: U.S. Geological Survey Water-Resources Investigations Report 94-4112, 48 p.

R.D. Instruments, Inc., 1989, Acoustic Doppler current profilers—Principles of operation. A practical primer: R.D. Instruments, San Diego, California, 36 p.

———, 1994, Users manual for R.D. Instruments' Transect Program for use with broadband acoustic current profilers: R.D. Instruments, Inc., San Diego, California, 190 p.

———, 1995, Direct reading and self contained broadband acoustic Doppler current profiler technical manual for Firmware version 5.XX: R.D. Instruments, Inc., San Diego, California, 460 p.

———, 1996, Principals of operation. A practical primer for broadband acoustic Doppler current profilers (2nd ed.): R.D. Instruments, Inc., San Diego, California, 51 p.

———, 1999, Workhorse Rio Grande technical manual. P/N 957-6101-00. http://www.rdinstruments.com. Accessed February 2000.

Simpson, M.R., and Oltmann, R.N., 1993, Discharge measurement using an acoustic Doppler current profiler: U.S. Geological Survey Water-Supply Paper 2395, 34 p.

Theriault, D.B., 1986, Incoherent multibeam Doppler current profiler performance: IEEE Journal of Oceanic Engineering, v. 11, no. 1, p. 7–25.

Urick, R.J., 1975, Principles of underwater sound. (2nd ed.): McGraw-Hill, San Francisco, California, 375 p.

United States Geological Survey Open File Report 95-701

Quality Assurance Plan for Discharge Measurements Using Broadband Acoustic Doppler Current Profilers

U.S. GEOLOGICAL SURVEY
OPEN-FILE REPORT 95-701

By Stephen W. Lipscomb

CONTENTS

Abstract

The recent introduction of the Acoustic Doppler Current Profiler (ADCP) as an instrument for measuring velocities and discharge in the riverine and estuarine environment promises to revolutionize the way these data are collected by the U.S. Geological Survey. The ADCP and associated software, however, compose a complex system and should be used only by qualified per-sonnel. Standard procedures should be rigorously followed to ensure that the quality of data collected is commensurate with the standards set by the Water Resources Division for all its varied activities in hydrologic investigations.

Introduction

The Acoustic Doppler Current Profiler (ADCP) is an electronic instrument developed and manufactured by RD Instruments of San Diego, California, that is used to measure water velocities. The instrument transmits acoustic signals into the water column. When the frequency of the transmitted signals is compared with the frequency of backscatter signals reflected off particles in the water, the velocity of the particles and, hence, the water, can be calculated.

ADCP's have been widely used by oceanographers to measure currents in the deep-sea environment. More recently, the technology has been adapted to the riverine and estuarine environment and promises to revolutionize the way many streamflow discharge measurements are made by the U.S. Geological Survey (USGS).

As ADCP technology has been refined, it has begun to gain acceptance as a viable method for obtaining velocity and discharge data. The primary advantages of making discharge measurements using the ADCP compared with a Price or other point-current meter are that (1) the time required to complete a measurement is reduced; (2) data can be collected throughout the water column and cross section rather than at discrete points; (3) taglines or other stationing devices are unnecessary because the instrument keeps track of distance traveled, provided the bed is stable; and (4) the instrument can be boat-mounted, thus eliminating the installation, maintenance, and liability of costly cableways.

The primary disadvantages of using the ADCP compared with a standard Price current meter are its high initial cost; inability to function in shallow water; complexity, requiring an in-depth understanding of the physics, electronics, and software of the system prior to use; and the frequent revisions to hardware, firmware, and software due to the newness of the technology. These revisions generally result in improvements in the accuracy of the data collected; however, they pose problems in dealing with data collected using earlier systems and software.

The Office of Surface Water has recognized the utility of the ADCP for many of the tasks performed by various Water Resources Division offices. However, as with any technology or methodology adopted by the Division for the collection and analysis of water resources data, it is critical that strict measures be implemented to ensure the quality and reproducibility of the data throughout our agency. The purpose of this report is to provide a quality assurance plan that, when implemented, will ensure that data collected with ADCP's meet existing accuracy standards and that the procedures used to collect the data are consistent throughout the Division. Specific objectives of the plan are to ensure that:

1. Field and office procedures associated with the use of ADCP's adhere to applicable Division policies and standards governing the collection, analysis, and reporting of surface-water data.

2. Personnel who collect and analyze the data are adequately trained in proper and acceptable ADCP operational procedures.

3. All activities related to the collection, analysis, and reporting of data collected using ADCP's are reviewed regularly for accuracy, completeness, and conformance to Division standards.

4. Any deficiencies discovered during review are addressed immediately and corrective action is taken.

Training Requirements

Because of the complex nature of the ADCP and associated software, at least one person in the field crew is required to have formal training in the operation and maintenance of ADCP's. Acceptable training is available through RD Instruments and the USGS National Training Center in Lakewood, Colorado, or equivalent training can be provided by personnel within the Water Resources Division. Eventually, qualified personnel within Districts will be designated as trainers.

Reference materials on the theory, operation, and maintenance of the ADCP are available from the manufacturer in the form of user's manuals for both the ADCP and the associated software package "Transect" (RD Instruments, current versions). These manuals are the primary source of information for the setup and operation of the instrument and peripheral equipment. The manuals also contain sections dealing with configuration file setup and the use of Transect for system configuration, data acquisition, playback, output, and data manipulation. A report on field procedures for ADCP's (M.R. Simpson, U.S. Geological Survey, written commun., 1995) is the primary source of information on accepted Divisionwide procedures for collecting velocity data and making discharge measurements.

Field personnel responsible for data collection using the ADCP must be completely familiar with these reference materials. Procedures for data collection and ranges of acceptable conditions described in these documents must be strictly adhered to.

Pre-Field Office Procedures

To avoid delays in the field and to ensure that the data collected are complete and of the highest quality, some preparations prior to departure are recommended. These preparations should include a determination as to whether the instrument is utilizing the most recent software and firmware upgrades and that the complete system, including the field computer and power supply, is operational.

Software and firmware revisions

Because of the newness of ADCP technology, there have been, and likely will continue to be, frequent upgrades to both software and firmware associated with the system. Many of these upgrades will result in only minor improvements to internal processing speed or data output capabilities and will not substantively affect the quality of discharge measurements made with the instrument.

Less frequently, major upgrades could affect the quality of measured velocity or discharge data. Upgrades of this type will require field testing at one of the validation sites described in the report by Morlock (in press) prior to Division acceptance, to ensure that the instrument is performing up to required standards. The Office of Surface Water will determine, prior to implementation of all software and firmware upgrades, whether field testing is necessary.

Before the ADCP is taken to the field, the most recent Division-accepted version of Transect should be installed on the primary and backup field computers. In addition, a backup of this software should be copied to a diskette and kept with the computer in the event that the copy on the hard drive is inadvertently erased. In every office having an ADCP, a contact person will be assigned to obtain and distribute the most recent copies of Transect from the manufacturer. This person will be responsible for notifying users of software and firmware revisions and for installing firmware upgrades as they become available from the manufacturer.

These upgrades can be installed either by computer download from RD Instruments via modem or by manually replacing chips within the instrument's circuit boards. If the latter approach is required, an electronic technician, trained in the procedures for opening the ADCP pressure case, should install the firmware upgrades in a static-free environment.

Pre-field inspection

A pre-field inspection must be made to ensure that the instrument is functioning correctly. This inspection consists of connecting the ADCP to a computer, preferably the one that will be used in the field, connecting a power supply to the deckbox, and powering the system up. The system then can be checked by entering the "Acquire" mode of the Transect software and attempting to "wake the system up." If any problems are encountered at this point, the ADCP and Transect user's manuals (RD Instruments, current versions) should be consulted.

Inclusion of all required cables and connectors should be ascertained and any spare parts that might be difficult to obtain in the field, such as fuses for the deckbox, batteries for the ADCP and the computer, cables, and diskettes for making backup copies of data files should be assembled as part of the pre-field inspection.

Field Procedures

General field procedures for making discharge measurements with the ADCP are described in a report by M.R. Simpson (U.S. Geological Survey, written commun., 1995) and therefore will not be discussed here. However, certain precautions should be taken that will ensure the accuracy, precision, and completeness of the data collected.

Vessel installation

The ADCP is typically mounted on either side of a boat or in a well through the hull. The instrument should be rigidly attached in a vertical position so that the transducers are submerged at least 3 inches (8 cm) below the water surface. In rough water, the transducers may have to be lowered further to ensure that their heads stay submerged and that no cavitation occurs in their vicinity during the entire measurement. The mount used to attach the ADCP to the boat should be designed to withstand the combined forces of water velocity resulting from the boat's movement and the ambient stream velocity.

The mount should be designed so that the instrument can be quickly raised or rotated out of the water for moving from one site to another or for quickly traversing the cross section. The ADCP must not be mounted near steel or any other ferrous material that would affect the functioning of the internal flux-gate compass. For this reason, a boat with a steel hull should not be used and the instrument should be mounted as far as possible from any ferrous objects on the boat, such as an engine with a cast-iron block or heads. A rule of thumb is to keep the compass, located near the top of the ADCP pressure case, away from any ferrous object on the boat by at least the longest dimension of the object. For instance, if the longest dimension of a steel davit mounted on the boat is 4 feet, the ADCP should be mounted no less than 4 feet from the davit to avoid interference with the compass.

Instrument check

After the ADCP is mounted and the required cables to the computer and power supply are connected, the instrument must be checked to ensure that all circuits and sensors are operating properly. Several subroutines in BBTALK, which is a program provided as part of the ADCP software package, perform internal diagnostic and calibration tests on the ADCP and display its internal setup. These subroutines will test the circuits and sensors of the ADCP and, upon request, will write the results to a user-designated file. Specific procedures for initializing the self-test subroutines in BBTALK are detailed in a predeployment test procedures document (RD Instruments, current version) provided by the manufacturer with each ADCP or upon request and must be performed prior to each deployment of the ADCP. If the instrument fails to pass any of the self-test subroutines, the ADCP technical manual and Transect user's manual (RD Instruments, current versions) should be consulted. If the problem cannot be corrected, the manufacturer's field service representative should be contacted and corrective action taken. If the ADCP has failed any of the self-tests and data are collected, the data should be clearly marked as suspect and the nature of the test failure documented in the remarks section of the ADCP fieldnote sheet.

During the initiation of communication between the computer and the ADCP, a comparison of the configuration file and the ADCP setup is performed. If the ADCP fails to respond, or if any error messages are displayed, the ADCP and Transect user's manuals (RD Instruments, current versions) should be consulted. Many times, the problem can be solved by ensuring that all connections, including the power supply to the ADCP, are properly made.

Sometimes an error message will warn that the configuration file is not in agreement with the ADCP setup. Again, these problems usually can be solved by rechecking the configuration file for proper communication settings, transducer frequency, or head orientation (upward or downward looking). If the problem cannot be discerned by consulting the user's manual, a manufacturer's field service representative should be contacted and all problems related to failure of self-tests or error messages should be resolved before proceeding.

Configuration file setup

The configuration file must be matched to the physical conditions of the cross section. Such parameters as bin size, mode, bottom track and water pings per ensemble, and blanking distance require setting by a trained user to optimize the quality of data collected for the existing conditions. Proper setup of the configuration file is beyond the scope of this report but is addressed in a report describing discharge measurement procedures using ADCP's (M.R. Simpson, U.S. Geological Survey, written commun., 1995). That report provides specific details on selecting cross sections and setting up configuration files for a variety of conditions and should be consulted prior to collecting data.

Currently, the configuration file is stored on the computer separately from the files that contain the raw velocity data. Therefore, each raw data file must be linked in some way to the configuration file used during data collection so that the parameters used during playback and postprocessing of the raw data files are the same as those that were used during data acquisition. The raw data files and configuration file used for a specific measurement must be saved on the hard drive of the computer and copied to a diskette for a backup as soon as possible following completion of the discharge measurement. Space on an ADCP fieldnote sheet adopted by the Office of Surface Water has been designated for listing raw data filenames and associated configuration filenames.

Discharge measurements

The ADCP discharge measurement procedures guide (M.R. Simpson, U.S. Geological Survey, written commun., 1995) describes procedures for making discharge measurements, including site selection criteria, configuration file setup, and postprocessing of raw data. That reference provides details for field use of ADCP's and postprocessing of data as accepted by the Office of Surface Water and should be adhered to rigorously. Any variation from the procedures described in that publication must be documented and reviewed before the data can be released.

Before discharge data are collected using the ADCP, preliminary information describing the site, date, personnel, equipment, and versions of software and firmware used should be entered on the ADCP fieldnote sheet. The remainder of this sheet should be completed as data are collected. Information related to the distance to riverbanks at the beginning and ending of individual transects and raw data and configuration filenames must be entered immediately. This information is critical to the accurate calculation of discharge, and any delays in entering it on the fieldnote sheet will increase the likelihood of errors.

Individual transects can be viewed as instantaneous discharge at a particular site. It is therefore necessary to average multiple transects to reduce variation due to turbulence and velocity surges. Averaging is analogous to the Division's policy of measuring velocity with a Price current meter over at least 40 seconds to minimize instantaneous fluctuations in stream velocities. In general, at least four transects must be made at each site to ensure a valid determination of discharge. More transects will be needed under certain conditions, such as extremely turbulent water. If any one of the first four transects differs from the mean discharge by more than 5 percent, it should first be evaluated to determine if there is any reason to justify discarding it. A determination to discard a single transect might be made on the basis of a bad ensemble; a "Made Good" distance that differs significantly from the total distance; anything that might have affected the velocity profiles during the measurement, such as boat traffic in the vicinity; or any number of other factors. If a transect is discarded, another should be made so that the discharge measurement is calculated from the average of at least four transects. If there is no justifiable reason for discarding the transect, four additional transects should be made and all of them, including the outlier, should be averaged to determine discharge.

During a transect, the ADCP measures the velocity in the water column relative to the movement of the vessel to which it is attached. The vessel velocity relative to the channel bed is also measured and is used to calculate the actual water velocity. This calculation assumes a fixed bed. If, however, the bed is in motion, the calculation of actual water velocity will be in error. Therefore, assessment of bed movement is necessary before a discharge measurement can be made. Bed movement can be assessed by anchoring the vessel to the bed or to a fixed object such as a bridge, or by holding the boat at a fixed location within the channel while a series of ensembles is collected. If the bed is stable, the Shiptrack display will indicate no significant movement of the vessel after a period of a few minutes. If, however, the bed is moving, it will be reflected in the Shiptrack display by an apparent gradual movement of the vessel in an upstream direction. If this movement is significant relative to the average water-column velocity, an alternate site should be sought. Often, bedload movement varies considerably from one point to another across a channel. As a result, it may be necessary to check for bed movement at several locations across the channel to ensure that the bed is stable throughout.

After the discharge measurement has been made, each raw data file should be reviewed using the Playback mode in Transect to ensure that the data are complete and do not include any bad ensembles, that depths and velocities do not exceed the prescribed limits set for the instrument in use, and that no velocity spikes are recorded because stream velocity equaled the ambiguity velocity. The instrument limitations and ambiguity velocity for specific instruments and configurations are discussed in a report by M.R. Simpson (U.S. Geological Survey, written commun., 1992). Measurements of conditions that exceed instrument limitations or that contain velocity spikes should not be included in the determination of a final discharge value. If a raw data file contains bad velocity ensembles or velocity spikes, the measurement should be repeated until at least four complete measurements with no bad data have been obtained.

Once a sufficient number of transects have been made and reviewed for completeness, the nearshore discharge estimate section on the back of the fieldnote sheet must be completed to determine total discharge, including the unmeasured sections near each bank. The Transect software contains a utility for making the nearshore estimates on the basis of the first and last valid velocities and depths measured. Procedures for using this function are provided in the Transect user's manual (RD Instruments, current version). Care should be taken to determine the direction of boat movement during collection of the ensemble that is used for determining the nearshore discharge. Boat direction determines whether a positive or negative sign should be assigned to the estimated discharge before the total discharge can be calculated.

A gage height from a staff or some other reference should be obtained before and after each measurement and entered into the space provided on the front of the fieldnote sheet. Otherwise, the gage heights corresponding to the time of each measurement should be obtained from the gage recorder and entered. A mean gage height and discharge then can be calculated and entered into the space provided on the upper part of the fieldnote sheet.

Measurement assessment

An overall assessment of the mean discharge measurement should be made after completion of the transects composing the measurement. This assessment is based on a qualitative judgment of conditions encountered in making the measurement and a quantitative evaluation of the individual transects. Completeness of the measurement, in terms of the percentage of the total cross-sectional area measured, and overall measurement conditions must be assessed. Conditions such as turbulence, eddies, reverse flows, surface chop, and proximity of the instrument to ferrous objects, which, under certain circumstances, might affect the results of the measurements and velocity profiles, should be noted under the appropriate sections on the fieldnote sheet and used in assigning a rating for the measurement.

The mean and standard deviation of the discharge measurement and the coefficient of variation (CV), which is the ratio of the standard deviation to the mean discharge (s/Q), should be calculated. The CV then should be entered as a percentage in the space provided on the fieldnote sheet. The CV is a measure of the grouping of individual transects around their mean and is a useful statistic for making a quantitative assessment of the measurement. If the CV is greater than 5 percent, additional transects should be made. In some cases, one or more transects will be apparent outliers and will result in a large CV. If there is an obvious reason for the variation, the transect can be eliminated from the mean discharge calculation after the circumstances are noted on the fieldnote sheet. Additional transects may be needed if one or more is eliminated so that at least four are used for computing the average discharge. If the mean discharge varies from the applicable rating or shift curve by more than 5 percent, the measurements should be repeated.

The final discharge rating is assigned by circling the appropriate entry on the front of the fieldnote sheet. This rating is based on the qualitative evaluation of the measurement and the CV, which provides a quantitative measure of precision.

After the fieldnote sheet is completed, all raw data and configuration files resulting from the discharge measurements should be copied onto a disk-ette as a backup in case of damage to the computer's internal hard drive.

Post-Field Office Procedures

The ADCP should be inspected after it has been returned from the field to determine the condition of the transducers, pressure case, connectors, cables, and deckbox. Damage or undue wear to any of the components should be reported to the person responsible for maintenance of the instrument.

Discharge measurement review

All discharge measurements must be reviewed by a second qualified person in the office. Special attention should be given to the calculation of total discharge, including nearshore estimates. All calculations used to derive the mean discharge and gage height should be checked and the fieldnote sheet should be reviewed for accuracy and completeness. The reviewer then must initial the front of the fieldnote sheet.

Documentation and archival of discharge measurements

Eventually, Transect will include an option to generate a standard output file that will contain the information in the configuration file and a summary of the discharge measurement. This file will include information similar to that on the standard 9 - 275 discharge measurement form -- width, depth, area, mean velocity, and discharge at incremental locations across the section. Until this option is available, the raw data should be processed and an ASCII output file generated that contains a summary of stationing and velocity data at approximately 30 equally spaced locations across the section.

Copies of the configuration, subsystem self-test, and the discharge measurement summary files should be printed and attached to the fieldnote sheet for filing as soon as practical after returning from the field. Information from these documents should be used to enter the measurement on the 9 - 207 discharge measurement summary form and into the computer database of discharge measurement summaries (HT - 1). In both the paper and computer summaries of the measurement, it should be noted in the remarks section that the measurement was made using an ADCP.

Generation of a paper copy of the raw data files is not practical because of their size and binary format. However, contained in these files is a significant amount of information, such as horizontal and vertical velocity vectors calculated for each ensemble, that should be retained. At this time, there is no accepted method for permanent archival of digital data files within the Water Resources Division. Until an acceptable archival method is approved, the raw data and configuration files should be copied to as permanent a storage medium as is available. Preferably, the files should be copied to some type of semipermanent storage medium such as CD-ROM. Eventually, these files could be transferred to a more permanent storage medium when the technology becomes available.

Annual Instrument Check

Each ADCP must be checked annually by making a discharge measurement at a site where the ADCP-measured discharge can be compared with a known discharge derived from some other source. An example of such a site would be one where a stable stage-discharge relation with no significant shifting has been established over a period of several years. The site ideally would be chosen to minimize the amount of unmeasured sections near the banks or in shallows and should not be near any large steel structures, such as bridges, that might affect the ADCP's compass. The discharge obtained using the ADCP must be within 5 percent of the known discharge. If these measurements fail to agree with the known discharge, the ADCP must be returned to the manufacturer for further evaluation and calibration if necessary. These check measurements must be fully documented and a summary log of the results kept on file in the District or Field Office and noted in the applicable station analysis.

Periodic Review

Every 3 years, each District's procedures for ADCP measurements, documentation, and data archival will be reviewed by Office of Surface Water personnel or their designees during the District Surface Water Review. This review will include an evaluation of site selection, suitability of configuration files, measurement completeness and accuracy, documentation of discharge and check measurements, and archival of data files. In addition, the review will evaluate the maintenance procedures followed by each office to ensure that the most current firmware and software upgrades have been implemented and that the instrument and peripheral equipment are being properly maintained. Recommendations by the Surface Water Review team will be immediately addressed by the appropriate District personnel.

In summary, it is the primary objective of this plan to ensure that all data collection and analyses performed in conjunction with the use of ADCP's be conducted in a professional manner commensurate with the standards set by the Water Resources Division for all its varied activities in hydrologic investigations. Because of the complexity of the ADCP and associated software and the dynamic nature of its application to the riverine and estuarine environment, the ADCP should be used only by qualified personnel and standard procedures should be followed
rigorously.

Selected References

Morlock, S.E., in press, Evaluation of Acoustic Doppler Current Profiler measurements of river discharge at 12 sites within the continental United States: U.S. Geological Survey Water-Resources Investigations Report 95 - 4218.

RD Instruments, 1989, Acoustic Doppler Current Profilers -- principles of operation: a practical primer: San Diego, Calif., RD Instruments, 36 p.

RD Instruments, current version, Broadband direct reading ADCP pre-deployment test procedures: San Diego, Calif., RD Instruments, 10 p.

RD Instruments, current version, Direct-reading broadband Acoustic Doppler Current Profiler technical manual: San Diego, Calif., RD Instruments, 49 p.

RD Instruments, current version, User's manual for RD Instruments Transect program (for use with broadband ADCP): San Diego, Calif., RD Instruments, 88 p.

Simpson, M.R., and Oltmann, R.N., 1992, Discharge-measurement system using an Acoustic Doppler Current Profiler with applications to large rivers and estuaries: U.S. Geological Survey Water-Supply Paper 93 - 2395, 32 p.