Australian Government
Bureau of Meteorology

WATER MONITORING STANDARDISATION TECHNICAL COMMITTEE

National Industry Guidelines for hydrometric monitoring

PART 8: APPLICATION OF ACOUSTIC DOPPLER CURRENT PROFILERS TO MEASURE DISCHARGE IN OPEN CHANNELS

NI GL 100.08–2019
February 2019

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In 2017 and 2018 the Water Monitoring Standardisation Technical Committee (WaMSTeC) led a periodic review of the National Industry Guidelines for hydrometric monitoring. WaMSTeC subcommittees conducted the review process and coordinated extensive industry consultation.

2018 review subcommittee members:

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(Note that at the time of contribution, individuals may have been employed with different organisations and some organisations were known by other names).

ADCP Matrix (Appendix C) created by Mark Randall, Daniel Wagenaar and Malcolm Robinson. Additional guidance was received from David Williams and David Mueller.

Foreword

This guideline is part of a series of ten National Industry Guidelines for hydrometric monitoring. It has been developed in the context of the Bureau of Meteorology's role under the *Water Act 2007* (Cwlth) to enhance understanding of Australia’s water resources.

The Bureau of Meteorology first published these guidelines in 2013 as part of a collaborative effort amongst hydrometric monitoring practitioners to establish standardised practice. They cover activities relating to surface water level, discharge and water quality monitoring, groundwater level and water quality monitoring and rainfall monitoring. They contain high level guidance and targets and present non-mandatory Australian industry recommended practice.

The initial versions of these guidelines were endorsed by the Water Information Standards Business Forum (the Forum), a nationally representative committee coordinating and fostering water information standardisation. In 2014, the functions and activities of the Forum transitioned to the Water Monitoring Standardisation Technical Committee (WaMSTeC).

In 2017, as part of the ongoing governance of the guidelines, WaMSTeC initiated a 5-yearly review process to ensure the guidelines remain fit-for-purpose.

These revised guidelines are the result of that review. They now include additional guidance for groundwater monitoring, and other updates which improve the guidelines' currency and relevance. WaMSTeC endorsed these revised guidelines in December 2018.

Industry consultation has been a strong theme throughout development and review of the ten guidelines. The process has been sponsored by industry leaders and has featured active involvement and support from the Australian Hydrographers Association, which is considered the peak industry representative body in hydrometric monitoring.

These guidelines should be used by all organisations involved in the collection, analysis and reporting of hydrometric information. The application of these guidelines to the development and maintenance of hydrometric programs should help organisations mitigate program under-performance and reduce their exposure to risk.

Organisations that implement these guidelines will need to maintain work practices and procedures that align with guideline requirements. Within the guidelines, the term “shall” indicates a requirement that must be met, and the term “should” indicates a recommendation.

The National Industry Guidelines can be considered living documents. They will continue to be subject to periodic WaMSTeC review at intervals of no greater than five years. In the review phase, WaMSTeC will consider any issues or requests for changes raised by the industry. Ongoing reviews will ensure the guidelines remain technically sound and up to date with technological advancements.

National Industry Guidelines for hydrometric monitoring

This document is one part of the National Industry Guidelines for hydrometric monitoring series, which can be found at http://www.bom.gov.au/water/standards/niGuidelinesHyd.shtml.

The series contains the following parts:

Part 0: Glossary

Part 1: Primary Measured Data

Part 2: Site Establishment and Operations

Part 3: Instrument and Measurement Systems Management

Part 4: Gauging (stationary velocity-area method)

Part 5: Data Editing, Estimation and Management

Part 6: Stream Discharge Relationship Development and Maintenance

Part 7: Training

Part 8: Application of Acoustic Doppler Current Profilers to Measure Discharge in Open Channels *(this guideline)*

Part 9: Application of in-situ Point Acoustic Doppler Velocity Meters for Determining Velocity in Open Channels

Part 10: Application of Point Acoustic Doppler Velocity Meters for Determining Discharge in Open Channels

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National Industry Guidelines for hydrometric monitoring Part 8: Application of Acoustic Doppler Current Profilers to Measure Discharge in Open Channels

1 Scope and general

1.1 Purpose

The purpose of this document is to provide guidelines for recommended practice to ensure that the collected measured streamflow data are:

a) accurate;
b) defendable; and
c) consistent across water monitoring organisations operating under these guidelines.

This is the minimum guideline that shall be followed to allow the collected data to withstand independent validation and data integrity checks. Additional field procedures may vary between organisations and States.

1.2 Scope

This document deals with the use of boat-mounted or mobile acoustic Doppler current profilers (ADCPs) for determining streamflow in open channels. It specifies the required procedures and methods for collecting data by Australian operators. It specifies procedures for the collection and processing of surface water data collected by ADCPs.

This document does not include or rewrite instrument manufacturers' operating instructions for their individual instruments. Nor does it detail Standard Operating Procedures (SOPs) of organisations using these instruments. However, it is expected that those SOPs are sufficiently robust to withstand independent scrutiny.

This document contains images and examples sourced from instrument manufacturers or suppliers. Inclusion of these images, with reference to the source, is solely for the purpose of providing examples, additional information and context, and is not to be interpreted as endorsement of any particular proprietary products or services.

1.3 References

This document makes reference to the following documents:

- Callede, J., Kosuth, P., and Guimaraes, V.S., 2000, 'Discharge determination by acoustic doppler current profilers (ADCP): A moving bottom error correction method and its application on the River Amazon at Obidos', *Hydrological Sciences- Journal-des Sciences Hydrologiques*, vol.45, no. 6, pp. 911-924.
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- International Organization for Standardization 2007, *Hydrometry – Measurement of liquid flow in open channels using current-meters or floats*, ISO 748:2007.
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- Mueller, D.S., Wagner, C.R., 2009, *Measuring discharge with acoustic Doppler current profilers from a moving boat*, U.S. Geological Survey Techniques and Methods 3A–22, viewed 2 October 2018, <http://pubs.usgs.gov/tm/3a22>.

1.4 Bibliography

Cognisance of the following was taken in the preparation of this guideline:

- Mueller, D.S, and Wagner, C.R., 2006, *Application of the loop method for correcting acoustic Doppler current profiler discharge measurements biased by sediment transport*, U.S. Geological Survey Scientific Investigations Report 2006-5079, 26 pages.
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- Sontek YSI Incorporated 2013, *RiverSurveyor S5/M9 System Manual*, Sontek, San Diego.
- Teledyne RD Instruments 2007, *WinRiver II user's guide, Teledyne RD instruments*, San Diego.
- Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, *Guidelines and standard procedures for continuous water quality monitors – Station operation, record computation, and data reporting*: U.S Geological Survey Technique and Methods 1-D3.

1.5 Definitions

For the purpose of this document, the definitions given in the National Industry Guidelines for hydrometric monitoring, Part 0: *Glossary*, NI GL 100.00–2019 apply.

2 Description of Acoustic Doppler Current Profilers

ADCPs are a family of acoustic based instrumentation used to measure water velocity and depths and boat velocity. Measurements are undertaken by transmitting an acoustic pulse of known frequency into the water and measuring the "Doppler shift" of returned signals from reflective particles in the water.

All ADCPs fit into one of three general categories, based upon the method by which the Doppler measurements are made:

1. Pulse incoherent – Known as 'narrow band' ADCPs they transmit a single long pulse to calculate velocity. Although velocity measurements are robust over a large velocity range they have a high, single ping uncertainty which is reduced by averaging multiple pulses transmitted over a short time period.
2. Pulse-to-pulse coherent – The most accurate of the three Doppler systems however they are limited with their maximum operational depth and velocity range. Coherent systems transmit a single short pulse and record the return signal. Once the first pulse is no longer detectable a second pulse is transmitted. Velocity is calculated from the phase difference between the signal returns. Violation of the depth and velocity limits will render the data unusable.
3. Spread Spectrum (Broadband) – Velocity is calculated from the phase change of two transmitted pulses however the pulses are within the profile range at the same time. This is achieved by imposing a pseudo random code on the wave form. This code allows multiple independent velocity measurements to be made from a single pulse. Uncertainty levels for broadband instruments are between that of a) and b) and are a function of the processing configuration used.

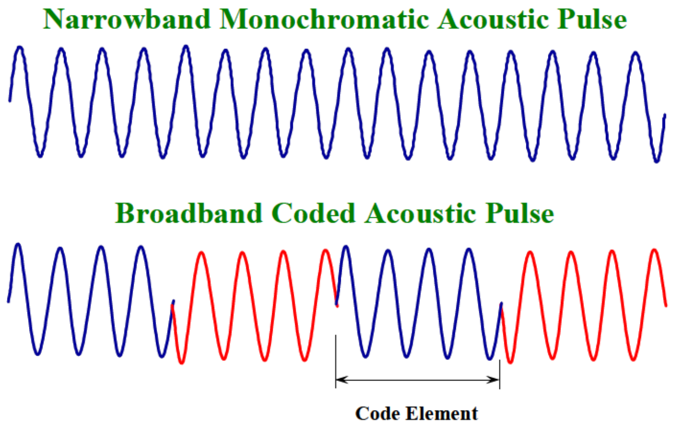

Figure 1. Acoustic pulses for narrowband and broadband ADCPs
(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

Incoherent and broadband processing are the primary processing techniques used in ADCP field applications.

Reference should be made to the relevant manufacturer's instrument manual to determine the type of instrument being used.

3 Instrument management

Each organisation should have its own office ADCP management record that contains instrument specific records containing details of:

a) the details of the person making the entry with details of the work carried out (in the case of manufacturer servicing, the details of work done and a copy of the maintenance report from the service provider);
b) time and date of the entry;
c) all calibration and operational checks carried out; and
d) installed software/firmware and/or relevant programs/modes that control the operation of the instrument.

Organisations may also choose to record other relevant information.

3.1 Instrument maintenance

Each organisation should have a maintenance schedule set in place and recorded in the ADCP management record. These maintenance procedures should be in accordance with the ADCP manufacturer's guidelines.

ADCP units shall be inspected before each field deployment with more detailed checks carried out on an annual basis for data quality control purposes. Any ADCP demonstrating maintenance issues that could compromise data integrity shall not be used to record streamflow data.

Each organisation shall have instrument maintenance and servicing requirements identified in their SOPs based on manufacturer's specifications and recommendations.

3.2 Instrument tests

ADCPs should be periodically tested to ensure the validity of the data recorded. These tests may include operating the instrument at a site with a known and stable stage-discharge relationship such as below a control weir and/or conducting comparison measurements between multiple ADCP meters at the same time and location. Multi-mode instruments should be tested while operating in each mode.

Further checks that shall be periodically undertaken and recorded in the ADCP instrument record include checking the ADCP reported depth with actual measured depth (by using a gauging rod at a specific point) and the ADCP reported channel width with actual channel widths (using a tagline).

NOTE: The ADCP uses these two measurements to calculate the channel area used in discharge computation. Therefore, any error in the ADCP's ability to accurately measure these variables is transferred to the reported discharge.

Where an ADCP possesses an internal diagnostic check, it shall be conducted during an ADCP pre-deployment process in accordance with the manufacturer's guidelines. This diagnostic check verifies that the ADCP is functioning correctly and will issue a 'pass' or 'fail' to that unit. Where an ADCP unit fails its diagnostic test, it shall not be used for measuring streamflow. Appropriate defect management processes shall be implemented to resolve the failure.

3.3 Firmware and software upgrades

Software and firmware upgrades should be installed as recommended by the ADCP manufacturer and with guidance from national and international industry users (i.e. peer feedback and recommendations).

All firmware upgrades shall be recorded in an ADCP instrument record. Details of the software and firmware used when undertaking and processing a discharge measurement shall be recorded in the measurement details for future reference to allow a measurement to be reprocessed using a software update.

4 Operating personnel

The integrity of ADCP data is determined by the experience of the operator at the time of collection. Operating personnel shall therefore have completed training that covers the deployment of ADCPs as well as the collection and post processing of their data.

This training should be specific to the brand of ADCP unit, the deployment mode, and the associated software that will be used to post process the data.

Training should be sought from an individual or organisation that has demonstrated expertise in the use of ADCP technology.

ADCP data shall not be collected by an untrained individual without an experienced operator being present.

Post processed data shall be reviewed by an additional trained and experienced operator before the data is archived.

ADCP technology is continually evolving and users should remain up to date on software updates, improvements to the equipment, and changes in recommended operational methodologies. Refresher training for field deployment, data collection, processing, and quality control procedures should also be sought.

5 Pre-deployment checks

Before entering the field, the following pre-deployment checks shall be carried out:

a) all instrumentation is checked to ensure that it is in good working order;
b) the approved firmware and software is in use;
c) all ancillary equipment is communicating with the ADCP data collection software;
d) ancillary equipment is calibrated, where necessary;
e) there is an adequate power supply for all devices to complete the measurement;
f) the ADCP unit selected is appropriate for the environmental conditions expected at the measurement site to ensure the integrity of the data; and
g) all workplace health and safety requirements have been fulfilled.

6 Field deployment guidelines

6.1 Site selection (moving boat and stationary methods)

The ADCP essentially measures velocity, channel depth and channel width, and therefore is bound by similar site selection criteria for traditional current meter gaugings as described in ISO 748:2007. The ADCP, however, may be able to deal with skewed flow conditions, and irregular velocity structures across the measurement cross-section in some instances, which may provide some more flexibility when selecting a gauging site. It is important that the ADCP operator is suitably trained and skilled in identifying appropriate measurement locations and stream conditions at the site.

NOTE: The term moving boat method refers to the ADCP collecting data continuously while in transit across the channel. It is not a direct reference for the method used to mobilise the ADCP.

The following apply when selecting a cross-section for discharge measurements:

1. The channel bed should be as smooth as possible. Large boulders, logs, and excessive weed growth should be avoided. Where undesirable site conditions cannot be avoided then additional transects for moving boat method or additional vertical observations for the stationary method, shall be undertaken to reduce the measurement uncertainties.

2. Sites that display excessive small-scale turbulence and aeration of the water column shall be avoided because the ADCP is unable to measure accurate water velocities and depths.

   NOTE: Waters that contain minimal suspended particles may not allow the ADCP to measure water velocity. In these conditions a higher frequency should be used. Water that contains excessive suspended sediment may cause the complete attenuation of the beam signal. In these circumstances a low frequency ADCP should be used in conjunction with a depth sounder.

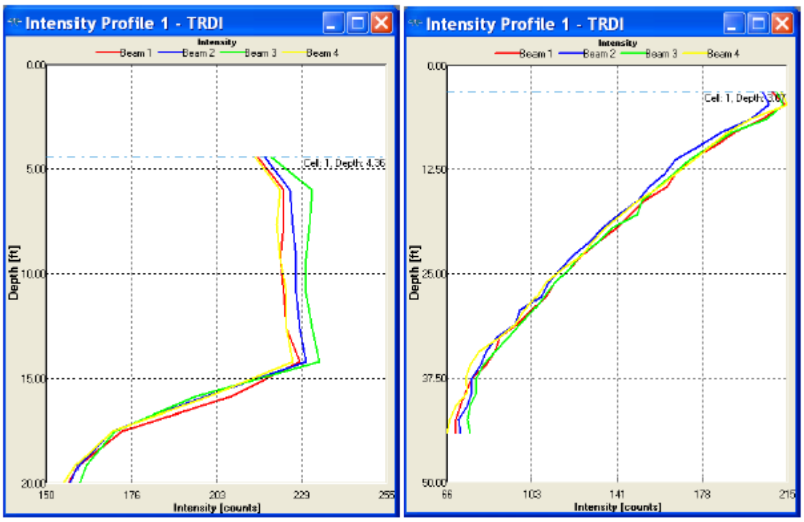

Figure 2. Example of excessive backscatter (left) and excessive signal attenuation (right) due to high concentrations of suspended sediment as displayed in WinRiver

(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

3. Encountered water velocities shall be within the ADCP operational boundaries as stated by the manufacturer.
4. The minimum and maximum water depth at the measurement site shall be within the measuring capacity of the ADCP model to be used and the settings available. The water depth at the site shall accommodate:
   a) the transducer depth;
   b) blanking distance;
   c) the unmeasured area at the bed; and
   d) a minimum of two depth cells (bins) per ensemble across 95% of the transect.

   NOTE: A minimum of two depth cells allows the more accurate extrapolation of the velocity profile into the unmeasured sections of the water column.

For the moving boat method,. advances in ADCP methodologies mean that moving bed conditions at a site no longer need to be avoided as corrections to total discharge values can be calculated, e.g., the Loop Method (see Appendix A, Clause A.2).

6.2 Deployment methods

There is a range of ADCP deployments for both moving boat and stationary methods depending on the site characteristics and ADCP model to be used. Regardless of the deployment method, the operational requirements and procedures to collect valid data remain the same.

Where an ADCP is unable to locate the bed across the entire transect and has no valid GPS data then the stationary method shall be used, or a new measurement location found.

The manufacturer's documentation should be consulted for any specific mounting requirements.

6.2.1 Boat mounted

For boat mounted deployments, the ADCP shall be securely mounted to a vessel in such a position that it avoids measuring velocities that are contaminated by bow waves or the hull of the vessel. The most common mountings are over the bow, or over one of the sides.

Fittings to secure the ADCP should:

a) be of a non-ferrous material to avoid misalignment of the internal fluxgate compass, and
b) allow the depth of the unit to be adjusted according to site conditions.

Figure 3. Examples of side (left) and bow mount (right) for a boat.
(Photograph: Mark Randall, Queensland Government Department of Natural Resources, Mines & Energy)

The boat operator shall ensure that the boat traverses the channel in a steady and controlled manner ensuring minimal disturbance of the flow. In very slow water velocities this will require the use of a cross wire rather than using the boat's outboard motor.

NOTE: A bow mounting may reduce directional bias.

6.2.2 Tethered deployment

This methodology for both moving boat and stationary measurements requires the ADCP to be mounted on a floating platform which is tethered by a rope or cable. The operator moves the ADCP across the channel using a tow rope, pulley system, or existing cableway. This is a simple, efficient method for using the ADCP which is ideal for small channels and measuring from bridges.

For the moving boat method, the operator shall maintain slow steady continuous movement of the ADCP across the channel while remaining perpendicular to the flow. This method shall not be used for larger velocities as the capabilities of the floatation platform can become compromised. The ADCP operator should pay particular attention to aeration of the ADCP beams which may be created by the floating platform. Refer to the manufacturer's specifications for the rated velocity of the platform.

ADCP units designed specifically for tethered deployment communicate wirelessly.

Figure 4. Example of a tethered ADCP deployment utilising a remotely controlled traveller system which ensures a consistent boat speed across the transect

(Photograph: Mark Randall, Queensland Government Department of Natural Resources, Mines & Energy)

6.2.3 Remote controlled vessel (boat mounted only)

Remote controlled vessels are available for mounting ADCPs. The manufacturer's specifications should be consulted in regard to the operating range and rated water velocities.

This method may be used at sites that are difficult to access with a manned boat or the establishment of a tethered deployment.

The same principles of boat operation apply to remote controlled vessels.

6.2.4 Incorporating a GPS

Where the deployed ADCP is able to support a differential GPS of sufficient accuracy (minimum of five decimal places) and update rate, it should be used. A differential GPS is required because the GGA positional data string requires differential correction. If only the VTG data string is to be used, then the operator may use a standard GPS of sufficient accuracy.

> NOTE: A GPS is required because it provides a secondary reference for calculating velocity which may be required during the collection process or for the post processing of the data. It is also a necessity when testing and accommodating for moving bed conditions and therefore an essential piece of ancillary equipment.

When using a GPS, it shall be mounted above the ADCP to avoid rotational errors. An accurate magnetic declination for the measurement location shall be entered into the measurement software or an inaccurate total discharge will be calculated by the ADCP. Magnetic declination values shall be obtained from Geoscience Australia.

The ADCP compass shall be correctly calibrated if GPS data is to be used as the track reference to avoid the introduction of errors in the reported discharge totals.

Any internal filtering within the GPS unit shall be disabled.

The quality of the GPS data shall be examined and verified if it is to be used as the ADCP track reference for discharge calculation. Two indicators of errors within the discharge totals that can be examined include bottom track discharge variations and abnormal rises in the cumulative discharge.

6.2.4.1 GPS data strings

There are two data options available when using a GPS as the ADCP track reference.

6.2.4.1.A GGA

GGA data is based on received positional data and is susceptible to multipath errors. GGA data therefore requires differential correction for sub-metre accuracy which requires channel widths of less than 20 metres.

6.2.4.1.B VTG

VTG data is based on received velocity data consisting of speed and track direction calculated from the Doppler shift between the satellites. VTG data is not subject to multipath errors and therefore does not require differential corrections for sub-metre accuracy. The use of VTG data requires that the channel width is greater than 20 metres and that the boat speed is greater than 0.1m/s.

Errors in VTG data are more difficult to identify than GGA errors and will therefore require closer examination by the operator before being used as the ADCP track reference.

A more detailed discussion on the use of GPS is available in Appendix B.

6.2.5 Depth sounders

Depth sounders are only required as part of a standard deployment procedure where the ADCP is not able to locate the streambed.

Where the ADCP is unable to locate the bottom, for example, due to excessive signal attenuation due to a large volume of suspended and moving sediment, or where water bias is causing the ADCP to record a false bed, a depth sounder shall be used. The type of depth sounder used should be able to communicate with the ADCP software at the fastest update rate available.

The quality of the depth sounder used shall be of survey grade.

Depth sounder frequency shall be sufficiently different from that of the ADCP to avoid acoustic signal contamination.

6.3 Stationary method

The stationary (or section by section) method involves utilising the ADCP for area-velocity discharge measurements, as defined in ISO 748:2007.

In summary, the method involves collecting time-averaged velocity profiles and depth recordings at a number of verticals along a stream section perpendicular to the direction of flow, which are combined at the completion of the transect to record a discharge.

The ADCP shall be mounted to ensure that physical movement of the ADCP at each measured section is minimised. However, some movement is allowed and is compensated by the instrument's internal compass and the correct azimuth input by the user. An accurate compass calibration shall be carried out at each site measured. Typically, a tethered deployment method is used as defined in Clause 6.2.2.

In low velocity situations affected by wind, deployment of a small drogue chute, training line or harness will assist in maintaining the position of the perpendicular to the section azimuth also ensuring that the same bed depth location is measured throughout the sampling interval at the section.

Velocities perpendicular to the tag line (i.e. normalised velocity) are required for final discharge calculations. If a software option is available the azimuth value is entered into the ADCP measurement file, which references the compass orientation of the tag line facing towards the right bank (Figure 5).

Tagline azimuth can be determined using ADCP software functions (if available) or handheld compass. This is a magnetic azimuth.

At sites with fixed infrastructure such as travellerways and fixed tag lines the tagline azimuth should be surveyed to Magnetic North so that any field measurements of the azimuth at time of undertaking a discharge measurement can be assessed further for magnetic interference as an addition to the compass calibration process.

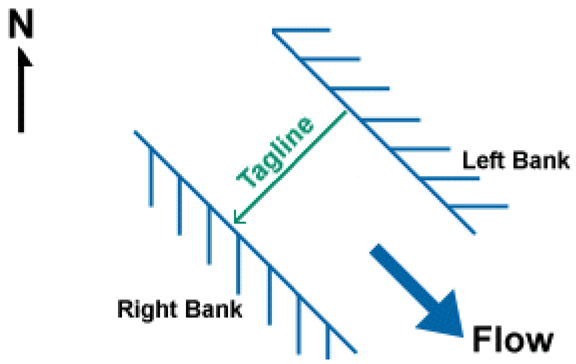

Figure 5. Defining the direction of the tagline azimuth
(Source: Sontek YSI Incorporated, 2013)

Where this software option does not exist, the section flow angle shall be observed and input manually based on the flow angle at the surface for each vertical, as per ISO 748:2007.

Distances from the bank should be defined as accurately as practicable. This can be achieved with taglines, traveller counters, and electronic distance measurers as examples.

On larger stream sections where moving boat techniques could be applied, GPS locations can be utilised to define the distance/location of the measurement vertical when utilising stationary method, wireless boat discharge measurement techniques.

As per ISO 748:2007, a minimum of 22 measured sections should be collected over the cross-section. Each section should represent as close to 5% of the total discharge as reasonably practicable.

These recommendations may not be achievable in practice however, and the streamflow for any individual measured section should not exceed 10% of the total streamflow.

Time of exposure (sample period) shall be a minimum of 40 seconds at each vertical. Sample periods used for measurement at each section are dependent on the flow conditions, but the duration should be sufficient to ensure repeatability of the velocity measurement at any given section.

For stream widths greater than 5 metres, overall time of exposure (total sample duration) shall exceed 800 seconds per discharge measurement. Exposure time less than this will result in downgrade of quality of the discharge measurement.

For stream widths less than 5 metres, ISO 748:2007 allows appropriate reductions in measured sections. In these instances, overall exposure time may be reduced, and quality shall be assessed with regards to the representativeness of the measured sections.

Where there are difficult conditions, such as low velocities (<0.1 m/s), or under pulsing conditions, sample periods should be increased.

Where conditions present a danger to operators or infrastructure, such as floating debris, sample periods may be decreased.

Depth measurement may be achieved by depth sounder or bottom track methods. Bottom track depth determination shall not be used where moving bed conditions exist.

Measurements that utilise bottom track depth measurement shall be assessed for moving bed conditions as per Appendix A and quality assessed accordingly. In moving bed situations, bottom track depth measurement may be affected by water bias as described in Appendix A, Section A.1.1. The resulting negative bias in cross sectional area computations contribute to negative bias in the discharge computation.

Many of the Quality Rating Criteria defined for an ADCP moving boat gauging are not applicable to a gauging collected using this method.

Software designed for ADCP stationary discharge measurements may report estimated uncertainty based on instrument, measurement, and site characteristics, and should be used where available. Uncertainty may also be calculated using ISO 1088 for current meter gaugings. The quality of a gauging performed using this method should be considered as:

a) Band 1, where estimated uncertainty is ≤ 5%;
b) Band 2, where estimated uncertainty is >5% and < 10%;

c) Band 3, where estimated uncertainty is ≥ 10% and ≤ 20%; and
d) Unrated, where estimated uncertainty is >20%.

Refer to Appendix E for an explanation of the quality codes.

7 Data collection

The following guidelines are the minimum requirements that shall be followed to ensure the integrity of the data collected. Detailed field notes shall be kept with the measurement files/field sheets.

7.1 Pre-collection QA/QC procedures

The following procedures shall be part of a QA/QC system of checks to ensure the integrity of the data collected. Where an ADCP fails to meet the applicable criteria then it should not be used to collect data. If the ADCP cannot be brought back within specification, then the manufacturer should be contacted to determine a solution to the issue.

1. The water temperature at the face of the transducer shall be recorded and compared to the ADCP thermistor. The ADCP measured temperature should be within 2°C of an independent calibrated measuring device. The temperature difference shall be recorded in the measurement quality documentation. Water temperature is critical in the speed of sound calculations to accurately measure water velocities and depth and is therefore a significant source of potential error.

   ADCPs that have been exposed to temperatures significantly different to the stream temperature shall be allowed to equilibrate in the stream, to stream temperature, before commencing the measurement.

   NOTE: A 5°C difference in temperature results in a 2% bias error in the measured discharge (*Mueller et al, 2009*). If the ADCP temperature is less than the independently measured temperature, the bias introduced will be negative. Conversely, if the ADCP temperature is more than the independently measured temperature, the bias introduced will be positive.

2. Transducer depth shall be measured from the transducer face to the water level, taking into account the effect of pitch angle and shift in operator location during measurement. Transducer depth shall be measured within 20 mm of actual depth. The reported stream depth by the ADCP should also be checked to ensure the correct setup and operation of the ADCP.

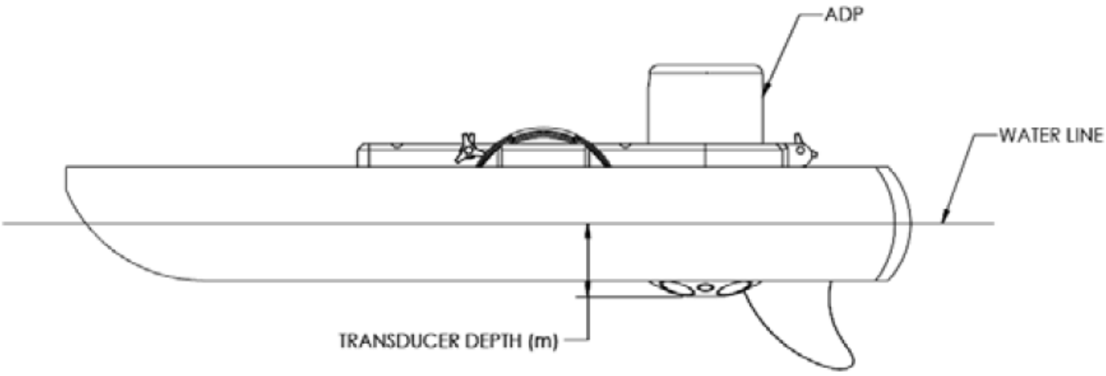

Figure 6. Transducer depth of an ADCP mounted on a hydroboard
(Source: Sontek YSI Incorporated, 2013)

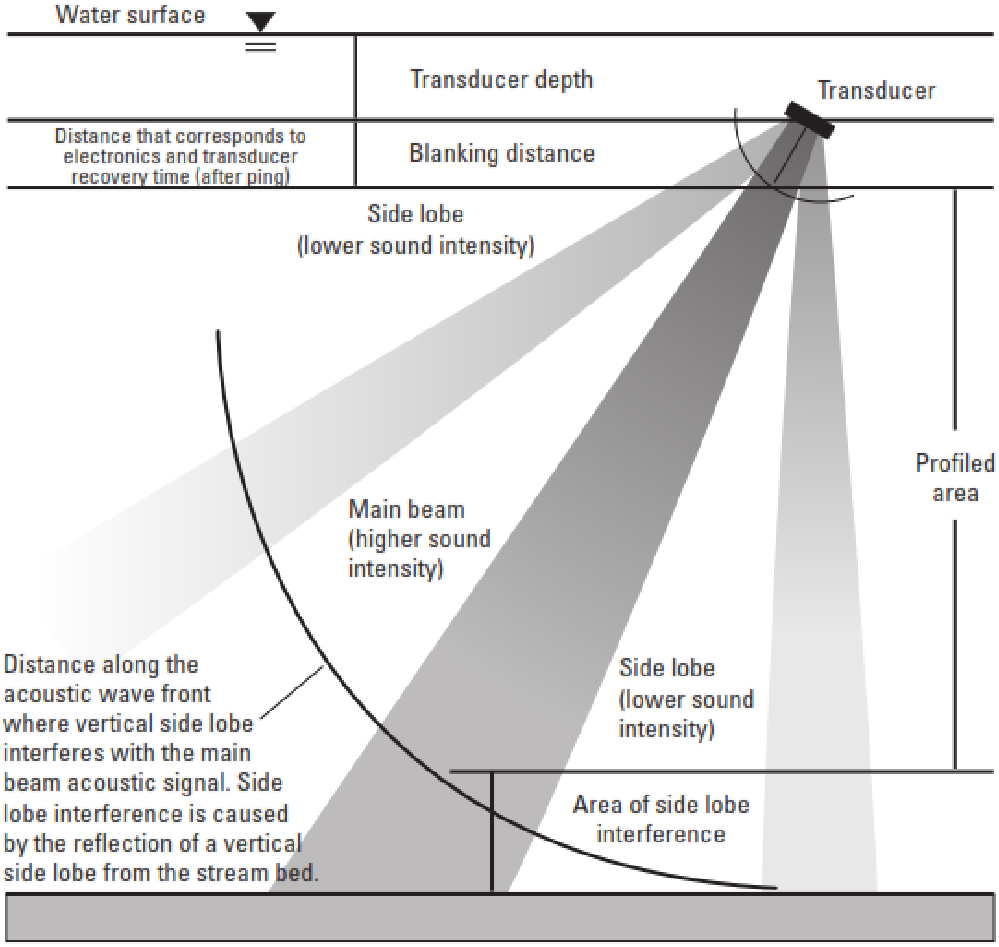

Figure 7. Acoustic Doppler current profiler beam pattern and locations of unmeasured areas in each profile.
(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

3. Electrical conductivity shall be measured at the ADCP face and entered within the measurement software when operating in environments where the salinity may differ from that of freshwater such as estuarine environments. In tidal sections, salinity shall be measured at the start and end of the measurement and the mean salinity entered into the data processing software. Salinity is critical in the speed of sound calculation to accurately measure water velocities and depth and is therefore a significant source of potential error.

   NOTE: A salinity change of 12 parts per thousand (PPT) equates to a 1% bias error in the speed of sound calculation and a 2% error in the velocity calculation. Freshwater is 0 PPT and sea water is 30-35 PPT. If the salinity entered is less than the independently measured salinity, the bias introduced will be negative. If the salinity entered is more than the independently measured salinity, the bias introduced will positive. Refer to Appendix F.

4. The necessary instrument diagnostic tests shall be run according to the manufacturer's instructions. The test result file shall be stored with the ADCP measurement file.
5. The ADCP clock shall be set within a two minute tolerance of the measurement location time and zone as reported by a GPS unit. GPS time is an accurate and verifiable time source by which all time pieces shall be set.
6. A compass calibration/evaluation shall be undertaken on site before a measurement is undertaken. The compass shall be well calibrated to minimise compass error when using a GPS with a moving boat for determining a moving bed. This process may need to be run more than once to achieve the desired result. The compass shall be calibrated at the measurement location and with the ADCP in its data collection mounting to accommodate for electromagnetic interference. The manufacturer's documentation shall be consulted for specific ADCP compass tolerances. The compass calibration file shall be attached to the measurement file.

   NOTE: If a series of measurements are to be undertaken at the same location during the course of a day a single compass calibration may only be undertaken before the first of the day's measurements. Later measurements shall include a reference to the location of the compass calibration/evaluation result within the measurement notes.

7. The ADCP shall be configured to record the best possible data at the measurement site. This may involve manually setting deployment modes, depth cell (bin) sizes, and water depths within the ADCP. A trial transect should be undertaken by a competent operator to determine the quality of the measurement site and that the operational settings are appropriate. All changes to settings as well as the final settings should be recorded along with a description of the site conditions and why the changes were made.
8. The operator shall look to measure at a cross-section that will provide the least amount of uncertainty which may involve changing the measurement location to retain or improve the quality of the data. The level of training and experience of the operator is fundamental in correctly determining the most appropriate site location and required ADCP commands to record the optimum quality of data.

9. If using the moving boat method, a moving bed test should be conducted prior to making any discharge measurement and stored with the measurement file. During flood conditions, measurements shall be checked for bed movement more frequently as bed movement may only be present during a certain period of the of the rising and falling hydrograph limbs. The three acceptable moving bed tests below are in order of preference:

   1. Loop correction.
   2. Stationary with a GPS.
   3. Stationary without a GPS.

   The ADCP operator should be aware that higher frequency ADCPs are more susceptible to moving bed conditions and may record the occurrence of a moving bed at a site where a lower frequency unit will not. This can be independent of the site characteristics and flows encountered.

   Any measurement affected by a moving bed shall have the total discharge value corrected for the negative bias introduced into the measurement when bottom track is used as the ADCP track reference.

   Further information on moving beds can be found in Appendix A.

10. In some environmental situations thermal or saline stratification may exist within the water column. In these situations, the user should look to undertake vertical profiling to quantify the possible influence on the speed of sound calculations for velocity. Some instrument manufacturers provide integrated vertical profiling options.

7.2 Data collection procedures

The measurement procedures required to collect quality discharge data can vary depending on the flow regime located at the site. Despite differences in the procedures required, the data quality indicators remain consistent.

7.2.1 Steady flow

Steady flow refers to the condition whereby fluid properties (such as density, velocity, and pressure, etc.) at a point in the system do not change over time. Steady flow can be further categorised as uniform steady flow whereby the flow variables are constant over distance and time or as nonuniform steady flow. Non-uniform steady flow takes two forms. Gradually varied steady flow which occurs when flow variables change over distance but not time. Rapidly varied steady flow displays substantial variations in vertical and/or transverse flow.

The following procedures shall be adhered to during the measurement of steady flow:

1. For the moving boat method, a single discharge measurement should consist of a minimum of four transects consisting of reciprocal pairs to identify and eliminate directional bias. Under steady flow conditions, variation in discharge should not exceed 5% from the mean of all transects. If the variation exceeds 5% then additional paired transects should be undertaken to reduce the level of measurement uncertainty.

NOTE: If, after review of all transects, a decision is made to remove any transects from the final result, transects should be removed in pairs. That is, if a right transect is removed then a left transect should be removed to eliminate bias.

Consideration should be given to satisfy the minimum exposure time of 800 seconds if removing transects.

Decisions to remove transects should take into account changing flow rates/stage heights during the measurement process. If flow rate/stage is changing throughout the measurement it may be better to accept all transects and apply time weighted stage heights to the final result of the measurement and assess quality accordingly.

2. For the moving boat and stationary methods, total measurement sample time should not be less than 800 seconds. For small streams this may mean the collection of more than four transects.

   NOTE: A measurement sample time of greater than 800 seconds is necessary to reduce the errors associated with variations in streamflow over the course of the measurement. Any less will result in the quality of the measurement being downgraded.

   Mueller *et al*, 2009 states that the cumulative time over which data is collected and averaged during a discharge measurement is the key to reducing measurement uncertainty.

3. For the moving boat method any boat/platform movement should be smooth and steady; speed should be equal to or less than the water speed. When water velocities are slow enough to complicate boat manoeuvrability, a tagline or traveller system shall be used to correctly traverse the channel and maintain data integrity. The stationary method may also be considered for use in slow water situations if practical.
4. For moving boat and the stationary method the start and end point of a transect should be marked as the point closest the shore where the ADCP can still measure two depth cells. To ensure the accuracy of the near-shore discharge estimates, the distance to the shore from the starting and end points of the measurement transect shall be measured with a distance measuring device, e.g., tag lines, range finder. A buoy or marker should be placed at the starting and stopping point within the stream and a marker placed on the water's edge adjacent to the buoys to assist in maintaining consistent distance measurements.
5. Where there are steep/vertical channel banks, measurements should not be taken closer than a water depth away from the bank, otherwise signal lobe interference might occur. The operator shall be aware that the lobe interference will bias the velocity data towards zero i.e. the speed of the bank.
6. For moving boat method near-shore discharge should be estimated by taking a stationary measurement at the starting and end points of the transect. The time for this measurement should be long enough to provide a representative estimation, typically five to ten seconds.
7. Variation in pitch and roll shall be minimized below 5°. Excessive roll is particularly detrimental to measurement accuracy.

8. Compass errors and magnetic declination errors have a significant effect on the measured total discharge when using a GPS as the boat velocity reference. The severity of the compass error influence on measured discharge is also proportional to boat speed. When using a GPS, the ADCP internal compass shall be well calibrated and a slow boat speed shall be used to traverse the channel. Compass error can also create directional bias of the measured discharges between reciprocal transects. Magnetic declination shall be site specific and may be entered during the post processing stage. If the compass is recalibrated due to error, all transects should be repeated and the initial transects shall not be used for discharge calculation.

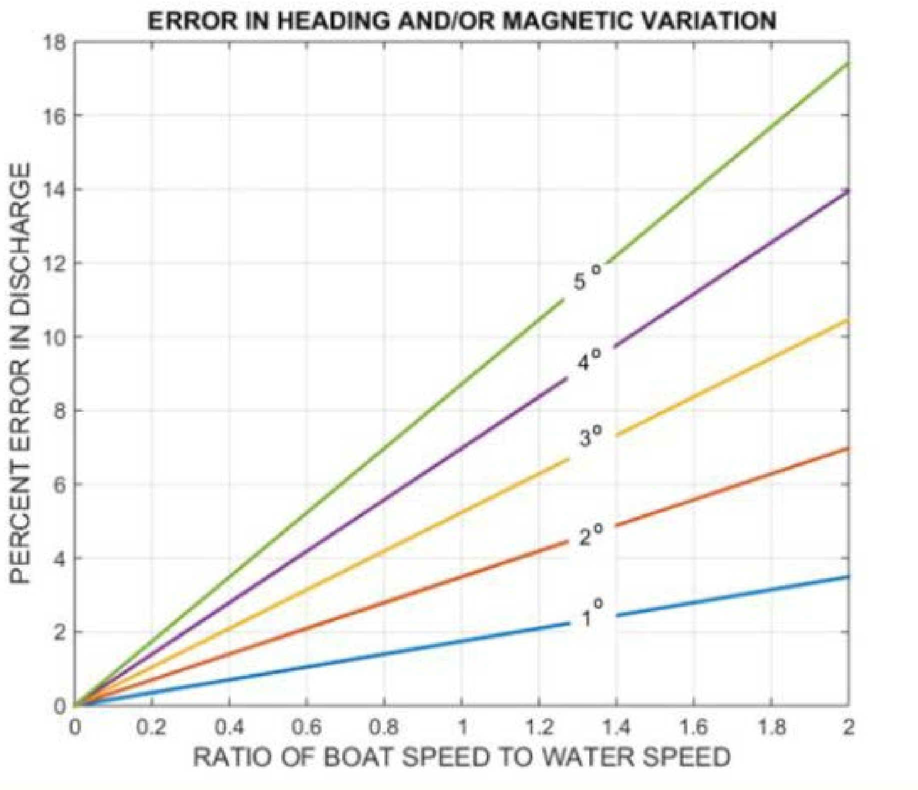

Figure 8. Effect of heading and magnetic variation errors on discharge for increasing boat to water speed ratios
(Source: USGS, viewed 2 October 2018, https://hydroacoustics.usgs.gov/training/SW1321_TEL_V2.00/Lesson_6/presentation.html)

7.2.2 Unsteady flow

Unsteady flow refers to the condition where fluid properties at a point in the system do change over time. Unsteady flow is non-uniform and can be further described as gradually varied or rapidly varied unsteady flow.

The data collection guidelines outlined in 7.2.1 also apply to unsteady flow with one notable exception. Unsteady flow conditions such as bi-directional flow or rapidly changing stage during a flood or tidal event will cause measured streamflow variations in excess of 5% between transects for moving boat measurements. In this instance the operator shall examine the need to treat individual transects as a completed measurement and the justification for this decision noted in the measurement documentation by the operator while in the field. Whenever possible under these circumstances the operator should collect reciprocal pairs of transects to be treated as measurements to eliminate the effects of directional biases. This will also mean that exposure time may be greatly reduced from the recommended 800 seconds.

When using the stationary method in these flow situations the principles of ISO 748:2007 shall be applied.

When bi-directional flow is encountered, the ADCP operator shall ensure that the assigned positive and negative flows are correctly identified and that the left and right banks have been assigned correctly according to standard convention.

In estuarine waters it is especially important to monitor and account for changes in salinity. Therefore, salinity shall be measured at the start and end of each measurement and correctly entered within the ADCP data collection software. If a significant change in salinity has occurred over the course of a measurement, then the midpoint value should be used for the speed of sound calculations.

> NOTE: Within many tidal sections it is extremely common to get saline wedges which would require salinity measurements at multiple depths and locations across the measurement track. These measurements would need to be averaged and correctly entered within the ADCP software. An example of salt wedge impacts is provided at Appendix H.

Where changes in stage occur during a measurement due to tides or flood, a gauge height should be collected at the start and end of each measurement. Additional gauge heights through the discharge measurement period will assist in weighting the gauge height appropriately.

If this is not possible, water levels recorded at a suitable gauging station may be used. The ADCP operator should determine the most appropriate method of determining stage and changes in stage as appropriate and required.

8 Post measurement review procedures

The ADCP operator shall review the transect data as it is collected in the field to ensure its integrity. For the moving boat method where the data collected lacks integrity, the operator shall collect additional transects, and/or change the location of the measurement and/or if available change the ADCP.

For the stationary method an onsite inspection of the discharge data collected can identify non-conforming sections of the gauging and it may be possible to undertake additional vertical measurements to improve the final discharge result. The operator may also change the location of the measurement or change the ADCP.

All relevant information should be documented in the field notes for future reference. A more thorough review should be conducted by the ADCP operator as soon as possible after the measurement has been completed. All measurements should be backed up on a non-volatile storage device while still in the field.

8.1 In the field

Where data is collected at the same measurement cross-section, the ADCP operator shall examine the data in accordance with the following:

1. Transect widths shall be consistent in length.
2. The measurement software extrapolates a discharge value for the edges, top, and bottom sections for each transect where the ADCP is unable to measure. The variance between transects for each extrapolated section should be below 5%.
3. The quality of the GPS data should be monitored and reviewed because GPS systems are not always able to provide accurate positional references due to multipath errors, and locatable satellite numbers and signal quality. Points to check in ADCP software include GPS quality assurance tables, irregular ship track plots and spikes/lags in the boat speed time series.
4. Where a critical data error is identified in a transect, it should not be used for discharge computation. Where flow conditions have not changed, an additional transect should be recorded in the same direction of travel as the discarded one.
5. Where the discharge measurement is undertaken using the Stationary Method, the ADCP operator will examine the data in accordance with the following and with reference to ISO 748:2007:
   a) the verticals are spaced to adequately define the bed profile, and subsequently the cross sectional area, accurately;
   b) assess the percentage flow in each sub section;
   c) assess side lobe interferences from SNR plots at each vertical;
   d) assess flow angles at each vertical; and
   e) where a data error or insufficient data is identified it may be possible to undertake additional vertical samples or, if the error identified is irretrievable, another stationary method discharge measurement should be undertaken.

8.2 Office review procedures and data quality indicators

The measurement data shall be examined in detail by the ADCP operator and checked by a second individual with sufficient ADCP experience and training. Data shall be managed and stored in accordance with the organisational procedures. The data quality indicators to be examined shall include but not be limited to the following:

1. Field notes should match the configuration, and collection parameter settings i.e. edge distances, ADCP (transducer) depth, temperature, and salinity.
2. ADCP system test, moving bed test, and compass calibration shall have been conducted before starting the measurement.
3. Total measurement time should be in excess of 800 seconds.
4. For moving boat measurements, the boat speed has remained consistent and ideally below that of the water speed. Reasons for excessive boat speed should be documented in the measurement notes. Pitch and roll should not be excessive as this can cause the de-correlation of the acoustic signal resulting in invalid

ensembles. The measurement quality should be downgraded where these variables are excessive.

5. Missing ensembles result from communication problems between the ADCP and computer which leads to data not being recorded by the measurement software. Where a significant percentage of the missing ensembles are clustered, the measurement quality should be downgraded.

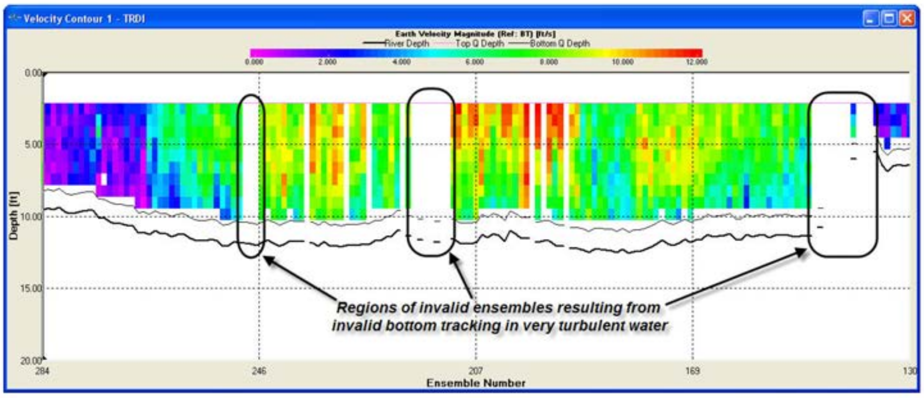

Figure 9a. Invalid ensemble data as displayed in ADCP data collection software
(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

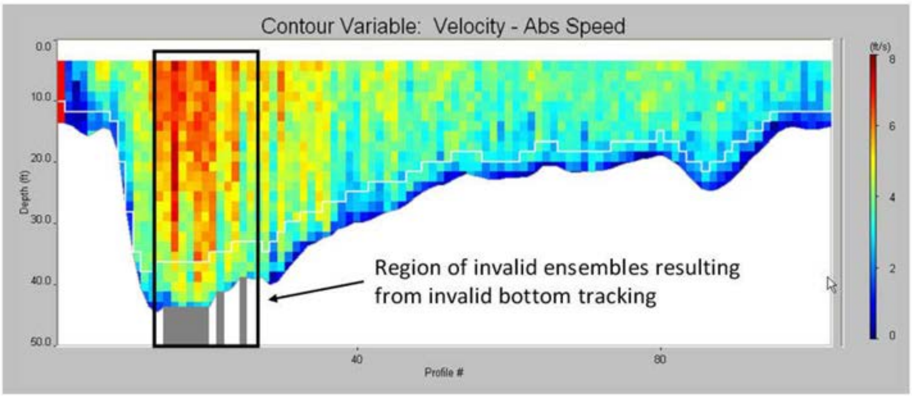

Figure 9b. Invalid ensemble data as displayed in ADCP data collection software
(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

6. Invalid ensembles occur when the ADCP frequency has been unable to measure the water velocity. Unlike missing ensembles, the measurement software has recorded the data however it does not meet valid velocity criteria. The cause of this could be:

   a) invalid bottom tracking;
   b) de-correlation of the acoustic pulse from turbulence, submerged debris, high shear—this prevents a valid measurement of the Doppler shift;
   c) low backscatter which results in insufficient returned signal for the Doppler shift calculation;
   d) air entrainment blocking the acoustic signal; or
   e) user specified data quality criteria.

As with missing ensembles the quality of the measurement should be downgraded if the invalid ensembles are concentrated together in areas of the transect rather than randomly spaced across the transect. An alternate measurement site should be considered.

7. Invalid depth cells are similar in definition to invalid ensembles and the quality of the measurement should be downgraded.
8. For the moving boat method, ambiguity velocity errors are indicated by velocity spikes and misdirection when plotted against valid velocities on the ship track. These shall be removed via filtering if available in the instrument software.

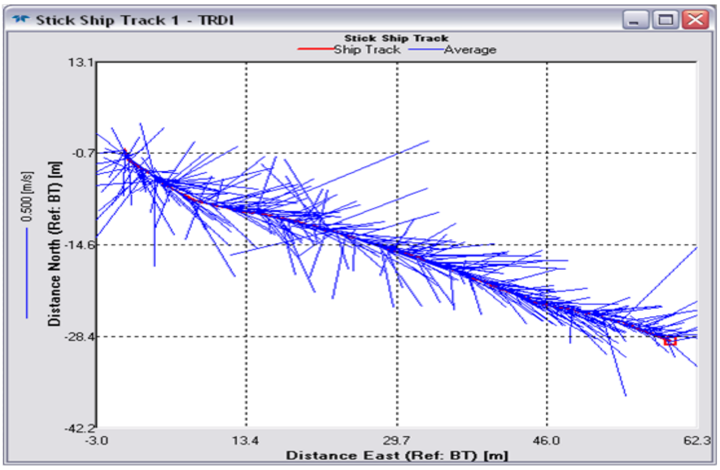

Figure 10. Erroneous velocity measurements caused by ambiguity errors as displayed in WinRiver

(Credit: Mark Randall, Queensland Government Department of Natural Resources, Mines & Energy)

9. Where beam intensities are inconsistent and do not gradually lessen with increasing depth then show a larger reflected intensity indicating the bottom, the measurement uncertainty should be increased.

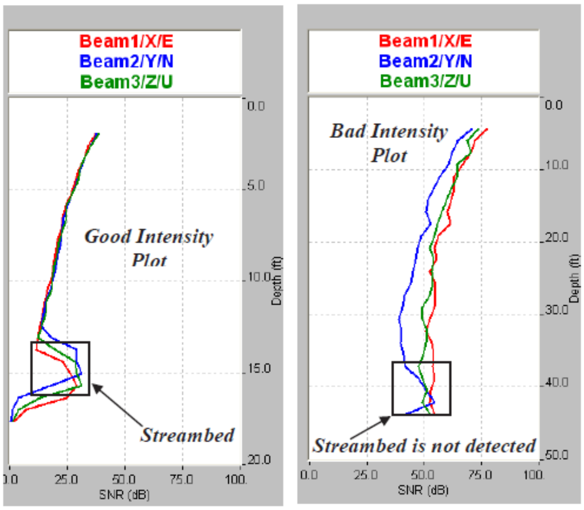

Figure 11. An example of a good and bad intensity plot in detecting the streambed

(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

10. Irregularities with the bottom tracking depth measurements are represented as spikes in the measured velocity at the streambed. This causes a bias in the cross-sectional area creating inaccuracies in the measured discharge. Post processing data screening shall be employed to remove these spikes.
11. GPS signal shall be checked for the errors associated with using the GGA or VTG streams. A poor GPS signal used as a reference can degrade the quality of the measurement. Appendix B gives further requirements for the use of GPS technology.
12. The extrapolation methodology for the top and bottom estimated discharges shall be reviewed and changed where an experienced operator determines that a more suitable method is required.
13. The operator shall determine the correct extrapolation method by averaging ensembles (if able) or using a third-party software. Any change in the method used shall be documented stating the reasoning behind the alteration.

8.3 ADCP quality matrix

To ensure conformity of post processing and quality code assignment between ADCP operators across different data collection agencies, Appendix C contains a data processing sheet that applies a quality coding matrix. The matrix is based on the procedures contained within this document and data quality indicators provided by the ADCP software. The matrix consists of a point allocation system for each criteria whereby the total points accrued assigns a particular quality code to the measurement. Should the ADCP operator disagree with a particular point allocation assigned by the matrix they may adjust the allocation but shall document the reasoning behind the change.

This sheet provides an important means of identifying and quantifying any issues or data uncertainties associated with an ADCP measurement.

All ADCP measurements should be processed using this quality matrix. A copy of the completed matrix shall be stored with the measurement record.

An explanation of the codes used is contained in Appendix E.

8.4 Data quality assessment tools

Data analysis tools created by ADCP manufacturers and the USGS are available to provide the ADCP operator with an effective and simple means of quantifying the uncertainty of ADCP discharge measurements. Independent programs can accept data from a range of ADCP models and manufacturers, providing detailed analysis of (but not limited to) the following:

a) moving bed corrections, identification, and quantification of a moving bed providing adjustment factors;
b) GPS quality analysis; and
c) extrapolation analysis and identification of the most suitable velocity extrapolation method.

The use of these programs should be as an additional tool to improve the quality of ADCP discharge measurements and reduce data uncertainty.

NOTE: These programs may be found at: http://hydroacoustics.usgs.gov/movingboat/mbd_software.shtml

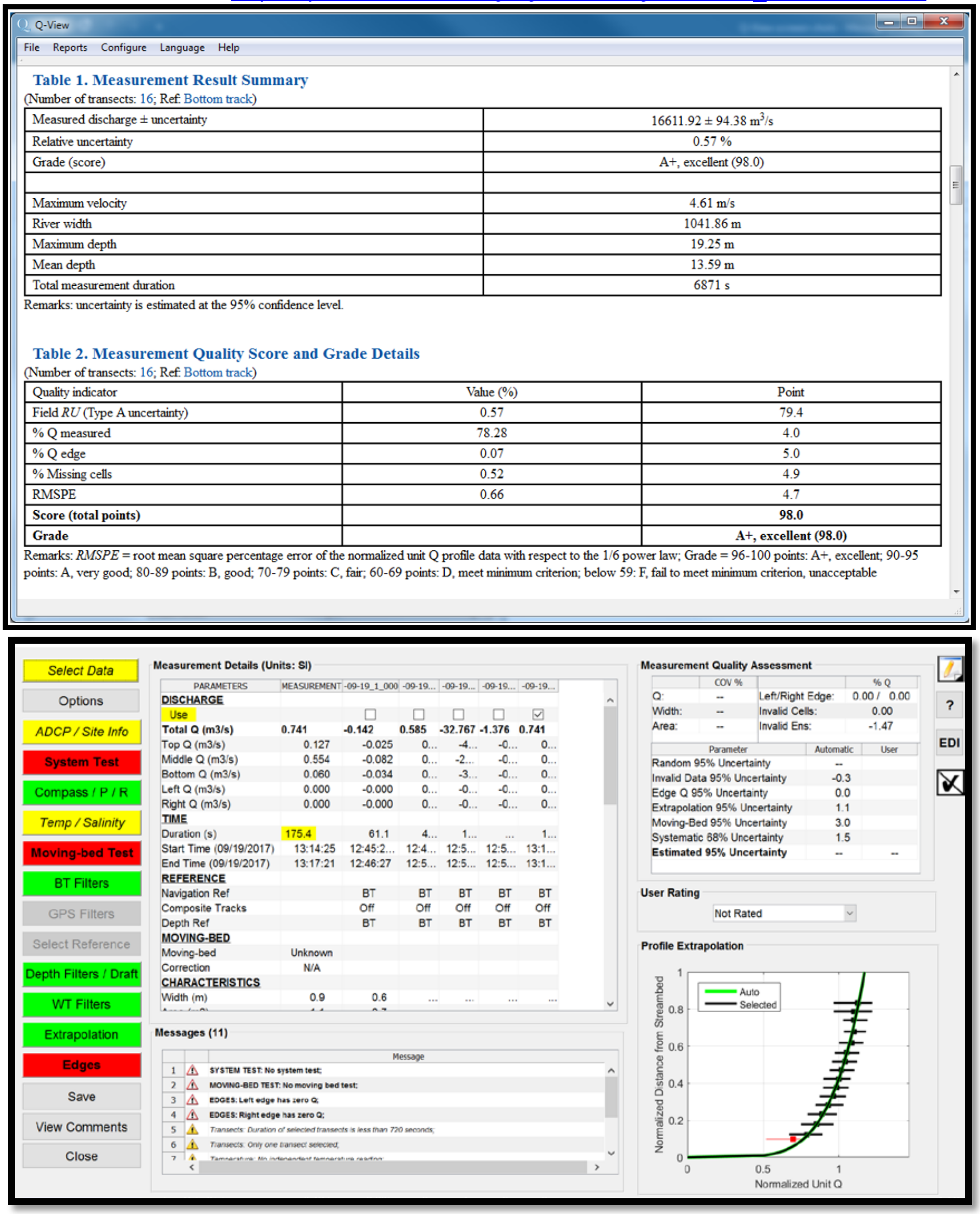

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Table 1. Measurement Result Summary

(Number of transects: 16; Ref: Bottom track)

Measured discharge ± uncertainty	16611.92 ± 94.38 m³/s
Relative uncertainty	0.57 %
Grade (score)	A+, excellent (98.0)
Maximum velocity	4.61 m/s
River width	1041.86 m
Maximum depth	19.25 m
Mean depth	13.59 m
Total measurement duration	6871 s

Remarks: uncertainty is estimated at the 95% confidence level.

Table 2. Measurement Quality Score and Grade Details

(Number of transects: 16; Ref: Bottom track)

Quality indicator	Value (%)	Point
Field *RU* (Type A uncertainty)	0.57	79.4
% Q measured	78.28	4.0
% Q edge	0.07	5.0
% Missing cells	0.52	4.9
RMSPE	0.66	4.7
Score (total points)		**98.0**
Grade		**A+, excellent (98.0)**

Remarks: *RMSPE* = root mean square percentage error of the normalized unit Q profile data with respect to the 1/6 power law; Grade = 96-100 points: A+, excellent; 90-95 points: A, very good; 80-89 points: B, good; 70-79 points: C, fair; 60-69 points: D, meet minimum criterion; below 59: F, fail to meet minimum criterion, unacceptable

Figure 12. Real time measurement summary and measurement quality score from ADCP data collection software Qview (top) and USGS post processing software Qrev (bottom)

(Source: Qview image courtesy of Teledyne RDI Instruments Qrev image provided by Mark Randall)

9 Uncertainties in discharge measurements

The following information regarding hydrometric and discharge measurement uncertainties has been sourced from ISO/TR 24578:2012 which makes reference to ISO 5168, ISO/TS 25377, ISO/IEC 98-1 and ISO/IEC 98-3. It is the responsibility of the operator to refer to the original documents for future ISO updates on measurement uncertainties.

9.1 Description of measurement uncertainty

All measurements of a physical quantity are subject to uncertainties and therefore the result of a measurement is only an estimate of the true value and only complete when accompanied by a statement of its uncertainty. The discrepancy between the true value and the measured value is the measurement error which is a combination of component errors that arise during the performance of the various elementary operations of the measurement process.

When a measurement depends on several component qualities then the total measurement error is a combination of all the component errors. Therefore, the determination of a measurement's uncertainty is a combination of all the identified component measurement errors, quantification of their corresponding uncertainties and then a combination of those component uncertainties.

The component uncertainties are combined in a manner that accounts for both systematic and random errors and are termed 'standard uncertainties' which correspond to one standard deviation of the probability distribution of measurement errors. One standard deviation equates to a confidence level of 68%. The uncertainty at two standard deviations is twice the standard uncertainty which if estimated can be multiplied by two to obtain the uncertainty at two standard deviations, or 95% confidence level. The multiplication factor is termed as the coverage factor. Therefore, if the uncertainty is expressed at three standard deviations the coverage factor would be three and represent a confidence level of 99%.

When stating uncertainties, it is also necessary to state the confidence level or the coverage factor i.e. the number of standard deviations.

NOTE: For example, if a discharge measurement of 50 cumecs had an uncertainty of 9% at the 95% confidence level the statement of uncertainty should be documented as follows:

Discharge = 50 m^3s^{-1} with an uncertainty of 9% at the 95% confidence level based on a coverage factor of k=2.

9.2 Estimating the uncertainty in an ADCP discharge determination

ADCPs calculate streamflow by measuring velocity and area. Therefore, the accuracy of an ADCP is dependent on how it is set up and how it is operated. ADCP manufacturers provide potential values of error within their technical specifications for the ADCP sensors. These error values are for the measured velocity of the reflective particles in the sampled section of the water column and not for the accuracy of the streamflow measurement. Further points of introduced error occur from:

1. Depth measurement – Depth is an important factor within the streamflow calculation. Therefore, the accuracy and sensitivity of the depth measurement is very important.
2. The ability of the ADCP to reference its own position and velocity from bottom tracking or GPS has a direct bearing on the estimation of water velocity and area.
3. The percentage of the measurement that is measured as opposed to estimated.

The key to minimising uncertainty in ADCP measurements is to ensure that the operating staff have the required level of training and experience to ensure that the correct operational procedures are adhered to and that the data are accurately processed to quantify all introduced sources of uncertainty. Field procedures should be implemented according to the environmental conditions encountered at the measurement site. All equipment shall be checked regularly to identify any potential sources of error that could be introduced to a measurement. These checks shall be documented to demonstrate due diligence.

For the moving boat method, a 95% uncertainty of the final ADCP averaged discharge can be calculated using the following equation supplied by David Mueller of the USGS:

$$Qu=COV*f/sqrt(n)$$

where:

COV =	Coefficient of variation of total discharge as supplied by the ADCP discharge measurement summary sheet
f =	the multiplier from a t distribution table to achieve 95% for degrees of freedom of the measurement (n - 1) where n is the number of transects
sqrt =	square root.

For Stationary Method, uncertainties can be estimated with reference to ISO/TS 25377, ISO 5168:2005.

Some ADCP software can calculate this uncertainty as can some third-party software/database systems.

Appendix A Moving bed tests and corrections for the moving boat method.

A.1 General

A.1.1 What is a moving bed?

When an ADCP measures water velocity from a moving platform it measures the relative velocity i.e. the velocity of the water relative to its own position. The relative velocity includes the velocity of the moving platform as well as the water so as the speed of the moving platform increases so does the relative velocity. To determine the actual water velocity, the ADCP uses a fixed reference to determine the speed of its own movement and subtracts this from the relative velocity to calculate the actual water velocity. The fixed reference it uses is the streambed and is measured via bottom tracking.

The key assumption of bottom tracking is that the bed is indeed stationary, however this is often not the case when flow conditions can cause the bed load to move with the flow. In a moving bed scenario, the ADCP partially measures the velocity of the bed load in addition to the velocity of the moving platform and is illustrated in the ADCP data collection software as an apparent upstream movement of the ADCP when held in a stationary location. This moving bed condition results in a negatively biased discharge.

A second cause of a moving bed condition is known as water bias. In this situation, suspended sediment and organic matter moving near the streambed is dense enough to provide a false Doppler shift which the ADCP mistakes for the streambed. In this case, not only does the ADCP demonstrate upstream movement it also records a shallower stream depth resulting in a negatively biased cross-sectional area. To compensate for the effects of a moving bed, there are three acceptable methods to quantify the level of bias being introduced by the moving bed.

A.1.2 Method selection

A moving bed condition can be determined by using any of the methods described in this Appendix. The method used shall be appropriate for the environmental conditions at the measurement site.

The loop method should be used for identifying a moving bed condition in the field provided that:

a) bottom track can be maintained throughout the loop;
b) the compass is well calibrated; and
c) the loop can be started and stopped at the same point.

For a description of the loop method, see Clause A.2 and Figure 13.

Where these provisions cannot be met, and a loop test is not appropriate to identify a moving bed, the stationary test (see Clause A.3) should be used.

Two other methods for identifying a moving bed condition are described.

Clause A.4 describes the multiple moving bed test. The advantages of this method are that it requires no GPS or calibrated compass and can be used at sites with inconsistent bottom tracking. However, it is time consuming, has no correction for ADCP movement and the measured velocities are still biased low.

Clause A.5 notes the existence of the azimuth method, however it should not be employed.

A.2 The loop method

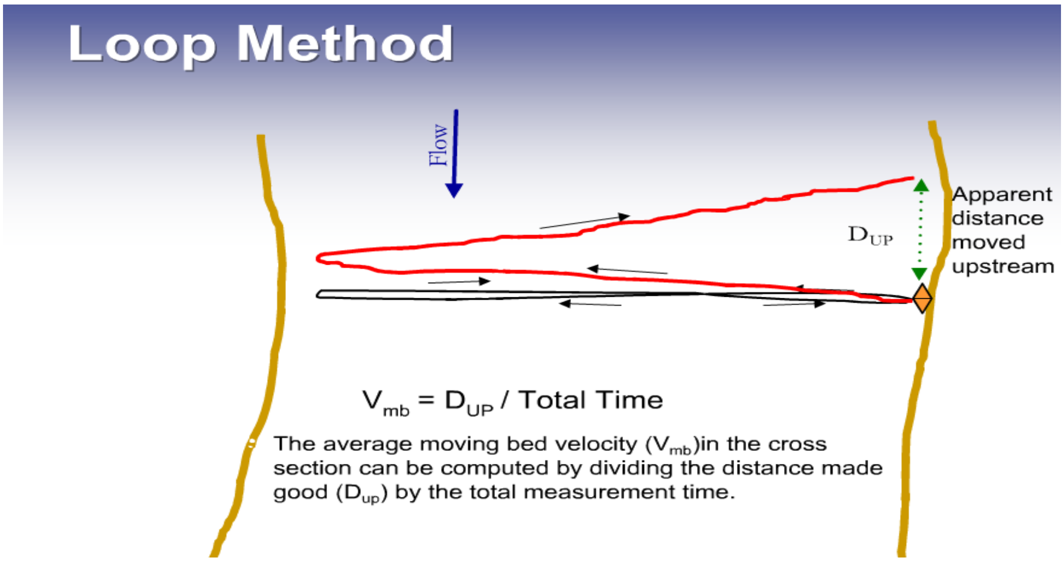

Figure 13. An illustration of a loop transect displaying a moving bed scenario
(Source: USGS, http://hydroacoustics.usgs.gov/movingboat/index.shtml, viewed 1 Aug 2013)

Where the loop method is employed, the following procedure shall be followed:

1. Calibrate the compass: this is critical to reduce the effects of compass error. A calibration accuracy better than 2° or an excellent rating should be achieved. Compass errors greater than this should be avoided because they can introduce misclose errors within the loop.
2. Establish a start/finish marker.
3. Move slowly and smoothly across the channel without stopping on the opposite side but instead returning the ADCP to within 0.3m of the starting point.
4. Check the start and finish points of the ship track. If a moving bed is present, the ship track will indicate that the ADCP returned to a point upstream of the actual start/finish point.
5. The traverse time shall be a minimum of 180 seconds to reduce measurement uncertainty and a steady speed should be maintained which does not exceed 1.5×water speed.
6. Do not collect any stationary edge ensembles.
7. The moving bed velocity is calculated by dividing the distance made good (DMG) by the total measurement time. DMG is a measure of the actual distance between

the moving platform and the transect start point when variations in the course track have been removed.

8. As the compass error naturally prevents the loop from closing, refer to Clause A.2.1.
9. Where the moving bed velocity exceeds 0.012 m/s, the ratio of the mean moving bed velocity and the mean water velocity shall be calculated. If this ratio is greater than 1% then this will cause a minimum -1% bias in discharge. This is the potential error caused by the moving bed.
10. The discharge measurement should be undertaken using a GPS as the reference. Where a GPS is not used, the discharge shall be corrected during the post processing of the data.

There are two methods documented by Mueller and Wagner 2006 to correct discharge measurements biased by a moving bed measured by the loop method. These are the mean correction and the distributed correction methods and described in A.2.3 and A.2.4

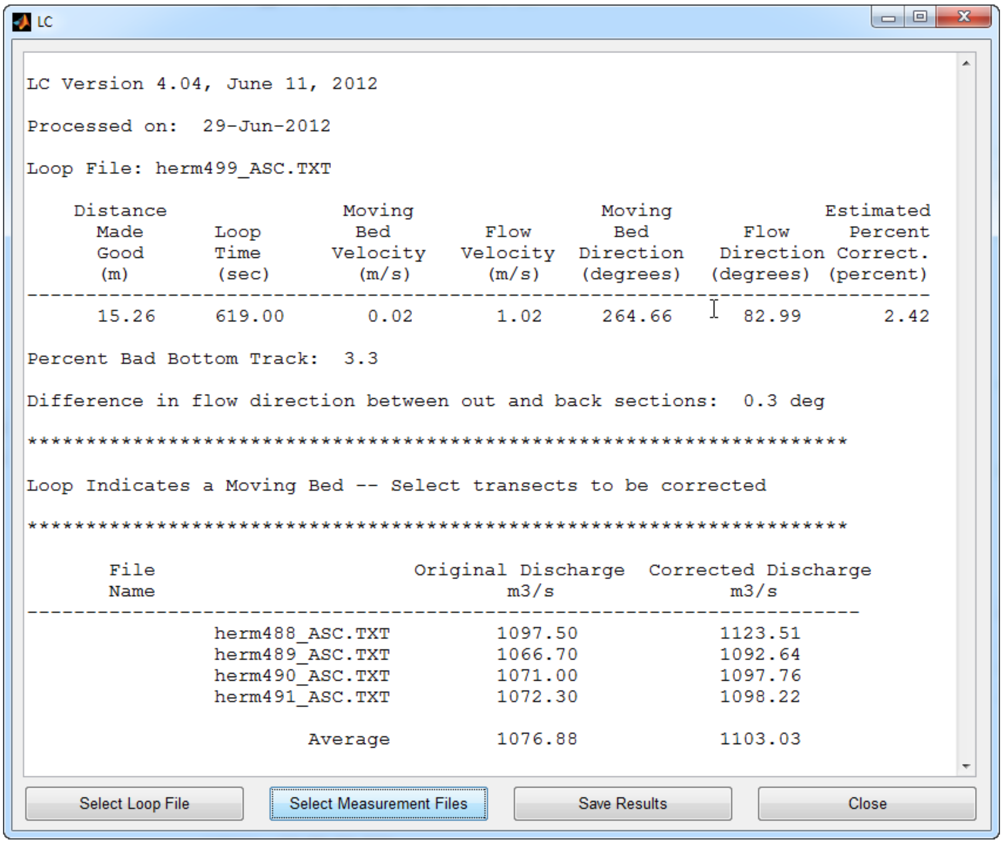

Figure 14. Analysis of a loop transect to quantify and correct for a moving bed using the LC program created by the USGS.

(Source: USGS https://hydroacoustics.usgs.gov/movingboat/LC1.shtml viewed 2 Oct 2018)

A.2.1 Compass error

The greater the value of the compass error, the greater the misclose of the loop.

The operator shall reduce the effects of compass error by:

a) calibrating the compass to as low an error value as can be achieved on site; and
b) increasing the length of time to complete the loop.

A ship track that indicates a downstream movement of the ADCP demonstrates an ill configured ADCP compass.

If the ADCP operator is uncertain with the configuration value or correct operation of the compass, then they should not use the loop method to identify moving bed and should not use GPS as a reference track.

A.2.2 Mean correction

This is a simple method that can be calculated manually. The discharge adjustment is equal to the mean velocity of the moving bed multiplied by the cross-sectional area. The cross-sectional area shall be calculated as perpendicular to mean flow.

> NOTE: If the area is calculated parallel to ship track as measured by the ship track it will be biased due to the distortion caused by the moving bed.

This method does not accommodate for the cross-sectional shape and the spatial correlation of the sediment transport with the spatial distribution of the discharge within the cross-section. As a result, those streams that display a high spatial variability in sediment transport and discharge may not be accurately represented using this method; where this is assessed as being the case, the mean correction method should not be used.

A.2.3 Distributed correction

This method requires the aid of computer software. It uses the 1/6th power curve to provide a consistent estimate of the near bed velocity at any point in the cross-section. Although the actual moving bed velocity is unknown, it is assumed that it is proportional to the near bed velocity, Callede et al 2000. The near bed velocity is calculated using the 1/6th power law which is fitted through zero at the bed and through the mean velocity of the last two valid velocity measurements in each profile.

To ascertain the required correction, the measured mean moving bed velocity from the loop is distributed to each ADCP ensemble by a ratio of near bed velocity for each ensemble and the mean near bed velocity for the cross-section. The distributed moving bed velocities for each ensemble are then applied to the water and boat velocities for all depth cells within that ensemble. This is undertaken for all ensembles within the measured portion of the cross-section.

The final corrected discharge is calculated using the ratio of the corrected and uncorrected measured portions of the discharge to correct the sum of the measured and top and bottom estimated discharges. No correction is applied to the left and right bank discharge estimates because it is assumed that the velocity would not be fast enough to create a moving bed.

A.3 Stationary test

The stationary test may be conducted with or without a GPS. When testing for a moving bed with an ADCP that does not possess a compass, all lateral movement shall be eliminated by adequate tethering.

NOTE: Lateral movement of the ADCP during a stationary test would produce a false measurement and would indicate a moving bed even if there were none.

A.3.1 Without a GPS

A point in the measurement cross-section should be chosen where the maximum amount of sediment transport is expected. When it is difficult to identify where this would be, multiple stationary moving bed tests should be performed. The vessel and the ADCP shall be held stationary at the selected point for a minimum of five minutes if an anchor is used, or ten minutes without an anchor. In the ship track the ADCP will appear to move upstream if a moving bed is present.

The moving bed velocity and error ratio is calculated in the same manner as described with the loop test with the same 1% criteria applied.

A.3.2 With a GPS

Repeat the stationary test procedure as explained in Clause A.3.1 while recording GPS positional data. If good GPS data is being received, then ADCP data can be recorded for a minimum of five minutes. Compare the ship track plots of the GPS and bottom track references. The moving bed velocity is calculated by dividing the apparent upstream movement by the measurement time. In this case the distance travelled upstream is calculated by adjusting the bottom track reference by the actual distance travelled in that direction as measured by the GPS (BMG-GMG mag). The potential error shall then be calculated as specified in Clause A.2, Item 7.

A.4 Multiple moving bed test

To perform a multiple moving bed test, a minimum of three stationary moving bed tests shall be conducted across the channel and their locations noted. A normal discharge measurement is then undertaken. A choice of three computational methods is available to correct the discharge: the subsection method (see Clause A.4.1), the average method (see Clause A.4.2) and the distributed method (see Clause A.4.3).

A.4.1 Subsection method

The mean moving bed velocity is calculated for each moving bed test, (DMG/Time). Each transect is then subsectioned into three so that each of the moving bed test locations would be located in the centre of each new subsection. The cross-sectional area perpendicular to the mean flow is calculated for each of the three subsections of each transect. The cross-sectional areas are averaged between their corresponding subsections. The three averaged cross-sectional areas are each multiplied by their associated moving bed velocity. The result is three discharge adjustments that, when added to the measured discharge, provides the adjusted discharge for moving bed bias.

A.4.2 Average method

Calculate the moving bed velocity for each moving bed test and add these together. Divide the total by the number of moving bed tests plus two. This accounts for a zero moving bed velocity at the edges and provides an averaged moving bed velocity. The moving bed correction is calculated by multiplying the cross-sectional area perpendicular to mean flow by the average moving bed velocity.

A.4.3 Distributed method (stationary moving bed analysis)

A linear regression is used to resolve the coefficient 'a' which relates the near bed velocity with the moving-bed velocity. The corrected total discharge is computed using the ratio of the corrected measured and uncorrected measured discharge in the portion of the transect cross-section. No correction is applied to the edge estimated discharges as it is assumed that the moving bed velocity would be near zero. This method is best applied using available computer software.

A.5 The azimuth method

This method should not be used to estimate moving bed corrections. As a result, the method will not be covered in this document however comprehensive descriptions are readily available in most ADCP operating literature.

Appendix B Using GPS

(This section primarily applies to Moving Boat Method, but aspects of this appendix can also be utilised in Stationary Method discharge measurements)

Where the ADCP unit allows, a GPS unit should be run as a standard part of the measurement procedure. GPS data is not immune to errors that if not noticed will have an impact on the accuracy of the ADCP generated discharge.

The operator using a GPS as a reference for the ADCP shall assess the quality of the GPS output at the time of the discharge measurement. ADCP data collection software contains tools that allow the operator to easily undertake this task.

When using a GPS with an ADCP, the GPS update rate shall be at least equal to the ensemble update rate. The baud rate shall be able to support the update rate. Any positional filters in the GPS unit shall be turned off.

B.1 GPS measurement methods

There are two options available for providing an accurate position of the Acoustic Doppler Current Profiler: differentiated position using the GGA National Marine Electronics Association (NMEA)-0183 sentence; or the velocity reported in the VTG NMEA-0183 sentence.

1. The use of differentiated position requires differential correction to acquire a high degree of accuracy in the position. There are two common methods to provide a differential correction for a GPS:
   a) Real Time Kinematic (RTK) systems, which require a user operated base station and a separate rover receiver.
   b) Code-phased differential corrections.

      Code phased differential corrections can be obtained from the following differential correction services:

      - Satellite Based Augmentation System (SBAS) was developed for aviation requirements and supplies differential correction at no cost. The current SBAS satellite network does not cover the Australian continent, however these services could be available in the future.
      - Commercial satellite differential service providers provide differential correction with various levels of accuracy at cost.
2. The velocity reported in the VTG sentence is based on the measurement of the Doppler shift in the satellite signal.

Both the differentiated position and velocity reported methods are sufficiently accurate for ADCP flow measurement purposes. The user shall be aware of the following factors that can influence the methods selection and accuracy of measurements:

Differentiated position	Velocity reported
Position based data string	Velocity-based data string
Possible multi-path errors	Direction (track) and speed information
Requires differential RTK correction for sub-metre accuracy	Uses “Doppler-based” measurement speed
>20m river width required with “Differential” GPS correction (sub-metre) solution	No possibility of multi-path errors
<1m river width possible for “RTK” correction	Does not require differential correction for sub-metre accuracy
	Requires a minimum vessel speed (about 0.1m/s conservatively)
	>20m river width required when using VTG

B.2 Multipath errors

This error arises when the satellite signal is reflected around before reaching the GPS receiver rather than taking a straight-line approach. Structures such as tall or overhanging trees, bridges, steep banks and buildings can cause the signal to be reflected which can result in significant and highly variable position errors. This error is site specific and difficult to eliminate.

B.3 Dilution of precision (DOP)

These errors are associated with the geometry of the visible satellites and are dependent on the relative angles of the satellites in the sky. This geometry can increase or decrease the level of error associated with other sources of uncertainty. GPS receivers monitor the geometry of the satellites and use those satellites that reduce this error. The horizontal dilution of precision, (HDOP) measures the possible error of only the horizontal plane (lat/long). The positional dilution of precision (PDOP) measures the possible error in both the horizontal and vertical plane (altitude). The lower the HDOP or PDOP value, the lower the rate of error. If GPS data is to be used, then this value shall be less than six. DOP values vary depending on location and time and cannot be improved by the ADCP operator.

B.4 GGA and VTG data strings

ADCP data collection software utilises the two data output options available from the GPS unit: GGA and VTG. The GGA sentence provides geographic information only. The velocity data is calculated within the ADCP software by analysing two data strings, computing the distance travelled and dividing it by the time stamp on the two strings. GGA data is much more affected by multipath errors and requires differential correction for acceptable accuracy.

The VTG sentence provides velocity relative to the ground and includes speed and direction; it does not contain positional data. The VTG velocity is calculated from the Doppler shift in the satellite carrier phase frequencies which results in a much faster sampling time. Due to this quicker sampling time, VTG data is minimally impacted by errors associated with multipath and satellite changes and therefore the precision of the measurement is much less impacted upon. This means that differential corrections are not required with VTG unlike the GGA sentence, however the inaccuracies that can occur with VTG data are more difficult to identify in the variation of boat speed data than with the GGA data.

VTG data can introduce errors when boat movement is particularly slow and channel widths are small.

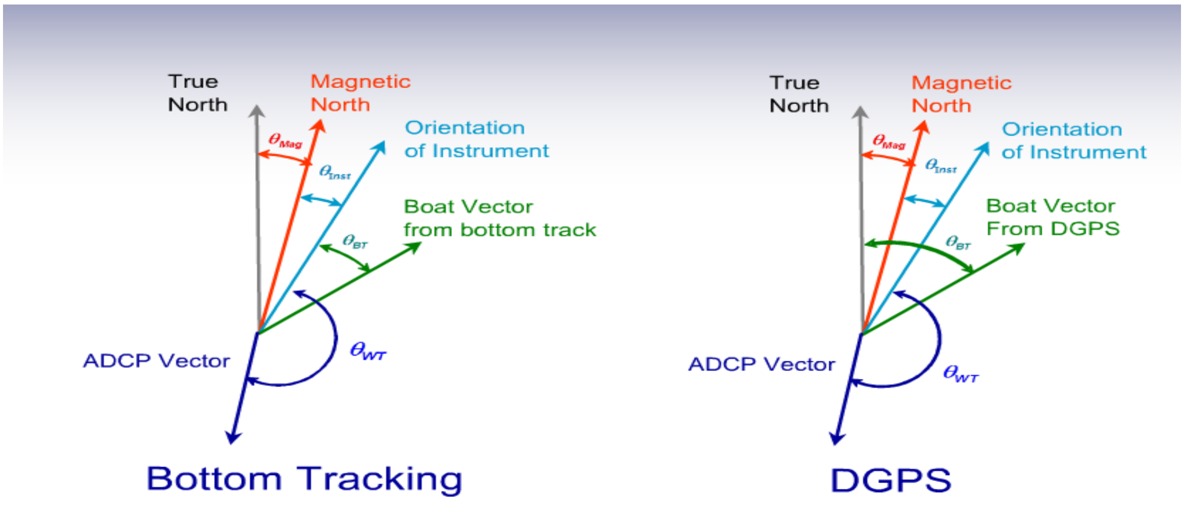

Figure 15. An illustration of how an ADCP references its position when using bottom tracking and a DGPS

(Source: USGS, Mueller, D.S., Wagner, C.R., 2009)

B.5 Discharge computation

When an ADCP calculates discharge, it requires the angle between the water velocity vector and the bottom tracking velocity vector. When bottom track is the reference, both vectors are referenced to the same point, i.e. the ADCP. When the GPS is used to reference the boat velocity vector, it is referenced to true north by the DGPS co-ordinates and the water velocity vector remains referenced to the ADCP. Therefore, to return both vectors to the same co-ordinate system, the orientation of the ADCP in respect to true north shall be determined. The compass is used to determine the orientation of the ADCP referenced to magnetic north and then the magnetic declination for that site shall be entered to transfer the ADCP into a true north reference.

As a result, when bottom track is used, compass errors associated with the boat velocity reference will not cause errors with the discharge measurement. This is not the case with GPS. Compass errors and magnetic declination errors have a significant effect on the measured total discharge when using a GPS as the boat velocity reference. The severity of the compass error influence on measured discharge is also proportional to boat speed. When using a GPS, the ADCP internal compass shall be well calibrated and a slow boat speed shall be used to traverse the channel. Compass error can also create directional bias of the measured discharges between reciprocal transects. Magnetic declination shall be site specific and may be entered during the post processing stage.

B.6 Quality assurance checks when using GPS

ADCP data collection software contains inbuilt tools to assist the operator in determining the quality of the GPS positional reference. Tabular views are provided informing the operator of HDOP and PDOP values, the number of valid satellites and satellite changes. The software generally flags any quality issues in red and can be viewed easily while collecting data.

The operator should also check the boat speeds recorded during a transect. As described in Clause B.5, excessive boat speed with a GPS as the reference will result in irregular water velocity measurements. The operator should look for spikes and drop outs in the boat speed during the transect which would indicate poor quality GPS data that should not be used as the reference. Time lags in the GPS referenced boat speed would indicate that GPS update and/or baud rates are too slow.

The third tool available to check the quality of the GPS reference data is the ship track plot. All three ship tracks (BT, GGA and VTG) should have a similar shape and spatial orientation and if a moving bed is present then the BT will be rotated upstream relative to good GPS data. Bottom track discharge variations and sudden jumps in the cumulative discharge are also indicators of poor GPS data.

Appendix C ADCP discharge measurement field sheet and quality matrix for the moving boat method.

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Site Number			
Gauging Number			
Date		**Time**	
Instrument software version		Instrument firmware version	

Measurement	Requirement	Yes	No	Notes	Checked
Site Information					
Gauge Board Reading [1]		☐	☐		☐
Meas. Water Temp [1]		☐	☐		☐
Salinity [1]		☐	☐		☐
Magnetic Variation [1]		☐	☐		☐
Edge Dis. Measured [1]		☐	☐		☐
Instrument Configuration					
Transducer Depth [1]		☐	☐		☐
Maximum Velocity [1]		☐	☐		☐
Maximum Depth [1]		☐	☐		☐
ADCP Tests Undertaken					
Diagnostic Test [1]		☐	☐		☐
Compass Calibration [1]		☐	☐		☐
Bed Movement					
Moving Bed Test (if bed movement is not present due to site conditions, ignore requirements)	Performed [1]	☐	☐		☐
	Method Used?				☐
	Is a flow Adjustment required?	☐	☐		☐
	Amount of bias (cumecs)?				☐
	Applied to total discharge?	☐	☐		☐
GPS	GPS Used [1]	☐	☐		☐
	HDOP value less than 6?	☐	☐		☐
	No. of Sats. greater than 4?	☐	☐		☐
	Data string used as positional reference? If None, Why?	☐	☐		☐
Post Processing					
Extrapolation	Top and Bottom Extrapolations checked [1]	☐	☐		☐
	Top method used?				☐
	Bottom method used?				☐

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No	Criteria	5 Points.	2 Points	1 Point
		Quality Matrix		
1	Gauging Method	<7/13 (Bed Movement) <6/11 (No Movement) of criteria with subscript 1 completed in accordance with the National Guideline. ☐	7-11/13 (Bed Movement) 6-9/11 (No Movement) of criteria listed with subscript 1 completed in accordance with the National Guideline. ☐	>11/13 (Bed Movement) >9/11 (No Movement) of criteria listed with subscript 1 completed in accordance with the National Guideline. ☐
2	Channel Description.	Bed debris and vegetation disrupting flow and bed profile, a large amount of non uniform and turbulent flow. Aeration of the water ☐	Some Non uniform flow, asymmetrical channel shape, some bed debris/ vegetation causing moderate flow and channel disturbance. ☐	Uniform flow, smooth uniform X-section profile, no large bed debris or vegetation disruption of flow within the channel profile ☐
3	Measurement Time (total)	0 - 500 sec ☐	501 to 799 sec ☐	800 + sec ☐
4	Extrapolation Accuracy.	Large areas in top and/or bottom extrapolated and extrapolation fits is uncertain. ☐	Extrapolation is uncertain but top and bottom areas are small or extrapolation is good and top and bottom areas are large. ☐	Extrapolation fit is a good representation of unmeasured areas ☐
5	C.O.V of Q	≥ 8 % ☐	< 8 % > 5% ☐	≤ 5% ☐
6	Area C.O.V	≥ 10% ☐	< 10% > 5% ☐	≤ 5% ☐
7	Invalid Data	≥ 20% consistently clustered in the main area of flow within the transects ☐	10% - 20% Randomly distributed across the channel ☐	≤ 10% Randomly distributed across the channel. ☐
8	Edge Estimates	Edge estimates > 15% of total discharge ☐	Total edge estimates < 15% and > 5% of total discharge ☐	edge estimates < 5% of total discharge. ☐

95% uncertainty of the final average discharge can be calculated using the following equation:

Qu=COV*f/sqrt(n)

Where f is the multiplier from a *t* distribution table to achieve 95% for degrees of freedom of the measurement (n - 1) where n is the number of transects.

Total Points	

Quality Score

Band 1 = 8 - 10pt ☐	Band 2 = 11 - 19 pts ☐	Band 3 = 19- 34 pts ☐	Unrated = 35+ pts ☐

Comments:

Processed by:	Checked by:	Archived ☐

Appendix D Stationary measurement sheet

STATIONARY MEASUREMENTS SITE DETAILS SHEET

DATE ______________________ **PARTY** ____________ **SITE NO** __________________

GAUGING SITE ____

SITE DESCRIPTION ____

RIVER CONDITIONS ____

RATED DISCHARGE m^3/s ______________________ **Salinity** ______________ **Temperature** __________

REF. METHOD ______________________________ **AZIMUTH (Sontek):** ______________________________
(eg gauge board,logger data or other)

REFERENCE LEVEL START (m) U/S ________________ **TIME AT START** __________

REFERENCE LEVEL START (m) D/S ________________

REFERENCE LEVEL FINISH (m) U/S ________________ **TIME AT FINISH** __________

REFERENCE LEVEL FINISH (m) D/S ________________ **BIN SIZE (m)** __________

BOAT ________________ **AVERAGE TIME (sec)** __________

Set Velocity Ref : B-Track/ADCP **TRANSDUCER DEPTH (m)** __________

Sontek ☐ ***Win River*** ☐ ***Instrument Model/Serial No.***

COMPUTER ____________________ **DIRECTORY C:** __________________

Station No.	Station Q (m^3/s)	Accum Q (m^3/s)	% of Rated	Velocity (m/sec)	Distance (m)	Depth (m)	Comments

(Credit: Dr Daniel McCullough, Department for Environment and Water, South Australia)

Appendix E Measurement quality codes

Code	Description	Remark
Band 1	Uncertainty ≤ 5% at the 95% confidence limits	a. The method of data collection complies with the requirements outlined in the guideline. b. Staff are trained in using the ADCP and associated software. c. Data has undergone complete post processing and adjustment where necessary. d. Data has been collected in accordance with site conditions. e. The data provides the best possible representation of the environmental 'subject' of interest at the time of collection.
Band 2	Uncertainty > 5% ≤ 10% at the 95% confidence limits	a. The method of data collection complies with most requirements of the guideline. b. Staff are trained in using the ADCP and associated software. c. Data has undergone most of the post processing requirements. d. Data has been collected in accordance with site conditions. e. The data provides an acceptable representation of the environmental 'subject' of interest at the time of collection.
Band 3	Uncertainty > 10% ≤ 20% at the 95% confidence limits	a. The method of data collection complies with some requirements of the guideline. b. Staff have limited training in using the ADCP and associated software. c. Data has undergone most of the post processing requirements. d. Site and flow conditions are detrimental to data collection. e. The data provides a limited representation of the environmental 'subject' of interest at the time of collection.
Unrated	Uncertainty > 20% at the 95% confidence limits	a. The method of data collection complies with few requirements of the guideline. b. Staff are not trained in using the ADCP and associated software. c. Data has undergone basic or no post processing. d. Data has not been collected in accordance with site conditions which are unfavourable for data collection. e. The data is unlikely to represent the environmental 'subject' of interest at the time of collection.

These quality codes are presented as a guide only. Individual organisation's quality assurance processes and requirements may vary from this guide. Band 1, Band 2 and Band 3 are commonly referred to as good, fair and poor in current practice within the Australian water industry. These codes may be subject to future changes to remain in accordance with nationally agreed quality coding systems as they are developed.

Appendix F Conductivity conversion table.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; ppt, parts per thousand; (00480), ADAPS parameter code for salinity in ppt]

Specific conductance, in µS/cm	Salinity, in ppt (00480)	Specific conductance, in µS/cm	Salinity, in ppt (00480)	Specific conductance, in µS/cm	Salinity, in ppt (00480)
100	0.040	11,000	6.229	38,000	24.124
300	0.131	13,000	7.463	41,000	26.252
500	0.226	15,000	8.714	44,000	28.405
700	0.324	17,000	9.983	47,000	30.582
1,000	0.474	20,000	11.914	50,000	32.783
2,000	0.997	23,000	13.878	53,000	35.008
3,800	1.984	26,000	15.872	56,000	37.257
5,000	2.664	29,000	17.895	59,000	39.530
7,000	3.826	32,000	19.945	62,000	41.826
9,000	5.016	35,000	22.022	65,000	44.146

(Source: USGS, Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006)

Appendix G Trouble shooting guide for ADCP data

NOTE: FLD = Field, OFF = Office. The ADCP commands supplied as remedies only relate to those units that allow the user to change the operating configuration. Command codes may vary depending on the ADCP unit and are offered on a guide only basis. ADCP manuals should be consulted for specific unit remedies.

Care shall be taken in changing default parameters and configuration (determined from max depth, velocity, etc.) of instrument. It is recommended that default configuration is used for initial gaugings. If inconsistent results are obtained then the configuration/parameters may be changed, from where another set of gaugings is performed. The operator shall then report on the changes made and impact on gaugings.

A. Routine checks

1. QA/QC checks.

Problems (and causes)	Remedies
a. ADCP test not done at the start of each gauging day	1. FLD, OFF **Test ADCP ASAP** (even if it's only done back at the office!) 2. OFF **Comment in the Gaugings database about the lack of an ADCP test**, and also on the results of the follow-up test.
b. Failed some of the ADCP tests	1. FLD **Use another ADCP if available**. 2. OFF **Evaluate & comment in the Gaugings database** on the likely impact of the failed tests Sometimes none, e.g. an historic beam rub test failure in extremely humid conditions.
c. Compass calibration not done on-site This introduces errors into all GPS data, but not into BT data except for Ship Track & Loop-test data.	1. FLD **Calibrate & evaluate the compass on-site ASAP**. 2. OFF **Comment in the Gaugings database** about the lack of a compass calibration.
d. Compass calibration & evaluation Total Error >1% Total Error = Peak Double + Single Cycle Error Evaluations consistently show far lower errors, because the reports are against the previous calibration.	1. FLD **Re-calibrate & evaluate the compass**. 2. OFF **Compare BT & GPS tracks on the Ship Track plot** It'll probably be inconclusive, but at least comment on it.

2. Discharge report.

Set the velocity Bottom Reference to the most appropriate of Bottom Track, VTG (GPS) or GGA (GPS)

a. Lost ensembles From a communications failure, which results in the data displaying as gaps (i.e. vertical white stripes) on a *Velocity Contour Plot*, without any bed trace or velocity bins. Bad Ensembles sometimes look the same as Lost Ensembles.	1. FLD **Close all programs except WinRiver II**, including all computer power management & other resident-type programs **<**R-click lower program bar icons; or Control Panel?**>** 2. FLD **Re-route ADCP communications cable** further away from motors, generators, large electrical equipment & batteries, and never coil it around large metal objects! 3. FLD **Minimise keyboard input while gauging**, and depress keys lightly & briefly. The keyboard takes priority over the serial port. 4. FLD **Lower & synchronise communications speed** (e.g. from 115,200 bps to say 57600 bps). The optimum speed is probably computer & serial port specific.

	5. FLD **Change the port or computer**, preferably using a buffered 16550 UART serial port. It temporarily stores any data overflows. 6. OFF **Set up a computer hardware profile**.
b. Bad ensembles From BAD depth or bottom velocity, which results in the data displaying as gaps (i.e. vertical white stripes) on a *Velocity Contour plot*, always with no water velocity bin data and sometimes without a bed trace. Causes: b1. **Unsounded bottom** (i.e. no bed trace) due to insufficient ADCP range, or due to weak signal returns from a fluidised sand bed or through deep sediment-laden water. Warmer & more saline water also usually decrease the ADCP range. Missing data for BAD Ensembles is erroneously infilled using the same discharge as the previous good ensemble, which leads to systematic bias errors where there are large clusters near the banks.	1. FLD **Increase Max. Water Depth setting** 2. FLD **Optimise WN and WS settings** (Water Number of cells, ≈30; Water Size, in cm) so WS x WN ≅ 1.1 x Max. Depth (vs usual 1.15-1.20) <Ctrl Z, Commands Preview page, e.g. WN30, WS100>. Use WK instead of WS if using Water Mode WM11 or WM12 . **CAUTION:** Decorrelation increases in large depth cells if water velocities vary much with depth within the cells! 2 x WS gives ≈ 1.1 x Range, ½ x Random Noise, ¼ Pings required for same Standard Deviation, ½ X Power Consumption 3. FLD **Switch to a lower frequency ADCP.** A 600 kHz ADCP has ≈2-4 x Range of a 1200 kHz, but has only ≈1/2 x Resolution! 4. FLD **Revert to Narrowband ADCP operation** <Ctrl Z, Commands Preview page, WB1> (WV is then limited to WV330, vs WV700). WB1 gives ≈1.3 x Broadband Range, but has ≈2 x Velocity Std Deviation of the default WB0. However, it can only measure 8.04 $m.s^{-1}$ apparent velocity, vs 17.05 $m.s^{-1}$ for Broadband.
b2. **Weak or anomalous signal intensity.**	See *5. [Signal] Intensity Profile plot*.
b3. **Depth trace spikes**, up-spikes are due to submerged vegetation or logs or large boulders or fish, whereas down-spikes are due to multiple signal return path errors.	1. FLD, OFF **Select Screen Depth setting** It excludes any beam depth that's >75% different to other beams. 2. FLD, OFF **Try to screen out spikes using BT**. (This might be difficult though!)
b4. **Depth trace locally-distorted near abrupt depth changes** (esp. at the toe of steep banks or near large boulders), due to one beam having a valid but much different depth to the other three beams.	1. FLD **Keep the boat heading virtually upstream over the toe of steep banks.** Thus at least 2 beams will be at or near the correct depth. 2. FLD, OFF **De-select Screen Depth setting** Otherwise the beam depth that's >75% different to the other 3 beam depths would erroneously be excluded from the calculations!
b5. S**udden erratic boat speed & heading changes**, including shifting the motor in & out of gear, which exacerbate the following BT decorrelation (b6) and non-homogeneous BT velocities (b7) problems.	1. FLD **Slowly traverse stream** (boat speed < water speed), with slow speed heading changes. 2. FLD **Use a smaller motor or manually traverse** across a rope or cable if gauging slow water.
b6. **De-correlation of bottom track scatterers** across the timegate span, due to multiple bottom scatterers moving across beams into the less-accurate slightly-divergent beam edges, or due to rapid pitch & roll changes in large swells.	1. FLD **Reduce BC setting** (Bottom track Correlation) e.g. BC200>, from the default 220 counts. **CAUTION:** Risks spikes from false bottom detections!
b7. **Non-homogeneous bottom track velocities**, due to different beams seeing different bed slopes at the toe of steep banks or on large boulders, or due to rapid pitch &	1. FLD **Increase BE setting** (Bottom track Error velocity) BE1000>, from a default of BE100 (in $mm.s^{-1}$). 2. FLD, OFF **Increase BT Up Velocity screening threshold** e.g. to 0.50 from the default 0.305 $m.s^{-1}$.

roll changes in large swells (inducing large BT Up velocities). E.g. 4 beams 0.137 m apart at 90° spacings, which splay signals out cone-like at 20° from the vertical. The circular spread of the 4 beam centrelines at depth D is 2D Tan 20° + 0.137 m (≈0.728D + 0.137 m).	3. FLD, OFF **Increase BT Error Velocity screening threshold**, e.g. up from the default 100 $mm.s^{-1}$. **CAUTION:** Only effective if ≤ BE command setting! Screens for inhomogeneous BT velocity data.
c. Bad Bins = >25% From BAD water velocities, due to exceedance of a WT (Water Track) velocity screening threshold (especially from strong turbulence and high velocity shear).	See *3. Velocity Contour Magnitude plot*.
d. Total ensembles (per transect) = <150 From slow communications speed, narrow streams, fast traverses, or an ADCP ping rate that's slower than optimal.	1. FLD **Increase & synchronise communications speed** (e.g. to 115,200 bps). See *APP. 1 Communications Settings*. 2. FLD **Traverse slower if possible, or measure more transects**. 3. FLD **Decrease Bottom maximum tracking look-for depth** to about 1.3-1.5 x Max. Depth e.g. BX130 if 10 m deep**.** The Wizard uses an overly-conservative 2.0-2.5 x Max. Depth!
e. Incorrect ADCP time	1. FLD **Synchronise times** after stopping logging & pinging 2. OFF **Adjust logged times** on copies of the electronic transect files
f. ADCP temperature >5°C different from water temperature!	1. FLD **Wait a while and check if it equilibrates.** 2. FLD, OFF **Check that the ADCP value seems realistic** if water temperature wasn't independently measured. 3. OFF **Calculate & enter a fixed Speed of Sound value** in the Playback Configuration

3. Velocity Contour Magnitude plot.

a. Bad Ensembles = >10%	See *2. Composite Tabular report*.
b. Bad Bins = >25% From BAD water velocities (white velocity cells), due to exceedance of a WT (Water Track) velocity screening threshold (especially from strong turbulence and high velocity shear. Causes: b1. **Weak or anomalous signal intensity.**	See *5. [Signal] Intensity Profile plot*.
b2. **Sudden erratic boat speed & heading changes**, including shifting the motor in & out of gear, which exacerbate the following WT decorrelation (b3) and non-homogeneous WT velocities (b4) problems.	1. FLD **Slowly traverse stream** (boat speed < water speed), with slow speed & heading changes. 2. FLD **Use a smaller motor or manually traverse** across a rope or cable if gauging slow water.
b3. **De-correlation of water track scatterers** across the timegate span, due to multiple water scatterers moving: (i) Up or down the beams into a different depth bin, because of strong water turbulence or rapid pitch & roll changes in large swells.	1. FLD **Use Water Mode WM1 for strong turbulence & boat heave** 2. FLD **Increase WV setting for strong turbulence & boat heave** (Water ambiguity Velocity, $cm.s^{-1}$) so WV ≅ 1.2 x [Boat + Horizontal Water Speed] <Ctrl Z, Commands Preview page, e.g. WV200> This reduces inter-pulse transmit delay and increases the chance of seeing the same scatterers twice. The default WV175 equates to 4.26 $m.s^{-1}$ (actually 5.12 $m.s^{-1}$ if the 1.2 safety factor is included!)

(ii) At different velocities at different levels in a depth bin because of strong velocity shear with depth (esp. if in the ambiguity resolving bin). (iii) Somewhat across-beam into the less-accurate slightly-divergent beam edges.	3. FLD **Decrease WS and optimise WN settings for high vertical-profile velocity gradients** (Water Size, in cm; Water Number of cells, ≈30?) so WS x WN ≅ 1.1 x Max. Depth (vs usual 1.15-1.20), e.g. WS100, WN30. Use WK instead of WS if using Water Mode WM11 or WM12. Smaller cells reduce the range of scatterer velocities within each cell. 2 x WS gives ≈ 1.1 x Range, ½ x Random Noise, ¼ Pings required for same Standard Deviation, ½ X Power Consumption 4. FLD **Reduce WC setting** (Water track Correlation), e.g. WC50 from the default 64 counts. **CAUTION:** Risks errors from false water velocity scatterer detections!
b4. **Non-homogeneous water track velocities**, due to different beams seeing different water velocities in areas of high turbulence or velocity shear (or from swimming fish), or due to rapid pitch & roll changes in large swells (inducing large WT Up velocities).	1. FLD **Increase WE setting** (Water track Error velocity), WE2000, from the default max. of WE1500 (in $mm.s^{-1}$). 2. FLD **Reduce WA setting** (Water false target threshold maximum count), e.g. WA40, from the default 50 counts. Risks errors from false water velocity scatterer detections (e.g. fish)! 3. FLD, OFF **Reduce Fish intensity screening threshold (count)** <f3, Processing page>, e.g. down to 40 from the WinRiver II default min. 50 counts. **CAUTION:** Only effective if ≥ WA command setting! Screens false scatterers like fish. 4. FLD, OFF **Increase WT Up Velocity screening threshold** <f3, Processing page>, e.g. to 0.60 from the default 0.50 $m.s^{-1}$. 5. FLD, OFF **Increase WT Error Velocity screening threshold** <f3, Processing page>, e.g. up from the WinRiver II default 1.067 $m.s^{-1}$. **CAUTION:** Only effective if ≤ WE command setting! A suggested screening value is 3-4 x Std Deviation. Screens for inhomogeneous WT velocity data.
c. Anomalous water velocity patterns From very slow water velocities or flow disturbances. Causes: c1. **Very slow & highly variable water velocities**.	1. FLD **Prefer Water Mode WM11** (over WM12 over WM1) if Depth x V_{ADCP} <2 $m^2.s^{-1}$ for 600 kHz; or <1 $m^2.s^{-1}$ for 1200 kHz. Aim for a configuration Std Deviation <1/6 x Water Speed. 2. FLD **Reduce WV setting for very slow water** (Water ambiguity Velocity, $cm.s^{-1}$) so WV ≅ 1.2 x [Boat + Horizontal Water Speed] <Ctrl Z, Commands Preview page, e.g. WV50> The default WV175 equates to 4.26 $m.s^{-1}$ (actually 5.12 $m.s^{-1}$ without the 1.2 safety factor). 3. FLD **Increase WS and optimise WN settings for very slow water** (Water Size, in cm; Water Number of cells, ≈30?) so WS x WN ≅ 1.1 x Max. Depth (vs usual 1.15-1.20) <Ctrl Z, Commands Preview page, e.g. WS100, WN30>. Use WK instead of WS if using Water Mode WM11 or WM12. 2 x WS gives ≈ 1.1 x Range, ½ x Random Noise, ¼ Pings required for same Standard Deviation, ½ X Power Consumption
c2. **Shadowy water velocity shapes downstream from bridge piers**, due to much lower velocities.	1. FLD **Accept them or find a better gauging section**.

4. Ship track plot

a. Moving bed loop-test end plots well upstream from start! From bed movement caused by high water velocities, or from compass calibration errors (less likely).	1. FLD **Install GPS sensor & use VTG as position reference data source** <Ctrl V>. 2. FLD **Calibrate & evaluate compass** <Shift f10, Calibrate; then Evaluate>. 3. FLD **Regularly do Loop Moving Bed Tests** if doing multiple gaugings.

Can also subsection and check the difference in the mean flow direction for the out & back parts of the loop.	4. OFF **Calculate bed velocity** (V_{Bed} = Distance MG/Duration); a moving bed is deemed if >0.006 m.s^{-1} and V_{Bed}/ V_{Water} >0.01. 5. OFF **Adjust gaugings Q, V, $V_{Max.}$ using V_{Bed}.**
b. Fractured or twisted ship track From localised compass errors induced by nearby ferrous objects, including steel & concrete bridges and high voltage powerlines (often most apparent in only one traverse direction).	1. FLD **Move further away from steel or concrete bridges and high voltage powerlines.** 2. FLD **Move ferrous objects further away from ADCP.**
c. Anomalous water velocity stick spikes (overly long, and often from the wrong or a skewed direction) They also display as anomalous vertical coloured stripes in *Velocity Contour (Error) plots*). Also check bins at other levels <PageDown or PageUp>. From water velocities incorrectly assumed by WinRiver II to have rolled over a WV Ambiguity Velocity limit (e.g. 0 or 4.26 m.s^{-1}), due to sudden sharp changes in boat speed pushing the apparent water speed over the boundary.	1. FLD **Increase WV setting** (Water ambiguity Velocity, cm.s^{-1}) so WV ≅ 1.2 x [Boat + Horizontal Water Speed] <Ctrl Z, Commands Preview page, e.g. WV200> The default WV175 equates to 4.26 m.s^{-1} (actually 5.12 m.s^{-1} without the 1.2 safety factor). The tradeoff is increased single ping standard deviation. 2. FLD, OFF **Reduce WT Error Velocity screening threshold** <f3, Processing page> in stages from the WinRiver II default 1.067 m.s^{-1} till most spikes disappear (also be guided by changes to the % Bad Bins value and the Velocity Contour Magnitude plot). **CAUTION:** Only effective if ≤ WE command setting! Screens for inhomogeneous WT velocity data. 3. OFF **Test both 3 & 4-beam BT & WT solutions** <f3, Processing page>.
IF GPS used: Also view the Ship Track plot, and R-click & select VTG & BT data selection.	
d. Divergent VTG (GPS) & BT track From a moving bed, or from time lags between GPS & ADCP data, or from incorrect rotation of the GPS data into Earth coordinates (compass calibration or alignment errors).	1. FLD **Synchronise GPS & ADCP data times <see manual>**. Maybe test runs with straight line tracks & 90° bends might yield insights? 2. FLD, OFF **Enter calculated or measured local magnetic variation value** <**f3, Offsets page>.**
e. Spiky or abruptly-offset VTG (GPS) track From satellite constellation changes, or from signal multipath errors caused by dense trees, deep gorges, or nearby bridges. Affects both boat & water velocities.	1. FLD **Find a wider more open gauging section.** 2. FLD **Monitor both ship tracks**, looking for anomalies. 3. FLD **Monitor GPS reception statistics** <**GPS Tabular pane>**.
f. Convergent or divergent water velocity stick spikes, often pointing the wrong direction and with anomalous lengths They might also vary with depth and the boat heading. From a compass calibration or alignment error, but amplified when target velocities are low (including those deep in vertical profiles).	1. FLD **Calibrate & evaluate compass** <Shift f10, Calibrate; then Evaluate>. 2. FLD, OFF **Enter calculated or measured local magnetic variation value** <**f3, Offsets page>.**
5. [Signal] Intensity plot	
a. Weak signal intensity (decreases sharply with depth, may cut out before the bed) From beams blocked at the ADCP faces by entrained air bubbles or snagged debris, or	1. FLD **Check if ADCP beams are blocked by snagged debris.** 2. FLD **Increase the ADCP draft if air is likely being entrained** under the ADCP at high apparent water velocities.

from a fluidised sand bed, or from traversing deep sediment-laden water. Warmer & more saline water also usually decrease the returned signal strength.	3. FLD **Find a gauging section with less-abrupt bank slopes or less submerged vegetation.** 4. FLD **Reduce BA setting** (Bottom detection Amplitude minimum) <Ctrl Z, Commands Preview page, e.g. BA20>, from the default BA30 counts. **CAUTION:** Risks spikes from false bottom detections! 5. FLD **Log data using 3-beam solutions** <Ctrl Z, Commands Preview page, EX11111 command>. 6. FLD, OFF **Test 3-beam solutions for both Bottom Track and Water Track** <f3, Processing page>. If ≤2 beams are valid, a BAD mean depth is assigned to that ensemble.
b. Anomalous signal intensity (especially on one beam compared to others) Anomalous signals are from reflections from sidewalls, submerged vegetation, or entrained debris (the bed sometimes shows as a higher-intensity bump).	1. FLD **Avoid walls by a distance equal to the depth.** 2. FLD **Log data using 3-beam solutions** <Ctrl Z, Commands Preview page, EX11111 command>. 3. FLD, OFF **Test 3-beam solutions for both Bottom Track and Water Track** <f3, Processing page>. If ≤2 beams are valid, a BAD mean depth is assigned to that ensemble.

6. Discharge profile plot

A pseudo velocity profile, but only check a few transects. Temporarily average 10-20 ensembles, then later reset to 1 <**Ctrl f9>.**

a. Poor top velocity layer extrapolation From wind & waves, or submerged trees along the flow streamline.	1. FLD, OFF **Test & record changed top extrapolation method** <f3, Configuration Dialog page>, e.g. to 3-Point Slope (record %Q change). Slower velocities near the surface are usually associated with narrow streams or relatively strong upstream winds.
b. Poor bottom velocity layer extrapolation From: (i) An incoming tide, with reverse flow at the bottom. (ii) A very rough bed profile. (iii) Submerged trees somewhere along the flow streamline.	1. FLD, OFF **Test & record changed bottom extrapolation method** <f3, Configuration Dialog page>, e.g. to No Slip (record %Q change). Any infilled missing velocity bin data through vegetation would likely be biased high by the faster velocities over the vegetation tops. However, that might be somewhat counterbalanced if the depth was biased low because of one or more spurious vegetation canopy return signals.

7. Total discharge time series plot

a. Directional bias pattern in transect discharges (e.g. every second one higher) From: (i) Changes in ADCP depth caused by boat roll & pitch forced by high boat or water velocities (wind has lesser effects). (ii) Boat-induced near-surface pressure waves & flow shadowing. (iii) Unsteady flow through highly asymmetrically-shaped gauging sections. (iv) Clusters of BAD Ensemble gaps recurring in the same location(s) near steep banks or where velocities change rapidly (esp. if only one traverse direction has the data gaps).	1. FLD **Driver should monitor & maintain ADCP depth**, by slightly moving seating position(s) to vary it. 2. FLD **Try to keep ADCP out of boat disturbances to flow streamlines.** Often not possible. 3. FLD, OFF **Gauge then average even pairs of reciprocal-direction transects.** Averaging reduces directional bias, but won't necessarily reduce it to zero. 4. OFF **Average less transects in highly unsteady flow!** A pair of reciprocal transects is a desirable minimum, but it's not essential, as gaugings are effectively averaged again when forming rating curves. 5. OFF **For BAD Ensembles**, see *2. Composite Tabular report*. Missing data for BAD Ensembles is erroneously infilled using the same discharge as the previous good ensemble, which leads to systematic bias errors where there are large clusters near the banks. **For GPS** 1. FLD **Calibrate & evaluate compass** <Shift f10, Calibrate; then Evaluate>.

(v) Incorrect rotation of GPS data into Earth coordinates (compass calibration or alignment errors).	2. FLD, OFF **Enter local magnetic variation value** <**f3, Offsets page>.**

8. Q Measurement summary

a. Negative Q (if non-tidal) From an incorrect start bank entry, or from reverse flow if only on one or more edges.	1. FLD **Find a better gauging section (if possible)**. 2. FLD, OFF **Change the start bank** <f3, Edge Estimates page>.
b. COV values = >5% (higher if unsteady flow) COV = Coefficient Of Variation = Std Deviation/ Mean Std Error = Std Deviation/$N^{0.5}$ From one of the many random error sources.	1. FLD, OFF **Look for anomalous COV values in one or more parameters** (e.g. Left & Right edges, Width, Area, Velocity). 2. FLD, OFF **Think about what might have caused those errors.** You should probably know the likely reason by the time you get this far! 3. See 2d *Total Ensembles >150*.
c. Individual transect Q = >5% from the gauging mean (higher if unsteady flow) The outliers are in red type on the f12 report. From one of the many systematic or random error sources.	1. FLD **Do extra reciprocal-direction transect pairs to average** if there's steady flow. (If flow is quite unsteady, just do more flood gaugings!)
d. Left or Right edge Q estimate = >5% of Total Q From large shore distances because of lack of boat access or ADCP depth limitations (due to shallow depths, floodplains, dense vegetation, or fences).	1. FLD **Find a better gauging section** (if possible). 2. FLD **Switch to a higher frequency ADCP.** A 1200 kHz ADCP has only ≈½-¼ x Range of a 600 kHz, but ≈2 x Resolution! 3. FLD **Log more edgepoint ensembles if in reverse or surging flow.** 4. OFF **Closely review the left & right edge shape coefficients** (see below).
e. Non-triangular Left or Right edge shape	1. FLD **Find a better gauging section** (if possible). 2. FLD, OFF **Review & change the left & right edge shape coefficients.** Infer them from the shape of previously-surveyed sections and the shore distances and the bed trace shown in *3. Velocity Contour Magnitude plot*).

Appendix H An example of salt wedge impacts

To develop a velocity index relationship at Johnstone River at Innisfail (-17.526020, 146.037612), a series of measurements over two days was conducted over the daily range of tidal flows at the Innisfail gauging station. Johnstone River @ Innisfail is a tidal site, 300 metres wide located around 5 kilometres from the river mouth. Installed at the site is a 300 kHz Horizontal ADCP (HADCP). It was found the freshwater slice of water sitting atop the salt water below affected the velocity index relationship.

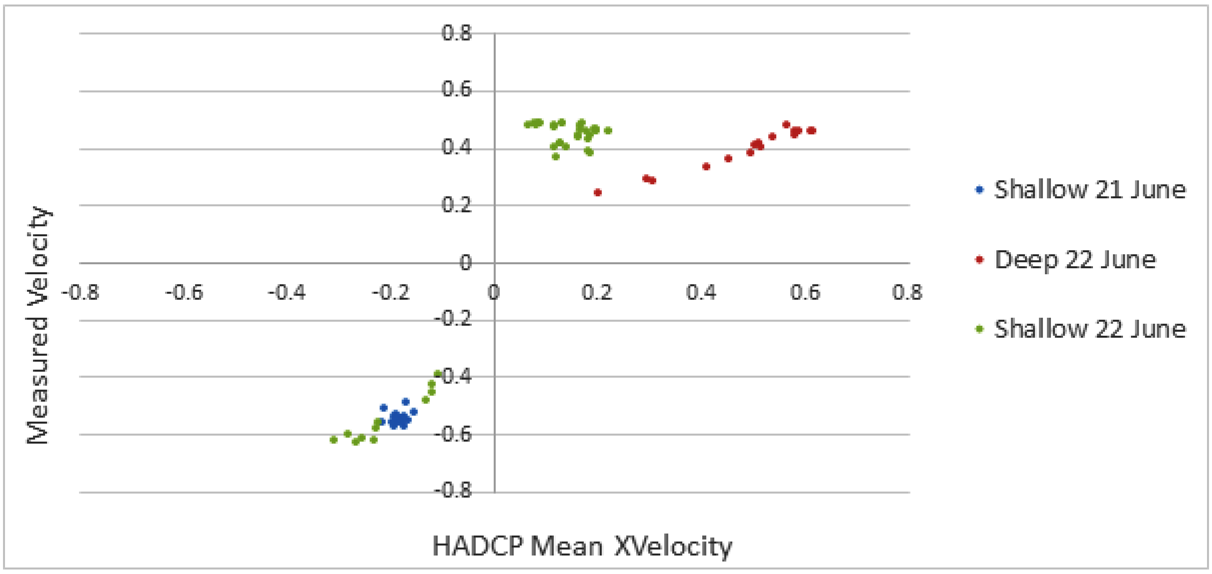

Figure 16: Salt wedge impacting shallow water velocity index results, June 21-22, 2017
(*Credit: Stephen Wallace, Queensland Government Department of Natural Resources, Mines & Energy*)

Figure 16 shows the velocity measured by the HADCP stagnating around 0.1-0.2ms^{-1} while the measured velocity is 0.4-0.5ms^{-1}. Where there is shallow depth of water above the HADCP, the HADCP is only measuring a slice of freshwater sitting on top of the salt wedge. The freshwater is essentially dammed by the salt water downstream and hence there is no correlation between channel velocity and the measured velocity in the fresh water.

Horizontal ADCP velocities impacted by salt wedge should not be used for velocity index determination or calculations.

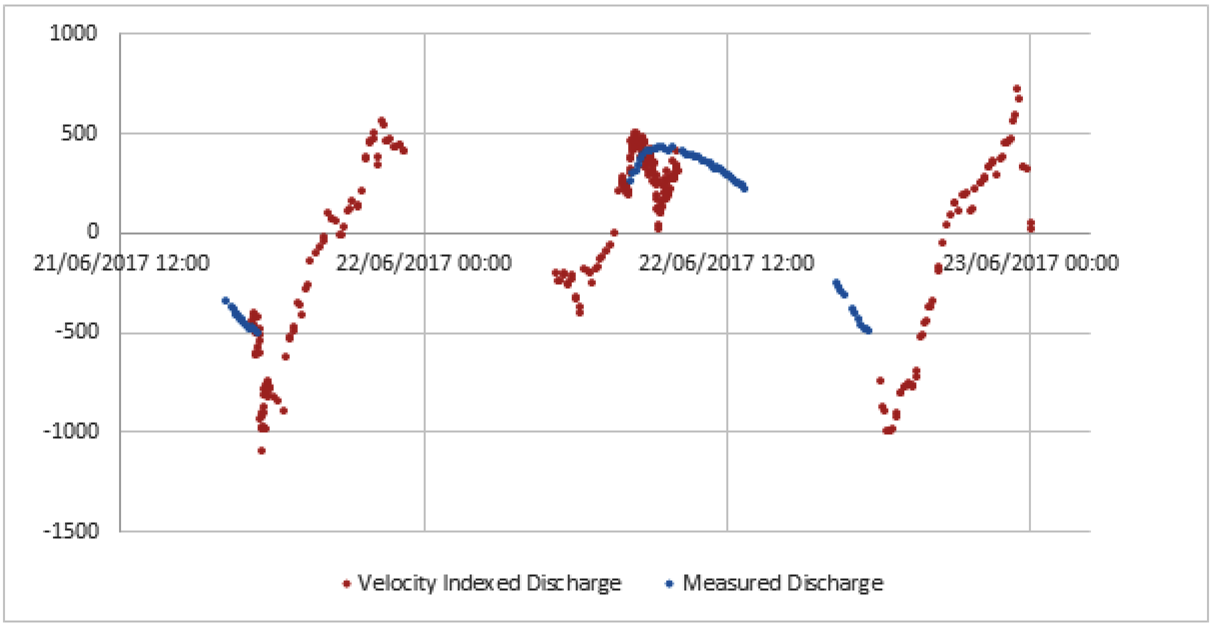

Figure 17: Gaugings undertaken on 21-22 June 2017
(Credit: Stephen Wallace, Queensland Government Department of Natural Resources, Mines & Energy)

Figure 17 is a time series of velocity indexed computed discharge data for Johnstone River @ Innisfail overlayed with actual manned boat ADCP measurements. There is no velocity index relationship for the measured velocities in shallow water affected by salt wedge as seen in Figure 16. Those HADCP measurements are excluded from the time series and discharge is interpolated between the outgoing and incoming tide data.

A method for determining influence of freshwater/saltwater interaction, such as salinity profiling, could be useful as an independent factor in velocity indexing.

Appendix I Training

I.1 Training session outline

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
Identify and understand the 1.1 Purpose and 1.2 Scope of this guideline	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the purpose of this guideline. Outline its scope.	Face to face delivery
2 Description of Acoustic Doppler Current Profilers	Copies of all guidelines and definitions documents. Access to all reference material.	Address Define Discuss Explain	Face to face delivery
3 Instrument management	Copies of all guidelines and definitions documents. Access to all reference material.	Address instrument management records.	Face to face delivery
3.1 Instrument maintenance	Copies of all guidelines and definitions documents. Access to all reference material.	Address instrument maintenance and effect on data integrity.	Face to face delivery
3.2 Instrument tests	Copies of all guidelines and definitions documents. Access to all reference material.	Explain instrument testing by checking it at a site with a known stage-discharge relationship and running any internal diagnostic checks.	Face to face delivery
3.3 Firmware and software upgrades	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss firmware and software upgrades and records.	Face to face delivery
4 Operating personnel	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss training of ADCP operating personnel, data processing and technology evolution.	Face to face delivery
5 Pre-deployment checks	Copies of all guidelines and definitions documents. Access to all reference material.	Address pre-deployment checks to ensure all hardware and software is ready and appropriate.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
6 Field deployment guidelines 6.1 Site selection (moving boat and stationary methods)	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the freedom and limitations of site selection for an ADCP.	Face to face delivery
6.2 Deployment methods	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss deployment methods and data validity.	Face to face delivery
6.2.1 Boat mounted	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss mounting of an ADCP to a boat for accurate measurement.	Face to face delivery
6.2.2 Tethered deployment	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss tethered deployment of an ADCP and channels suited to this method.	Face to face delivery
6.2.3 Remote controlled vessel (boat mounted only)	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss deployment of an ADCP by remote controlled vessel.	Face to face delivery
6.2.4 Incorporating a GPS	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss incorporating a GPS into the deployment of an ADCP and explain why it is required where possible.	Face to face delivery
6.2.5 Depth sounders	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss depth sounders and the circumstances when a quality depth sounder shall be used.	Face to face delivery
6.3 Stationary method	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the stationary method for deploying an ADCP. Discuss data quality produced by this method.	Face to face delivery
7 Data collection	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss data integrity and note keeping.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
7.1 Pre-collection QA/QC procedures	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss pre-collection QA/QC procedures including: • calibration of measurements of temperature, depth, electrical conductivity, time and compass; • performing instrument diagnostic checks; • configuring the ADCP as appropriate for measurement at the site; and • performing a moving bed test.	Face to face delivery
7.2 Data collection procedures	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss data collection procedures and data quality.	Face to face delivery
7.2.1 Steady flow	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the procedure for collecting data from a stream with steady flow including: • 4 transects; • 800 seconds sampling time; • boat speed; start & end points; • steep/vertical banks; • near-shore discharge; • pitch and roll; and • compass and magnetic declination errors.	Face to face delivery
7.2.2 Unsteady flow	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the adjustments to data collection, processing and interpretation required for measurement of discharge from a stream with unsteady flow.	Face to face delivery
8 Post measurement review procedures	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss data review for integrity, additional transects, field notes for continuous improvement and data security.	Face to face delivery
8.1 In the field	Copies of all guidelines and definitions documents. Access to all reference material.	Explain field reviews of collected data and checking of: • transect width; • discharge variance; and • GPS data. Discuss replacement transects.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
8.2 Office review procedures and data quality indicators	Copies of all guidelines and definitions documents. Access to all reference material.	Explain office reviews of collected data which include: • validity of data collection parameters; • pre-start tests and calibrations; • minimum 800 seconds sampling time; • boat speed, pitch and roll; • missing ensembles and whether to downgrade data quality; • invalid ensembles and whether to downgrade data quality; • invalid depth cells; • velocity errors; • beam intensity; • bottom tracking irregularities; • GPS data; and • extrapolation methodologies. Explain missing and invalid ensembles.	Face to face delivery
8.3 ADCP quality matrix	Copies of all guidelines and definitions documents. Access to all reference material.	Identify where to find the Field sheet and quality matrix for the moving boat method in Appendix C. Identify where to find an explanation of the data quality codes in Appendix E.	Face to face delivery
8.4 Data quality assessment tools	Copies of all guidelines and definitions documents. Access to all reference material.	Identify where to find data analysis tools online.	Face to face delivery
9 Uncertainties in discharge measurements	Copies of all guidelines and definitions documents. Access to all reference material.	Identify international standards covering hydrometric and discharge measurement uncertainties.	Face to face delivery
9.1 Description of measurement uncertainty	Copies of all guidelines and definitions documents. Access to all reference material.	Define and explain the uncertainty of measurement of physical quantities and the level of confidence in recorded and calculated values.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
9.2 Estimating the uncertainty in an ADCP discharge determination	Copies of all guidelines and definitions documents. Access to all reference material.	Give examples of sources of uncertainty in estimating ADCP discharge determination. Discuss use and maintenance for error minimisation.	Face to face delivery
Appendix A Moving bed tests and corrections A.1 General A.1.1 What is a moving bed	Copies of all guidelines and definitions documents. Access to all reference material.	Define “moving bed” and “water bias” and explain how these can affect the calculation of discharge from ADCP measurements.	Face to face delivery
A.1.2 Method selection	Copies of all guidelines and definitions documents. Access to all reference material.	Address the selection of a method to correct for moving bed or water bias.	Face to face delivery
A.2 The loop method	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the loop method for correcting for moving bed or water bias including the traverse and data processing.	Face to face delivery
A.2.1 Compass error	Copies of all guidelines and definitions documents. Access to all reference material.	Explain compass error, its effect on the loop method and how to reduce it.	Face to face delivery
A.2.2 Mean correction	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the mean correction method, its advantages and limitations.	Face to face delivery
A.2.3 Distributed correction	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the distributed correction method.	Face to face delivery
A.3 Stationary test	Copies of all guidelines and definitions documents. Access to all reference material.	Outline the stationary test.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
A.3.1 Without a GPS	Copies of all guidelines and definitions documents. Access to all reference material.	Address requirements for the stationary test without a GPS and identify the calculation method.	Face to face delivery
A.3.2 With a GPS	Copies of all guidelines and definitions documents. Access to all reference material.	Identify the procedure and explain the requirement for the stationary test with a GPS. Explain and identify calculations.	Face to face delivery
A.4 Multiple moving bed test	Copies of all guidelines and definitions documents. Access to all reference material.	Outline the requirements and choices applicable for the multiple moving bed test.	Face to face delivery
A.4.1 Subsection method	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the subsection method and its calculations.	Face to face delivery
A.4.2 Average method	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the average method and its calculations.	Face to face delivery
A.4.3 Distributed method (stationary moving bed analysis)	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the distributed method and its calculations.	Face to face delivery
Appendix B Using GPS	Copies of all guidelines and definitions documents. Access to all reference material.	Identify when GPSs are used and their limitations	Face to face delivery
B.1 GPS measurement methods	Copies of all guidelines and definitions documents. Access to all reference material.	Explain GPS differential correction.	Face to face delivery
B.2 Multipath errors	Copies of all guidelines and definitions documents. Access to all reference material.	Explain GPS multipath errors.	Face to face delivery

LEARNING ELEMENTS	RESOURCES	DESCRIPTION	
B.3 Dilution of precision (DOP)	Copies of all guidelines and definitions documents. Access to all reference material.	Explain GPS dilution of precision.	Face to face delivery
B.4 GGA and VTG data strings	Copies of all guidelines and definitions documents. Access to all reference material.	Explain how an ADCP references its position and velocity vector by GPS via GGA positional references and VTG velocity references.	Face to face delivery
B.5 Discharge computation	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the effect on discharge computation of the angle between the water velocity vector and the bottom tracking vector. Explain how this angle is calculated.	Face to face delivery
B.6 Quality assurance checks when using GPS	Copies of all guidelines and definitions documents. Access to all reference material.	Explain the three quality assurance checks that can be conducted when using an ADCP with a GPS: 1) inbuilt QA reviews, 2) operator checks of boat speed data, and 3) checks of the three ship tracks (BT, GGA, and VTG).	Face to face delivery
Appendix C ADCP discharge measurement field sheet and quality matrix	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss the purpose and use of the ADCP discharge measurement field sheet and quality rating criteria.	Face to face delivery
Appendix E	Copies of all guidelines and definitions documents. Access to all reference material.	Discuss the quality codes and their application to discharge measurement and calculation.	Face to face delivery

I.2 Training learning resources

I.2.1 Introduction

Welcome to the learner resource for National Industry Guidelines for hydrometric monitoring, Part 8: *Application of Acoustic Doppler Current Profilers to Measure Discharge in Open Channels*, NI GL 100.08–2019. The purpose of this resource is to develop your knowledge and skills and improve your competency in this guideline.

I.2.2 Section references

The table below shows elements of the guideline that are covered in this learner resource. This may help the learner to map their progress as they work their way through this resource.

Section	Unit element
1 Scope and general	1.1 Purpose 1.2 Scope
2 Description of Acoustic Doppler Current Profilers	2 Description of Acoustic Doppler Current Profilers
3 Instrument management	3 Instrument management 3.1 Instrument maintenance 3.2 Instrument tests 3.3 Firmware and software upgrades
4 Operating personnel	4 Operating personnel
5 Pre-deployment checks	5 Pre-deployment checks
6 Field deployment guidelines	6 Field deployment guidelines 6.1 Site selection (moving boat and stationary methods) 6.2 Deployment methods 6.2.1 Boat mounted 6.2.2 Tethered deployment 6.2.3 Remote controlled vessel (boat mounted only) 6.2.4 Incorporating a GPS 6.2.5 Depth sounders 6.3 Stationary method
7 Data collection	7 Data collection 7.1 Pre-collection QA/QC procedures 7.2 Data collection procedures 7.2.1 Steady flow 7.2.2 Unsteady flow
8 Post measurement review procedures	8 Post measurement review procedures 8.1 In the field 8.2 Office review procedures and data quality indicators 8.3 ADCP quality matrix 8.4 Data quality assessment tools

Section	Unit element
9 Uncertainties in discharge measurements	9 Uncertainties in discharge measurements 9.1 Description of measurement uncertainty 9.2 Estimating the uncertainty in an ADCP discharge determination
Appendix A Moving bed tests and corrections	Appendix A Moving bed tests and corrections A.1 General A.1.1 What is a moving bed A.1.2 Method selection A.2 The loop method A.2.1 Compass error A.2.2 Mean correction A.2.3 Distributed correction A.23 Stationary test A.3.1 Without a GPS A.3.2 With a GPS A.4 Multiple moving bed test A.4.1 Subsection method A.4.2 Average method A.4.3 Distributed method (stationary moving bed analysis)
Appendix B Using GPS	Appendix B Using GPS B.1 GPS measurement methods B.2 Multipath errors B.3 Dilution of precision (DOP) B.4 GGA and VTG data strings B.5 Discharge computation B.6 Quality assurance checks when using GPS
Appendix C ADCP discharge measurement field sheet and quality matrix	Appendix C ADCP discharge measurement field sheet and quality matrix
Appendix E Measurement quality codes	Appendix E Measurement quality codes

I.2.3 Who needs this competency?

This learning material covers the skills and knowledge required for a person to use and understand National Industry Guidelines for hydrometric monitoring, Part 8: *Application of Acoustic Doppler Current Profilers to Measure Discharge in Open Channels*, NI GL 100.08–2019.

I.2.4 Learning outcomes

At the completion of this learner resource you will be competent in the following:

- use the guideline document for reference
- use the guideline in day to day operations
- access the material referenced in the guideline document

- understand procedural standards for using acoustic instruments to gather water data
- use and understand related internal procedures and work instructions.

I.2.5 Health and safety considerations

Health and safety legislation shall always be considered when implementing National Industry Guidelines, workplace procedures and work instructions.

Employees carrying out work related to the National Industry Guidelines should be adequately trained in all relevant health and safety matters.

I.2.6 Environmental considerations

Compliance with this guideline may involve working in the environment. As such care should be taken to:

- prevent unnecessary damage to river banks
- prevent unnecessary disturbance of the river system
- carefully construct any infrastructure to minimise impacts on the environment and river flow conditions
- plan access roads to sites to minimise impacts during all seasonal conditions.

I.2.7 What resources will I need?

- Workplace policies and procedures
- Manufacturer manuals, requirements and specifications
- Codes of practice
- Workplace equipment, tools and instruments
- Workplace reports
- Workplace maps, plans and instructions
- Permits and access to locations and worksites

Other useful resources

- Relevant Health and Safety Act
- Manufacturer’s instruction manuals
- Organisation’s procedures and work instructions
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