National Environmental Monitoring Standards

Open Channel Flow Measurement

Measurement of Open Channel Flow Data

Version: 2.0.0 FINAL DRAFT FOR COMMENT
Date of Issue: March 2026

This version of the Open Channel Flow NEMS has been released for users to access and provide feedback, via the NEMS website, by 30 April 2026: - https://www.nems.org.nz/feedback/.

Feedback will be considered by the Working Group, and a final version of this document will be released as soon as all feedback has been considered.

As this version has not been proofread it may contain spelling, grammatical and format errors however, feedback is only sought in regard to technical content.

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Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.1	Jun 2013			Initial release
2.0.0	Mar 2026	Reviewed, and new document format applied, with content restructured and edited throughout. Much of the previous content has moved and the document modified to include additional gauging methods, as well as additional guidance and/or clarification being provided in many sections. Minor corrections have been made to several parts of the document.		

Table of Contents

The National Environmental Monitoring Standards

The National Environmental Monitoring Standards (NEMS), and associated codes of practice, Glossary, and National Quality Code Schema can be found at www.nems.org.nz.

Development

The strategy that led to the development of these Standards and associated documents was established by Jeff Watson (Chair) and Rob Christie (Project Director) of the initial National Environmental Monitoring Standards (NEMS) Steering Group, in 2014.

The NEMS initiative is supported by the Environmental Data Special Interest Group (ED SIG) (formerly the Local Authority Environmental Monitoring Group (LAEMG)), who contribute members to the NEMS Steering Group.

Implementation of the strategy is overseen by the NEMS Steering Group, which currently comprises Glenn Ellery (Chair), Jeff Watson (Technical Advisor), Phillip Downes, Rachel Herbert, Jon Marks, Charles Pearson, Jochen Schmidt, Michael Ede, Dan Elder, Abi Loughnan, Sonja Miller, and Raelene Mercer (Project Manager).

The NEMS Steering Group directs preparation of NEMS documents on authority from the Chief Executives of the regional and unitary councils and the Ministry for the Environment (MfE).

The development of these documents involves consultation with regional and unitary councils across New Zealand, major electricity generation industry representatives, research institutes, and organisations providing supporting services such as laboratory processing. These agencies together are responsible for the majority of environmental monitoring in New Zealand.

Implementation

Stationarity

NEMS Standards are intended for long-term monitoring programmes. Stationarity of record, whereby changes to methods and instruments do not introduce bias over the lifetime of the record, is an essential property (see also NEMS *Glossary*), without which a record cannot be confidently analysed for temporal trends.

Because the methods of collecting and processing environmental data do change over time, the Standards include provisions for identifying and mitigating potential loss of stationarity.

Data fit for purpose

To facilitate data sharing, the NEMS Steering Group recommend that NEMS Standards are adopted throughout New Zealand and all data collected be processed and quality coded in accordance with the methodologies described in the Standards.

The quality code is determined from the Standard adopted and applied at the time of data acquisition. The degree of rigour with which requirements of the Standards are applied may depend on the quality of data sought. The highest quality code (QC 600) may be assigned to data that meet the stated requirements for good data.

Data of lesser quality are accommodated but are assigned a lower quality code (i.e. less than QC 600). They may be fit for the current intended monitoring purpose but restricted in their use for a range of other current and future purposes.

Measured data coded as QC 500 (fair), or QC 400 (compromised) may be the best practicably achievable due to site limitations and/or transient lapses in data quality.

Health and safety

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments shall be complied with.

NEMS Codes of Practice (COP) provide additional guidance on health and safety issues and structural design. Use only the most recent published version of any NEMS COP.

Limitations

It is assumed that, as a minimum, the reader of these documents has an understanding of environmental monitoring and data processing techniques, and some competency in their application.

The documents do not relieve the user (or a person on whose behalf they are used) of any obligation or duty that might arise under any legislation, and any regulations and rules under those Acts, covering the activities to which these documents have been or are to be applied.

Instructions for manufacturer-specific instrumentation and methodologies are not included in NEMS documents.

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Neither NEMS nor any organisation involved in the compilation of the documents guarantee that the information is complete, current, or correct and accepts no responsibility for unsuitable or inaccurate material that may be encountered.

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Funding

Core funding of the NEMS project at the time that this document was developed was provided by the Ministry for the Environment with in-kind contributions from New Zealand regional councils and unitary authorities.

A full list of those who have contributed funding and time to the NEMS project is available at www.nems.org.

Review

This document will be assessed for review within one year of its initial release and thereafter will be assessed for review approximately once every two years. Document status and proposed review dates can be found at www.nems.org.nz.

Feedback

If you wish to provide feedback regarding this version of the document, please provide it to https://www.nems.org.nz/feedback/.

About This Standard

Introduction

Open channel flow measurements are routinely made on many rivers in New Zealand. They provide information on flow at the time of measurement, and for the development of discharge ratings used to derive continuous flow data from water-level stations. Key to planning, maintaining and recording open channel flow is understanding and catering for stationarity.

The earliest open channel flow measurements collected in New Zealand were from the Wairua River at Wairua Falls in May 1911. These data were collected for a hydro-electric power station that was being built at this site. The need for further flow information for rivers for hydro-electricity development began in earnest in the late 1920s and many measurements were collected for this purpose.

The establishment of the first Hydraulic Survey parties in 1949 oversaw the start of specialist flow monitoring in rivers on a national basis, and during the 1950s and 1960s many rivers were measured for a wide variety of purposes including flood control and soil conservation studies.

The majority of open channel flow measurements are made to rate a water-level station to enable derivation of continuous flow from the water-level record. By 2011, 995 stations with flow measurements associated with their data records were recorded on the national water resources database.

The most common method of measuring flow from the first measurements until recent time has been the Velocity-Area method that uses sounding devices and mechanical rotating-element current meters. Acoustic technology emerged in the 1990’s, implemented as current meter devices using the Velocity-Area method. By the 2010’s acoustic technology had been adopted by most data collection agencies. The development of the ADCP Moving Boat method enabled flows to be measured efficiently in rivers and in situations that are difficult to measure with mechanical current meters.

The dilution method for measuring flow has long been recognised as having the potential for accurate flow measurement in sections that are turbulent or difficult for the use of current meters or ADCPs. This method has also benefited with the development of accurate real time water quality sensors enabling measurements and is now included in this standard as a method.

Objective

The objective of this Standard is to ensure that single open channel measurements, made using the methods in this standard are obtained, quality assured, and preserved in a verifiable, consistent, and documented manner to a known standard over time throughout New Zealand, and are therefore suitable for:

- their current intended applications
- at-site analysis over time
- regional and national comparative analysis over space and time, and
- conceivable future applications.

Scope

This Standard covers all processes associated with the selection and application of methods for the measurement of open channel flow.

Exclusions

Methods used to measure open channel flow by continuous methods, with the exception of side looking ADCP's, are excluded from this Standard.

Terms, definitions and symbols

Relevant definitions and descriptions of symbols used in this Standard are contained within the NEMS *Glossary* available at www.nems.org.nz.

Normative references

This standard shall be read in conjunction with the following references:

- NEMS *Glossary*
- NEMS *Quality Code Schema*
- NEMS *Processing-of-Environmental-Time-series-Data*
- River discharge from surface velocity measurements: A field guide for selecting alpha - H. Biggs et.al
- National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021(Australian Government Bureau of Meteorology).

The Standard – Open Channel Flow

Requirements and recommendations for the application of this Standard are summarised in the following tables:

- Minimum requirements for the application of all Standards.
- Requirements for open channel flow data irrespective of quality.
- Additional requirements for open channel flow data of good quality.
- Other requirements, guidelines, and recommendations.

Data that are collected, processed, and archived to meet requirements of the first three tables, in a verifiable and consistent manner, can be assigned the highest quality code (QC 600). When these requirements are not met, a lower quality code is assigned, deduced from the quality coding flow chart for open channel flow data. If requirements of the first table are not met the data cannot claim to be in accordance with NEMS and cannot be assigned a quality code.

Note: Guidance and tools to assist with implementation of requirements and application of quality codes are provided in the remainder of this document.

Quality assurance requirements ensure the measurement system is robust so that the impact on data quality of unexpected circumstances or unanticipated combinations of factors is minimised. Their influence on data quality is therefore consequential and usually assessed during data processing, which is outside the scope of this document.

Note: Guidance on the application or modification of quality codes during data processing can be found in NEMS Data Processing*.*

Additional guidelines and recommended practices are those considered relatively easy to implement to enhance data quality, but are not mandatory and do not alter quality code assigned to the data.

Minimum requirements for the application of all Standards

Table 1 – Minimum requirements for the application of all Standards.

Health and safety	Scope	All current legislation, including relevant amendments, shall be complied with.
Stationarity		• Maintained wherever possible. • Documented in metadata if change occurs or is likely to occur.
Units of measurement		• Metric system. • SI units, unless stated otherwise (in the relevant Standard).
Timing of measurements	Time zone	Use New Zealand Standard Time (NZST), or Chatham Is. Standard Time (CHAST) as applicable. Do not use Daylight Time (NZDT or CHADT).
Metadata	Scope	• Recorded for all sites and measurements. • Permanently archived and discoverable.
	Identification of Standards	Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments.
	Identification of data	All data shall be identified by a minimum of: • a unique site name and/or identifier • the variable's name and units (as defined in its relevant NEMS), and • date and time of the measurement or record.
	Quality coding	All data shall be quality coded using the NEMS *National Quality Code Schema.*
Archiving	Original and final records	Store, retain indefinitely, and if electronic, back up regularly: • Original data (as defined by the recording agency). • Final data (as verified). • Supplementary measurements. • All required metadata (including all calibration, validation, verification and editing information). • Additional time series and/or metadata used and/or generated during data processing.

Requirements for open channel flow data irrespective of quality

Table 2 – Requirements for open channel flow data irrespective of quality.

Measurement	Units	Discharge shall be expressed as: m^3/s to three decimal places, or l/s, or ml/s for very small flows where measurement uncertainty is less than ±50ml/s.
Discharge Calculation	Velocity-Area Stationary Meter (3.7)	Mean-section method As calculated by QRevInt, where appropriate for the instrument type
	Velocity-Area ADCP Moving Boat (4.6)	Moving Boat Method As calculated by QRevInt
	Velocity – Area Surface Velocimetry (5.8)	As per supporting software packages
	Index Velocity (6.5)	As per the methodology described in section 6.5
	Volumetric (7.4)	As per the methodology described in section 7.4
	Indirect Discharge (8.4)	As per the methodology described in section 8.4
	Dilution (9.5)	As per the methodology described in 9.5
Uncertainty	Velocity-Area Stationary Meter (Annex F)	± 8% (expanded uncertainty, 95% confidence) Calculated using the methodology described in Annex F of *ISO 748:2021*. Note: Not all flow measurement methods have an accepted form of calculating uncertainty.

	Velocity-Area ADCP Moving Boat (Annex E)	± 8% (expanded uncertainty, 95% confidence) Calculated as per QRevInt software
	Velocity – Area Surface Velocimetry (Video)	Calculated using the supporting software packages *(Note: - a Surface Velocity (Video) discharge measurement shall not be assigned a QC greater than QC500)*
	Velocity – Area Surface Velocimetry (Handheld Radar or Timed Floats) (Annex F)	Calculated using the methodology described in Annex F of *ISO 748:2021*. *(Note: - a Surface Velocity (Handheld Radar or Timed Surface Floats) discharge measurement shall not be assigned a QC greater than QC400)*
	Index Velocity	N/A
	Volumetric	Calculated using the principles in *ISO 5168:2005*.
	Indirect Discharge	N/A *Note: - a Slope/Area or Contracted Opening discharge measurement shall not be assigned a QC greater than QC300)*
	Dilution	± 8% (expanded uncertainty, 95% confidence) Calculated using the SUNY ("Salt Uncertainty") software, or else Quality Code as QC400
Quality Assessment	Velocity-Area Stationary Meter (Annex C)	Classified under Annex C - Velocity-Area Stationary Meter Method Estimation of Quality Code
	Velocity-Area ADCP Moving Boat (annex D)	Classified as per Annex D – 'ADCP Moving Boat Estimation of the Quality Code'
Timing of measurements	Instrument resolution	1 s
	Instrument accuracy	± 90 s/month

	Time zone	Express time as New Zealand Standard Time (NZST). *Note: Do not use New Zealand Daylight Time (NZDT).*
	Discharge results	Assign date and time of mean gauge height (where applicable). 1 min resolution
Supplementary Instrument Measurements	Temperature	± 2.0 °C Required for acoustic methods
	Salinity	± 5 ppt (parts per thousand) Required for acoustic methods in brackish, or potentially brackish, water only
	Bearing	Compass calibrated on site Local magnetic variation to be entered Required for ADCP moving bed loop test and GPS referenced boat velocity
	Water level	Required if result is to be used for discharge rating. Discharge filed at the time of mean gauge height. Recorded at regular intervals over duration of discharge measurement
Validation Methods	Instrument tests Rotating element current meters (3.4.1.7)	Required pre-deployment, and post-deployment for rotating-element current meters.
	Instrument tests ADP and AECV (3.4.1.7)	General Instrument Tests (instrument specific)
	Instrument tests ADCP methods (4.3.1) (4.3.2) (4.3.3) (4.3.5)	Temperature check Instrument Diagnostics Compass calibration check Moving bed test

	Dilution (9.4)	Temperature and EC sensors are calibrated Complete mixing is achieved Critical analyses of the results produced by the SUNY Where the methodology is not compatible with the SUNY software Quality Code as QC400
	Surface Velocity (Video) (5.6)	Stable cross-section Alpha value(s) established for the site Alpha value filed with the measurement
	Surface Velocity (Radar and Timed Floats) (5.6)	Stable cross-section Alpha value filed with the measurement
	Volumetric	Measurement vessel volume validated to ±2%
	Slope/Area and Contracted Opening Methods	Water levels surveyed to ±3mm
	Calibrated structures	Verify by gauging at least once every twelve months and after any event that has potential to alter the calibration

Additional requirements for open channel flow data of good quality

As a means of achieving QC 600 under this Standard, the following requirements apply in addition to the requirements for the application of all Standards and the requirements for open channel flow data irrespective of quality:

Table 3 – Additional requirements for open channel flow data of good quality.

Calibration Checks[b]	Frequency (3.5)	Mechanical current meter: 2 years, or 300 hours of use ADV: 5 years AECV: 5 years ADCP: 3 years

		POEM: 2 years or 100 hours of use Volumetric: Current calibration of measurement vessel Dilution: Each site must have a calibration check before each measurement, or at least once per year when using pre-established calibration factors. Imagery – N/A Surface Velocity
	Method (3.5)	Where relevant follow manufacturers' specifications, *AS3778.6.3, ISO 3455:2007* and *ISO 748:2021*. Further details are contained within this Standard.
Metadata	Scope	Metadata shall be recorded for all discharge measurements.
Deployment	Site selection	Use criteria within this Standard, method dependent
	Sampling *Velocity-Area Stationary Meter method* *(3.4.1.3)*	≥ 40 s velocity measurement at ≥ 20 verticals, and each partial segments with < 10 % of the total discharge
	Sampling *Velocity-Area Moving Boat method* *(4.4)*	≥ 720 s total sampling time, and reciprocal transect pairs
	Width Measurement *Velocity-Area Stationary Meter method* *(3.3.1.2)*	± 0.5% of total cross-section width (Velocity-Area Stationary Meter method)
	Depth Measurement *Velocity-Area Stationary Meter method* *(3.3.2.1)*	≥ 22 verticals to ± 5 mm for depths <= 0.3 m, or ±10 mm for depths > 0.3 m

	Dilution (9.2)	Temperature compensation of EC measurements has been completed using linear or non-linear functions and referenced to 25 °C (ECT) Ensure that complete mixing has occurred using the EC trace showing a single, smooth well defined salt curve. Dry Tracer salt weighed to ± 1 %, or better
	Surface Velocity (Video) (5.5.1.1)	Video camera resolution of at least 1080p or 4k A minimum video duration of 30 to 90 seconds Entire width of the channel is visible in the imagery And for Vertical Imagery: -A minimum of 2 water levels (left bank, right bank) are surveyed Oblique Imagery: - A minimum of 6 Ground Control Points (GCPs) on channel banks (and visible in the imagery), surveyed to provide x,y,z coordinates.
	Surface Velocity (Radar and Timed Floats) (5.5.3)	Radar: - is held parallel to the direction of the flow and at a vertical angle of 45^0 Radar: - A minimum of 40 seconds exposure time for each velocity reading
	Volumetric (7.3.2)	A minimum of 10 observations of time to fill the measurement vessel
	Slope/Area and Contracted Opening Methods	Slope/Area: -

	(8.2)	• a minimum of 10 water levels surveyed along the observation reach • Reach surveyed is a minimum of 5 times channel widths • No abrupt bends or change of gradient occur within the observation reach

Other requirements, guidelines, and recommendations

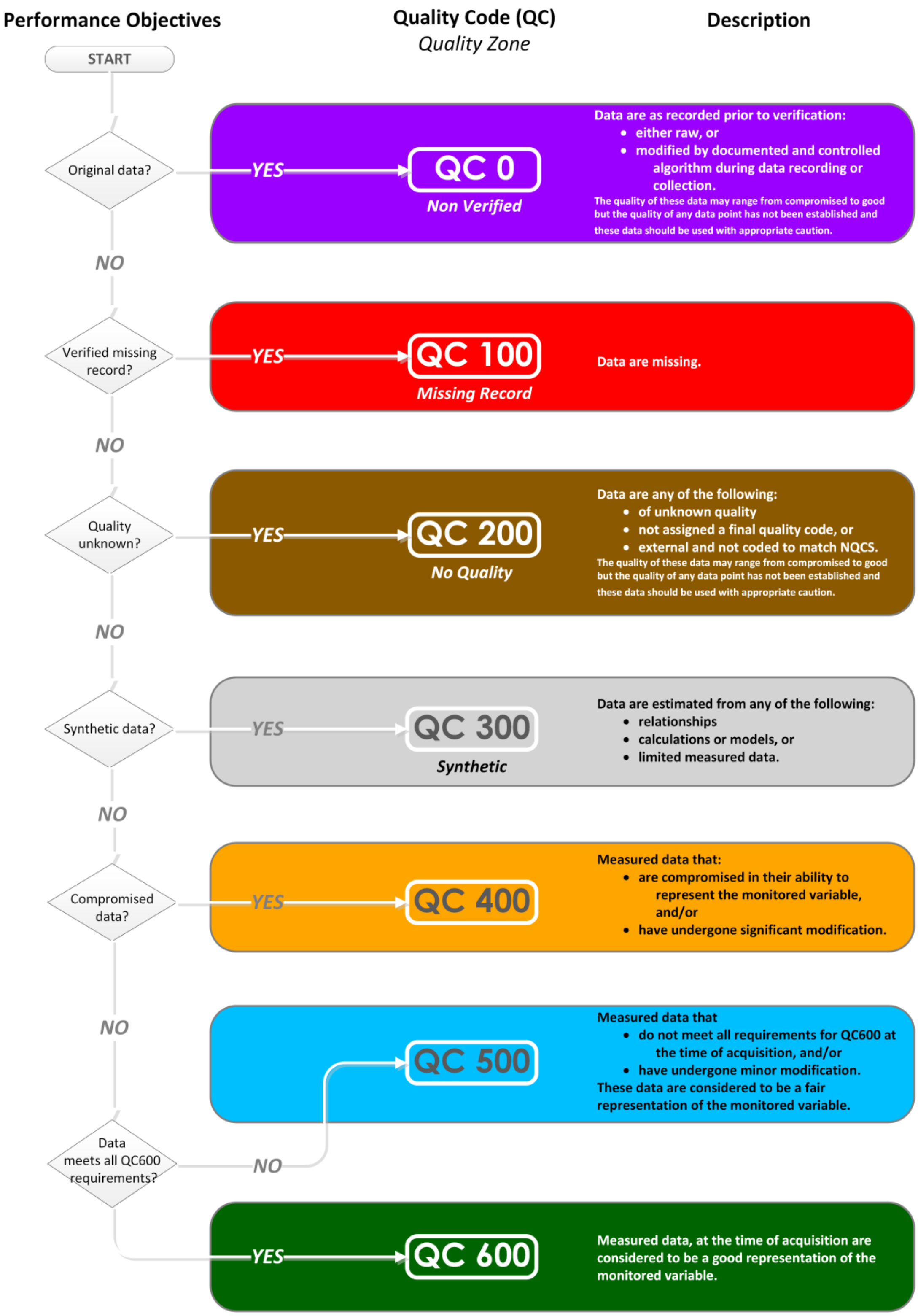
The following table summarises other requirements and guidelines (e.g. for quality assurance or lower quality codes), and additional recommended practices that are either not relevant to or not required for QC 600 but if implemented will enhance work practices and data quality.

Table 4 – Other requirements, guidelines, and recommendations

Validation Methods	Inspection of measurement devices	Perform at least annual inspections to ensure calibration remains stable
Archiving	Original and final records	File, archive indefinitely, and back up regularly: • raw and processed records • primary reference data • supplementary measurements • validation checks • calibration results, and • metadata.

Quality coding of open channel flow data

Note: For this standard QC100 has been deemed as not applicable.



QC 0 – Non Verified

Data are as recorded prior to verification:

- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 100 – Missing Record

Data are missing.

QC 200 – No Quality

Data are any of the following:

- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 300 – Synthetic

Data are estimated from any of the following:

- relationships
- calculations or models, or
- limited measured data.

QC 400

Measured data that:

- are compromised in their ability to represent the monitored variable, and/or
- have undergone significant modification.

QC 500

Measured data that

- do not meet all requirements for QC600 at the time of acquisition, and/or
- have undergone minor modification.

These data are considered to be a fair representation of the monitored variable.

QC 600

Measured data, at the time of acquisition are considered to be a good representation of the monitored variable.

Quality coding of open channel flow data Velocity-Area Stationary Meter Method

These methods employ similar principles and are the most common means of measuring open channel flow for most agencies.

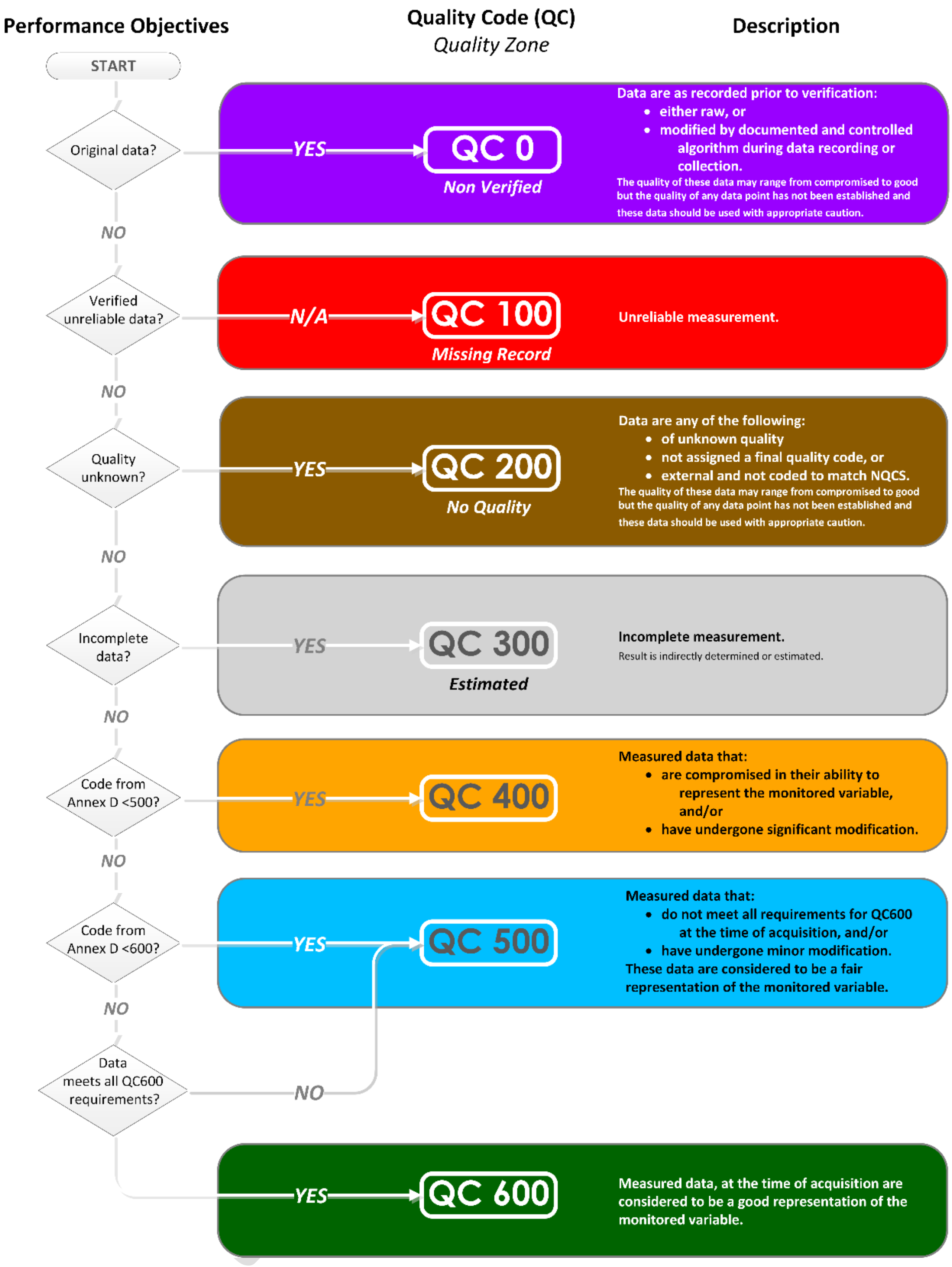
With the large datasets and resources available for these methods, many QA/QC parameters have been identified beyond a simple statistical uncertainty.

Refer to Annex C for a method specific quality coding matrix, and a site quality assessment table common to both methods before using this flow chart.

Powerful QA/QC software packages have also been developed for discharge measurements utilising Flowtracker 1 and 2 ADV instruments. The relevant software QRevMS for Stationary meter method) must be used to achieve a QC above 0. Refer to Annex E QRev Software use and explanation.

The POEM (Pressure Operated Electronic Meter) is a relatively rarely used instrument that is neither used as a stationary meter, nor from a moving boat, but does share similarities with other technologies in this group in the way that it estimates discharge. For this reason, it has been included in Annex C for assigning a quality code and therefore, this flowchart

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated.



QC 0 – Non Verified

Data are as recorded prior to verification:
- **either raw, or**
- **modified by documented and controlled algorithm during data recording or collection.**

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 100 – Missing Record

Unreliable measurement.

QC 200 – No Quality

Data are any of the following:
- **of unknown quality**
- **not assigned a final quality code, or**
- **external and not coded to match NQCS.**

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 300 – Estimated

Incomplete measurement.

Result is indirectly determined or estimated.

QC 400

Measured data that:
- **are compromised in their ability to represent the monitored variable, and/or**
- **have undergone significant modification.**

QC 500

Measured data that:
- **do not meet all requirements for QC600 at the time of acquisition, and/or**
- **have undergone minor modification.**

These data are considered to be a fair representation of the monitored variable.

QC 600

Measured data, at the time of acquisition are considered to be a good representation of the monitored variable.

Quality coding of open channel flow data Velocity-Area ADCP Moving Boat Method

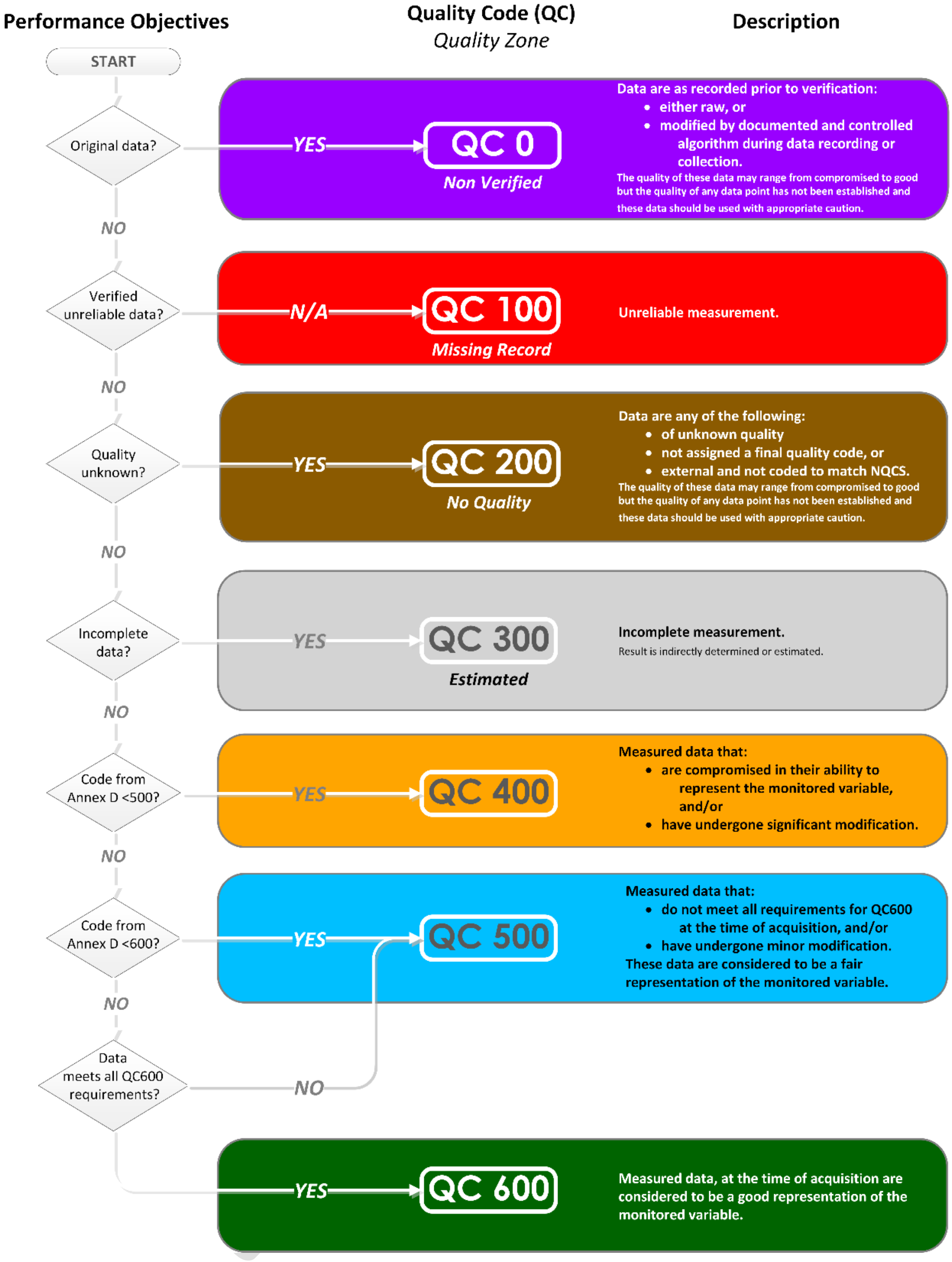
This method employs similar principles and are the most common means of measuring open channel flow for most agencies.

With the large datasets and resources available for these methods, many QA/QC parameters have been identified beyond a simple statistical uncertainty.

Please refer to Annex D for a method specific quality coding matrix, and a site quality assessment table common to both methods before using this flow chart.

Powerful QA/QC software packages have also been developed for discharge measurements utilising ADCP. The relevant software (QRev/QRevInt for moving boat must be used to achieve a QC above 0. Refer to Annex E QRev Software use and explanation.

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated.



QC 0 (Non Verified): Data are as recorded prior to verification:

- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 100 (Missing Record): Unreliable measurement.

QC 200 (No Quality): Data are any of the following:

- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

QC 300 (Estimated): Incomplete measurement.

Result is indirectly determined or estimated.

QC 400: Measured data that:

- are compromised in their ability to represent the monitored variable, and/or
- have undergone significant modification.

QC 500: Measured data that:

- do not meet all requirements for QC600 at the time of acquisition, and/or
- have undergone minor modification.

These data are considered to be a fair representation of the monitored variable.

QC 600: Measured data, at the time of acquisition are considered to be a good representation of the monitored variable.

Quality coding of open channel flow data Surface Velocity Method

Surface Velocimetry methods are:

- Image Velocimetry (STIV/LSPIV)
- Surface Floats

- Handheld radar

Index Velocity methods are:

- Side-looker ADCP
- Fixed radar

The calculation of uncertainty associated with a discharge measurement is an important component for the assignment of a quality code. However, at the time of the production this version of the Open Channel Flow NEMS, a reliable method for calculating the uncertainty of measurements conducted by Fixed Radars, Side-looker ADCPs and Image Velocimetry had not been devised.

Refer to "Annex C – Estimation of Quality Code for Stage–Discharge Rating Curve Segments" within the NEMS: -Rating Curves for quality coding of discharge measurements from Index Velocity methods.

Surface velocimetry discharge measurements always rely on assumptions, theoretical relationships, and often with data collected at different points in time, which makes them very difficult to accurately define the quality code. For this reason, the maximum achievable Quality Code for Image Velocimetry Measurements is QC500 as it is very difficult to define.

The maximum achievable Quality Code for all other types of Surface Velocimetry and all Indexed Velocity Measurements is QC400.

To achieve QC500, an Image Velocimetry method measurement requires an established alpha and a known cross section.

Definitions:

Established Alpha:

Where the relationship between surface velocity and mean velocity has been measured and expressed as a decimal fraction (2d.p.), which is then plotted against discharge to construct a curve/rating for the site. The alpha value for any given discharge can then be read off the Discharge/Alpha curve. The curve can be extended beyond the highest and lowest measured points, but to qualify as "established" an alpha must be within 25% of the lowest or highest measured point on the Discharge/Alpha curve.

To establish the surface velocity/mean velocity fraction, the surface velocities would ideally be measured concurrently with the full velocity profile e.g. flying a drone after an ADCP measurement.

Alternatively, for ADCP users, surface velocities can be derived from the "Extrap" tab in QRev. This second method introduces more uncertainty, but allows for using historical measurements to quickly build up a site Discharge/Alpha curve.

To qualify as “established” an alpha value must be derived from a Discharge/Alpha curve that meets the following requirements:

- Has five or more measurements to construct the curve
- A verification measurement of QC600 standard must be completed every 12 months and following an event of significance that has the potential to alter the slope and/or the effective cross-sectional area of the reach.
- Verification measurements must plot within 8% of the established curve
- Constructed using data collected from the same gauging location.
- Be from a part of the curve that is not extended by more than 25% beyond the highest or lowest measured point.

If a verification measurement falls outside 8% of the established Discharge/Alpha curve, or a new measurement site needs to be chosen, a new Discharge/Alpha curve needs to be developed.

Known Cross Section:

The cross section is either measured at the time of the measurement (e.g. concurrent ADCP) or known to be stable e.g. lined water race or during low-medium flows and visibly unchanged since the cross section was last measured.

Surveying a cross section before and after a flood event does not qualify a cross section as known.

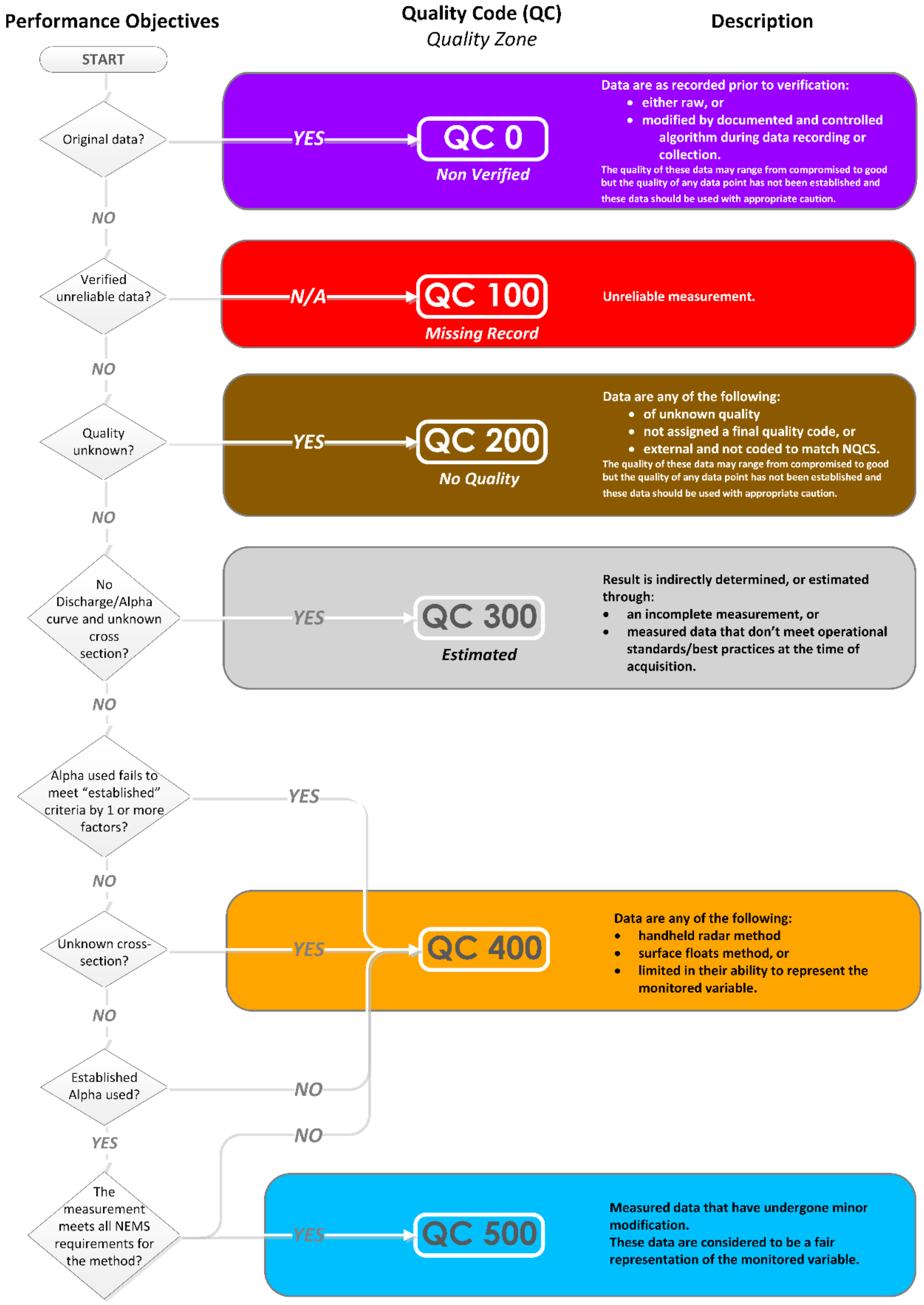
Refer to Annex H – Surface Velocity - Handheld Radar and Calculation of cross-sectional area and Discharge for current *industry* best practise, and; *River discharge from surface velocity measurements: A field guide for selecting alpha - H.Biggs et.al*

Guidance Note:

> *To assist with implementation of quality coding surface velocity discharge measurements:*
>
> *Any Surface Velocimetry discharge measurement, where a discharge/alpha curve and a known cross-section do not exist may be quality coded no greater than QC300.*
>
> *Measurements using Surface Floats or Handheld Radar may be quality coded no higher than QC400.*
>
> *Surface velocimetry discharge measurements that exceed the defined range of an established discharge/alpha curve by greater than 25% and/or utilise a cross-section of unknown stability at the flow being measured, may be quality coded no greater than QC400.*

Surface velocimetry discharge measurements that fall within the range of an established discharge/alpha curve that has been defined by alternate discharge measurement methods and has a known stable cross-section, may be quality coded no greater than QC500.

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated.



Data are as recorded prior to verification:
- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Unreliable measurement.

Data are any of the following:
- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Result is indirectly determined, or estimated through:
- an incomplete measurement, or
- measured data that don’t meet operational standards/best practices at the time of acquisition.

Data are any of the following:
- handheld radar method
- surface floats method, or
- limited in their ability to represent the monitored variable.

Measured data that have undergone minor modification.
These data are considered to be a fair representation of the monitored variable.

Quality coding of open channel flow data Volumetric

When performed correctly, a volumetric discharge measurement is the most accurate form of discharge measurement.

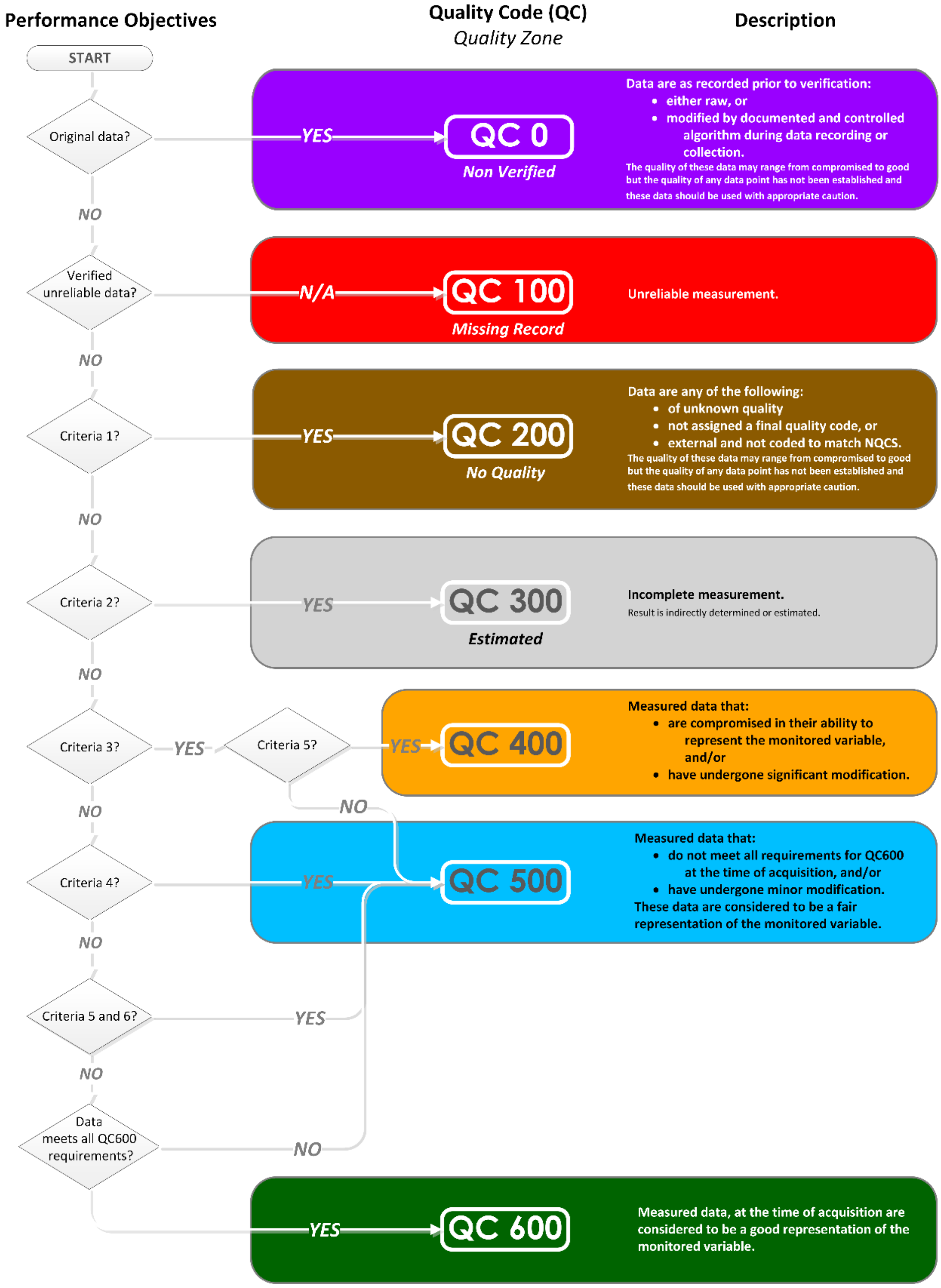
Being a very simple form of measurement, there are relatively few criteria that need to be met during data collection and processing.

Below are six critical criteria that need to be overcome to achieve QC600. These criteria are referred to in the Volumetric Measurement Quality Coding Flow Chart.

1. Uncalibrated container - Container used is not verified to within 2% of stated volume
2. Container filled 5 times or less
3. Mean filling time for container is less than 10 seconds
4. Variation in filling times varies by more than 5%
5. Container filled less than 10 times
6. Uncertainty not calculated, or calculated and above 8%

Guidance note: To assist with implementation of quality coding Volumetric measurements if the volume of the container has not been calibrated/validated to within 2% of a known volume, coded no higher than QC400

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated.



Data are as recorded prior to verification:

- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Unreliable measurement.

Data are any of the following:

- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Incomplete measurement.

Result is indirectly determined or estimated.

Measured data that:

- are compromised in their ability to represent the monitored variable, and/or
- have undergone significant modification.

Measured data that:

- do not meet all requirements for QC600 at the time of acquisition, and/or
- have undergone minor modification.

These data are considered to be a fair representation of the monitored variable.

Measured data, at the time of acquisition are considered to be a good representation of the monitored variable.

Quality coding of open channel flow data

Indirect Measurement

Indirect measurements are generally used for estimating flow when a direct measurement is deemed too dangerous, difficult or cost prohibitive to execute, often due to the remote nature and inaccessibility of the site during flood events.

Using empirical and/or numerical data, Indirect Measurements can also be used to estimate peak discharge after a high flow event.

Indirect measurements always rely on assumptions, theoretical relationships, and often with data collected at different points in time, which makes it very difficult, if not impossible to accurately quantify uncertainty.

For this reason, the maximum achievable Quality Code for most Indirect Measurements is QC300.

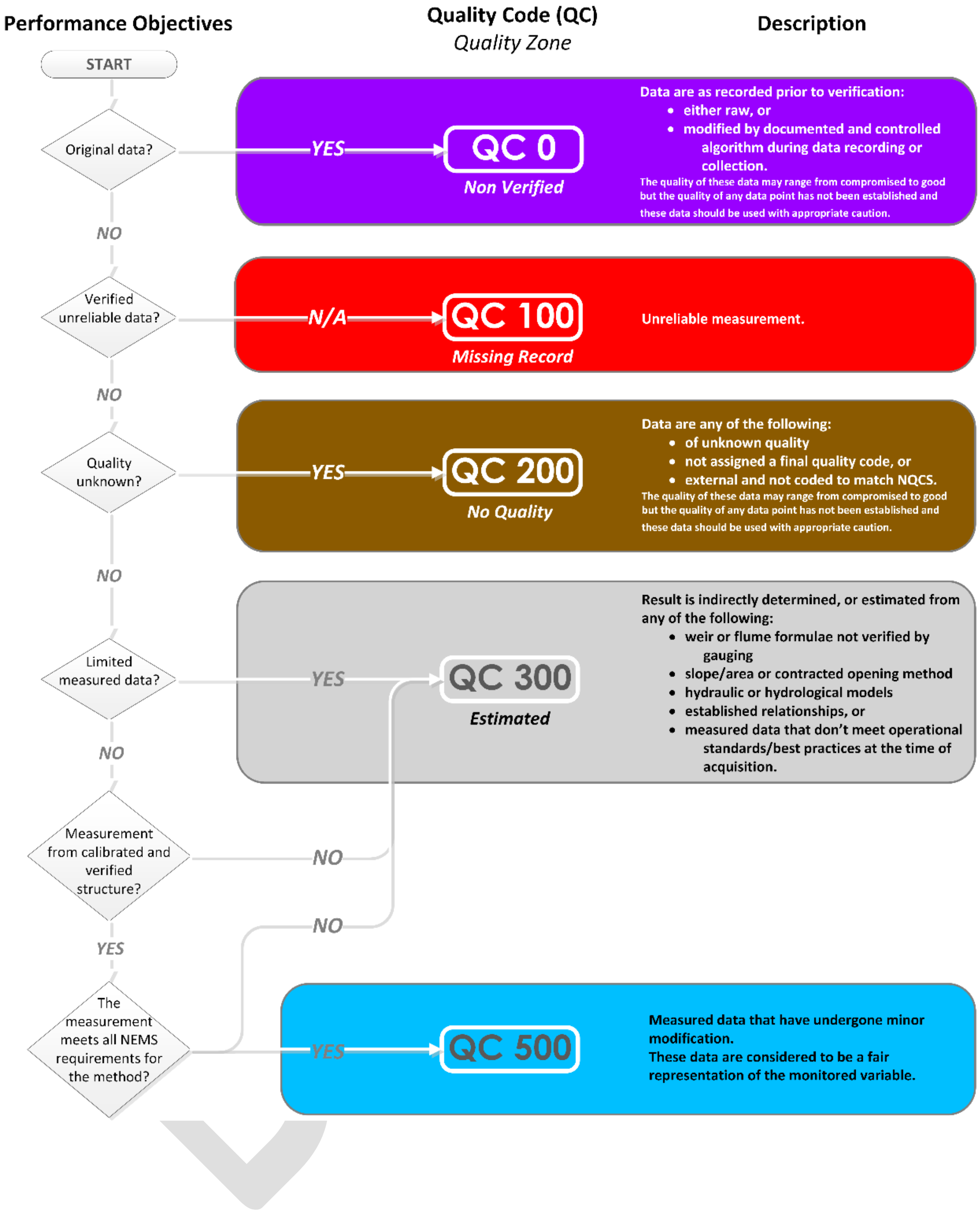
Properly installed and maintained rated structures such as weirs can however achieve measurements with a QC code of QC500 when verified by gauging.

For the purposes of verifying the stage/discharge rating associated with a structure, a measurement of QC600 standard must be completed every 12 months and following an event of significance that has the potential to alter the slope of the reach or the effective cross-sectional area of the structure.

Guidance Note: To assist with the implementation of quality coding for indirect discharge measurements:

- *Indirect discharge measurements that do not meet all the requirements of the standard shall be assigned QC 300*
- *Visual estimates of discharge shall be coded as QC 200.*
- *Slope/area and contracted opening discharge measurements shall be quality coded no higher than QC 300*
- *Discharge measurements derived from formulae applied to unverified structures such as weirs and flumes, shall be quality coded no higher than QC 300.*
- *Discharge measurements derived from formulae applied to verified structures such as weirs and flumes, shall be quality coded no higher than QC 500.*

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated..



Data are as recorded prior to verification:

- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Unreliable measurement.

Data are any of the following:

- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Result is indirectly determined, or estimated from any of the following:

- weir or flume formulae not verified by gauging
- slope/area or contracted opening method
- hydraulic or hydrological models
- established relationships, or
- measured data that don't meet operational standards/best practices at the time of acquisition.

Measured data that have undergone minor modification.
These data are considered to be a fair representation of the monitored variable.

Quality coding of open channel flow data

Dilution

SUNY Software shall be used if possible after each measurement, either via the built-in version in the latest TQ-Commander Software or by uploading the results to: https://alexandrehauet.shinyapps.io/SUNY_Salt_Dilution/

Measurement criteria that are required to be met:

1. Mixing/Probe placement – Sensor trace deviation between the probes (peaks/area) to be within 5% of each other (as per software prompts).

2. Detection/Salt dose – Instrument specific - refer to manual or software recommendations.

Guidelines:

- For base EC below 200µS, the peak increase should be at least 50 µS/cm (absolute) and not in percent, this improves the influence of the SNR and Probe accuracy.

  Example: using percentages – for a base EC of 30µS, a peak increase of 30% = 40µS. An EC disturbance of 2µS is an error of 2 x (1/40µS) =5%. Using absolute - if base EC is 30µS, a recommended peak increase of 50µS = 80µS. An EC disturbance of 2µS is an error of 2x (1/80µS) = 2.5%.

- For base EC above 200µS, use percentages (peak increase should be around 25% to 50%).

  Example: base EC is 200µS, peak increase is 25% = 250µS, an EC disturbance of 2µS is only an error of 2x (1/250µS) = less than 1%.

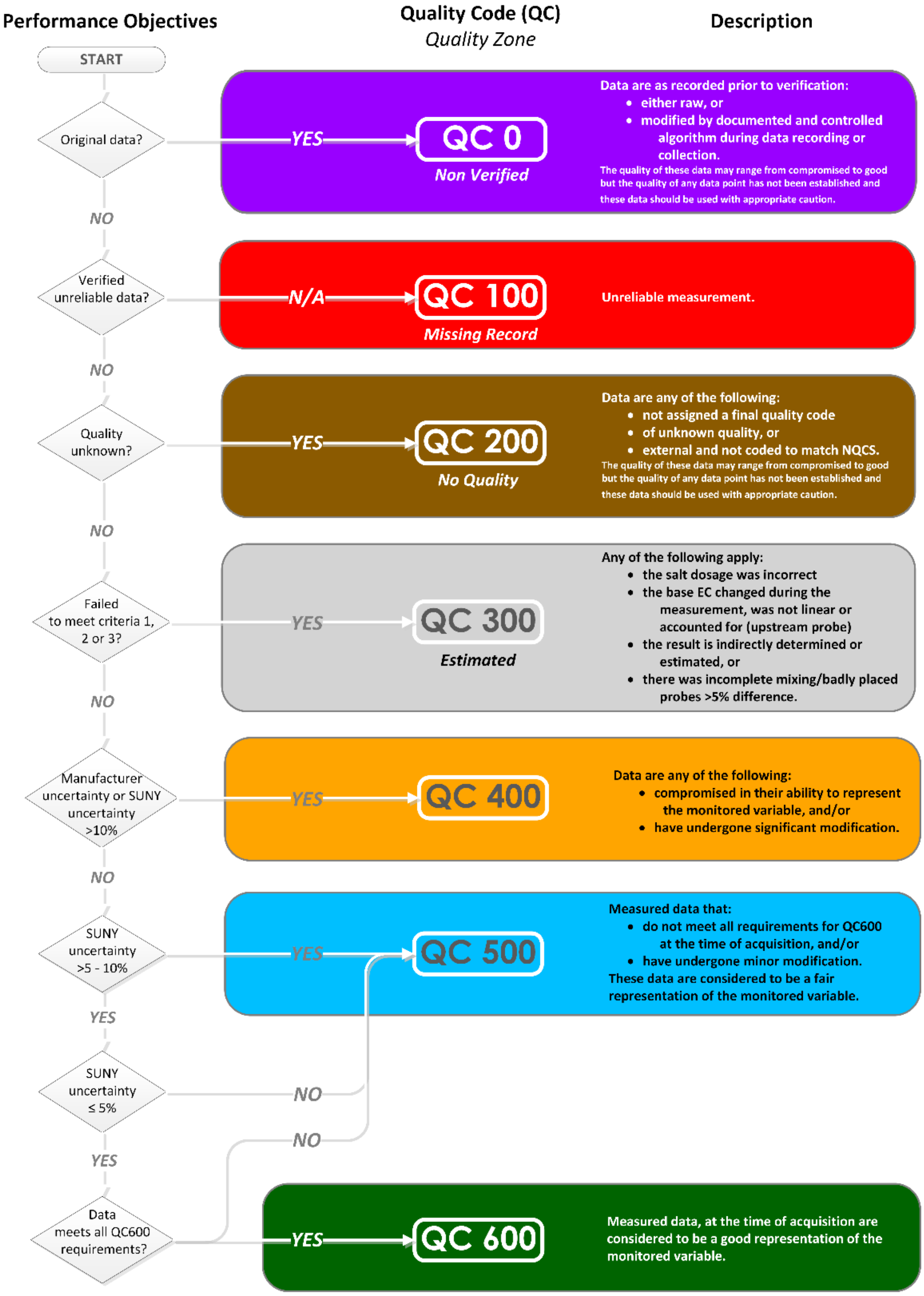
Base EC returns to starting EC levels.

If the base concentration changed during the measurement by more than 15uS (if below 200uS) or 15%, (if above 200uS) you need to consider the following:

- Was the change linear from the beginning of the measurement until the end. If so, the difference is not important, it can be corrected.

- If the change was not linear, you need a background probe for providing information for a correction, or need to repeat the measurement.

Note: For this standard QC100 has been deemed as not applicable as the measurement should be discarded and repeated.



Data are as recorded prior to verification:
- either raw, or
- modified by documented and controlled algorithm during data recording or collection.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Unreliable measurement.

Data are any of the following:
- not assigned a final quality code
- of unknown quality, or
- external and not coded to match NQCS.

The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.

Any of the following apply:
- the salt dosage was incorrect
- the base EC changed during the measurement, was not linear or accounted for (upstream probe)
- the result is indirectly determined or estimated, or
- there was incomplete mixing/badly placed probes >5% difference.

Data are any of the following:
- compromised in their ability to represent the monitored variable, and/or
- have undergone significant modification.

Measured data that:
- do not meet all requirements for QC600 at the time of acquisition, and/or
- have undergone minor modification.

These data are considered to be a fair representation of the monitored variable.

Measured data, at the time of acquisition are considered to be a good representation of the monitored variable.

Application

All data produced and archived under NEMS Standards shall be filed with all required metadata, including a quality code assigned in accordance with NEMS *National Quality Code Schema*. The schema permits valid comparisons within and across multiple data series.

The quality coding flowchart, as shown, shall be used as the framework to assign quality codes to open channel flow data.

Quality coding matrices shall be used to decide an initial quality code of QC 400, QC 500, or QC 600 for measured data within this framework (see section 9.4 and Annex A). This initial quality code is the maximum achievable for the data; the final quality code may be lower.

Open channel flow data can be assigned a final quality code of QC 600 (good) if the outcome of the quality coding matrices is QC 600, and the data have not been modified (i.e. edited, adjusted, or transformed during data processing).

Data that have undergone minor modification are eligible for a final quality code of QC 500 provided their initial quality code from the matrices is at least QC 500. An initial quality code of QC 500 from the matrices can be retained as the final quality code unless the data are subsequently significantly modified.

Regardless of initial quality code obtained from the quality coding matrices, final quality code cannot be higher than QC 400 if the data have undergone significant modification.

Quality coding matrices may identify data as not meeting QC 400 and needing remedial action. Data processing will then determine the final quality code to be applied. In the interim, affected data may be assigned QC 200 (not assigned a final quality code) or retain QC 0 (as recorded). Guidance on selecting and applying suitable quality codes during data processing is included in NEMS *Data Processing*.

Quality codes are determined from the Standard(s) applied at the time data are acquired. As Standards are updated there is no requirement to review and possibly revise the quality codes of data already archived. The Standard(s) and version(s) applied must therefore also be tracked in the metadata by way of a Stationarity Comment when a new Standard and/or version is adopted.

1 Method and Equipment Selection

In this section

This section describes the methods for measuring open channel flow and outlines the principles of each method. It emphasises selecting methods and equipment that are appropriate to site conditions, flow characteristics, safety considerations, and data quality requirements, with the aim of producing reliable, comparable, and verifiable flow measurements over time.

1.1 Velocity–Area Stationary Meter Method

The Velocity-Area Stationary Meter method is a widely used approach for measuring flow in open channels. This method is valued for its adaptability and reliability in a variety of channel conditions.

In this method the wetted cross-sectional area of the channel is determined, and the average velocity of water is measured at specific points using a stationary current meter. The current meter is held stationary at selected depths and locations across the channel width, where it measures the velocity. By multiplying the measured average velocity by the corresponding area, and summing across all segments, the total discharge or flow rate can be accurately calculated.

1.2 Velocity–Area ADCP Moving Boat Method

The velocity–area Acoustic Doppler Current Profiler (ADCP) moving boat method is an advanced technique used to measure discharge in open channels and rivers, particularly where flow conditions are complex or rapidly varying.

In this method, an ADCP is mounted on a moving boat and guided across the channel along one or more transects. As the boat traverses the cross-section, the ADCP continuously measures water velocity throughout the depth using acoustic Doppler principles, while simultaneously determining water depth.

The instrument divides the channel cross-section into numerous vertical cells and computes velocity profiles for each cell in real time. Discharge is calculated by integrating the measured velocities with the corresponding cell areas across the entire transect. Position and movement of the boat are tracked using either bottom tracking or GPS referencing to ensure accurate velocity measurements relative to the channel bed.

By completing multiple transects and averaging the results, the ADCP moving boat method provides a reliable estimate of total discharge and detailed information on spatial velocity distribution. This method is valued for its speed, accuracy, and ability to safely measure high flows, deep channels, and turbulent conditions that are difficult to assess using stationary instruments or manual techniques.

In deep channels that have a high sediment load an ADCP may not be able to determine the depth, and/or the velocity at depth, for significant parts of the cross-section. In these situations, a POEM is a more suitable instrument.

1.3 Surface Velocimetry and Index-Velocity Methods

The surface velocimetry and index velocity method estimates discharge in open channels by combining non-contact surface velocity measurements with a calibrated relationship between surface velocity and mean channel velocity.

Surface velocities are obtained using techniques such as floating tracers, radar, or image-based analysis, while an index velocity relationship—developed from site-specific calibration data—converts surface measurements to depth-averaged velocities. Discharge is calculated by multiplying the calibrated mean velocity by the channel cross-sectional area.

This method is valued for its safety, efficiency, and suitability for high flows or sites where in-stream measurements are impractical, and it provides reliable results when appropriately calibrated and maintained.

1.4 Index-Velocity Method

Hydroacoustic current meters can be deployed in multiple configurations—such as side-looking, upward-looking, and downward-looking—to suit a wide range of river and open channel measurement applications. One of the most prevalent uses of these instruments is at streamflow-gaging stations, where they are integral to the computation of streamflow using index-velocity methods.

In this context, the hydroacoustic current meter measures water velocity at a specific location or portion of the river. This measured velocity acts as a surrogate, or "index," for the mean-channel velocity. By establishing a calibrated relationship between the index velocity and the mean velocity of the channel, it is possible to convert ongoing velocity measurements into reliable estimates of mean-channel velocities over time.

The mean-channel velocities obtained through index-velocity methods are then used to generate continuous records of river streamflow. This approach enables consistent and accurate monitoring of flow conditions, supporting a variety of hydrological analyses and water resource management applications.

1.5 Volumetric Method

Volumetric measurements are a direct method for measuring discharge in small channels or low-flow conditions by capturing the entire flow over a measured period of time.

The flow is collected in a container of known (calibrated) volume, and the discharge is calculated by dividing the measured volume by the collection time. This method is most suitable for small streams, weirs, flumes, or outlets where flow can be easily contained and controlled.

Volumetric gauging is valued for its simplicity and high accuracy at low flows, and it is commonly used for calibration, verification of other methods, and spot measurements where more complex instrumentation is unnecessary.

1.6 Indirect Discharge Method

Indirect measurements are generally used for estimating flow when a direct measurement is deemed too dangerous, difficult or cost prohibitive to execute, often due to the remote nature and inaccessibility of the site during flood events.

Using empirical and/or numerical data, Indirect Measurements can also be used to estimate peak discharge after a high flow event.

Indirect measurements always rely on assumptions, theoretical relationships, and often with data collected at different points in time, which makes it very difficult, if not impossible to accurately quantify uncertainty.

1.7 Dilution Method

The dilution gauging method is an indirect measurement used to measure flow in open channels by analysing the dilution of a tracer introduced into the flow.

A known quantity of tracer, commonly salt or dye, is injected upstream and allowed to fully mix across the channel. The resulting change in tracer concentration is measured downstream over time or at steady state, and discharge is calculated based on the injection rate and the degree of dilution observed.

This method is particularly suited to turbulent, shallow, or irregular channels where conventional velocity–area measurements are impractical. Dilution gauging is valued for its accuracy under difficult hydraulic conditions, provided adequate mixing and appropriate tracer selection are achieved

2 Site Selection OR Monitoring Site Location

In this section

This section describes the physical requirements of a good open channel flow measurement site .

2.1 Sources of information

Use the following sources of information, where available or reasonably obtainable, to help decide the most appropriate stretch of river in which to locate the site:

- topographical maps
- aerial photographs and plans, including historical aerial photography
- local advice on access, stability, and history
- land ownership
- consent information about local water takes and discharges
- cross-sections, long-sections, bathymetry, and/or LiDAR
- historic and current information about other extreme measurements

2.2 Risk management

2.2.1 Site access

Site access shall be secure and safe for the period of measurements, and over the full anticipated range of measurement.

A long-term access agreement with any landowner(s) whose land must be crossed to gain access to the site is recommended.

2.2.2 Safety

Hazards (for observers, the public, livestock, and wildlife) related to the location and the measurement activity shall be identified and minimised.

2.2.3 Hazard review

On selection of a measurement site, a hazard review shall be carried out in accordance with:

- NEMS: - *Safe Acquisition of Field Data in and Around Fresh Water*
- relevant legislation

- relevant WorkSafe guidelines, and
- the recording agency’s organisational hazard management processes.

Any potential for human activity (e.g. vandalism) to affect measurements or curtail the life of a station shall be identified and minimised.

2.3 Site factors open channel flow measurement locations

When undertaking a discharge measurement using the Velocity-Area stationary meter method, it is important that the approach velocity is laminar.

Laminar flow (Figure 1)– When a fluid flows layer by layer, then this type of flow is called laminar flow.

Turbulent flow (Figure 1) – When a layer of a fluid gets mixed with other layers of the fluid, then this type of the flow is known as turbulent flow.

Within open channels, truly laminar flow seldom occurs however, within a good gauging reach that is 3-5 times the width and without significant in-channel obstructions the flow can be expected to be approximately laminar. In general, sites with a higher hydraulic radius (deeper, with a rectangular, trapezoidal or U-shaped channel) will produce a more standard velocity profile.

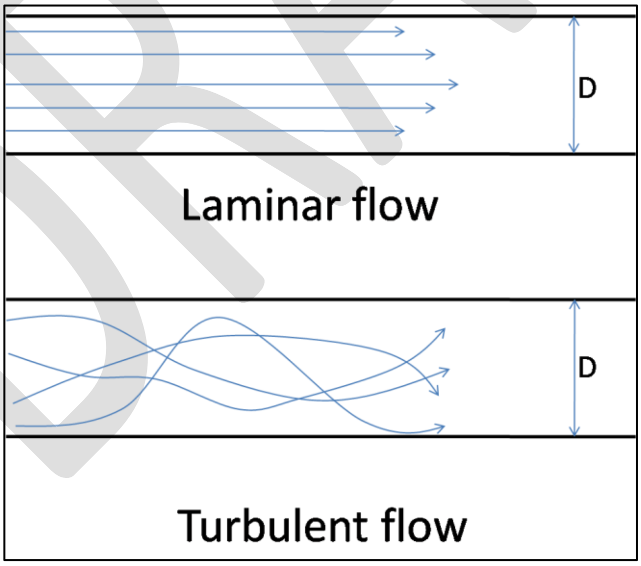
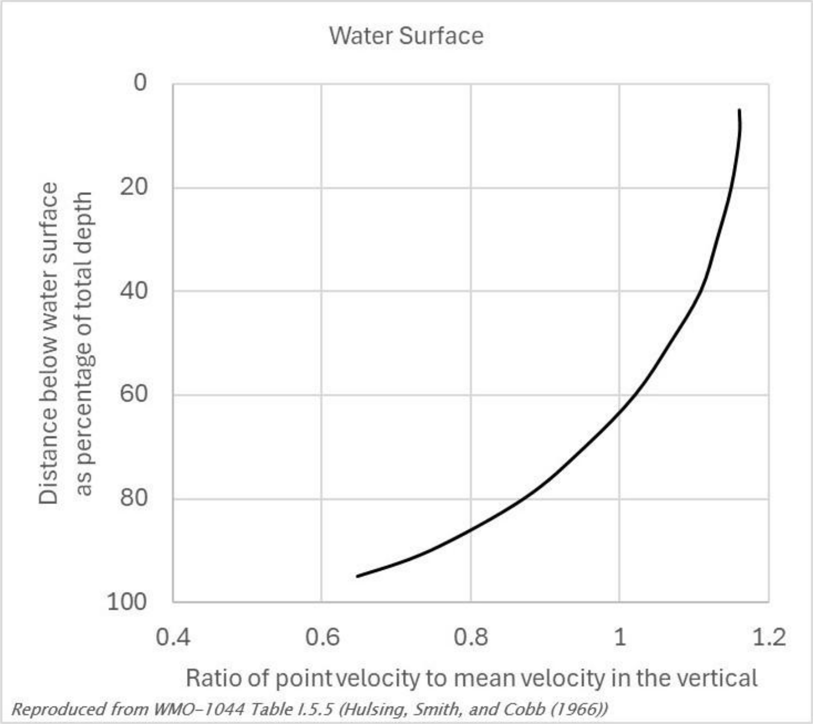


Figure 1 Schematic of laminar and turbulent flow

In the absence of laminar flow, the mean velocity measured at 0.6 of the depth, or that obtained by deriving the average of velocities measured at 0.2 of the depth and 0.8 of the depth, or that obtained by measuring the velocity at 0.2 of the depth, 0.6 of the depth and 0.8 of the depth [where the mean velocity in the vertical is calculated as {(V0.2 + V0.8/2) + (V0.6)}/2] will not approximate the mean velocity in the vertical.

Figure2 shows the velocity distribution, in a vertical, that should occur in a gauging cross-section that has laminar flow.



Reproduced from WMO–1044 Table I.5.5 (Hulsing, Smith, and Cobb (1966))

Figure 2:- Water depth versus the ratio of at point velocity to mean velocity

Figure provided by Hydronet Ltd.

For laminar flow to occur in a gauging cross-section it is generally accepted that a straight reach of a stream, or river, that is 3 -5 times the channel width is required upstream of the cross-section being measured. Figure 3 shows a gauging being undertaken in a very good cross-section that also meets the channel width versus reach length criteria described above.

Figure 3 - Very good gauging cross-section where flow should be close to laminar

Photo: - Environment Canterbury

However, even when undertaking a flow measurement in a channel that meets the above requirements, the velocity distribution in a vertical can still be severely affected by the presence of coarse bed material and the presence of weed growth within the channel. Figure 4 shows a stream where velocity observations taken at 0.6 depth are unlikely to provide a reasonable estimate of the mean velocity, even with considerable effort to clear weed from the channel.

While the removal of weed growth by raking of the stream bed can improve the vertical velocity distribution, a substantial length of channel will need to be cleared to achieve the 3-5 times channel width that can be expected to result in the vertical velocity distribution shown in Figure 5. If weed growth is removed downstream of the recorder location, the water level is likely to drop as the velocity will tend to increase. In such circumstances a rating change is likely to occur as a result of this weed clearance and thought needs to be given as to whether the flow measurement should apply to the rating prior to the removal of weed, or following it.

Where large bed material (diameter relative to water depth) exists within the gauging reach, consideration should be given to removing this material in order to create a good gauging reach that will not be subject to turbulence. Where it is not practical to remove the large bed material, other means of measurement (such as salt dilution gauging) should be considered. Figure 4 below shows a gauging reach where the use of a Flow Tracker (or similar instrument) or mechanical current meter is inappropriate and salt dilution gauging is likely to provide a superior measurement of flow.

Figure 4 Shows a gauging reach that is unlikely to have laminar flow and would be more suited to the salt dilution gauging methodology.

Photo: - Environment Canterbury

At higher flows and fast velocities, the existence of a sharp bend at the upstream end of the gauging reach can result in rotation of the water column to the extent that the fastest velocity may occur closer to the bed than to the surface. The vertical velocity distribution should normalise again within 3 -5 channel widths downstream.

Some of the strategies for minimising gauging errors due to the velocity in the vertical(s) not following the theoretical distribution are provided below:

1. Where weed is present (Figure: -5), measuring velocities utilising the 0.2, 0.6 and 0.8 method will generally provide a better estimate of the mean velocity (even in relatively shallow water) in the vertical than just measuring the velocity at the 0.6 depth.

Figure 5: - Stream with severe weed growth

Photo: - Horizons Regional Council

2. Where coarse bed material (boulders) exists upstream of (or within) the gauging section, and it can’t be removed, the 0.2, 0.6 and 0.8 method will generally provide a better estimate of the mean velocity in the vertical than just measuring the velocity at the 0.6 depth.

3. Where boulders exist, or the depths is changing abruptly, within or close to the gauging cross-section the measurement of velocities in additional verticals will significantly improve the accuracy of the gauging.

4. Where a sharp bend exists at the upstream end of the gauging reach, at least one gauging should be undertaken utilising the 0.2, 0.6 and 0.8 method, at higher flow to determine if the velocity at 0.6 depth (which is a method used to undertake a gauging as quickly as possible when stage is changing rapidly) provides a good representation of the mean velocity in each vertical.

Gauging's undertaken to test the validity of the 0.6 method of gauging should be calculated twice. Once using the 0.2, 0.6 and 0.8 depth velocities and then using just the velocities observed at the 0.6 depth. If these two calculations do not result in a discharge that is within 2% of each other, the 0.2, 0.6 and 0.8 depth velocity method should be adopted and all future high stage gauging's should be undertaken using the 0.2, 0.6 and 0.8 depth velocity method, or a boat mounted ADCP, as these methods will provide a better representation of the velocities in gauging sections where a non-standard distribution of the velocities exists.

The "gauging reach" is defined as being the distance above and below the gauging section, and at least 3-5 times greater than the width of the gauging section. For most situations, if this reach is clear, uniform, and free from obvious turbulence e.g. too steep, the velocity profile can be assumed to be reasonably laminar. For narrow, deep sections the above rule may not be adequate.

Using the width/length ratio of the section as a guide to determine site quality is simple, useful and particularly relevant in the case of a sharp bend at higher velocities as mentioned above. For the case of obstructions in the water interfering with the normal progression of flow downstream, however, the ratio of distance to obstruction vs depth is more relevant.

The distance required to return the flow to a normal distribution is dependent on many variables such as, the obstruction's height, roughness and shape, the ratio of the water column obstructed, the speed of the water, depth at the measurement site and bed roughness. For the purposes of this document, an obstruction is anything that obstructs more than 30% of the water column, all the way up to the surface, at which point it becomes an island, e.g. a boulder that sits 100mm off the bed in 290mm of water. Considering the lack of available data, and due to the many variables, a conservative requirement of greater than twenty times the measurement depth to the nearest obstruction can be used.

For most gauging sections, the width/length ratio provides a sufficiently conservative guide to account for effects of in-stream obstructions. In the below example, if the gauging section was 1m wide, a "clear" reach would only have to extend greater than 3m upstream. A requirement of a clear reach for twenty times the depth provides for better site quality assurance in this type of scenario.

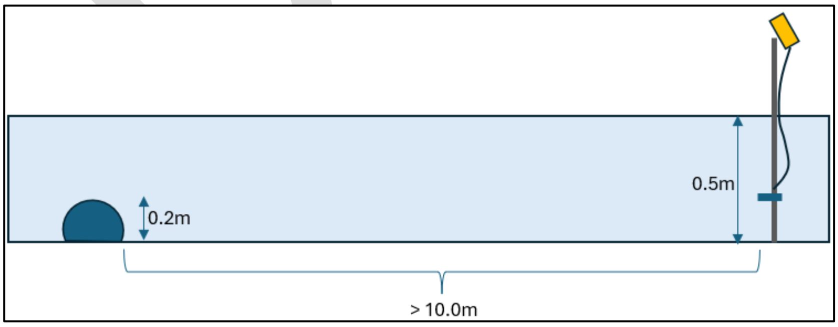


Figure 6 Graphical example of the distance to obstruction vs depth ratio approach

If a suitable site can be located (see section 3.2) and a unit is available, an ADCP (Acoustic Doppler Current Profiler) will produce more accurate results than either a mechanical current meter or hand-held ADV (Acoustic Doppler Velocimeter) or AECV (Acoustic Echo Correlation Velocimeter).

2.3.1 Monitoring purpose

Open Channel Flow measurements are often conducted at or near river level stations for the purpose of establishing rating curves to enable a continuous flow record to be produced.

See NEMS Water Level for details on full consideration of site factors beyond just the open channel flow measurement.

2.3.2 Location

If flow is to be derived by rating curves from the open channel flow measurements, the measurement site shall preferably be located in a long, straight reach that is also suitable for water level measurement (see NEMS Water Level). If some or all gauging must be undertaken in a different reach, account for conceivable inflows or outflows between the water level recording installation and the gauging location(s).

Note: High flows may need to be gauged from a bridge or cableway some distance from the recorder (and wading gauging section). In highly mobile rivers, gauging location may differ with each measurement. The further the distance between recorder and gauging sections the more uncertainty is introduced to the stage discharge rating due to possible inflows and outflows and time of travel. Inflows and outflows may arise from surface tributary inflows or diversions, gains from or losses to groundwater, or discharges to water or water takes,that may be seasonal or intermittent.

2.3.3 Access and legal requirements

Consider the following, in addition to section 2.2.1:

- the ability to position all equipment during measurement
- provision of safe access to the water's edge to carry out discharge measurements.

2.3.4 Range of measurement

The measurement site should preferably contain the full flow for the expected range of flows.

3 Velocity – Area Stationary Meter Method

In this section

This section contains information on measuring discharge in open channels using the Velocity-Area method with stationary current meters. This method has Standards associated with the following:

- site selection
- site primary reference
- measurement of cross-sectional area
- measurement of velocity
- calculation of discharge, and
- uncertainty in discharge measurement.

3.1 Principles

The discharge measurement shall be made by:

- meeting site-selection requirements
- subdividing a channel cross-section into segments, and then
- measuring the depth and velocity at the boundaries of each segment (referred to as 'verticals').

3.2 Site Selection

One of the most important steps to collecting high-quality data is site selection (Section 2).

Note: Many stationary meter measurement problems can be solved by moving to a better measurement site.

3.2.1 Selection Criteria

Where practicable, in addition to the overall site selection requirements identified in Section 2, the selected site shall:

- have enough depth across the channel to collect at least one velocity measurement at each vertical.

3.2.2 Flow Velocity

Where practicable, the selected site shall:

- have a cross-section with mean velocities within the current meter's calibrated range and

Note: Measurements can be made in lower velocities but it can be difficult to keep boat speeds, particularly large manned boats, less than or equal to the water velocity in these conditions.

- not have excessive turbulence, such as standing waves, large eddies and non-uniform flow lines.

3.2.3 Proximity to Water-Level Station

The measurement section shall be relatively close to the water-level station (if applicable) to avoid the effect of:

- tributary inflow between the measurement section and the control, and
- channel storage between the section and control at times of changing water level.

Note: These criteria may not be important for one-off spot measurements of flow but would be important for measurements used to derive water-level flow ratings at a water-level station.

3.2.4 Sites to Avoid

Where practicable, sites showing the following characteristics shall be avoided:

- water with insufficient acoustic scatterers as the amount of acoustic energy returned to the ADV and AECV would be too low to determine velocity.

Note: This can be avoided by seeding the flow upstream with sufficent material to create scatters.

3.3 Measurement of Cross-Sectional Area

Measurement of the cross-sectional area requires measurements of:

- width, and
- depth.

These measurements shall be taken, with calibrated equipment at sufficient points to establish the shape of the bed.

3.3.1 Measurement of Width

Width measurements:

- define the location of the required depth and velocity measurements across the selected cross-section, and

- provide the width parameter of each segment.

3.3.1.1 Criteria

Width measurements shall be made:

- as close as possible to right angles to the direction of flow
- along a horizontal plane in the line of the cross-section, and
- from, or to a fixed reference point.

Note: Where practicable, this reference point shall be installed permanently so that all measurements at a site have distances measured in the same terms.

3.3.1.2 Direct Physical Measurement

Width measurements by direct means shall use a graduated tape or suitable marked wire.

The graduations on tapes or wires shall be graduated to an accuracy of ± 0.5% of the total cross-section width, and have regular cumulative graduations (coded or digital).

3.3.1.3 Instrument Derived Measurement

Where the channel is too wide or impractical for direct physical means, measurements shall be made using one of the following technologies:

- optical distance meters
- electronic distance meters, or
- a Differential Global Positioning System (DGPS).

Note: These technologies may not achieve an accuracy ± 0.5% of the total cross-section width requirement and in this case the discharge measurement shall be quality coded accordingly.

3.3.1.4 Bridges and Cableways

On bridges or cableways, permanent width markings suitable for the vertical spacing or a calibrated tape or wires shall be used. The accuracy of the permanent markings shall be within ± 0.5% of the total width.

3.3.2 Measurement of Depth

Depth measurements:

- define the cross-sectional area, and
- provide the basis for locating the current meter velocity measurements.

3.3.2.1 Criteria

Depth measurements shall be made:

- at intervals close enough to define the cross-sectional profile accurately
- with intervals between verticals not greater than 1/20th of the width
- at 22 or more separate verticals

Note: A vertical is defined as a measurement of depth or velocity so edge measurements are included in the required number.

- at all verticals that velocity is measured
- at a resolution of ± 5 mm for depths < 0.3 m, or ±10 mm for depths > 0.3 m, and
- with instruments calibrated to ± 0.5 % of the instrument's range.

Note: Where abrupt changes in depth occur within the cross-section being measured, additional depth and velocity observations should be taken at these points of change.

3.3.2.2 Measurement Instruments

Depth measurements shall be made using any one of the following tools:

- pressure transducer
- echo sounder
- Acoustic Doppler Current Profiler
- wading rod, or
- gauging reel with sounding weight.

Note: Wading rods are commonly used for shallow water measurements, and gauging reels in deeper un-wadeable water. Pressure transducers, echo sounders and acoustic profilers are typically used in higher-velocity deeper water where there may be difficulty measuring the depth with a gauging reel and sounding weight.

3.3.2.3 Pressure Transducers, Echo Sounders and Acoustic Profilers

When using pressure transducers, echo sounders or acoustic profilers, at least one depth reading shall be taken at each vertical.

Note: Software associated with these devices typically averages many readings taken during the time taken measuring velocity at the vertical time interval.

3.3.2.4 Wading Rods and Gauging Reels

When using wading rods or gauging reels, at least two depth readings shall be taken at each vertical.

If the depth readings taken at a vertical are within 5%, their mean value shall be adopted.

If the depth readings taken at a vertical differ by more than 5%, two more readings shall be taken, and the mean value of all four readings shall be adopted.

3.3.2.5 Depth and Velocity Measurements Made at Different Times

If depth measurements are made separately from velocity measurements and the water level is not steady, then where practicable, the water level shall be observed at the time of each depth measurement.

If this is not practicable, note the time of each depth measurement and take water-level readings at sufficient intervals for interpolating a level for each depth.

3.3.2.6 Depth Measurements Made During Bed Profile Change

The bed profile may change appreciably during times of flood. In these cases, depth measurements at a vertical shall:

- be an average over the velocity measurement, and
- in the case of current meter measurements, this shall be a measurement at the beginning and end of the velocity measurement.

3.3.2.7 Inaccuracies in Depth Soundings

Consideration shall be taken in relation to inaccuracies in depth soundings that result from:

- departure from vertical of the sounding rod or line, particularly where the water velocities are high

Note: The drag effect on the sounding line may be reduced by using a streamlined lead sounding weight. A correction shall be applied to the wetted length of line if the line is not normal to the water surface. (Correction details can be found in ISO748:2021).

- penetration of the streambed by the sounding weight or rod, and/or

Note: This may be reduced by fitting a base plate to the sounding rod.

For the purposes of the Velocity-Area stationary meter method matrix, a "soft bed" is one that does not produce an obvious and immediate resistance to the momentum of the sounding instrument.

- the nature of the bed when an echo sounder is used

Note: A low frequency echo sounder (200 kHz or lower) is often more effective at accurately defining the bed-water interface than a high frequency instrument.

3.4 Measurement of Velocity

Velocity measurements:

- define the mean velocity in a vertical, and

- are made at fixed points on a vertical.

3.4.1.1 Criteria

Velocity measurements shall be made to meet the following requirements:

- velocity vertical spacing
- exposure time
- sampling technique, and
- instrument capability.

3.4.1.2 Velocity Vertical Spacing

Velocity measurement verticals shall be made:

- at a minimum of 20 (preferably 25) verticals, and

Note: When more than 30 verticals are measured, there is little improvement in the overall accuracy of the discharge measurement.

- at intervals:
    - no wider than 1/15th of the total width for a regular bed profile, or
    - no wider than 1/20th of the total width for an irregular bed profile
- with no partial segment containing more than 10% of the total discharge, or
- as close as practically possible for channels < 1metre wide.

Note: For most small current meters the practical width limit between verticals is 50 mm.

3.4.1.3 Exposure Time

The time of velocity measurement shall be:

- after the current meter has stabilised at the ambient point velocity , and
- at each selected point for a minimum of 40 seconds.

Note: ISO748 sets the minimum exposure time at 30 seconds. Historic and recommended exposure time in New Zealand and current technique with the United States Geological Survey (USGS) is to use a minimum of 40 seconds.

Exception: At times of rapidly changing flow, velocity observations may be reduced to 20 seconds; these discharge measurements shall be quality coded lower than QC600.

3.4.1.4 Sampling Technique

3.4.1.5 Minimal Flow Disturbance

The sampling of velocity shall use techniques that cause minimal flow disturbance from the personnel, boat or sounding weight

Note: For a wading gauging, the person gauging shall stand at least 0.5 m downstream and 0.5 m to the side of the current meter.

3.4.1.6 Alignment of Current Meters

The sampling of velocity shall use correctly aligned current meters. Some current meters can correct for the flow angle.

Important: A rotating-element current meter shall be aligned to the flow angle rather than be held normal to the cross-section, and this angle between the flow direction and perpendicular to the cross-section shall be measured and corrected. An ADV shall always be held perpendicular to the cross-section even if the flow angle is oblique as the instrument can determine flow angle and correct for it automatically during discharge calculation. Not all AECV instruments are capable of detecting/adjusting for angle of flow and you should refer to the manufacturer’s instructions for particular instruments.

3.4.1.7 Pre-Deployment Test

A current meter-validation test shall be completed before and after each discharge measurement.

Note: For a rotating-element current meter this is a spin test to check the meter spins freely. (See the instrument’s calibration certificate or manufacturer’s specifications.) ADV, and AECV instruments, or other electronic current meters, shall have a manufacturer-specific diagnostic test completed before the measurement.

3.4.1.8 Visual Examination Checks

The sampling of velocity shall include visual examination checks of the current meter during the discharge measurement, generally after each vertical is completed.

3.4.1.9 Instrument Capability

Current meters used to measure velocity shall be used within their specified:

- calibrated velocity range, and

Note: Low velocities (< 0.1 m/s) should be avoided with a mechanical current meter as any small deviation in meter performance will cause a large percentage error in velocity. The calibrated velocity range will be defined on the meters calibration certificate.

- depth range, where no part of a rotating-element current meter shall:
    - break the surface of the water, or

- be used where the depth at the point of measurement is less than four times the diameter of the propeller, or the body of the meter itself, whichever is the greater.

Note: An exception to this is the case where the cross-section is very shallow at one side and this is the best available section.

3.5 Instrument Validation and Calibration

3.5.1 Instrument Type

Any of the following meters may be used for measuring velocity:

- rotating-element current meter
- Acoustic Doppler Velocimeter (ADV)
- Acoustic Doppler Current Profiler (ADCP) profiler used as a stationary vertical profiler
- Pressure operated electronic meter (POEM) or
- Acoustic Echo Correlation Velocimeter (AECV).

Current meters shall be calibrated to meet the velocity measurement uncertainty requirements as specified in Table E.5 of *ISO 748:2021*.

Figure 7 – Examples of Velocity Current Meters

From left to right: Rotating-element propeller, Rotating-element cup, ADV, ADCP, POEM, AECV. Photographer: A. Willsman, NIWA.

3.5.2 Rotating-Element Current Meters

Rotating-element current meters shall be manufactured, calibrated and maintained according to *AS3778.6.3, ISO 2537:2007* and *ISO 3455:2007*.

This shall involve recalibration after two years of use or 300 hours of service, whichever is shorter. A recalibration shall be completed when a meter consistently fails a validation.

If the meter has been used in a compromised condition, then:

- it shall be calibrated before and after repair, and
- any change in calibration shall be applied retrospectively to gaugings since it failed validation.

3.5.3 ADV and AECV Current Meters

ADV and AECV current meters shall be calibrated in an approved velocity-rating tank initially, and then a calibration check every five years in a velocity-rating tank.

Note: A velocity-rating tank facility shall have an auditable quality management system.

3.5.4 Pressure Operated Electronic Meters

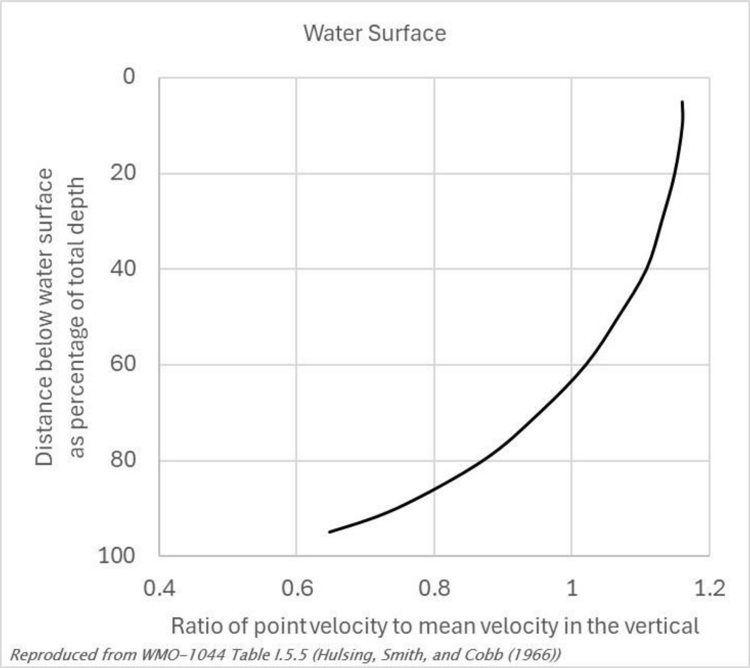
Pressure operated electronic meters shall be calibrated in an approved velocity-rating tank initially and then a calibration check every two years or 100 hours of service in an approved velocity-rating tank.

3.5.5 ADCP Instruments

ADCP shall be calibration checked when first acquired then every three years. Full details are described in subsection 4.5: ‘**Error! Reference source not found.**’.

3.6 Determination of Mean Velocity in a Vertical

Velocity typically varies throughout a vertical in a manner that is depicted in Figure 8. However, this only hold true where truly laminar flow exists. Conditions such as weed growth on the bed, a non-uniform cross-section, turbulence and other factors may alter this pattern markedly.



Reproduced from WMO–1044 Table I.5.5 (Hulsing, Smith, and Cobb (1966))

Figure 8: - Water Depth Versus Point Velocity to Mean Velocity Ratio

Diagram provided by Hydronet Ltd

The choice of method for determining velocity depends on a range of factors; for example:

- time available
- Rate of stage change
- depth and width of channel
- bed conditions in the measuring section
- rate of variation of flow, and
- equipment used.

A method may be classified as a:

- point method
- integration method, or stationary ADCP or AECV profiling method.

3.6.1 Point Methods

One-, two- and three-point methods are commonly used for routine discharge measurement because they take less time than the other multi-point methods. They are, however, based on theoretical velocity profiles shown in Figure 8

Note: Prior to adopting a single velocity point method, the accuracy of that method should be assessed by comparing results from a multi-point method to ensure that a single point method provides a discharge that is within 2% of the single point method.

Examples of reduced-point methods are:

- one-point method
- two-point method
- three-point method
- five-point method
- six-point method, and
- surface one-point method.

3.6.1.1 One-Point Method

Velocity observations shall be taken on each vertical by setting the current meter at 0.6 of the depth below the surface. The observed value is taken as the mean velocity in the vertical.

Note: This method is the least accurate, and it is preferable to use two or more points in the vertical. However, it is often necessary to use this method owing to depth limitations. For more information, see subsection 3.4.1.9: Instrument Capability, earlier in this document.

3.6.1.2 Two-Point Method

Velocities shall be measured at 0.2 and 0.8 of the depth below the surface, and the average of the two values is taken as the mean velocity in the vertical.

Note: This method is widely used and is recommended as the minimum standard method where depth allows (>0.5m).

3.6.1.3 Three-Point Method

Velocities shall be measured at 0.2, 0.6 and 0.8 of the depth below the surface. The mean velocity in the vertical may be calculated by first averaging the 0.2 and 0.8 measurements and then averaging the result with the 0.6 value, or by averaging the three values.

3.6.1.4 Five-Point Method

Velocities shall be measured at 0.2, 0.6 and 0.8 of the depth, and as near to the surface and the bed as possible. The mean velocity may be determined from a graphical plot of the velocity profile with a planimeter, or from the equation:

$$v = 0.1\left(v_{surface} + 3v_{0.2} + 3v_{0.6} + 2v_{0.8} + v_{bed}\right)$$

3.6.1.5 Six-Point Method

Velocities shall be measured at 0.2, 0.4, 0.6 and 0.8 of the depth, and as near as possible to the surface and the bed as possible. The mean velocity may be determined from a graphical plot of the velocity profile with a planimeter, or from the equation:

$$v = 0.1\left(v_{surface} + 2v_{0.2} + 2v_{0.4} + 2v_{0.6} + 2v_{0.8} + v_{bed}\right)$$

3.6.1.6 Surface One-Point Method

In flood or other conditions where the above methods are not feasible, velocity shall be measured at one point just below the surface. The depth of submergence of the current meter shall be uniform over all of the verticals and shall take account of the limitations related to meter rotor height; care shall also be taken to ensure that the observations are not affected by random surface or pressure waves or wind. In practice, a depth of 0.5 m or 1.0 m can be used.

The 'surface' velocity may be converted to the mean velocity in the vertical by multiplying it by a correction coefficient which will be specific to the vertical and to the discharge. The coefficient shall be computed for particular water levels by correlating the 'surface' velocity with the velocity at 0.6 or 0.2 and 0.8 depth. In general, this coefficient varies between 0.84 and 0.9 depending on the shape of the vertical velocity profile (although the coefficient can vary significantly).

Measurement of surface water velocities during medium- to high-stage gauging's will help to develop stage-mean velocity curves and mean velocity-maximum surface velocity curves, that can be used for higher-stage extrapolations.

3.6.2 Integration Method

In this method the current meter is lowered and raised at a uniform speed through the entire depth range of a vertical. The speed at which the meter is lowered or raised should be no more than 5% of the mean water velocity. At least 60 seconds of sampling shall be completed.

Note: This method:

- *shall not be used with rotating cup meters*
- *can be used with rotating-propeller current meters, but is not commonly used. For more details, see ISO 748:2021– section 7.1.5.4 .*

A pressure operated electronic meter (POEM) is the standard instrument for this method, as it is capable of sampling velocity and depth at the front of the instrument at a very high rate. This instrument and method is best suited to flooded river measurement as the POEM is not precise at water velocities < 1 m/s. The average velocity for the vertical is calculated in the POEM software by integrating the depth and velocity readings. For further information on the POEM instrument refer to Annex I

3.6.3 Stationary ADCP Profiling Method

Using an ADCP profiler mounted on a boat, velocity is measured in a vertical column from the surface. The ADCP is held in position on a boat at the surface and measures the velocities in the water column.

Measurements shall be taken at each vertical column.

Each water column shall be divided into depth cells, and a velocity is reported at each depth cell.

Note: An ADCP also measures streambed depth continuously, and so is also a depth-sounding device.

When measuring velocity:

- the ADCP shall be held stationary
- velocity readings shall be taken for a minimum duration of 40 seconds, and
- the flow angle between the ADCP and perpendicular to the cross-section shall be determined where necessary.

Note: Different methods exist within the Stationary ADCP Profiling Method. One requires that the ADCP is kept at 90 degrees to the tagline, one requires heading information from the ADCP and one ignores all angles, measuring magnitude only. Care must be taken to understand the differences and select the most appropriate method.

Note: An ADCP cannot measure velocity near the top of the water column because:

- *the transducers are submerged, and*

- *there is a blanking distance that corresponds to transducer and electronics recovery time.*

Note: An ADCP cannot measure velocity near the bottom of the water column because of acoustic signal side lobe interference.

3.6.4 Hand-held AECV's Method

Hand-held AECV's are point-velocity current meters that measure the full velocity profile in a vertical. Velocities are measured from the bottom to the surface simultaneously. Positioning at different sampling depths is not required.

Acoustic reflectors such as sediment particles and air bubbles that are present in the water are scanned with ultrasonic pulses and the reflected received signals are stored as echo patterns. Further ultrasonic scans are performed every few milliseconds and consecutive echo patterns are compared to determine the particulate movements, and thus water velocity, within the measurement window.

A full water depth velocity profile is determined by the instruments proprietary software, by analysing these measurements in up to 16 vertical slices or layers. The proprietary software also performs the discharge calculation and produces relevant hydraulic information, such as wetted perimeter and hydraulic radius.

The sampling methodology, site selection criteria and discharge calculation methods applied to undertaking a traditional mechanical current meter gauging also apply to the AECVs. These instruments types typically calculate discharge in accordance with ISO 748:2021 with options to use the Mean-Section or Mid-Section methods. The mean-section method shall be used in New Zealand.

AECV current meters are capable of operation in low velocities and shallow water depths.

3.6.4.1 Mean Vertical Velocity Calculation

The mean in vertical velocity is calculated in the ADCP and AECV software by averaging the measured velocities from the depth cells/layers, and velocity extrapolations at the top and bottom unmeasured areas.

Velocity extrapolations in unmeasured areas shall be checked for best fit by assessing:

- with field notes that record wind and current conditions at the time, and
- using specialised velocity extrapolation checking software, or other measuring instruments, for representative measurements at the cross-section.

3.7 Discharge Calculation Methods

There are two common arithmetic methods for calculating discharge from velocity and depth verticals, the differences being in the way the depths and velocities are averaged.

These methods are the:

- mean-section method, and

This method shall be the calculation method for this Standard.

- mid-section method.

This method is used in North America and Japan. For more information, see ISO 748:2021– section 8.3.2.

Two further arithmetic calculation methods are available for a unique flow condition or measurement type; these are:

- independent vertical method

This method is used for calculating rapidly changing discharge. For more information, see ISO 748:2021– section 8.4.

- float measurements

This is a calculation method used when velocity information is only available from time of travel of surface floats. For more information, see ISO 748:2021 – section 8.6.

Note: Either of these two methods shall only be used in rapidly changing flow or flood conditions.

3.7.1 Mean-Section Method

Discharge shall be calculated as follows:

- determine cross-sectional segments
- calculate the discharge of each segment, and then
- calculate total discharge.

Determine Cross-Sectional Segments

The cross-section is regarded as being made up of a number of segments, each bounded by two adjacent verticals (Figure 9)

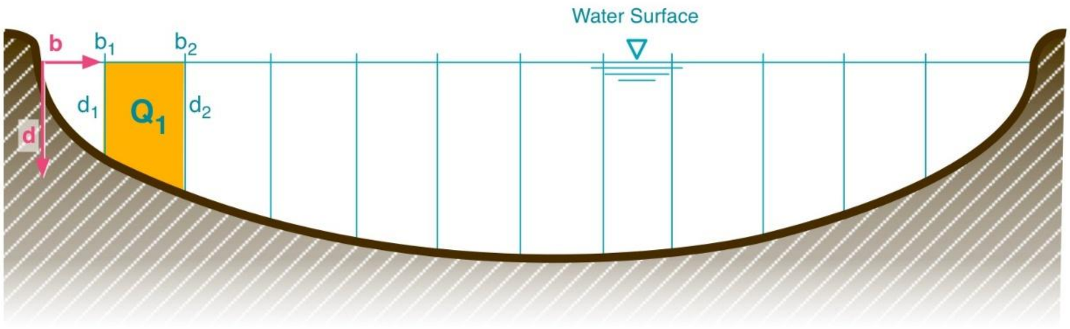


Figure 9 – Cross-Sectional Segments

Illustrator: Chris Heath

Calculate Segment Discharge

If v_1 and v_2 are the mean velocities at the first and second verticals, respectively, if d_1 and d_2 are the depths measured at verticals 1 and 2, respectively, and $(b_2 – b_1)$ is the horizontal distance between the verticals, the discharge in a segment is:

$$q_1 = (b_2 - b_1)\ x\ (d_1 + d_2)/2\ x\ (v_1 + v_2)/2$$

where:

- q_1 = discharge through segment 1
- b_1 = distance from initial point to vertical 1
- b_2 = distance from initial point to vertical 2
- d_1 = depth of water at vertical 1
- d_2 = depth of water at vertical 2
- v_1 = mean velocity in vertical 1, and
- v_2 = mean velocity in vertical 2.

Note: The additional discharge in the segments between the effective water's edge and the first vertical, and between the last vertical and the other effective water's edge can be estimated as a proportion of the velocity at the adjoining velocity vertical.

3.7.2 Calculate Total Discharge

The total discharge is obtained by summing the discharges for all segments.

4 Velocity – Area ADCP Moving Boat

In this section

Provide a concise summary of the section's content. The subheadings below should be in the order of, and flow logically from the summary.

4.1 Principles

4.1.1 Discharge Measurement

The Acoustic Doppler Current Profiler (ADCP) is a device that measures discharge by using sound and the Doppler principle.

It works by:

- boat mounting an ADCP with transducers beneath the water surface, aimed downward, and moving the boat across the river channel
- emitting acoustic signals from transducers and receiving acoustic energy reflected back from small particles of sediment and other material (collectively called scatterers) that are present in the water to measure Doppler shifts

Note: It is assumed that the scatterers are moving at the same velocity as the water.

- converting the measured Doppler to velocities parallel to the transducer emitting and receiving the acoustic energy
- obtaining three-dimensional velocities by the use of three or four beams pointing between 20 and 30 degrees from the vertical
- measuring velocities over a large part of the water column beneath the ADCP continuously
- using Doppler shift bottom tracking, or an external GPS, to determine the velocity of the boat over the streambed, then converting water velocities to a fixed reference system, and
- measuring depth in transducer beams, or with an echo sounder.

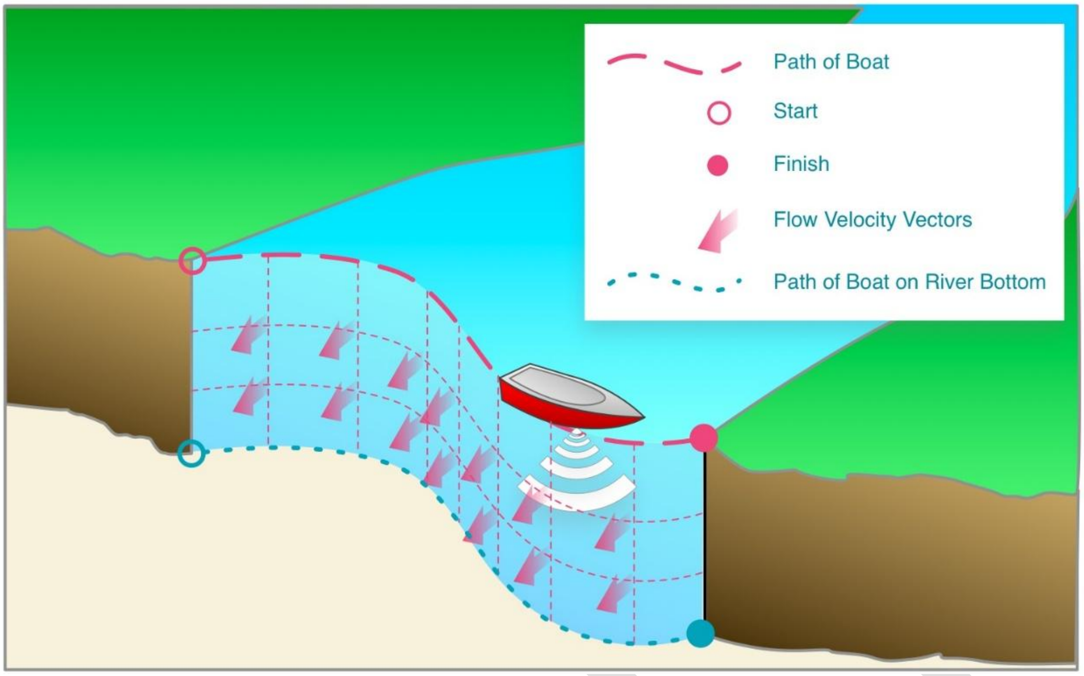


Figure 10 – An ADCP Mounted on a Boat Measuring Discharge of a River

Acoustic beams are directed down into the water as it guided across a river channel.

Illustrator: Chris Heath.

4.1.2 Speed of Sound

The velocity calculation is directly related to the speed of sound in the water, which varies with changes in:

- water temperature
- salinity
- pressure, and
- sediment concentration.

ADCPs that do not compensate for speed of sound changes shall not be used.

Note: Manufacturers of ADCP instruments measure water temperature, the most important sensitive component, near the transducer faces and apply correction factors to allow for temperature-related differences in the speed of sound.

If the instrument is to be used in waters of varying salinity then independent measurements of salinity shall be taken and instrument software shall be used to correct the speed of sound.

Note: A temperature change of 5 °C, or a salinity change of 12 parts per thousand, results in a change in speed of sound of 1%.

4.1.3 Discharge Calculation

Measurements of depth, velocity profiles, distance and direction travelled are then combined to calculate discharge.

Note: Complex calculations are involved in the discharge calculation requiring manufacturer software and a computer. Calculation details are in Mueller and Wagner (2009).

Measurement of all these parameters continuously means that:

- transects do not need to be in a straight line, or at right angles to flow
- measurements are much faster than standard Velocity-Area stationary meter methods
- many data points can be measured across the river as ADCPs measure velocities in large parts of the water column and depths at many points, and
- non-standard velocity profiles can be measured.

4.2 Site Selection

One of the most important steps to collecting high-quality data is site selection (Section 2).

Site selection guidelines for an ADCP measurement are very similar for the Velocity-Area stationary meter method although there are some differences.

Note: Many ADCP measurement problems can be solved by moving to a better measurement site.

4.2.1 Selection Criteria

Where practicable, in addition to the overall site selection requirements identified in Section 2 the selected site shall:

- have enough depth to collect two or more depth cells at the start and stop points, and
- have enough depth across the channel to collect at least two depth cells.

4.2.2 Flow Velocity

Where practicable, the selected site shall:

- have a cross-section with mean velocities greater than 0.1 m/s, and

Note: Measurements can be made in lower velocities but it can be difficult to keep boat speeds, particularly large manned boats, less than or equal to the water velocity in these conditions.

- not have excessive turbulence, such as standing waves, large eddies and non-uniform flow lines.

4.2.3 Proximity to Water-Level Station

The measurement section shall be relatively close to the water-level station (if applicable) to avoid the effect of:

- tributary inflow between the measurement section and the control, and
- channel storage between the section and control at times of changing water level.

Note: These criteria may not be important for one-off spot measurements of flow but would be important for measurements used to derive water-level flow ratings at a water-level station.

4.2.4 Sites to Avoid

Where practicable, sites showing one or more of the following characteristics shall be avoided:

- any large steel structures nearby that may have magnetic fields that cause ADCP compass errors
- when using GPS, locations where multipath interference is possible, or GPS satellite signals may be blocked

Note: Large obstructions on the banks such as trees and buildings or steep banks rising above the river may all cause problems for GPS systems. It may be possible to make successful measurements in these conditions but look for a better section first.

- water with insufficient acoustic scatterers as the amount of acoustic energy returned to the ADCP would be too low to determine velocity
- high sediment loads in the water column, as this can result in a reduced depth range, and/or
- excessive moving bed, particularly when alternative GPS reference systems are unavailable.

4.3 Pre-Measurement Checks

Before conducting field measurements, all of the following tasks shall be performed:

- water temperature
- salinity measurement (where applicable)
- instrument diagnostics
- compass calibration
- ADCP configuration, and

- moving bed tests Whenever possible and mandatory for bottom track reference boat velocity.

On completion, one or more of the above tasks, e.g. the moving bed test, may require you to find a more suitable site.

4.3.1 Water Temperature and Salinity Measurement

Water temperature and salinity can affect the speed of sound.

Prior to measuring discharge:

- water temperature shall be checked using a calibrated thermometer

Note: An ADCP in-built thermometer should be within ± 2 °C of an independent check. An error of 5 °C at a water temperature of 20C will potentially cause a 3% bias error in the discharge result.

- where saline water may be present, salinity shall be measured using a calibrated conductivity sensor. If salinity is likely to vary over time it shall be measured for every transect
- salinity may vary from bank to bank; in this case, multiple measurements shall be taken across the transects and the average salinity shall be used for the transect.

4.3.2 Instrument Diagnostics

Prior to measuring discharge:

- the ADCP internal clock shall be checked against local standard time, and a correction made if necessary, and
- internal instrument components shall be checked by running diagnostic software.

Note: Only use the diagnostic software that was provided by the manufacturer for the ADCP model you are using. ADCP software provides a file-archiving system to store diagnostic tests in each discharge data file.

4.3.3 Compass Calibration

The ADCP internal compass shall be calibrated prior to:

- completing a loop moving bed test, or
- using the GPS as the boat velocity reference.

Compass calibration shall be completed:

- using the manufacturer's software and procedure
- at the site and in the boat mount to represent the local magnetic conditions

- by minimising any ferrous material or electromagnetic sources in the immediate vicinity, and
- using rotation velocities specified by the manufacturer.

After calibration the total compass error should be less than that specified by the manufacturer, and/or the threshold in the data collection software.

Note: Some ADCPs do not have a compass so this calibration procedure is not required for these instruments.

4.3.4 ADCP Configuration

Prior to deploying the ADCP at any site, the following parameters shall be entered into the ADCP software:

- file names for the data files

Note: The file names shall follow a uniform documented naming convention.

- the depth of the ADCP reference point beneath the water surface

Note: Manufacturer documentation shall be used to determine the ADCP reference point.

- magnetic declination if a GPS reference is to be used

Note: Magnetic declination values are available for NZ from
https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination
A number of phone apps also are able to provide the current and previous magnetic declination. Ie MagVar

- information on site characteristics such as maximum water depth, type of bed material, and expected water and boat speeds, and

Note: Some ADCPs automatically set maximum water depth and speed as they collect data so this information will not be required at the configuration stage.

- wind speed and direction.

Note: Some ADCPs software may not be capable of accepting this information; in these cases, this information shall be documented on a gauging card/field sheet.

After configuration a trial transect may be useful in determining the appropriateness of the ADCP settings.

Note: Start and stop locations to satisfy a minimum of two depth cells can be determined during this trial transect.

4.3.5 Moving Bed Tests

Before making discharge measurements, a moving bed test should always be conducted. If using bottom track as the boat speed reference, a moving bed test must be conducted.

***Important**: ADCPs use bottom tracking. Bottom tracking assumes the streambed is stationary; however, sediment transport on or near the streambed can affect the Doppler shift of the bottom-tracking pulses. If sediment is moving, a stationary boat will appear to move upstream and will result in measured velocities and discharges that are biased low.*

There are two methods for testing for a moving bed, and procedures for measuring discharge if moving bed is present; these are the:

- stationary moving bed test, and
- loop moving bed test.

4.3.5.1 Stationary Moving Bed Test

A stationary moving bed test, e.g. Figure 11, shall be completed by:

- holding the boat at a stationary position on the river where there is potential for moving bed and collecting data for longer than 5 minutes; this requires a tether, anchor or GPS reference to maintain position, or
- if a boat operator is trying to hold station to visual reference points, at least 10 minutes of data shall be collected, and
- any apparent movement upstream in the boat ship track during the test shall be assessed for significance with the thresholds in Table 5, or computed using ADCP manufacturer or USGS software for this purpose.

Conduct further testing if there is any doubt about the validity of the test.

More tests should be made at other parts of the cross-section.

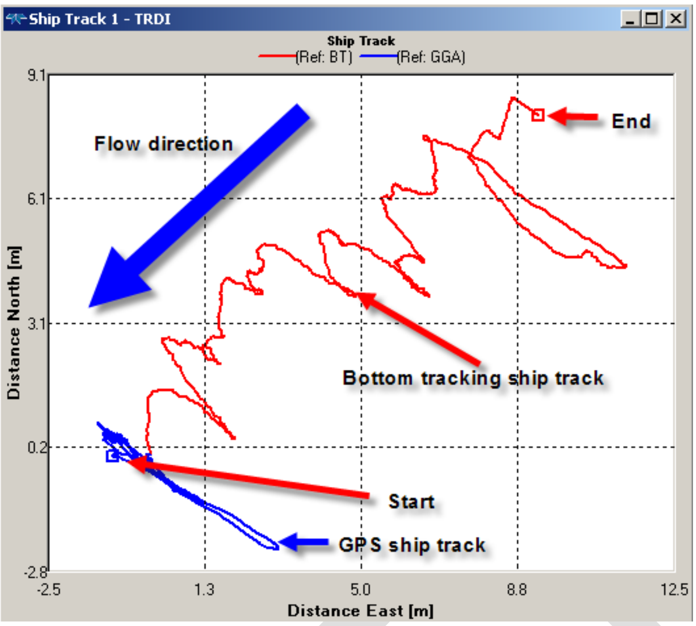


Figure 11 – Example of a Stationary Moving Bed Test Carried Out on an Anchored Boat with a GPS

The red ADCP bottom track has moved upstream 12 m over 10 minutes while the blue GPS ship track has not moved upstream, just swung sideways over time on the anchor. Moving bed velocity = 0.017 m/s. Illustrator: Andrew Willsman.

4.3.5.2 Loop Moving Bed Test

A loop moving bed test, e.g. Figure 12, can be more representative of moving bed conditions in the whole channel although it does require an ADCP with a compass.

This test shall be carried out by:

- ensuring the compass is well calibrated at the site
- collecting data as a loop is made from a known starting point on one bank across the river and back to the exact starting point, and

Note: This method requires bottom tracking to be maintained during the test.

- visually assessing the recorded ship track. If moving bed is present then the end position of the loop will be significantly upstream of the start position.

Any apparent upstream movement in ship track shall be:

- calculated for significance against thresholds (see Table 5), or
- computed using ADCP manufacturer or USGS software for this purpose.

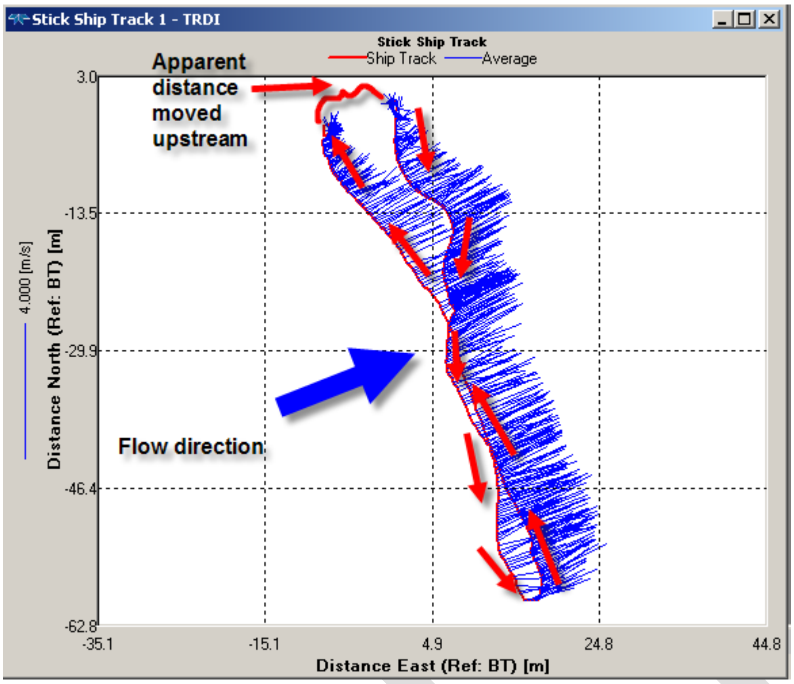


Figure 12 – Example of a Loop Test with a Distorted Ship Track Caused by a Moving Bed

Distance moved upstream = 8.1 m, duration = 275 s, average moving bed velocity = 0.029 m/s. Illustrator: Andrew Willsman.

4.3.5.3 Moving Bed Alternatives

If moving bed is found to be significant and it is not possible to find an alternative site with no moving bed, then one of the following methods may be used:

- GPS can be used as the reference for the boat velocity, if this is available and valid.
- The stationary ADCP profiling method can be used, as the bottom track reference is not required for this method.
- The discharge measurement can proceed, and the potential error determined by the moving bed test can be applied to adjust the discharge results. QREV shall be used to complete this calculation. For more information see Annex B – Moving Bed Test Correction Annex B – 'Moving Bed Test Correction'.

Note: No preference is implied by the order of this list as the accuracy of each alternative method will depend on the specific flow and site conditions at the time of measurement.

4.4 Discharge Measurement

When completing a discharge measurement during steady flow conditions, the following rules shall apply:

- The edge distances from the start and stop positions to the water's edge shall be measured.

- The draft of the ADCP must be measured.
- At least 10 ensembles of data shall be collected at the start and stop positions.
- An even number of transects (opposing directions) shall be collected.

Note: Opposing pairs allow for averaging of any potential directional bias.

- Where GPS is the boat velocity reference, a valid local magnetic variation must be entered.

Where practicable:

- the boat speed shall be less than the water speed for the majority of all transects (i.e. excludes edges).
- the total exposure time shall be at least 720 seconds (12 minutes)
- boat operation shall be as smooth as possible
- rapid course changes shall be avoided, and
- transects with identifiable problems shall be replaced with transects in the same direction.

Note: Common identifiable problems are:

- *improper boat operation*
- *significant loss of bottom track*
- *other boats passing*
- *configuration errors, and*
- *excessive pitch and roll.*

4.5 Instrument Validation and Calibration

The configuration, frequency and techniques used to configure the ADCP may limit the depth and velocities that can be measured.

Instrument specification sheets and instrument configuration wizards shall be used to determine the limits of measurement.

ADCPs fit into a range of general categories based on the:

- quantity of transducers
- configuration of transducers.
- transducer frequency, and
- techniques that are used to configure and process the acoustic signal.

4.5.1 Configuration of Transducers

Typically, four or eight transducers are used.

Figure 13 – Examples of ADCP Transducer Configurations

From left to right: 4-beam Janus; 8-beam dual frequency Janus with an addition echo-sounder transducer in the centre; phased-array configuration capable of generating 4 Janus beams from the flat transducer face.

From left to right: photographer: A Willsman, NIWA; used with permission from Sontek YSI; used with permission from Teledyne RDI.

4.5.2 Transducer Frequency

Typical frequencies used for river discharge measurements vary between:

- 600 kHz, and
- 3000 kHz.

4.5.3 Instrument Quality Assurance

Although ADCPs have no moving parts and typically require no calibration, the instruments and associated software and firmware are complex. Quality assurance procedures will help identify potential instrument issues.

Procedures shall be established for:

- software and firmware upgrades
- calibration checks, and
- changes to ancillary equipment.

  For example, depth sounder, thermometers, GPS, travelling system.

4.5.3.1 Software and Firmware Upgrades

Upgrades to software and firmware are common, and many upgrades result in minor improvements that do not substantially change the quality of the discharge result.

There is the potential for major changes that can affect the results so the following practice shall be adopted:

- An instrument history log shall be kept to track firmware changes over time.

- A transformation matrix check shall be made after the firmware change to ensure that the instrument-specific matrix has been retained.

Note: Details of the instrument's original transformation matrix will be supplied by the manufacturer. Instrument software will output the current matrix with an instrument test command.

- The most recent version of software and firmware approved by the USGS Office of Surface Water shall be used.

Note: The USGS provide information at the OSW hydroacoustics web page hhttps://www.usgs.gov/hydroacoustics.

- Any versions of software and firmware not approved by the USGS Office of Surface Water shall be tested before using the instruments for routine data collection.

Note: Testing shall involve making comparison discharge measurements with discharge measurements from some other source, such as a rotating-element current meter.

4.5.3.2 Calibration checks

The purpose of calibration checks is to verify that the ADCP is working to enable accurate discharge measurements.

Each instrument shall have its calibration checked:

- when the ADCP is first acquired
- after factory repair or modification, and
- within three years of the previous calibration check.

Calibration checks can be performed using one or more of the following methods:

- Conduct a beam alignment check in a tow-tank or against a GPS reference system.

Note: This is recommended for a new ADCP or after a transducer repair or replacement along with a comparison measurement check. Details can be found in Mueller and Wagner (2009); see Annex A.

- Compare ADCP measured discharge with rated discharge at a site with a known stable rating.
- Compare ADCP discharge results with concurrent measurements made using an independent method.

Note: Check at different sites at periodic intervals so a range of hydrologic conditions are reflected in the tests.

The discharge obtained from the ADCP should be within 5% of the known stable rating or independently measured discharge.

Note: If the ADCP measurement departs by more than 5% from a discharge rating, then it is possible that the rating has shifted. Another measurement with a second ADCP or other current meter should be made to check the validity of the rating.

A consistent bias in measurements not attributable to rating change shall be investigated.

4.6 Discharge Calculation Methods

Software from different manufacturers use different algorithms for various aspects of the data processing and discharge computation. The final discharge calculation shall be made using the QRev/QRevInt software (See Annex E).

In steady flow conditions the discharge shall be calculated by taking the mean of the individual transect discharges.

Note: Transect with identified quality problems shall not be included in the discharge average.

During unsteady flow conditions it may be necessary to use individual transects as discrete measurements of discharge, although it is preferable to use reciprocal pairs to reduce directional bias. These measurements will be downgraded when the Quality Coding matrix is applied.

The rationale for using individual transects shall be documented and stored in the metadata associated with the measurement.

4.7 Ancillary Equipment

The ADCP is the primary equipment although ancillary equipment will help achieve an accurate measurement in a variety of conditions. Not all equipment is necessary for every measurement as this is dependent on the conditions encountered.

Ancillary equipment that is available for ADCP measurements include:

- GPS instruments
- echo sounders
- specialised boats, and
- distance measuring equipment.

4.7.1 GPS Requirements

Using GPS to measure boat velocity is the preferred method of data collection for a moving transect when:

- moving bed conditions are present, and/or
- bottom tracking fails.

GPS provides two options, either of which shall be used for providing boat velocity:

- Differentiated position (GGA sentence): this requires a differential GPS correction source from a real-time kinematic (RTK) system, or a wide area correction service transmitted over satellite, radio, or cell phone systems.
- Velocity and direction (VTG sentence): this is based on Doppler shifts in the satellite signals and does not require differential corrections. This does require more complex

receivers that are capable of providing accurate non-filtered results. At slow boat speeds (< 0.25 m/s) and in narrow channels (< 25 m wide) considerably more variation may occur in the discharge transects.

Note: USGS OSW hydro acoustics and manufacturers can provide recommendations for GPS receivers that can output accurate VTG sentences.

4.7.2 Echo Sounders

Streams with high concentrations of fine sediment and sand being transported on or near the streambed may cause inaccuracies in ADCP water-depth measurements. In these conditions, using a low-frequency echo sounder (approximately 200 kHz) to measure water depth may be necessary.

If an echo sounder is used it shall be calibrated as part of the pre-measurement procedure by using:

- a bar check procedure, or

Note: A bar check involves lowering a flat plate beneath the transducer to known depths to calibrate the echo sounder. This standard procedure may be impractical at many river discharge measuring stations due to the difficulty in suspending and holding a plate in a stable position in moving water.

- by calibrating echo sounder data to an independently measured depth in a stable part of the channel.

4.7.3 Boat Requirements

Every measurement site has unique features that may determine the best type of ADCP deployment boat. Site features may include hydraulic characteristics, such as water velocity, and access considerations, such as the presence of boat ramps, bridges or cableways.

Three common types of ADCP boats are:

- manned boats
- tethered boats, and
- remote controlled boats.

4.7.3.1 Manned Boats

An ADCP can be mounted on either side, off the bow, or in a well in the centre of the boat. There are advantages and disadvantages for each of these locations, and details of these can be found in Table 4 of Mueller and Wagner (2009).

An ADCP mount on a boat shall meet the following criteria:

- be constructed of non-ferrous material, and be situated away from other ferrous material in the boat so as to not cause ADCP compass errors

Note: A good rule of thumb is that an ADCP should not be mounted any closer to a steel object than the largest dimension of that object.

- be situated far enough away from the engine of the boat so electromagnetic forces do not cause ADCP compass errors
- allow the ADCP transducers to be positioned free and clear of the hull to minimise hull flow disturbance
- hold the ADCP in a fixed vertical position so the transducers are submerged at all times
- be adjustable for depth, and boat pitch-and-roll, and
- be rigid enough to withstand the force of water caused by the combined water and boat velocity.

4.7.3.2 Tethered Boats

These are a small, unmanned boat generally less than three metres long that are attached by a tether or rope that enable them to be deployed from a bridge, cableway or temporary bank-operated cableway.

Tethered boats shall meet the following requirements:

- be equipped with a mount that meets the criteria of the boat mount, and
- be deployed using a method of towing where the operator is not standing in the water upstream of the boat or standing in the water in a position close enough downstream to cause flow disturbance.

Note: If a tethered boat is to be hand towed from in the water then a long pole shall be used to enable the operator to position himself well downstream of the boat.

4.7.3.3 Remote-Controlled Boats

These allow deployments where a manned or tethered boat may not be feasible or ideal. Mount and operational requirements are the same as manned boats. Regular maintenance of the boat and control radios is critical to ensure reliable operation.

Note: Remotely controlled boats that are utilised for environmental monitoring purposes (primarily utilised for, but not limited to, undertaking ADCP gauging and bathymetric surveys) msay be considered by Maritime New Zealand to be commercial vessels, and as such their use may need to comply with Maritime New Zealand Rules and regulations. Therefore, it is likely that these craft may need to operate under MOSS, or under a specified limits plan under Part 20 of the Maritime Safety Act; 1994. Check with Maritime New Zealand to ensure that you meet their requirements for the use of such craft.

5 Velocity – Area Surface Velocity Method

In this section

This section sets out the minimum requirements that shall be followed to allow the collected data to withstand independent validation and integrity checks and to ensure consistency in the methodology applied across organisations.

The required procedures and methods for collecting and processing of surface water velocity data using image velocimetry and radar systems are specified.

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 will be sufficiently robust to withstand independent scrutiny and be aligned with this standard.

This section must be read in conjunction with the National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021(Australian Government Bureau of Meteorology). http://www.bom.gov.au/water/standards/documents/NI_GL_100.11-2021.pdf

http://www.bom.gov.au/water/standards/niGuidelinesHyd.shtml.

5.1 Principles

Surface velocimetry enables the estimation of discharge using non-contact methodologies. These methodologies are generally utilised when higher flows preclude the use of more accurate methods such as ADCP's or mechanical meters. Surface velocimetry is currently undertaken within New Zealand using surface velocity radar and video imagery.

The application of an Alpha value (the ratio of mean velocity to maximum surface velocity) is required to obtain a discharge when using either of these two methodologies and every endeavour should be made to derive stage/alpha and/or discharge/alpha curves for all sites where these measurement methodologies are utilised. These relationships can be established by extracting the maximum surface velocity and mean velocity from all gaugings undertaken, using more robust gauging methodologies, at medium to high flows.

5.2 Site Selection

The water at the site selected must have sufficient surface traces to enable flow directions to be detected on the imaginary. These trace elements can be either natural or artificial and/or surface flow patterns. The natural tracers could include, sticks, debris and bubbles. In the absence of natural tracers, biodegradable artificial tracers can be distributed across the water surface (such as lightweight breakfast cereal or wood chips).

The effects of pier, or other flow disturbances should be avoided and if near a structure such as piers that produce a wake then the video should be taken looking upstream to eliminate the effects of such disturbances.

The river reach of the video should ideally have a stable cross section and not be subject to erosion. This is not that common in New Zealand rivers so repeated surveys of cross sections over a period of time and after major flood events will help to determine if the site is stable.

It is important that the chosen site has a stable cross-section that does not change during flood events.

Scouring, or deposition, of material in gravel bed rivers during flood events can result in very significant changes to cross-sectional area, and hence the discharge at high flows. These changes in cross-sectional area may also result in variability in the Stage/Alpha curve established for a site. Therefore, surface velocimetry methods for determining discharge should be used with caution in gravel bed rivers.

5.3 Pre Measurement Checks

5.4 Measurement of Cross-Sectional Area

Requirements and limitations pertaining to method and equipment choice after a suitable site has been selected. May refer back to Site factors (section 2.3).

Peg the waters edge at the time of measurement (or take a photo of waters edge with visible fixed references visible). The cross-section can be surveyed at the time, or after flood event.

Cross-section bathymetry, typically surveyed after the event.

- Cross section start and finish points should be pegged on the channel banks and be visible in the collected imagery, or;
- the cross section should span between fixed reference points (e.g. rocks, trees etc.) and be visible in the collected and orthorectified imagery.

5.5 Measurement of Velocity

5.5.1 Velocity for Drone Video

5.5.1.1 Video Requirements

The video camera resolution should be at least 1080p or 4k, which most smart phones having a minimum of 24 frames per second (NI GL 100.11-2021) can achieve.

A minimum video duration of 30 to 90 seconds is recommended with the target being 60 seconds and no wide angle lens or other distortions to ensure a good quality image.

A drone platform should be as stable as possible with the camera pointed in a vertical (nadir – directly below) position..

5.5.1.2 Field of View Requirements

The entire width of the channel must be visible in the imagery at the measured cross section or in a flood situation where multiple videos are required to cover the total wetted width.

5.5.1.2.1 Visible items (Vertical imagery)

Fixed reference points on both sides of the channel must be visible and easy to identify.

Cross-section start and finish marks must be placed at the water edges so that the section can be surveyed later. It would be an advantage to have a survey of the cross section pre and post image capture, but this is not always possible.

The water level must be pegged at the time of the collection of the surface velocity imagery and be visible on the imagery to enable a cross section to be surveyed after the image capture.

A minimum of 2 points (x,y left bank, x,y right bank) should be surveyed to establish their position and be visible on the imagery to enable scaling the image. Alternatively, you could place a survey staff horizontally and parallel to the water's edge and use that for the scaling of the video.

Knowledge of changes in cross sections at the site over time would be an advantage as it may provide some insight into how the channel changes during flood events.

5.5.1.2.2 Visible items (Oblique imagery)

The entire width of the channel must be visible in the imagery at the measured cross section or in a flood situation where multiple videos are required to cover the total wetted width and the fixed reference points must be visible for section measurement.

A minimum of 6 Ground Control Points (GCPs) with 3 on each side of the channel is required, 8 (4 each side of the channel) is best practice (NI GL 100.11-2021). These GCP's require 3D surveying (x,y,z positioning) with total station, or RTK/PPK GPS in order to accurately determine their location. These points should be evenly distributed on both banks.

Alternatively, 4 GCPs at water level, with 2 each side of the channel (can be at waters edge), that are visible in the imagery and are surveyed at the time (or later) can be utilised. Distances between all the GCPs (including diagonals) are required for orthorectification, but not their elevations, therefore RTK/PPK GPS, or total station, survey is not required.

5.5.1.2.3 Camera angle

For oblique imagery a high angle is best (should be 90°, vertical, Nadir), therefore look down on the water as opposed to looking across it and ensure that all the ground control points are visible in the fields of view. If standing on the bank, ensure angle to the water level at the far bank is greater than 15°.

If standing on a bridge, ensure all visible fixed reference points are in the field of view**.**

5.5.1.2.4 Lighting

To ensure the best possible imagery minimise shadows and reflections on the water surface and also try to minimise sun-glint, which can be difficult to achieve for all hours of the day and different seasons

5.5.1.3 Control Points and Additional Measurements

The correct placement of survey control points for video imagery is fundamental to obtaining a useful discharge measurement and care should be taken to ensure that the desired outcome is achieved

5.5.1.3.1 Control Points (Vertical imagery)

A minimum of 2 ground control points (x,y) is required for scaling imagery. The larger the object, or further apart the points the better (as the scaling will be more accurate).

Objects for scaling could include: survey staff, kayak/boat, fence posts, bridge piles (if vertical), vehicles. Other objects, or points for scaling could include:

- visible objects/points along waters edge (e.g. vegetation, boulders),
- reference pegs,
- visible objects/points on either side of cross section.

These points should be located at or as close as possible to the water surface and the distance between these points known or can be measured.

5.5.1.3.2 Control Points (Oblique imagery)

A minimum of 6 Ground Control Points (GCPs) with 3 each side of the channel is required, 8 GCP's with 4 each side of the channel is best practice (NI GL 100.11-2021). These GCP's require 3D surveying (x,y,z positioning) with total station, or RTK/PPK GPS in order to accurately determine their location. These points should be evenly distributed on both banks.

Alternatively you could use 4 GCPs at water level with 2 each side of the channel (can be at waters edge), that are visible in the imagery and are surveyed at the time (or could be later). Distances between all the GCPs (including diagonals) are needed for orthorectification, but not their elevations, so does not require RTK/PPK GPS or total station.

When only using 4 GCPs at water level, they do not need to form a perfect square. Survey stakes can be used, or rocks, trees etc.

5.5.1.3.3 Additional Measurements

The distances between the 4 ground control points (GCPs) at water level, including diagonal distances need to be surveyed and recorded using RTK GPS or survey tape.

The 3D locations of GCPs using RTK GPS (for 6+ GCPs on channel banks). Must also be surveyed and recorded.

5.5.2 Velocity for Handheld Video

5.5.2.1 Video Requirements

The video camera resolution should be at least 1080p or 4k, which most smart phones having a minimum of 24 frames per second (NI GL 100.11-2021) can achieve.

A minimum video duration of 30 to 90 seconds is recommended with the target being 60 seconds and no wide-angle lens, or other distortions to ensure a good quality image. Ensure that the camera platform is as stable as possible by mounting it on a tripod or bracing it against a fixed object.

5.5.2.2 Field of View Requirements

The entire width of the channel must be visible in the imagery at the measured cross section or in a flood situation where multiple videos are required to cover the total wetted width.

5.5.2.2.1 Visible items

The entire width of the channel must be visible in the imagery at the measured cross section or in a flood situation where multiple videos are required to cover the total wetted width and the fixed reference points must be visible for section measurement.

A minimum of 6 Ground Control Points (GCPs) with 3 on each side of the channel is required, 8 (4 each side of the channel) is best practice (NI GL 100.11-2021). These GCP's require 3D surveying (x,y,z positioning) with total station, or RTK/PPK GPS in order to accurately determine their location. These points should be evenly distributed on both banks.

Alternatively 4 GCPs at water level, with 2 each side of the channel (can be at waters edge), that are visible in the imagery and are surveyed at the time (or later) can be utilised. Distances between all the GCPs (including diagonals) are required for orthorectification, but not their elevations, therefore RTK/PPK GPS, or total station, survey is not required.

5.5.2.2.2 Camera angle

For oblique imagery a high angle is best (should be 90°, vertical, Nadir), therefore look down on the water as opposed to looking across it and ensure that all the ground control points are visible in the fields of view. If standing on the bank, ensure angle to the water level at the far bank is greater than 15°.

If standing on a bridge, ensure all visible fixed reference points are in the field of view.

5.5.2.2.3 Lighting

To ensure the best possible imagery minimise shadows and reflections on the water surface and also try to minimise sun-glint, which can be difficult.

5.5.2.3 Control Points and Additional Measurements

5.5.2.3.1 Control Points

A minimum of 6 Ground Control Points (GCPs) with 3 each side of the channel is required, 8 GCP's with 4 each side of the channel is best practice (NI GL 100.11-2021). These GCP's require 3D surveying (x,y,z positioning) with total station, or RTK/PPK GPS in order to accurately determine their location. These points should be evenly distributed on both banks.

Alternatively, you could use 4 GCPs at water level with 2 each side of the channel (can be at waters edge), that are visible in the imagery and are surveyed at the time (or could be later). Distances between all the GCPs (including diagonals) are needed for orthorectification, but not their elevations, so does not require RTK/PPK GPS or total station.

When only using 4 GCPs at water level, they do not need to form a perfect square. Survey stakes can be used, or rocks, trees etc.

5.5.2.3.2 Additional Measurements

The distances between the 4 ground control points (GCPs) at water level, including diagonal distances need to be surveyed and recorded using RTK GPS or survey tape.

The 3D locations of GCPs using RTK GPS (for 6+ GCPs on channel banks). Must also be surveyed and recorded.

5.5.3 Velocity for Handheld Surface Velocity Radar Gun

The Surface Velocity Radar Gun (SVR) is used to estimate water surface velocities for calculation of flow gaugings in conjunction with water level and gauging cross-section data. As it is a non-contact method of gauging, it is particularly useful for the observation of high flows where a bridge spanning the river is available.

There are many manufacturers of Surface Velocity Radars (SVR's) and these should all be shipped from the factory already calibrated. Do not attempt to recalibrate it.

Some SVR's are not water-proof or rain-proof. Take appropriate measures to protect the device from water damage.

5.5.3.1 Radar technique

Whilst there are different makes and models of Surface Velocity Radar sensors, details on the set up and use of radars can be found in the manufacturer's manual, but particular attention should be given to the following.

5.5.3.2 Direction of flow

The radar can be set to measure velocity which is flowing towards the user, or away from the user. For example, you could measure the velocities from the upstream side of a bridge, or from the downstream side of a bridge. If the flow is coming towards the user, the radar should be set to inbound. If the flow is moving away from the user, the radar should be set to outbound. This setting can by changed by pressing the “Flow” button on the keypad.

5.5.3.3 Rain setting

The velocity readings can be affected by rain, so the device has a rain setting that can be adjusted to suit the conditions. Further details on this setting can be found in the manufacturer’s manual.

5.5.3.4 Horizontal angle

As with other current meters, the radar should be held parallel to the direction of the flow. Measuring at larger horizontal angles will result in errors in velocity readings. The SVR user manual contains further details on making corrections if measuring at an angle cannot be avoided.

5.5.3.5 Exposure time

The velocity should be measured at a minimum of 22 verticals across the measured cross-section and the exposure time for each velocity reading should be a minimum of 30 seconds. (40 seconds recommended).

5.5.3.6 Angle of radar and height above water

The target area measured by the radar will vary depending on the angle of the radar and the height above the water. The steeper the angle of the radar, the smaller the target area will be.

The radar also averages the point velocities measured within the target area, so care should be taken when taking velocity measurements close to the bank.

Consideration needs to be given to the height above the water and the width of the channel. For example, if you are 5 m above a river that is 5 m wide, there is no benefit in doing 20 verticals as each vertical will be overlapping.

Table 6 provides a reference for the sample size area depending on the angle of the radar and the height above the water.

Table 6: SVR sample size area.

SVR Gun with 12° Beam Angle – Size of Sample Area			
Airline (Vertical height of SVR above water surface) (m)	Vertical Angle (Angle of depression of SVR gun) (degrees)	Distance to point of incidence (m)	Width of measurement area (m)
1	35	1.7	0.4
1	45	1.4	0.3
1	55	1.2	0.3
2	35	3.5	0.7
2	45	2.8	0.6
2	55	2.4	0.5
5	35	8.7	1.8
5	45	7.1	1.5
5	55	6.1	1.3
10	35	17.4	3.7
10	45	14.1	3.0
10	55	12.2	2.6
15	35	26.2	5.5
15	45	21.2	4.5
15	55	18.3	3.8
20	35	34.9	7.3
20	45	28.3	5.9
20	55	24.4	5.1
25	35	43.6	9.2
25	45	35.4	7.4
25	55	30.5	6.4

5.6 Instrument Validation and Calibration

5.7 Determination of Alpha (Surface to Mean Velocity)

In theory, the 'correction coefficient' (known as alpha, α) between the surface velocity and the mean velocity in the vertical water velocity profile of a typical river, where near laminar flow exists, is typically between 0.84 - 0.90. Due to variations in conditions at individual sites this coefficient can vary substantially depending upon a number of physical and hydrological factors (stage, channel width, depth, substrate, hydraulic control, approach, etc.). Gathering specific site data to confirm a plausible value for alpha for medium to high flow conditions at a site should be undertaken to allow a better estimate for extrapolating high flow discharges, when only SVR can be used.

During medium to high flow events, measuring discharge with an ADCP and measuring surface velocities with an SVR at the same time can help determine more accurately what the surface velocity correction coefficient should be. This can be done by adjusting the velocity correction coefficient (alpha) to match the ADCP discharge.

If this process is carried out at different stage heights, a stage to alpha rating curve can be developed and a much-improved estimate of alpha at higher stages may be obtained by extrapolation of the relationship.

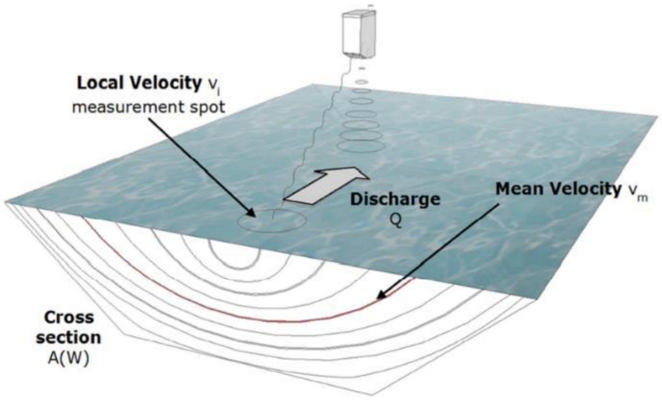


Figure 14 Showing the difference between observed surface velocity and mean velocity

If it is not possible to carry out ADCP and radar measurements at medium to high flows to derive a stage/alpha relationship a surface velocity correction coefficient (α) of 0.85 should be used.

It is important that the alpha value is filed with the discharge measurement so that it is possible in the future to determine what alpha was used in an archived measurement (it may need to be changed in the future with the acquisition of subsequent information relating to the value of alpha). The requirement for applying the alpha value to the method code also relates to STIV measurements.

Method codes for surface velocity measurements and the inclusion of the alpha value utilised are provided in Annex C, along with a footnote describing how these method codes are to be utilised to incorporate the alpha value applied to a discharge measurement.

Further information on the measurement and estimation of alpha can be found in:

Biggs, H., Smart G., Doyle, M., Holwerda, H., McDonald, M. & Ede, M. (2021). River discharge from surface velocity measurements – A field guide for selecting alpha. Envirolink Advice Report, Christchurch, New Zealand.

https://www.researchgate.net/publication/352833904_River_discharge_from_surface_velocity_measurements_A_field_guide_for_selecting_alpha

5.8 Discharge Calculation Methods

The supporting software packages calculate surface velocities and convert these surface velocities to depth averaged velocities, then combines them with a cross section to calculate discharge.

The Alpha value utilised with a surface velocity gauging shall be stored with the measurement.

Refer to the National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021(Australian Government Bureau of Meteorology) for more details http://www.bom.gov.au/water/standards/niGuidelinesHyd.shtml.

Refer to Appendix B of the National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021(Australian Government Bureau of Meteorology).

6 Index-Velocity Method

In this section

This section contains information relating to the measurement of continuous discharge in open channels using the Index-velocity method with ADVMs. This method has recommendations associated with the following which are presented in order of the steps that should be taken for this method:

- site selection
- instrument selection
- installation and configuration
- discharge calibration
- stage-area rating
- index-velocity rating
- calculation of discharge, and
- rating validation

Note: No international standards currently exist for the derivation of flow using the Index velocity method. Refer to:- USGS Techniques and Methods 3-A23 for further information.

6.1 Principles

The development of acoustic doppler velocity meters (ADVMs) that measure continuous cross channel velocity has meant the application of continuous discharge calculation using the index-velocity method is possible at a relatively low cost compared to previous acoustic velocity time of travel meters.

An ADVM measures velocity (the index-velocity) in a portion of the cross section that is representative of the mean-channel-velocity.

As the velocity calculation is directly related to the speed of sound in the water, which varies with changes in:

- water temperature
- salinity
- pressure, and
- sediment concentration.

ADCPs that do not compensate for changes in the speed of sound shall not be used.

Note: Manufacturers of ADCP instruments measure water temperature, the most important sensitive component, near the transducer faces and apply correction factors to allow for temperature-related differences in the speed of sound.

If the instrument is to be used in waters of varying salinity then independent measurements of salinity shall be taken and adjustments made to correct for the speed of sound in the water body being measured.

Note: A temperature change of 5 °C, or a salinity change of 12 parts per thousand, results in a change in speed of sound of 1%.

The orientation of the ADVM may be horizontal or vertical, more commonly a horizontal orientation is used.

Stage records and index-velocity are collected continuously so discharge can be calculated continuously.

Continuous discharge is calculated by separating area and velocity into two ratings, the index-velocity rating, and the stage-area rating. The outputs from each of the ratings, channel mean-velocity and the cross-sectional area are then multiplied to calculate a discharge.

This method can be used at locations where stage-discharge methods are used, but are commonly used where more than one discharge can be measured for a specific stage. Typically, this would be at sites where stage-discharge methods are not accurate, often due to variable backwater or unsteady flow conditions.

The USGS have implemented the most index-velocity flow stations and have developed the best advice guidance for the method (Levesque and Oberg, 2011). For detailed information refer to this technical guide.

6.2 Site Selection

Site selection is the key component of developing an accurate index-velocity station. This step should be completed before deciding on an ADVM installation as the information from this will determine instrument choice and potential accuracy of the method.

The criteria for a good stage-discharge site are applicable to this method. The ideal site for the ADVM should be where its measurement volume:

- is in relatively parallel and uniform flow lines, and the beams are measuring approximately the same water velocities
- is near a region of maximum velocity that is free from boundary effects on flow (e.g.; pier wakes, or eddies)
- is located 5 to 10 channel widths upstream or downstream of any inflows or flow control structures
- In addition, the instrumentation should be located where:

- the channel is relatively straight for 5 to 10 channel widths upstream or downstream.
- there is a stable channel shape that is not subject to frequent scour or fill
- the total flow is confined to one channel
- a satisfactory reach for measuring discharge at all stages is nearby. This does not need to be the same cross section for all discharge measurements.

The main requirements are uniform horizontal and vertical flow distributions, parallel flow lines, and a stable cross section shape.

ADCP moving boat cross sections should be completed as part of the site survey to determine flow conditions, and channel depths as this information is important for selecting both the site, measurement volume, and the instrument choice.

Note:- the measurement volume refers to the specific area or region within the water column where the instrument's acoustic beams are focused to measure water velocity. The size and shape of this measurement volume are determined by the ADVM's transducer frequency, beam angle, and user-defined settings.

6.3 Instrument Selection

Instrument selection should occur after the flow conditions and channel bathymetry of the site are known. ADVM’s can be orientated horizontally (referred to from here on as a sidelooker) or vertically (referred to from here on as an uplooker).

A horizontal ADVM is best suited when:

- channel water depths are sufficient in the representative section so that the beams don’t impinge on the bed or surface
- there is a relatively uniform horizontal flow distribution, and consistent vertical profile over a range of flows

the region of maximum velocity in the cross section can be sampled

A vertical ADVM is best suited when:

- channel water depths are shallow
- the vertical profile changes over a range of flows

However, the requirement to have the sensor on the bed near the area of maximum velocity means that the instrument may be vulnerable to damage or obstruction by moving bed material.

ADVM frequency should be chosen based on the range of measurement that can be accurately measured on site. Range is inversely proportional to the frequency, so for example a lower frequency has greater minimum and maximum range than a higher frequency. A higher frequency will measure with a lower velocity standard deviation than a lower frequency.

Frequency choice should be optimised to measure in the measurement volume which is usually not in the full channel width or depth.

ADVM's measure velocity using doppler shift parallel to each beam, then compute the values of velocity in the direction of flow (perpendicular to the instrument axis, referred to as Vx), and parallel to the instrument axis (across river, referred to as Vy). As the velocity of sound through water varies with water temperature, the water temperature data available from the ADVM should also be recorded and validated at site visits with a calibrated temperature sensor.

Stage measurement is required at the site at a measurement interval to match the ADVM measurement interval and an accuracy to capture the change in flow conditions and develop an accurate stage-area rating. Many ADVM's have either vertical beam stage sensors, or pressure sensors that can be configured to record stage along with velocity. Alternatively, a nearby water level sensor could provide this information if it was representative of the stage change at the cross section utilised for velocity measurement.

6.4 Installation and Configuration

Installation of an ADVM requires a mount system that:

- is rigid and resists vibration and movement
- allows adjustment for instrument pitch, roll, and heading
- is designed so the instrument returns to the same location after servicing or replacement
- is accessible during most flow conditions

Positioning of a sidelooker ADVM should be:

- so that the beams measure approximately equidistant between the streambed and water surface in the measurement volume.
- with approximately zero pitch and roll, although a small pitch could be applied either way depending on the channel bathymetry or any potential vertical velocity change.
- where the beams do not impinge on the bed in the measurement volume
- where minimum and maximum stages can be measured

Positioning of an uplooker ADVM is similar to the sidelooker with the addition of:

- a bottom mount that is sufficiently robust to withstand any potential bed changes and any heading changes
- a method for protecting the cable from the sensor
- being installed in a representative position where it will measure the channel mean-velocity.

- a way of avoiding debris or sediment accumulating on the instrument and consequent blocking of the beams.

The assumption with these systems is that the velocity field measured by each beam is essentially the same, so an ADVM should be properly oriented to the primary flow direction. After installation individual beam velocity data can be evaluated for equal magnitude and opposite direction (see Figure 5, in 2011 USGS T and M 3-A23; Levesque and Oberg, 2011). This USGS document can be found at: - https://pubs.usgs.gov/tm/3a23/

After installation, an ADVM must be configured to measure the flow characteristics at the site, this involves setting:

- the measurement volume by sending commands for the minimum and maximum range, and cell sizes within this range. These settings are influenced by frequency, instrument noise level, boundaries and obstructions, as well as the concentration of scatterers in the water. Detailed information on setting these is included in instrument manuals and in the USGS T and M 3-A23.
- the measurement interval and averaging period. This is completed by setting a rapid interval and then analysing the data to see how accurately it represents the flow conditions. The averaging period should be maximised to reduce the standard deviation of velocity measurements yet still capture real velocity change. At most sites the optimum routine averaging period will be 15 to 60 seconds less than the measurement interval.
- a representative position for measuring the index-velocity and the channel mean-velocity.

6.5 Discharge Calibration

Discharge measurements are required to calibrate the index-velocity rating to the channel mean-velocity rating over a range of expected flows. This requires:

- synchronization of time clocks of the ADCP used for measuring discharge, and the ADVM
- setting the ADVM to a 1-minute rapid sampling interval to relate the index-velocity with the channel mean-velocity from the discharge measurements. This 1-minute ADVM velocity data can then be averaged to match the respective channel mean-velocity data.
- the ADCP discharge measurements to be undertaken at a cross section that is some distance from the ADVM beam paths so that there is no acoustic interference between the instruments or flow disturbance from any vessel. At least 5 channel depths away from the ADVM section are required particularly if the acoustic frequencies of both instruments are similar.

- using an ADCP to collect discharge data at a rate to match the flow conditions. Optimise this, depending on how quickly flow conditions change. Reciprocal pairs should be averaged together to reduce the possibility of directional bias.
- calculation of a channel mean-velocity by dividing the calibration discharge values by the respective area from the standard cross section (from the stage-area rating derived in the next section)

6.6 Stage-Area Rating

The stage-area rating is developed first, because a stage respective standard cross section area is required to compute the channel mean-velocity from the calibration discharge measurements. This channel mean-velocity is used for the calibration of the index-velocity rating (in the next section). Secondly, the stage-area rating is used to compute continuous discharge in conjunction with the computed continuous channel mean-velocity from the index rating.

The development of a stage-area rating comprises of:

- establishing a standard cross section as close as possible to the ADVM, perpendicular to the flow direction, and representative of the channel.
- surveying the cross section with standard techniques from the top of banks to the streambed. Using standard survey tools which may include the use of ADCP depth data to define the wetted area. The same vertical datum is used for the survey and the stage instrument.
- calculating the standard cross section areas for a given stage. Software tools such as those within your Time-series Manager or the AreaComp software available from the USGS are useful for calculation of a stage-area rating from the cross-section data.
- verification of this standard cross-section by repeat surveys over time to confirm that no changes to channel bathymetry have occurred. This should occur annually unless a change in cross-section is suspected in which case an immediate survey should be conducted. If no change occurs after three years the frequency of resurvey may be reduced.

Note: - The USGS software AreaComp can be found at: -

https://www.usgs.gov/software/areacomp-hydroacoustics-software

6.7 Index-Velocity Rating

After an adequate number of calibration discharge measurements are completed, the following information is used to develop the index-velocity rating:

- ADVM index-velocity 1 minute interval data (Vx, and Vy) collected concurrently with discharge measurements

- stage data collected concurrently with the discharge measurements
- discharge measurement data
- it is important to understand the time conventions of the systems that are being used in order to synchronize data. For example, the time recorded for each index velocity measurement may be the start time measurement, and the end time is determined by the averaging interval.

Worksheets are then used to compile the time synchronized index-velocity ADVM, discharge, and stage data. Then the index-velocity rating is developed using the following steps:

- range averaging of the ADVM index-velocity 1 minute interval data (Vx, and Vy) at an appropriate representative area of the cross section. This may be a process that needs to be subsequently reviewed to determine which range is most representative of the channel mean-velocity
- time averaging of the ADVM index-velocity 1 minute interval data (Vx, and Vy) collected concurrently with the duration of the discharge measurements
- averaging of the stage data collected concurrently with the duration of the discharge measurements
- calculation of the standard cross section area for each discharge measurement using the respective averaged stage value and applying the stage-area rating
- calculation of the channel mean-velocity by dividing the measured discharge values by the respective calculated standard cross section areas
- then the synchronized index-velocity and calculated channel mean-velocity values are plotted to observe the shape and distribution of the data. Note that it is important to assign the index-velocity to the x-axis as this is the independent variable, and the channel mean-velocity to the y-axis as this is the dependent variable
- if site selection, instrument location, calibration and synchronization were properly performed then a linear relationship should be evident. Simple linear regression can be used to calculate a best-fit relationship and statistical results for evaluation. This relationship is the index-velocity rating.
- some sites may require a compound linear regression rating due to the characteristics of flow that change with stage at the site.

A detailed explanation of the methodology and further analysis in contained in the USGS techniques and methods document (Levesque and Oberg, 2011)

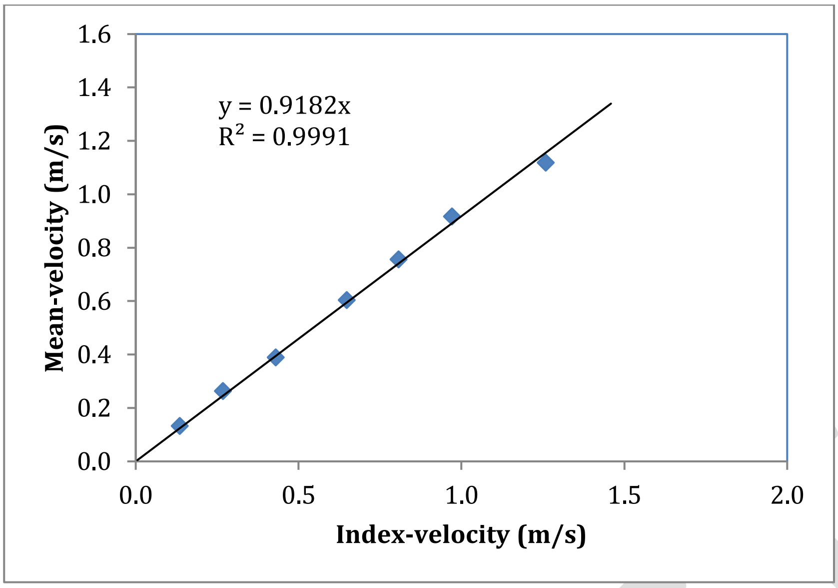


Figure 15 – Example of a linear index-velocity rating

6.8 Continuous Discharge Calculation

Continuous discharge (Q) is then computed as the summation of the products of the outputs of the two ratings (Area and Velocity):

- Area is calculated from the Stage-Area rating, using the continuous stage time series as the input to calculate a continuous standard cross sectional area time series
- Velocity is calculated from the Index-Velocity rating, using the ADVMs chosen index-velocity time series as the input to calculate continuous channel mean-velocity time series

6.9 Rating Validation

After implementation of the continuous calculation of discharge, the ratings need to be continually validated to check for any change over time.

This validation requires ongoing discharge measurements to check the rated discharge, and the index-velocity rating.

If a significant change is detected, then the index-velocity rating analysis process and standard cross section survey and stage-area rating process needs to be repeated.

The definition of what is a significant change is not set in this document as there are no international standards for this method. Although most organisations would consider a change of greater than +/-8% between a series check discharge and calculated discharge with a consistent bias as significant.

There is no accepted method for calculation of uncertainty in any international standards, and this document presents no options for Quality Coding other than unverified (QC200)

7 Volumetric Method

In this section

This section contains information on measuring discharge in open channels using the volumetric method. This method has Standards associated with the following:

- site selection
- measurement of volume
- measurement of time, and
- calculation of discharge.

7.1 Principles

The Volumetric Method determines discharge by directly measuring the volume of water collected over a known period of time. The principle underlying this method is that discharge is equal to the volume of water collected divided by the time taken to collect that volume.

This method provides a direct and easily understood measurement of flow and does not require velocity measurements or flow depth estimation.

7.2 Site Selection

The volumetric method is typically used on small discharges and it requires:

- sufficient fall to enable diversion of water to a container, and
- a structure or method of capturing all the flow.

Note: Ponds or reservoirs of known volumes can be used to capture flow

7.3 Measurement

7.3.1 Measurement of Volume

A container shall be used to capture the water. The container shall be:

- calibrated before use
- of a size that ensures filling times are greater than 10 seconds, and
- of a size that is manageable.

The container shall be filled a minimum of ten times and the average time to fill adopted. If any time to fill varies by more than 5% than that observation shall be deleted and the measurement repeated.

Note: This method may be applied to larger flows if large reservoirs or tanks, for which the volume can be accurately established, are available.

Note: As an alternative, the sample can be weighed and temperature corrected to derive the volume of water.

7.3.2 Measurement of Time

Time taken to fill the container shall be measured:

- with a stopwatch, and
- at least 10 separate filling measurements shall be made.

Note: The total duration of the filling measurement shall exceed 10 seconds to provide sufficient resolution of time. A filling duration that is as long as possible will provide a more accurate discharge.

The standard deviation of the time measurements shall be calculated for use in the uncertainty estimate.

7.4 Discharge Calculation Methods

Discharge is calculated by dividing the container's volume by the time taken to fill. Multiple measurements shall be averaged for the final discharge result.

The uncertainty of the discharge result shall be calculated using the principles in ISO 5168.

Quality codes shall be derived from the Volumetric Measurement Quality Coding Flow Chart.

Note: The observation shall be repeated, at least ten times, and the average time to fill the container shall be utilised for the determination of discharge {any outlying values (those that differ by more than 5% should be discarded and those measurement repeated}.

8 Indirect Discharge Method

In this section

This section contains information on estimating discharge in open channels using indirect methods. This method has Standards associated with the following:

- flow conditions
- indirect discharge methods
- data collection, and
- calculation of discharge.

8.1 Principles

Indirect methods shall only be used for flood flows where it is*:*

- impossible or impractical to measure the peak discharge, or
- too dangerous to deploy current meters and sounding devices.

8.2 Site Selection

The reach chosen for the indirect discharge methods should be

- Be straight
- Contain the flow without overflow at the stages measured. Have as clear a waterway as possible
- Have relatively uniform cross-sections and preferably be converging; the increasing velocity through the reach minimises deposition of bed load and ensures a more stable bed profile.
- Be sufficiently long so that uncertainties in slope measurements will not be significant. The fall in water surface elevation down the reach shall be at least ten times the expected error in defining water-levels and levelling them. This is usually a minimum of 5 flood widths
- Have flood marks of good quality and quantity, in the case of measurements made following an event
- Be sufficiently far away from sharp bends, either above or below, so that water-levels on each bank will not differ greatly in height
- Be where significant backwaters or tidal effects do not occur.

8.3 Data Collection

Data collected for the indirect methods include:

- surveyed high-water-level locations and elevations
- cross-sections along the reach
- geometry of any structures relevant to the method, and
- selection of a roughness coefficient for the reach (See Section 8.4.1.1 Estimation of Manning's "n").

8.4 Discharge Calculation Methods

A number of different methods are available to calculate peak discharge, and these methods make use of the energy equation for computing discharge.

- The following methods are available:
- slope-area method, and
- contracted-opening method.

8.4.1 Slope-Area Method

This method is one of the most commonly used techniques of indirect discharge determination. A complete description of the method is detailed in ISO 1070:1992, and USGS Publication TWRI: 03-A2 (1968).

In summary, the velocity in a reach will be related to the slope of the channel and to the bed friction, which is due to the roughness of the bed material. The Manning's equation derives velocity from channel parameters and slope. These values are calculated for the reach, rather than a single cross-section, with the values thus being averaged between two or more cross-sections.

When determining the slope of the water surface a minimum of 10 observations of maximum water level should be surveyed along the reach and a best fit line fitted to these data points (with any obviously outlying observations being discarded prior to line fitting).

The version of the Manning's equation employed (Hicks and Mason, 1991) to compute the velocity is:

$$v = \frac{1}{n} R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

and, as discharge = velocity x area;

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

where:

- v is mean velocity (m/s)
- Q is discharge (m^3/s)
- R is hydraulic radius = A/P (m)
- A is mean cross-section area (m^2)
- P is wetted perimeter (m)
- n is the Manning's roughness coefficient.
- S_f is friction slope, where:

$$S_f = \frac{\Delta H + \Delta H_v - \Delta k(\Delta H_v)}{L}$$

where:

- ΔH is the change in elevation of the water surface between the upstream and downstream cross-sections
- ΔH_v is the change in velocity head between the upstream and downstream cross-sections, where:

  H_v at a cross-section = $\frac{\propto v^2}{2g}$,

  Where:

  α is usually assumed to be 1

  g = the acceleration due to gravity

  v = mean velocity in the cross-section (calculated from discharge/area)

- k is assumed to be zero for contracting reaches and 0.5 for expanding reaches, and
- L is the length of the reach.

A variation of the Manning's equation deals with energy gradients in diverging and contracting reaches by utilising two cross-sections. This methodology, which should provide a more accurate determination of discharge, was derived by the USGS and was simplified and applied by A. C. Hopkins of the Ministry of Works (circa 1969 training courses).

The conveyance of the reach is calculated using:

$$K = \frac{AR^{\frac{2}{3}}}{n}$$

where:

- K is the conveyance of the reach (m3/s)
- A is the mean of the upstream and downstream cross-sections (m2)
- R is hydraulic radius, and
- n is the Manning's roughness coefficient.

Then discharge in a contracting reach is:

$$Q = \frac{(2gL)^{1/2}\, K\, S^{1/2}}{\sqrt{(2gL) + \left(\frac{K}{A_2}\right)^2 - \left(\frac{K}{A_1}\right)^2}}$$

Note: For a diverging reach, replace (2gL) in the above formula with (4gL).

where:

- Q is discharge (m3/s)
- g the acceleration due to gravity (m/s2)
- L is the length of reach (m)
- S is the slope (m/m)
- A_1 is the upstream cross-section area (m2), and
- A_2 is the downstream cross-section area (m2).

Once the discharge calculation has been completed, the resulting discharge should be divided by the cross-sectional area to ensure that the resultant mean velocity is within the range that might be expected for the site. If the mean velocity appears to be too high, or too low, further consideration should be given to the value of "n" that has been utilised within the calculation.

8.4.1.1 Estimation of Manning's 'n'

Even when the slope and the channel geometry can be measured accurately, there will normally still be substantial uncertainty associated with the estimation of the Manning's roughness coefficient, "n".

The greater the roughness, the higher the "n" value. In gravel bed rivers, "n" is typically in the range 0.020 to 0.050, and tends to vary with discharge. The best way to define an appropriate "n" is to carry out a number of current meter gauging's at a site, at a range of flows and calculate "n" from the transposed Manning equation, i.e.

$$n = \frac{AR^{2/3} S_f^{1/2}}{Q}$$

Normally, as Q will be the unknown value of interest, it will not be possible to do this, particularly for high water-levels. However, other, usually lower-stage, gauging's at that site may be able to be used to calculate "n" values. As it is most likely that "n" will vary with stage, a stage "n" curve should be compiled and extended by eye in order to estimate "n" for higher flows.

The above method is recommended, as it is usually the only way of deriving "n" with any degree of confidence. In many cases, however, there will be insufficient data to extend the stage/"n" curve with confidence, and more approximate methods will need to be employed. These methods consist of:

- Reference to publications that provide examples of reaches with measured n values along with slope and bed material data and colour photographs of the reaches. Hicks and Mason (1991) provide New Zealand examples and Bames (1967) providesx U.S. examples. Arcement and Schneider (1989) give examples for vegetated flood plains.

- The use of an equation from Jarrett (1984) is recommended where the slope exceeds 0.02. This equation estimates "n" using slope and depth of flow parameters. The equation has been checked against data for some New Zealand rivers (Hydrology Centre, 1988) and found to be adequate.

The metric version of this equation is:

$$n = 0.32\ S_f^{0.38}\ R^{-0.16}$$

This equation assumes that the size of bed material (i.e., roughness) is related to slope, and relies on the latter parameter to take account of the former. This assumption will hold reasonably true for alluvial channels, but probably not, for instance, to bedrock ones.

8.4.2 Contracted Opening Method

The contraction of a stream channel by a bridge creates an abrupt drop in the water-surface elevation between an approach section and the contracted section under the bridge.

This method can be applied post flood by pegging water levels during a flood event, or by scaling water levels off photographs of flooding at bridges (or other contractions) and surveying the flood levels and cross-sections when flows drop sufficiently.

This contracted section framed by the bridge abutments and the channel bed can be used to estimate flood flows. High water marks and the geometry of the bridge and channel are used in this method.

Note: It is often difficult to measure the fall through the contraction during a flood event. Photographs can be used to provide reference points that can be surveyed after flood events.

A complete description of this method is in Matthai (1967).

Note: this is a US paper with formulae and examples in imperial units; coefficients unless dimensionless require conversion to metric units

A variation of the formula was derived and applied in New Zealand by Mr A. C. Hopkins of the Ministry of Works (circa 1969 Hydrology training courses). This version removes the components which have no significant effect on the discharge and so simplifies the calculation.

Flow is computed by firstly determining the velocity at the upstream cross section using

$$V_1 = C\,\frac{A_2}{A_1}\sqrt{2g\left(H + \alpha\frac{V_1^2}{2g}\right)}$$

where:

- V_1 is mean velocity in the upstream cross-section (m/s)
- A_1 is the upstream cross-section area (m^2)
- A_2 is the contracted cross-section area (m^2)
- H is the draw-down between the upstream and contracted cross-section (m)
- C is the discharge coefficient (assessment in Matthai (1967))
- α is the Coriolis coefficient estimated from the conveyance and area (refer to Matthai (1967)), and
- g is the acceleration due to gravity (m/s^2)

then:

$$Q = V_1 A_1$$

9 Dilution Method

In this section

9.1 Principles

Dilution gauging is a streamflow measurement method that involves measuring a tracer's dilution, a sufficient distance downstream from a point of injection such that the tracer is fully mixed across the stream channel. Although a range of tracers can be used, food-grade table salt (NaCl) is preferred as it is generally non-toxic at the concentrations typically involved in stream gauging (but see further comments below). Furthermore, NaCl is readily available and inexpensive, and can be accurately detected by monitoring changes in electrical conductivity of stream water.

9.2 Site Selection

Dilution gauging is generally used where traditional velocity–area methods are not reliable (e.g., irregular, or cascading channels) or where it is difficult or impossible to use traditional mean in section methods due to high velocities, turbulence, or debris. Tracer concentration requires complete mixing between the point of injection and the location at which the tracer mass is observed. However, for the slug injection methods, it is not the instantaneous concentrations that need to be uniform across the channel, but the time-integral of the conductivity exceedance over background.

Key to the success of dilution methods is the validity of the assumption of complete mixing of the tracer across the channel at the end of the mixing reach. Ideal measurement reaches will have boulder beds with numerous constrictions that promote rapid lateral mixing. Sharp bends promote overturning streamflow, which can enhance lateral mixing as well. An ideal site would be a location where a tracer could be injected upstream of a constriction with the measurement point downstream of another constriction, and minimal pool volume and no tributaries between the two locations.

The following are key things to consider with respect to ensuring adequate stream channel conditions for minimising uncertainty in the salt dilution methods.

9.2.1 Channel and mixing reach properties

The mixing reach should ideally have minimal pooling and lateral storage at the specific flow level being measured. It is important to note that mixing properties depend on water level and discharge, and inadequate mixing conditions may occur at certain flows. Descriptions of channel conditions must include features that facilitate mixing and enhance turbulence (e.g., irregular bottoms, steps, boulders).

Additional surface water inputs should not occur between the injection point and the downstream measurement location, unless the reach being rated is located below the tributary surface water input and is sufficiently far downstream that the tributary flow is fully mixed with the main channel flow. Measuring ECBG and temperature along the mixing reach, prior to tracer injection, can help identify areas of lateral inflow or groundwater discharge.

9.2.2 Injection (upstream) and measurement (downstream) location properties

Injection points ideally should be in, or above, an area of flow constriction, whereas measurement points should be in or below a flow constriction.

Measurement locations should avoid placement within aeration zones, lateral pools, and areas of recirculating flow (i.e., back eddies or in the lee of large substrate). Measurement points with substantial pool volumes and re-circulating streamflow should be avoided, as tracers moving into these zones can be stored and gradually released, significantly extending the duration of the tracer breakthrough curve (i.e., the EC exceedance over background).

Streams with significant in-stream vegetation are also not suitable, as the zone of reduced velocity and mixing (due to the presence of vegetation) will store and slowly release the tracer.

9.2.3 Mixing reach length

Studies have shown that a mixing length of 10-25 wetted channel widths below the tracer injection point is typically required for complete mixing. However, for some reaches, even a mixing length of 25 wetted widths may be inadequate. Therefore, completeness of mixing should always be confirmed using appropriate protocols such as probe trace comparison and carrying out further measurements at different locations (either closer or further away from the dosing point).

9.3 Dosing

Dosing, calibration, and other field procedures can have an important effect on the accuracy of any dilution measurement. To minimise uncertainty, it is critical that practitioners properly calculate and adjust tracer dose based on conservative approaches to protect aquatic life while ensuring an adequate signal to noise ratio.

Practitioners must also use methods to verify full mixing and ensure that k (calibration factor for salt in solution methods) and CFT (calibration factor for mass balance method) are properly performed. Finally, field methods to control for potentially variable, and possibly shifting, backgrounds must be employed. The following six points provide more details on these subjects.

9.3.1 Tracer dose

General guidance from literature and practitioner experience is to dose no more than 1 kg of NaCl per m^3/s of streamflow. This can be refined to much less amounts depending on the equipment used, and doses of 100mg per m^3/s can achieve great results, reducing the impact on the stream environment.

At sites with previously constructed rating curves, use the rating information to assist in estimating the appropriate salt dose. When operating at a new site, estimates of flow are required.

For example, based on estimates of width, depth, and velocity. A lower value should be used for an initial trial, and new practitioners should strongly consider reducing the calculated dose on first tracer run at a new site. Adjustments of subsequent doses can then be based on results of the initial, conservative trial run.

9.3.2 Exceedance over background, shape of breakthrough curve

For all gulp injection methods, recommendations on the magnitude, duration and shape of the breakthrough curve are not available currently. The injected salt dosage for any system should stay below identified or required environmental thresholds throughout the mixing reach. Dose strength required is dependent on signal to noise ratio that in turn is a function of both EC sensor resolution and ECBG stability. In the interim, a recommendation is to target 25-40 µS/cm over background (Figure 16). This recommendation does not imply that lower exceedances will not achieve a good quality measurement; rather, it is a general field procedure that, as far as possible, will provide adequate signal strength against background conductivity.

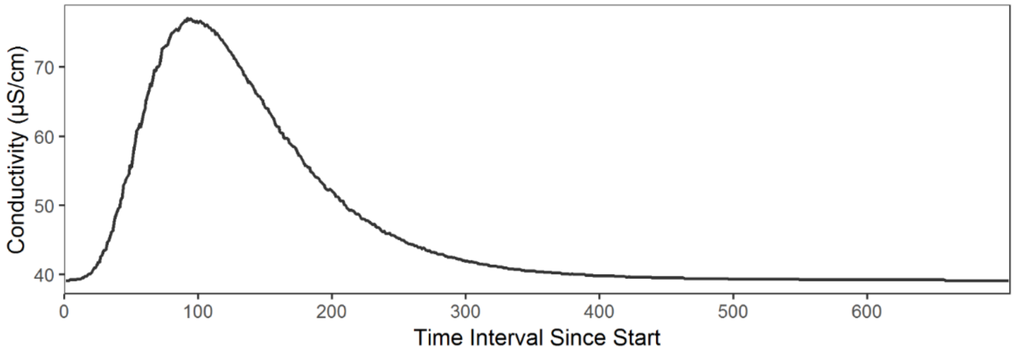


Figure 16:Typical breakthrough curve, with 38 µS/cm exceedance over background. ECBG = 39 µS/cm.

9.3.3 Derivation of CFT constant

The Calibration Factor (aka Concentration Factor) is the relationship between NaCl and electrical conductivity (EC). This is temperature compensated EC, denoted by EC.T (aka specific conductivity) and the associated CF.T (temperature compensated concentration factor). This results in a consistency of CF.T values between sites and measurements and allows a degree of QA/QC if we know what to expect for the CF.T. Before each measurement the user can either enter the CF.T manually or derive it in situ (preferred).

The CF.T should be approximately 0.48 ± 0.02 (mg/L)/(µS/cm) for NaCl in freshwater. However, this will depend on the unit's current calibration and to some degree (± 3 %) the stream chemistry. If the CF.T is already known from previous documented calibrations, enter this for the calculations, or carry out a CF.T calibration on site (recommended as conditions on the day may be different).

Note: It is very important that sensors are calibrated to the river conditions at the site as the natural background water chemistry can change over time. If you have documented CF.T for the range of flows these can be used to save time but it is still recommended you carry out a calibration is possible. As a last resort use the default value of 0.48. However, using the default value will result in a lower quality code being assigned to the gauging.

9.3.4 Procedure for calibration on-site:

The on-site calibration procedure takes 5-10 minutes. Use a "Salt Standard" which is a solution made in the lab of 5.00 g NaCl in 1.00 L of distilled water. During a CF.T calibration inject 1.00 mL of salt standard into 1.00 L of stream water. Then follow the steps provided below:

a) Firstly, prepare the 1.00 L stream sample in the provided flask

b) Place the probes in the stream to reach equilibrium, note the EC.T value in the stream

c) Then place in 1.00 L stream sample flask, note any change, repeat if it does and clean flask again

d) Inject 1.00 mL of 5.00 g/L standard into 1000 mL of stream sample, mix thoroughly without spilling any water

e) Note change in EC.T value, probe traces should follow each other and plateau out

f) Set this on the device or in the software

Repeat 4 more times to give 5 points in total until a total of 5.00 mL of the standard solution has been added to the 1000mL of stream water. Typical graphed results are shown in Figure 17.

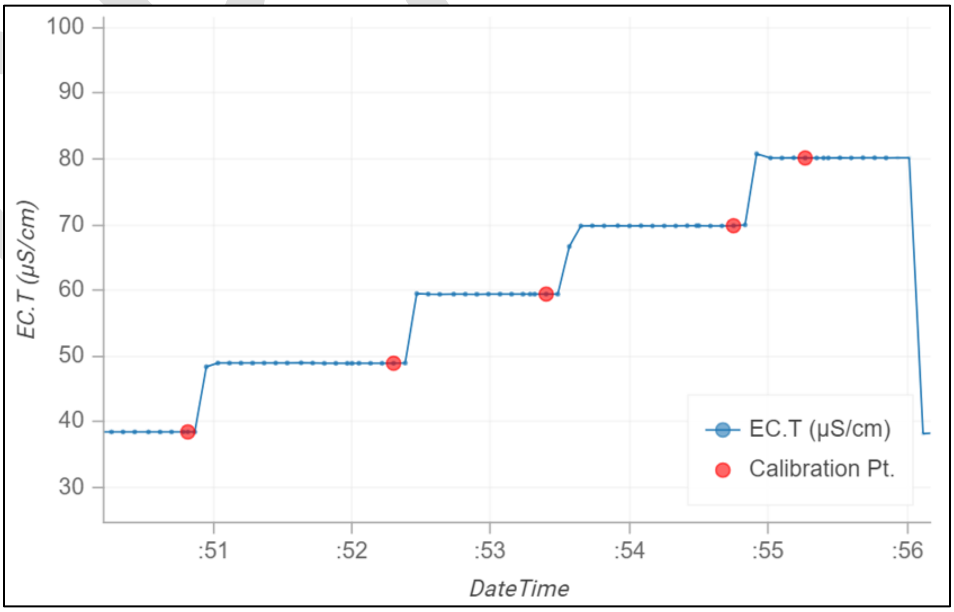


Figure 17 Typical graph of on-site calibration

After the last injection, the unit will calculate and display the final CF.T. and distilled water correction. Nothing needs to be done with these numbers as they are used for final calculation only.

9.3.5 Determining complete mixing and sensor placement

Place the probes in the stream in moving, but not turbulent or aerated, water. Ideally place the probes on opposite banks, 10-20 channel widths downstream of the point of injection. If this is not possible, then place one probe in the centre of the channel and the other on the near shore. If this is not possible, place one probe near shore and the second probe 7-10 channel widths downstream. Wait for the EC.T and temperature to stabilize. Lightly knock the shroud to release any entrapped air.

Ensure there are no upstream water inflows. These will show up as noise in the EC and likely only on one probe. This noise may be due to unseen groundwater inflows which would be constant and act like an offset lowering the readings on one of the probes.

Any dual sensor measurement configuration can be in error if the mixing reach is too short (i.e., insufficient mixing properties over the reach). Where sensors are installed on the same bank, measurement probes should also be placed at different distances from wetted edge to avoid potential false positives of complete mixing (Figure 18) The difference in final measurements between sensors should not differ by more than 7 %.

Figure 18: Example of a site with poor lateral mixing (as observed by the concentration of rhodamine WT dye in the centre of the channel with limited dispersal toward the banks.

Note : EC sensors placed in the centre channel upstream/downstream in these situations may produce false indications of complete mixing.

If only one EC sensor is available, a minimum of two salt runs are required per derived discharge measurement, and the single sensor (or the point of injection) should be moved between runs to lengthen the mixing reach to encourage more complete mixing. In these cases, water levels should remain constant among runs.

Results should not vary by more than 7 % between measurements when the probe is moved between salt runs. Alternately, a single run may be acceptable if the measured value plots no more than 5 % off an established, stable rating curve.

9.3.6 Sampling interval and trace

It is recommended that sampling intervals between consecutive ECT/temperature measurements not be more than 5 seconds apart (1 second preferred), and for runs with very short-duration salt pulses (i.e., less than 3 minutes), be no longer than 1 second apart.

As the salt wave travels past the EC.T probe(s), observe the EC.T trace rise and fall. The derived Q will change as the EC.T changes. The EC.T may take a very long time (> 1 hr) to reach BG EC.T, when this is smaller than ± 0.1 % and alternating about zero, it can be assumed to have reached BG EC.T. If time constraints (helicopter for example) prevent this and you need to stop the measurement earlier, there will be more uncertainty in the derived Q, and the measurement should be quality coded accordingly.

9.3.7 Shifting background ECT - control in the field

For all methods, ECT must return to the pre-injection background conductivity (ECBG) at the end of the breakthrough curve. In instances where the ECBG is changing (via snow melt, rain, or glacial melt, etc.), measurement of ECBG upstream of the injection is the preferred method to control for shifting background (point or continuous). Control of shifting background can also be compensated in the office (see below) using appropriate algorithms.

9.4 Equipment Validation and Calibration

Minimising uncertainty in application of salt dilution methods begins with ensuring all instrumentation is properly set-up and calibrated. Salt tracers need to be free of harmful added chemicals and uncertainty is best minimised by ensuring the dose of salt is precisely measured. The following are five key things to consider with respect to minimizing instrumentation and salt tracer uncertainty.

9.4.1 Temperature compensation of electrical conductivity (EC) measurements

Electrical conductivity (EC) is a measure of the ability of charged ions to move through a solution and is generally measured in the units of µS/cm (micro-Siemens per cm). Temperature compensation of EC measurements must be completed using linear or non-linear functions referenced to 25 °C (ECT). These compensations are standard options on most electrical conductivity sensors.

9.4.2 Conductivity sensor resolution

Sensor resolution is generally a function of a stream's background conductivity (ECBG), as most conductivity loggers have an auto-ranging function that in turn influences the resolution of output measurements. It is recommended that:

- for ECT measurements <200 µS/cm, a minimum instrument resolution of 0.1 µS/cm, and;
- for ECT measurements >200 µS/cm, a minimum instrument resolution of 1 µS/cm.

Both sensor resolution and background conductivity noise affect the injection ratios (aka salt dosing) required to achieve a sufficiently high signal to noise ratio (SNR) to achieve low measurement uncertainty. Higher salt concentrations (injection ratios) are generally required for ECBG > 200 µS/cm due to this change in instrument resolution.

9.4.3 EC and temperature sensor calibration

Instruments should be calibrated following manufacturer's instructions, see below for details on this.

Temperature measurements from equipment should also be verified, at least annually, with a calibrated thermometer of similar resolution. Records relating to instrument calibration and maintenance must be documented and retained.

9.4.4 Tracer composition and consistency

Salt tracers must be food grade sodium chloride (NaCl). For the protection of aquatic life, products such as road salt, pool salt, water softeners, etc. are not permitted as they contain added chemicals. Consistency in tracer composition is important; hence, meta-data on brand and make of table salt should be tracked and documented and stored with the site metadata.

9.4.5 Salt weight or volume

Uncertainty in salt weight or volume generally translates into an equivalent percent uncertainty in calculated final discharge value. Improperly stored salt (i.e., in wet areas) can result in tracers becoming moist thereby resulting in altered weights if weighed out when damp. It is therefore recommended all salt be stored in a warm, dry area and notes on NaCl storage and handling should be included in collected meta-data.

You can minimise salt weight uncertainty by using accurate, recently calibrated scales. Tracer salt should be weighed to ± 1 %, or better, to account for uncertainty caused by small changes in moisture content, losses during transport and scale uncertainty. Small salt amounts measured for use in CFT (temperature compensated calibration factor for mass balance method) derivation should be weighed on a scale with a resolution of 0.01 g or better. Greater precision in this step (e.g., using a scale to 4 decimal places) will help to render this source of uncertainty negligible. Weighing scales are required to be calibrated, at a minimum of annually.

9.5 Discharge Calculation Methods

The calculation of final discharge value is the final place where uncertainty in salt dilution measurements can be minimised. The majority of the recommendations in this section encourage good meta-data practices and data processing procedures that are transparent and reproducible.

9.5.1 Shifting ECT background - control in the office

Application of appropriate algorithms to address changing background (no return to pre-injection level) is an acceptable alternative to use of measurements upstream of injection (above) provided it can be shown the maximum potential error only increases measurement uncertainty in the final discharge values by less than 5 %.

For example, suppose ECBG exhibited an increasing trend prior to injection, and ECT displayed a peak followed by a decrease and then a shift to an increasing trend. In such a case, one reasonable approach would be to assume that ECBG exhibited an approximately linear increase through time, and an appropriate correction approach would be to fit a linear regression between the pre-injection trend and the post-peak rising portions, and then to subtract this estimated time-varying ECBG from the observed ECT values.

9.5.2 Data spikes and other outliers

Breakthrough curves should be examined for the presence of data outliers, spikes or other out of range measurements prior to calculating discharge values (Figure 19). Filtering and filling of such values should affect fewer than 5 instances per salt run.

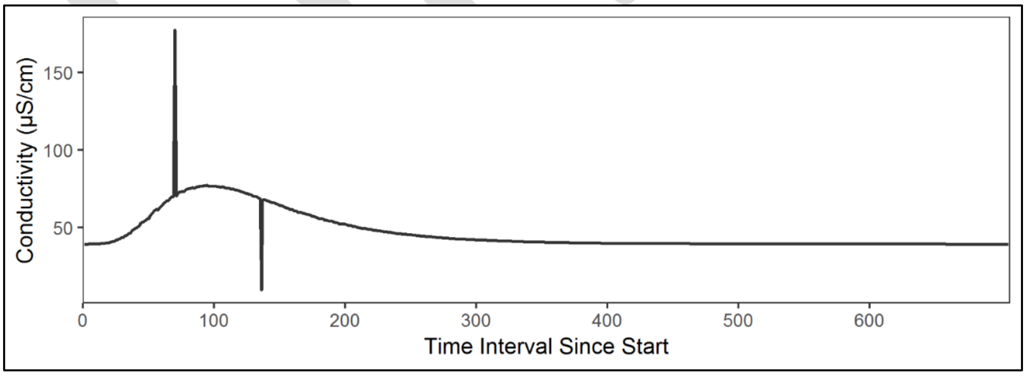


Figure 19: Breakthrough curve with outliers.

9.5.3 Shape of the breakthrough curve

At present there are no criteria for determining acceptable shapes (duration/magnitude) of breakthrough curves. “Noisy” breakthrough curves typically indicate inadequate mixing, but "smooth" breakthrough curves do not necessarily guarantee complete mixing. The following should be documented (imaged) through meta-data for each measurement:

- shape
- overall length (number of observations), and
- maximum exceedance over background.

9.5.4 Data calculations and review

Table 6. provides a summary of the equations that are utilised to calculate stream discharge from salt dilution field measurements.

Method	Equation for discharge
Slug injection – relative concentration	$Q = \dfrac{V}{k \cdot A_{BC}}$
Slug injection – mass balance	$Q = \dfrac{M}{CF_T \cdot A_{BC}}$

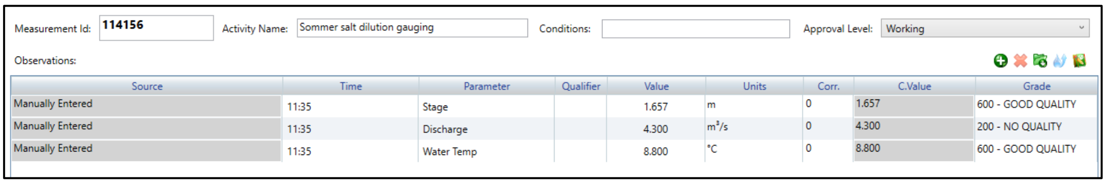
Table 6: Summary of the equations used to calculate stream discharge based on salt dilution field measurements.

(Q = stream discharge; k = relative concentration method calibration coefficient; EC_{BG} = initial background state, temperature compensated electrical conductivity; CF_T = mass balance method calibration coefficient; V = volume of salt solution injected; M = mass of salt injected; A_{BC} is the area under the EC breakthrough curve).

Note: If the dilution gauging departs by more than 5% from a stage/discharge rating, then it is possible that the rating has shifted. To facilitate future quality coding of the flow measurement another gauging should be undertaken utilising the dilution, method or another gauging technique, to check the validity of the first measurement and/or the validity of the rating and to facilitate quality coding of the flow measurement(s).

9.5.5 Data output & filing

The gauging output (usually a csv, pdf or xml file) is to be as per any other gauging and the results entered manually into your hydrological database. An example from the Aquarius time-series manager is provided as Figure 20.



Measurement Id: 114156 Activity Name: Sommer salt dilution gauging Conditions: Approval Level: Working

Observations:

Source	Time	Parameter	Qualifier	Value	Units	Corr.	C.Value	Grade
Manually Entered	11:35	Stage		1.657	m	0	1.657	600 - GOOD QUALITY
Manually Entered	11:35	Discharge		4.300	m^3/s	0	4.300	200 - NO QUALITY
Manually Entered	11:35	Water Temp		8.800	°C	0	8.800	600 - GOOD QUALITY

Figure 20: Aquarius software - manual dilution gauging entry example.

10 Quality assurance

In this section

This section includes quality assurance tools intended to prevent problems occurring, and guidance for method changes that may disrupt stationarity and management of quality assurance records.

10.1 Quality assurance tools

10.1.1 Inter-agency tests

Testing comparing methods of gauging can be a good way to ensure that the different methods produce similar results for the same flow conditions.

10.1.1.1 Regattas

The most effective approach for conducting multi-agency and multi-method testing is to organise a gauging regatta. During a gauging regatta, several agencies and various measurement methods are brought together at a single location under consistent flow conditions. Each agency applies its respective method to measure flow at the same site and time. The results obtained are then compared to assess the consistency and equivalence between agencies and methodologies.

10.2 Managing method changes

Significant change to measurement methods can disrupt stationarity of the record. Examples include a change of site and/or sensor location

- instrumentation type
- methodology change

10.3 Required records

All results obtained from the gauging regatta must be documented and made accessible to every participating agency. Any results that are identified as outliers should undergo thorough investigation, and necessary corrective actions must be implemented. These records should be preserved and used as supporting validation for the methods and outcomes assessed during the regatta.

11 Metadata

In this section

This section identifies the information required to be collected and preserved from the field (so that open channel flow measurement data collected can be verified and filed comments compiled) and provides requirements and guidance for assigning initial quality codes to the data.

11.1 Site details

Site metadata includes the following site details:

- the site identifier
- all records required from site selection (see section 2) and consideration of the selected site's characteristics (see section 2.3)

11.2 Measurement details

Measurement details are captured and collated into records Measurement records:

- are original records
- include the verification checks if undertaken during the measurement, and
- form part of the site metadata.

11.3 Other details

Site metadata may also include, as applicable:

- confidentiality agreements
- intellectual property, and
- any other restrictions related to data access.

Measurement metadata (see NEMS *Data Processing*) includes:

- data acquisition records (see section 7.7.4)
- quality codes (see section 9.4)
- data records and filed comments (see section 9.5), and
- data access agreements and/or waivers.

11.4 Quality coding

All time-series data produced under NEMS shall be quality coded in accordance with the NEMS National Quality Code Schema. The overall schema and guidance on its application are presented after Table 4 at the front of this document.

All requirements of Tables 1 and 2 must be met to assign any quality code to open channel flow data. In other words, Tables 1 and 2 set out the minimum requirements for any water level data to be considered as having been "produced under NEMS". To achieve QC 600, requirements of Tables 1, 2 and 3 must be met.

This version of this Standard introduces quality coding matrices (see Annex A) to help decide an initial quality code for each period of data between verification checks. The matrices provide a framework for resolving between QC 400 and the higher codes.

An initial quality code of QC 400 or higher sets the maximum final quality code attainable for the period of measured data up to the time of the relevant verification check. Data subsequently modified during data processing may have their final quality code reduced from the initial code assigned.

All completed quality coding matrices shall be:

- annotated with the site identifier
- signed and dated by the person completing the assessment

11.4.1 available when the data are processed (see NEMS *Data Processing*), and

- retained indefinitely as part of the site metadata.

11.4.2 Considerations

In most cases, open channel flow data collected as part of monitoring programmes will achieve at least QC 400. Quality codes lower than QC 400 are assigned directly from the flow chart.

11.4.3 Data that do not meet QC 600

11.4.4 Other variable-specific requirements

Data shall be quality coded QC 0 (non-verified) until reviewed and/or verified by a suitably trained and experienced person. QC 0 indicates that the data are in their original form (see section 12.1). Data may be quality coded QC 200 (not assigned a final quality code) if "provisional" but not original, i.e. data that are partially reviewed, verified, and/or processed. Data processing may elevate an initial quality code in the following situations:

- from QC 0, i.e. original, to partially or fully verified and processed data
- from QC 100, i.e. missing, to infilled with synthetic data, or

- from QC 200, i.e. “provisional”, to a final quality code once verification and processing are complete.

11.5 Comments

Comments may be one or more of:

- remarks noted in the field
- annotation and explanation during data processing, and
- filed comments timestamped and stored with the measurement..

Field remarks and comments noted during measurement may be informal. They are mostly intended for use by the recording agency; however, they must be retained indefinitely as original records, and for quality assurance and traceability purposes, respectively. Filed comments are intended for end users of the data.

They have a formal structure and text format. They can include, but are not limited to:

- routine information about the site, station, and data characteristics
- unusual features or events that data users should be aware of
- summarised explanation of methods
- alerts and supporting information related to data quality
- brief explanation of quality control actions, including data editing, and
- aspects not easily quality coded or otherwise quantified in point detail.

Refer to NEMS *Data Processing* for requirements, procedures, guidance, templates, and examples for all aspects of filed comments.

Note: All comments are metadata but not all metadata are comments

12 Data Management and Preservation

In this section

This section contains requirements and guidance for the management and preservation of data and metadata from the field, up to and including their storage in the office as original data and records.

Refer to NEMS: *Data Processing* for the requirements, procedures, and guidance for processing and editing the data, and final archiving of all data and *metadata.*

12.1 Original data

In general, original records comprise all information collected unaltered from the field. However, the original field data may not be unmodified, as described in section

12.1.1 Field records

All forms and field sheets completed in the field are original records and shall be secured and returned to the office in a timely manner.

They include:

- site visit records
- measurement records
- verification records
- validation records

12.1.2 Photos and video

Photos and video must be curated to avoid overwhelming storage with unnecessary and/or unidentifiable content. All photos and video retained as metadata must be:

- date-stamped
- indexed to the site
- informative, and
- named and/or annotated with the orientation and subject when not obvious (e.g. u/s of control, d/s of recorder, etc.).

Note: Audio can be used to 'annotate' video.

12.2 Preservation of data and records

The following data and records shall be permanently stored and retained indefinitely by the recording agency:

12.2.1 all required site and measurement metadata (see section 9)

- all other original records (see section 10.1)
- the original data, as defined by the recording agency (see section 7.6.3)
- quality assurance records (see section 8.3), and
- supplementary and/or complementary data used in the production of the final verified and measurement.

12.2.2 Electronic

Electronic records required to be retained indefinitely shall be:

- clearly identified
- catalogued
- backed up regularly, and
- retrievable in perpetuity.

Retrievable in perpetuity requires:

- a storage facility that is:
    - known (i.e. whereabouts and custodian)
    - secure, and
    - accessible.
- records be stored in a format that is either:
    - universally readable (e.g. text)
    - migrated as systems change, or
    - stored with the software to open and read them.

12.2.3 Paper records

Paper records required to be retained indefinitely shall be:

- Labelled

- indexed, and
- retrievable in perpetuity, i.e. stored in a facility that is:
  - known (i.e. whereabouts and custodian)
  - accessible, and
  - protects the records from damage and/or loss.

12.2.4 Data Archiving

The archiving procedures, policies and systems of the archiving body shall consider:

- future data-format changes
- off-site duplication of records, and
- disaster recovery.

Adequate mechanisms shall be put in place to store all relevant metadata with, or accessible from, or indexed from, the actual discharge measurements. The metadata shall include but not be limited to:

- instrument calibration records
- instrument validation records
- supplementary measurements
- the following flow measurement site details:
  - site purpose
  - recording agency
  - site location in standard and documented coordinate system
  - site name and past and present aliases
- comments.

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Annex A – Quality Coding Matrices

Quality coding matrices determine an initial quality code for the data based on site factors and field visit actions, observations, and verification checks.

If this initial quality code is QC 400 or above, it is then the maximum achievable final quality code for the data. The final quality code may subsequently be lowered from the maximum achievable by further data verification and subsequent actions during data processing, which are the subject of NEMS *Data Processing.*

For any quality code to be assigned, including QC 0, the requirements of Tables 1 and 2 of 'The Standard – <*Short title*>' must also be met.

Use of the matrices follows the concept of hierarchy in the NEMS *National Quality Code Schema.* Tick one of the boxes in every row applicable to the type of site being assessed. Where different site types have different criteria, strikethrough those that do not apply. For each applicable row in the matrix:

- Start with the QC 600 column and if the performance threshold is achieved, put a tick.
- If not QC 600, then consider the QC 400 column:
  - If the QC 400 performance description applies, put a tick.
  - If performance is between the QC 600 and QC 400 thresholds, or there is no QC 400 performance description, tick QC 500.
  - If performance is below (poorer than) the lower bound of a QC 400 performance band, tick QC 200.

    Note: QC 200 may not be available if there is no sensible concept of "poorer than" the relevant QC 400 performance requirement.

  - Action may be required instead, either immediately or subsequently, to resolve the performance issue and/or recheck.

The initial quality code to be assigned to the data is the lowest of all the boxes ticked.

- Initial quality code cannot be higher than QC 500 if any one QC 600 performance threshold is not achieved, by definition of Table 3 of the Standard.
- Data are considered to be of poor quality if any one QC 400 performance description applies.
- QC 200 indicates data quality is unknown until the affected data are processed and fully verified. Data processing may elevate or reduce an initial quality code of QC 200 depending on additional tests, other available evidence, and subsequent editing actions.

Note: Original data may retain quality code QC 0 until they are altered or fully verified and processed.

Annex B - Site Quality Table (for assessing adverse factors within the gauging reach that are >3 x width upstream and >2 x width downstream).

Criteria	0 Points	1 Point	2 Points	Points assigned
Straight channel	No discernible flow angles, or ADCP ☐	☐	> 45-degree flow angle ☐	
Change in depth	< 100% or ADCP/AECV ☐	☐	> 200% ☐	
Undercut banks	None ☐	☐	> 10% ☐	
Benthic weed	< 10% or ADCP/AECV ☐	☐	> 25% ☐	
Riverside/surface vegetation	< 10% ☐	☐	> 25% ☐	
Submerged obstructions (>1/3 of depth)	None or ADCP/AECV ☐	☐	> 10% ☐	
Partially submerged Obstructions	None or ADCP/AECV ☐	Sloping gravel or sand islands ☐	Bridge piles, Poles, Trees, Steep sided islands, Other ☐	
Total Points ***(To be applied to the Velocity-Area stationary meter method Matrix or ADCP Moving Boat Data Quality matrix)***				

Straight channel

Is the channel straight, with no noticeable changes in flow direction throughout the reach? This is to determine if there is rotation of the water column, not oblique flow angles at the gauging section (oblique flow is covered in the stationary method matrix).

Change in Depth

Does the depth change within the gauging reach? A depth upstream of the gauging cross-section of 0.5m changing to a depth of 1.0m at the cross section would equate to a 100% change? {Only applicable when the maximum depth (whether it be upstream, or at the cross section) is greater than 0.2m}.

Often the bed is not visible for part, or the entire reach. In these situations, discretion should be used to assess the site suitability. A basic understanding of flow characteristics, previous measurements, site visits or images from a time of clearer water conditions can assist in making this assessment.

Undercut banks

Are there any undercut banks, i.e. the water's edge is not visible? Bankside vegetation may obscure an undercut. Be sure to check.

Benthic weed

How much of the reach is covered by weed growing from the bed of any height? Includes filamentous algae but not benthic algae such as Phormidium.

Bankside/Surface vegetation

Are there any branches, grasses or other vegetation extending from the bank and into the water within the reach? Is there any vegetation growing/present on the surface? What is the percentage cover within the channel? See Figures 21 and 22.

Figure 21 The left image shows a site with excessive bankside/surface vegetation in the flow. The stream was 1m wide and vegetation extended into the flow approximately 0.3m from the true left bank and 0.2m from the right for the entire length (3m) of the reach. This equates to 50% coverage and a site score of two (QC400). The right image shows the channel after vegetation clearance. This site now meets the requirements for QC600. However, being 0.3m deep, any submerged obstructions would need to be greater than 6m upstream.

Figure 22 A zero points (QC600) site. (Left photo looking downstream, right photo looking upstream)

The bankside vegetation covers less than 10% of the gauging reach. It is also mostly out of the water and therefore not affecting the flow. The boulders in the bottom left of the upstream facing photo were moved to below the measurement section. The section is 8m wide and the nearest change in depth over 100% is 34m away (in the pool above the bridge).

Submerged Obstructions

Are there any obstructions e.g. logs, rubbish, boulders, weed beds, on the bed of the waterway that extend upwards from the bottom greater than 30% of the depth at that point? Use either the width or depth ratio method, whichever is greatest. Only applicable for depths greater than 200mm.

Partially submerged Obstructions

Are there any islands within the reach? If so, what are their nature? Gravel and sand islands will generally have sloping approaches on most if not all sides resulting in a smoother transition from and back to a standard velocity profile.

Are there any other obstructions within the reach that extend for the entire water column? For example, the measurement is conducted from a bridge that has piles within the gauging reach.

If deposited flood debris exists in the reach and only a small part extends to the surface, then discretion should be used as to whether the obstruction is behaving more as a “submerged” or “partially submerged” obstruction. Use either the width or depth ratio method, whichever is greatest.

Other considerations

Avoid reaches affected by tidal or other backwater effects.

Note – a backwater effect can be created by clearing items from within the reach such as weed, boulders etc.

Avoid vortices, reverse flow or dead-water zones. If reverse flow/eddies are encountered, (usually on an edge) then the reverse flow should be measured. Given the flow will be circulating, the flow angles will be changing rapidly, and care needs to be taken to ensure a true representation of the discharge is measured. Cross-sections with reverse flow should be avoided wherever possible.

Annex C - Velocity-Area Stationary Meter Method Matrix

Criteria			QC 600	QC 500	QC 400
Instrument Calibration valid (3.5)			Yes ☐		No ☐
Instrument used within calibrated velocity/depth range (3.5)			Yes ☐		No ☐
Pre-deployment test (3.4.1.7)			Completed with no errors ☐		Not completed, or completed with error/s ☐
Oblique flow (3.4.1.6)			Not present Or ADCP/ADV used ☐		Present, but not measured and calculated for ☐
Depth Measurement (3.3)	**ADCP/ AECV**		☐		
	Cable	**Firm bed**	No mobile bed. Wet/air-line angles absent or measured and applied. ☐		Mobile bed. Wet/air-line angles present and not applied. ☐
		Soft bed	Bed visible ☐		Bed not visible ☐
	Rod	**Firm bed**	No mobile bed ☐	Mobile bed ☐	☐
		Soft bed	Bed visible ☐		Bed not visible ☐
Maximum section discharge (3.7.1)			≤10% ☐		>10% ☐
Velocity profile (3.6)	**ADCP/ AECV**		☐		☐

	Proven regular velocity profile.	Single point <0.5m deep or Multi-point method ☐	Single point method >0.5m deep ☐	☐
	Known irregular or unknown velocity profile	≥3 point method or Single point method < 0.2m deep ☐	☐	Single point method >0.5m deep. ☐
QC Warnings Poor Boundary, Low SNR and Spikes only		None or ADCP used ☐	☐	4 + warnings ☐
Points derived from the Site Quality table (Annex B)		0 Points ☐	☐	2 + points ☐
95% Uncertainty (Annex E)		≤8% ☐	☐	> 10% ☐
Quality Code				

Note: -The quality code assigned to a discharge measurement will be that in the lowest column with boxes ticked (i.e. if you have ticked any box in the QC400 column that is the highest QC that the measurement can attain, ditto for the QC 500 column). Subsequent processing of the discharge measurement may result in the final QC being lowered.

Annex D - ADCP Moving Boat Data Quality Matrix

Criteria	QC 600	QC 500	QC 400
Instrument Calibration valid (4.3.2)	Yes ☐		No ☐
Compass calibration (if applicable) (4.3.3)	Completed without error and manufacturer threshold met or N/A ☐		Completed with error/s and manufacturer threshold not met or not completed ☐
Moving bed test BT referenced boat speed only (4.3.5)	Completed without error. Or N/A ☐		Not completed, ☐
Even number of transects in opposing directions (4.4)	Yes ☐		No ☐
GPS referenced Boat Speed (only) (4.4)	VTG with min. boat speed >0.24m/s or RTK/DGPS or N/A ☐	VTG with average boat speed <0.24m/s ☐	☐
Total exposure time (4.4)	> 12 min ☐		≤ 8 min ☐
Edge data Min. for any used transect (4.4)	≥ 2 bins Distance measured ☐		< 2 bins and/or Distance not measured ☐
Points derived from the Site Selection table (Annex B)	0 Points ☐		2 + points ☐
95% Uncertainty Using QRev default settings and Oursin method (Anex E)	≤ 8% ☐		> 10% ☐
QC Assigned			

Note: -The quality code assigned to a discharge measurement will be that in the lowest column with boxes ticked (i.e. if you have ticked any box in the QC400 column that is the highest QC that the measurement can attain, ditto for the QC 500 column). Subsequent processing of the discharge measurement may result in the final QC being lowered.

Annex E – QRev Software use and explanation

QREV Moving Boat

The use of acoustic Doppler current profilers (ADCPs) from a moving boat is a commonly used method for measuring streamflow. These streamflow measurements are then reviewed and post-processed using manufacturer supplied software coupled with the user's knowledge and experience to interpret the quality of the measurement, correctly configure discharge processing settings, and set appropriate thresholds to screen out erroneous data. This dependency on the software supplied by the manufacturer has created two problems.

1. The software supplied by the different manufactures have limited automated quality assessment features, and graphics and tables for user review are inconsistent among the manufacturers. Consequently, data quality assessment is not independent of the instrument used to make the measurement but rather is dependent on the capabilities of the manufacturer supplied software to review and assess the data quality. The lack of automated quality assessment features leaves the assessment to the knowledge and experience of the user and may result in inconsistent assessments of data quality.

2. Software from different manufacturers use different algorithms for various aspects of the data processing and discharge computation. Consequently, if the same dataset could be processed by each of the manufacturers' software, the resulting discharges could be different.

Teledyne RD Instruments (TRDI) WinRiver II provides the user the ability to filter data that appear to be erroneous by manually setting the parameters of several different types of filters. Properly setting these parameters requires some experience and may be an iterative process. WinRiver II also requires valid depth, boat velocity, and water velocity to compute discharge for an ensemble.

If any of these three data types are not valid, the ensemble is considered invalid and the ensemble duration of the next valid ensemble is increased. The valid data in the invalid ensemble are effectively ignored, and the invalid ensemble is back filled with data from the next valid ensemble. Global Position System (GPS) data, however, are an exception; if a new GPS referenced velocity is not valid, the ensemble uses that last valid value.

SonTek RiverSurveyor Live (RSL) and RiverSurveyor Discharge (RSQ) do not provide the user with any tools to filter erroneous data. If the ADCP fails to obtain a valid depth in an ensemble, the previous valid depth is used until a new valid depth is collected. If the ADCP fails to obtain a valid bottom track referenced boat velocity for an ensemble, the previous valid boat velocity is used until a new valid boat velocity is obtained or until 10 ensembles have passed.

After 10 consecutive ensembles with an invalid boat velocity, the boat velocity is set to zero for all subsequent ensembles until a valid boat velocity is obtained. This approach effectively computes zero discharge for those ensembles assigned a zero boat velocity. If the boat velocity reference is set to GGA or VTG (both satellite receiving options, only VTG available in NZ) and the boat velocity is invalid, the data for that ensemble are ignored and the ensemble duration for the next valid ensemble is increased.

What QREV does to solve these problems?

QRev uses the best available data and interpolates any invalid data. Computing discharge requires valid depth, boat velocity, and water velocity. Valid water velocity data require valid depth and valid boat velocity data. Boat velocity and depth data are independent. However, QRev uses transect length, which depends on boat velocity, to interpolate invalid depth data.

Therefore, the workflow in QRev is to filter and interpolate the boat velocity so that every ensemble has a boat velocity (measured or interpolated) associated with it prior to processing the depth data. The depth data are filtered and interpolated so that every ensemble has a depth. After every ensemble has boat velocities and depths, the water velocity data can be processed, filtered, and interpolated. The discharge for each ensemble can now be computed because each ensemble has a depth, boat velocity, and water velocity. All the valid data are used, and any invalid data are interpolated.

Table E1: Shows what the QRevInt software uses for the various measurement calculation parameters.

Table E1: Showing what the QRevInt software uses for the different measurement calculation parameters.

Characteristic	TRDI	SonTek	QRevInt
GPS based boat velocity	Nearest in time	Use last valid	Manufacturer
Edge coefficient	vertical = 0.91	vertical = f(width/depth)	Manufacturer
Edge ensembles	10 or user valid	Edge samples only	Manufacturer, with quality checks
Edge velocity	Simple average to get magnitude of measured velocity	Profile averaging includes extrapolation then projects the mean vector	Simple average to get magnitude of measured, with quality checks
Bottom extrapolation type	Constant not allowed	Constant is an option	Constant not allowed
Extrapolation exponent	Single	Top and Bottom	Single, Automated
Invalid water track	Increase dt	N/A	ABBA interpolation
Invalid bottom track	Increase dt	Hold last valid (9)	Linear interpolation
Invalid GPS	Hold last valid	Increase dt	Linear interpolation
Invalid depth	Increase dt	Hold last valid	Linear interpolation
Invalid depth cell	Interpolate or extrapolate	N/A	Interpolate or extrapolate
Data screening / filters	Manual	None	Automatic with manual override

Example

As a worst-case example, consider a measurement made during a flood on the downstream side of a bridge using a tethered boat. The bridge has two piers, and each has a debris pile collected on the upstream nose of the piers. The data were collected with a TRDI ADCP with GPS and initially processed with WinRiver II. As shown in Figure E1, WInRiver II did not have any valid data behind the two piers.

Using the algorithms in WinRiver II the next valid ensemble was projected back to the previous valid ensemble. Note the change in projected depth depending on the direction of boat travel. The result is that the high velocity data are projected as having occurred behind the piers with debris piles. The WinRiver II computed discharge was 3,183 m^3/s. Using QRevInt, there was valid boat velocity from the GPS, however, there was invalid depth data. QRevInt interpolated the invalid depth data using linear interpolation. Now with valid boat velocity and depth data the water velocity data could be used.

As shown in Figure E2, the water velocity behind the piers was very low with minor downstream flow due to the wake vortices caused by the piers and debris piles. The discharge computed using QRevInt was 2,690 m³/s. The discharges resulting from WinRiver II processing and QRevInt processing are substantially different with the QRevInt processed discharge validated by the existing rating and later by a measurement made with a manned boat that did not have the interference in flow from the piers. Such large differences can have a significant impact on the design and operation of flood mitigation structures, bridge design, flood predictions and many other uses of the derived flow series.

Smaller differences in discharge can occur during routine measurements that ultimately introduce errors in the measurement and the associated stage-discharge rating for a site.

The improved processing of ADCP measurements that are provided by QREV result in more accurate stage-discharge ratings and greater confidence in all subsequent uses of the gauged and rated discharges.

WinRiver II - Nav, Depth, WT => Ensemble

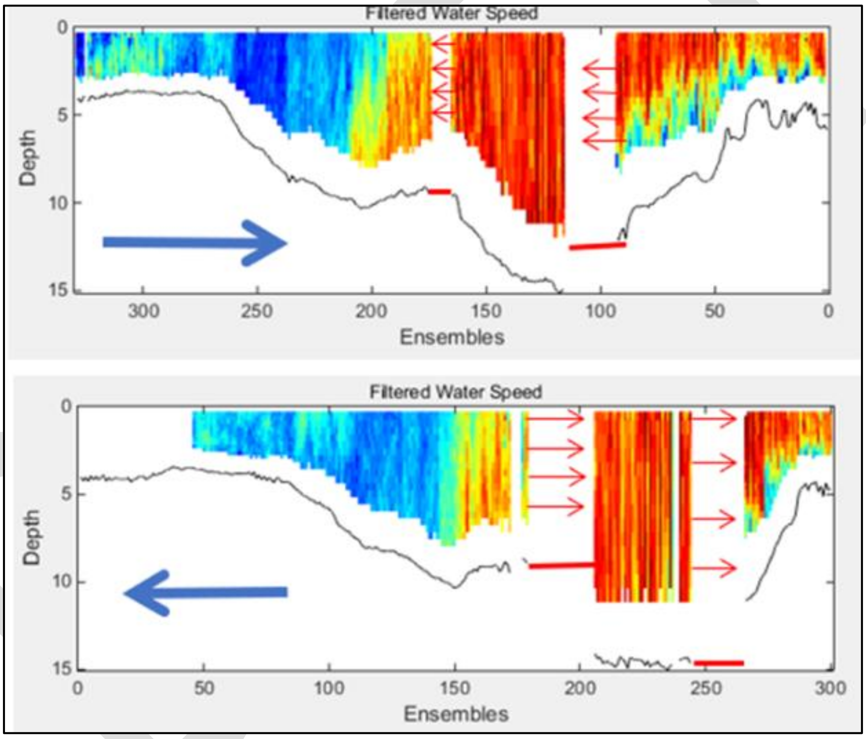


Figure E1. Example of TRDI ADCP data collected during a flood and processed with WinRiver II

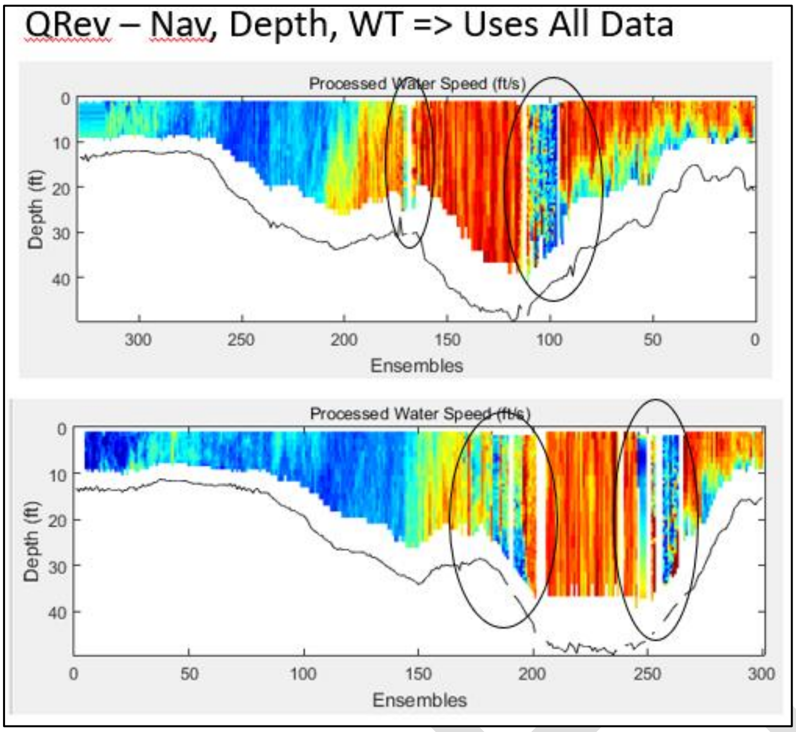


Figure E2: Same TRDI data processed with QRevInt.

How we use QRevInt

QRevInt is intended to be used both in the field and in the office. In the field, the measurement should be processed with QRevInt so that any issues identified by the automated quality checks can be addressed before leaving the site. In the office, the QRevInt user interface provides nearly everything a reviewer needs to see in a single window.

QRevInt is designed to be logical and tablet friendly. The information available from the opening tab provides the user an overview of the measurement quality and any final results and discharge totals. The colour highlighting and messages alert the user to any potential issues detected by the automated data quality assessment. Other tabs allow the user to explore the data or change the processing settings.

The interface is designed for the user to work from left to right along the major tabs. This approach leads the user through the premeasurement steps first. Navigation reference, depth, and water data are needed to compute discharge. By working left to right the best navigation data are obtained, then the best depth data, and finally the best water data, which are dependent on the navigation reference and depth. Thus, the final discharge is based on the best available data.

The tabs have both icons and colours to identify the data quality status based on the automated data quality assessment (ADQA). If a tab or icon is blue (user change), yellow (caution from ADQA), or red (warning from ADQA), an associated message will be in the Messages subtab at the bottom of the Main tab. Tabs, buttons, check boxes, radio buttons, and pop-up menus are used in lieu of menus to make QRevInt easier to use on a touch screen tablet. Each tab provides tables, text, options, and graphics needed to assess and process that aspect of the data in more detail. The options in the toolbar at the top can be accessed while viewing any tab.

Where to get QRevInt from and how to keep versions up to date and document (metadata) which version that you are using at any point in time?

QRevInt is available for download from the Genesis HydroTech LLC website (https://www.genesishydrotech.com/qrevint). The website provides a table showing the latest released versions with associated changes and bug fixes.

A user can sign up for email notifications of new versions using the provided link (https://docs.google.com/forms/d/e/1FAIpQLScwlS-_lAgK8iyB1GwL1KLYomirQ2zgsRkviYd4l-ttsTxJJA/viewform?usp=sf_link).

The version of QRevInt used to process the measurement is saved in the processed file *_QRevInt.mat and in the associated *_QRevInt.xm file.

Trick's" of usage that people should be aware of?

QRevInt automatically selects an extrapolation method based on the data collected and internal algorithms, however, the user should always visually check the extrapolation method selected to make sure it is reasonable based on observed site conditions.

Use the sensitivity table on the Extrap tab to assess the sensitivity of the final discharge to changes in the extrapolation method. Don't spend time deciding between methods if changing the method has little effect on the final discharge.

Comments added to the measurement are a permanent record. If a comment needs to be revised it cannot be edited. A new comment should be added to correct any previous comments.

Although most of the functionality is available through the buttons and tabs that can easily be used on a tablet, there are shortcuts keys available and right clicking on any graph will display the following context menu allows the user to save the figure and/or to change the axis limits.

The following keyboard shortcuts are supported:

Ctrl-F: Open file

Ctrl-O: Options

Ctrl-S: Save

Ctrl-N: Add note/comment

Ctrl-Q: Select discharge transects

Ctrl-B: Use bottom track

Ctrl-G: Use GGA

Ctrl-V: Use VTG

Ctrl-E: Use ensembles for x-axis

Ctrl-L: Use length for x-axis

Ctrl-T: Use time for x-axis

Ctrl-A: Show correlation and RSSI data below sidelobe on Adv. Graph

Ctrl-U: Show extrapolated speed on final speed contour plot

Up Arrow: Selects the transect above the currently selected transect

Down Arrow: Selects the transect below the currently selected transect

The Adv Graph tab provides the ability to compare various data associated with the measurement to analyze complex issues with the data. However, routine processing of measurements should not need to use the Adv Graph tab.

The agency can control the options available to the user in the Options dialog using the available settings in the QRev.cfg file. This file is an ASCII JSON formatted file and can be edited with any text editor.

QRevInt and the measurement being processed should be available on the local drive. Using QRevInt with a network drive can result in extremely slow operation.

Users should make frequent use of the comments to document that they have reviewed any issues highlighted by the ADQA or any changes made to the automatic settings.

QREV Mean Section method – or Stationary method

The following outlines the various problems that exist with gauging calculations and shows examples of the difference QREV makes?

Both SonTek (RiverSurveyor Stationary Live and RSQ) and SonTek FlowTracker (1&2) and TRDI (Section by Section Pro) have manufacturer provided software to collect and compute discharge measurements using the mid- and mean-section techniques with an ADCP or FlowTracker (1&2) However, the software provided have limitations and inconsistencies.

1. The edge computations for the mean-section measurement has a fixed edge coefficient of 0.5 in RiverSurveyor Stationary Live and a pull-down menu option which is user defined in the FlowTracker software. For the mean-section method the FlowTracker software only allows an edge coefficient of 0.5. If using the mid-section method, the software allows a custom coefficient.

2. RiverSurveyor Stationary Live and RSQ define the velocity correction factor as an adjustment on the velocity of a measured profile, which is not consistent with the common definition of velocity correction factor.

3. RiverSurveyor Stationary Live and RSQ do not provide access to the sample or ensemble data for a vertical. To access this data within Section by Section Pro, requires the measurement to be split into individual pd0 files and loaded into WinRiver II.

4. The methods used to compute the mean profile can be different.

5. Filtering of potentially invalid data is either not available or not automatically adjusted to the collected data.

6. The application of the ice exponent for ice covered situations is limited to an exponent of 0.1667 in Section-by-Section Pro.

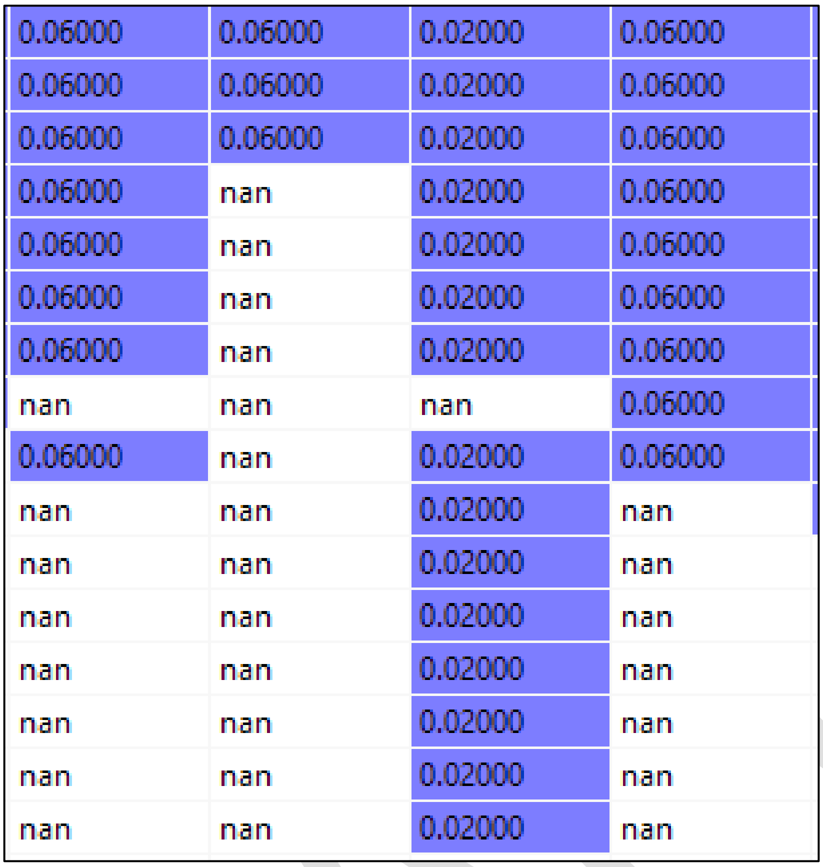
7. The application of the no slip condition to the ice water interface uses a different range of data to that applied for the application to the no slip condition at the streambed.

The following provides an example of computing mean profile with non-uniform cell sizes.

When the water velocity and/or depth are close to the threshold for a cell size or water mode change for auto adaptive ADCPs slight movement of the ADCP can cause a change. When this occurs the manufacturer's software take different approaches.

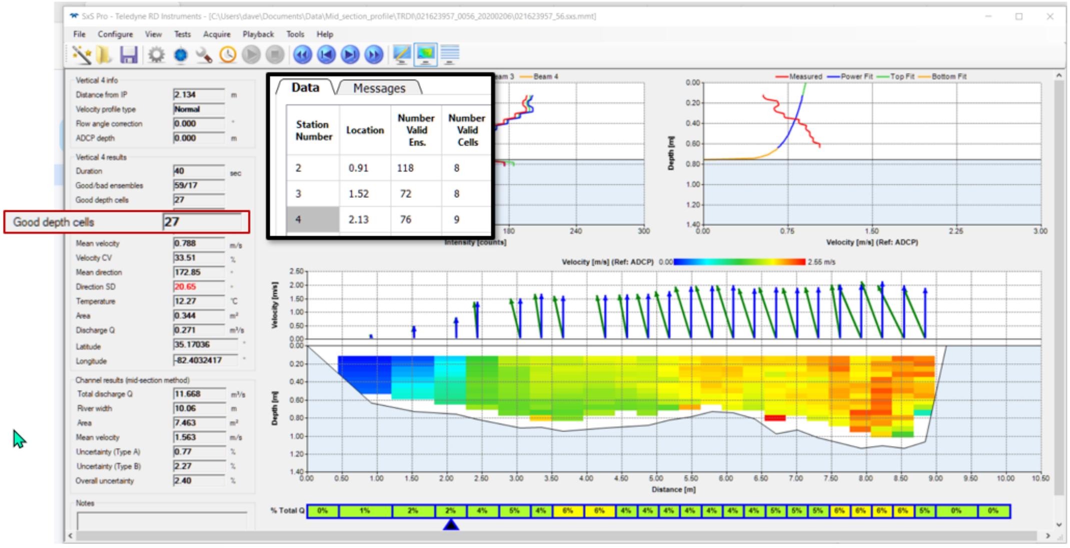
TRDI divides larger cells into multiple cells matching the smallest cell size for that vertical. While the result is a correct average profile, the reported number of cells implies more resolution in the profile than is present in the collected data.

In the following example only one ensemble had a cell size of 0.02 m while all of the other ensembles had cell sizes of 0.06 m. The result is that Section by Section Pro reported the number of cells as 27 rather than 9 as reported by QRevMS.



0.06000	0.06000	0.02000	0.06000
0.06000	0.06000	0.02000	0.06000
0.06000	0.06000	0.02000	0.06000
0.06000	nan	0.02000	0.06000
0.06000	nan	0.02000	0.06000
0.06000	nan	0.02000	0.06000
0.06000	nan	0.02000	0.06000
nan	nan	nan	0.06000
0.06000	nan	0.02000	0.06000
nan	nan	0.02000	nan
nan	nan	0.02000	nan
nan	nan	0.02000	nan
nan	nan	0.02000	nan
nan	nan	0.02000	nan
nan	nan	0.02000	nan
nan	nan	0.02000	nan

Figure E3: Cell sizes from QRevMS, showing only one ensemble with 0.02 m cell size.



Vertical 4 info
Distance from IP 2.134 m
Velocity profile type Normal
Flow angle correction 0.000 °
ADCP depth 0.000 m

Vertical 4 results
Duration 40 sec
Good/bad ensembles 59/17
Good depth cells 27
Good depth cells 27
Mean velocity 0.788 m/s
Velocity CV 33.51 %
Mean direction 172.85 °
Direction SD 20.65 °
Temperature 12.27 °C
Area 0.344 m²
Discharge Q 0.271 m³/s
Latitude 35.17036 °
Longitude -82.4032417 °

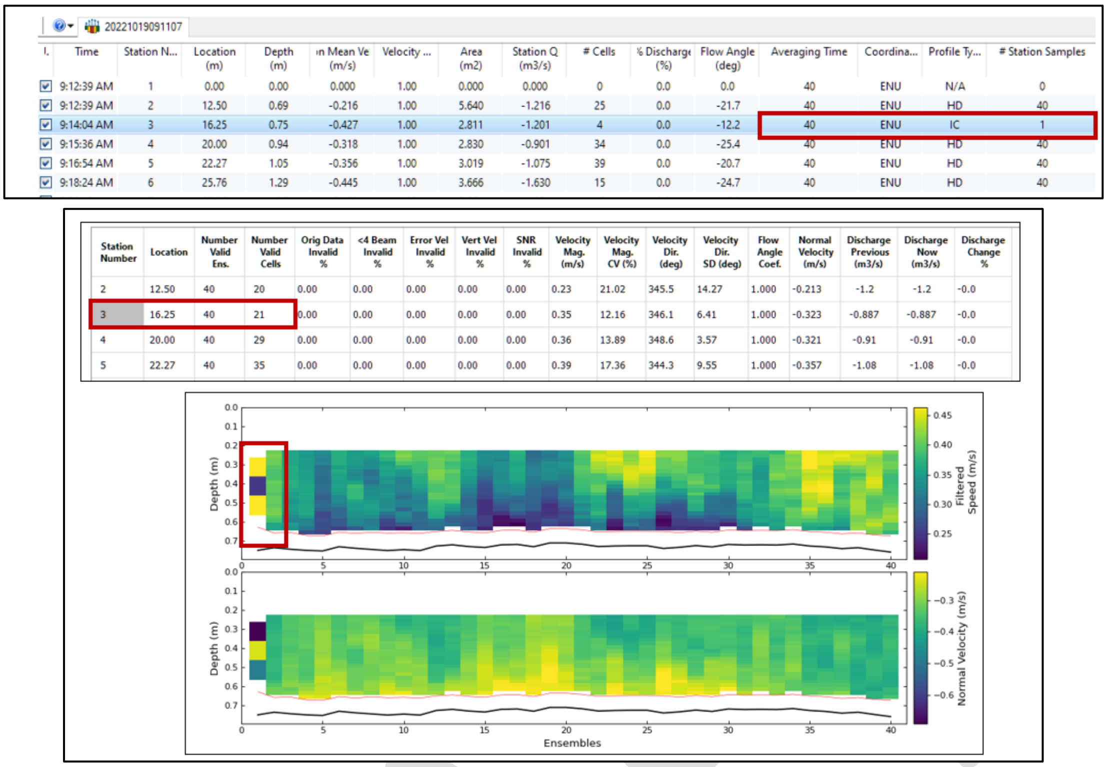
Channel results (mid-section method)
Total discharge Q 11.668 m³/s
River width 10.06 m
Area 7.463 m²
Mean velocity 1.563 m/s
Uncertainty (Type A) 0.77 %
Uncertainty (Type B) 2.27 %
Overall uncertainty 2.40 %

Notes

Station Number	Location	Number Valid Ens.	Number Valid Cells
2	0.91	118	8
3	1.52	72	8
4	2.13	76	9

Figure E4: Section by Section Pro reporting 27 good depth cells while QRevMS (inset) reported 9.

SonTek RiverSurveyor Stationary Live uses the cell size from the first ensemble as the reference. Any ensemble with a different cell size is not used in the computation of the mean profile. In station 3 of this measurement the table shows that data were collected for 40 seconds but only 1 sample was used.



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I.	Time	Station N...	Location (m)	Depth (m)	ın Mean Ve (m/s)	Velocity ...	Area (m2)	Station Q (m3/s)	# Cells	½ Discharge (%)	Flow Angle (deg)	Averaging Time	Coordina...	Profile Ty...	# Station Samples
☑	9:12:39 AM	1	0.00	0.00	0.000	1.00	0.000	0.000	0	0.0	0.0	40	ENU	N/A	0
☑	9:12:39 AM	2	12.50	0.69	-0.216	1.00	5.640	-1.216	25	0.0	-21.7	40	ENU	HD	40
☑	9:14:04 AM	3	16.25	0.75	-0.427	1.00	2.811	-1.201	4	0.0	-12.2	40	ENU	IC	1
☑	9:15:36 AM	4	20.00	0.94	-0.318	1.00	2.830	-0.901	34	0.0	-25.4	40	ENU	HD	40
☑	9:16:54 AM	5	22.27	1.05	-0.356	1.00	3.019	-1.075	39	0.0	-20.7	40	ENU	HD	40
☑	9:18:24 AM	6	25.76	1.29	-0.445	1.00	3.666	-1.630	15	0.0	-24.7	40	ENU	HD	40

Station Number	Location	Number Valid Ens.	Number Valid Cells	Orig Data Invalid %	<4 Beam Invalid %	Error Vel Invalid %	Vert Vel Invalid %	SNR Invalid %	Velocity Mag. (m/s)	Velocity Mag. CV (%)	Velocity Dir. (deg)	Velocity Dir. SD (deg)	Flow Angle Coef.	Normal Velocity (m/s)	Discharge Previous (m3/s)	Discharge Now (m3/s)	Discharge Change %
2	12.50	40	20	0.00	0.00	0.00	0.00	0.00	0.23	21.02	345.5	14.27	1.000	-0.213	-1.2	-1.2	-0.0
3	16.25	40	21	0.00	0.00	0.00	0.00	0.00	0.35	12.16	346.1	6.41	1.000	-0.323	-0.887	-0.887	-0.0
4	20.00	40	29	0.00	0.00	0.00	0.00	0.00	0.36	13.89	348.6	3.57	1.000	-0.321	-0.91	-0.91	-0.0
5	22.27	40	35	0.00	0.00	0.00	0.00	0.00	0.39	17.36	344.3	9.55	1.000	-0.357	-1.08	-1.08	-0.0

Figure E5: Water track data shown in QRevMS for each ensemble collected in station 3.

Example of velocity correction factor use

The velocity correction factor is a percentage of the normal velocity from the nearest measured station that is used as the velocity for an unmeasured station, typically an edge.

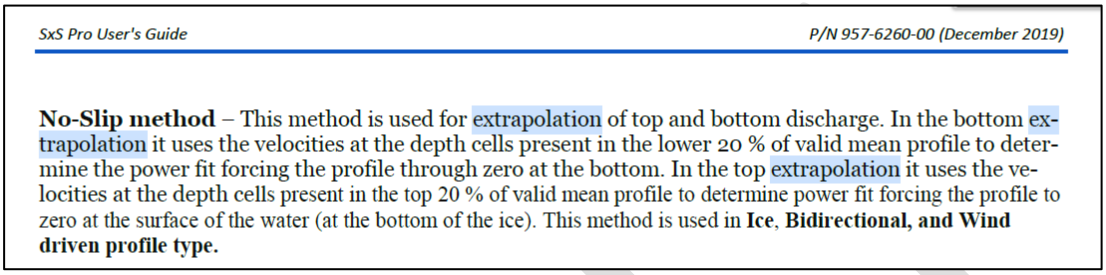
In Section by Section Pro the velocity correction factor is only available for an edge. Manual stations provide the previous verticals' velocity, but the user must enter a manual velocity rather than a correction factor.

For SonTek software the velocity correction factor is available for all measured verticals. It is set to 1 by default, but changing the value will result in changing the mean velocity for the measured vertical.

Example of computing the ice extrapolated velocity

WinRiver II, RSL, and RSQ for moving-boat discharge computations use the cells in the bottom 20% of the depth or the last cell if there are no cells in the bottom 20% to compute the bottom no slip extrapolation.

However, for the ice exponent both SonTek and TRDI use 20% of the valid profile (valid depth cells) rather than 20% of the range between the ice and the streambed. Thus, the no slip computations are not consistent at the bottom and at the ice surface.



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No-Slip method – This method is used for extrapolation of top and bottom discharge. In the bottom extrapolation it uses the velocities at the depth cells present in the lower 20 % of valid mean profile to determine the power fit forcing the profile through zero at the bottom. In the top extrapolation it uses the velocities at the depth cells present in the top 20 % of valid mean profile to determine power fit forcing the profile to zero at the surface of the water (at the bottom of the ice). This method is used in **Ice**, **Bidirectional, and Wind driven profile type.**

Figure E6: An explanation of the no-slip method from the Section-by-Section Pro User's Guide

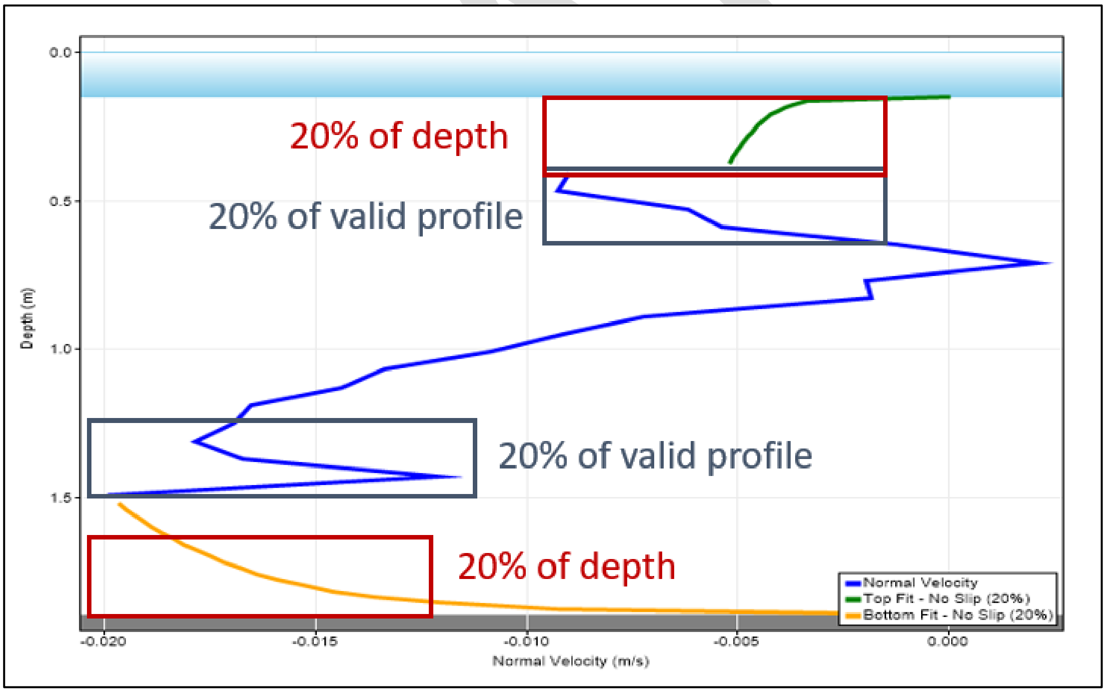
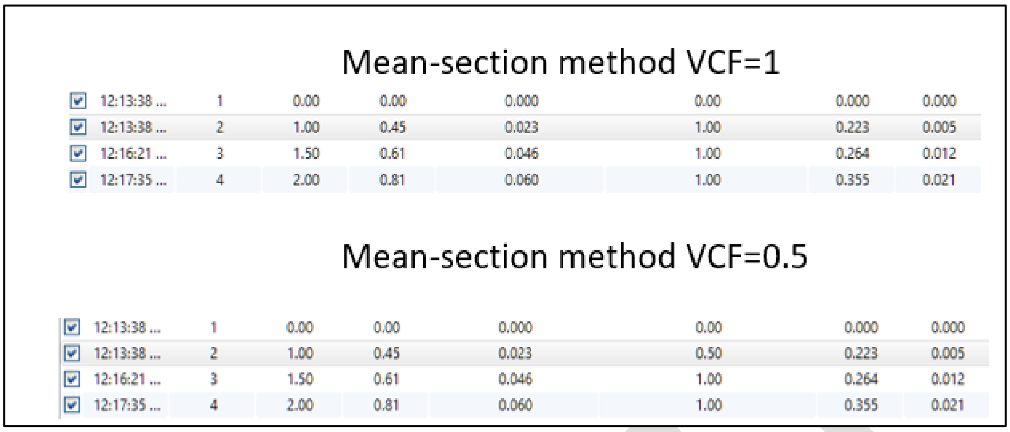


Figure E7. Figure illustrating the difference between 20% of depth and 20% of valid profile.

Example of edge discharge for mean-section method in RiverSurveyor Stationary Live

The edge coefficient for a mean-section method measurement cannot be changed in RiverSurveyor Stationary Live. The only option is to change the velocity correction factor, and it has no effect on the edge discharge.



Mean-section method VCF=1

☑	12:13:38 ...	1	0.00	0.00	0.000	0.00	0.000	0.000
☑	12:13:38 ...	2	1.00	0.45	0.023	1.00	0.223	0.005
☑	12:16:21 ...	3	1.50	0.61	0.046	1.00	0.264	0.012
☑	12:17:35 ...	4	2.00	0.81	0.060	1.00	0.355	0.021

Mean-section method VCF=0.5

☑	12:13:38 ...	1	0.00	0.00	0.000	0.00	0.000	0.000
☑	12:13:38 ...	2	1.00	0.45	0.023	0.50	0.223	0.005
☑	12:16:21 ...	3	1.50	0.61	0.046	1.00	0.264	0.012
☑	12:17:35 ...	4	2.00	0.81	0.060	1.00	0.355	0.021

Figure E8. Illustration of the lack of effect from changing the velocity correction factor of the edge discharge for a mean-section measurement in RiverSurveyor Stationary Live.

What QREV does to solve these problems

The USGS, Office of Surface Water developed a computer program, QRev, which has been subsequently enhanced for the international community as QRevInt.

Both QRev and QRevInt can be used to compute the discharge from a moving-boat ADCP measurement using data collected with any of the Teledyne RD Instrument (TRDI) or SonTek bottom tracking ADCPs. However, QRev and QRevInt do not support mid- and mean-section measurements.

QRevMS was developed to process mid- and mean-section methods (for both open water and under-ice conditions) using similar techniques and user interface as QRev, QRevInt and QRevMS appliy consistent algorithms for the computation of discharge independent of the manufacturer of the ADCP (or flowtracker 1 & 2 ADV's). In addition, QRevMS automates filtering and quality checking of the collected data and provides feedback to the user of potential quality issues with the measurement, along with various statistics and characteristics of the measurement.

QRevMS saves an extensible markup language (XML) file, a compressed JSON file, and an Excel file.

QRevMS provides many advantages to the manufacturer supplied software associated with ADCP's and Flowtracker instruments.

1. Automatic quality assurance checks
2. Automated filtering of data based on statistical properties
3. Access to view the ensemble data used to compute the average profile for a vertical
4. Automatic extrapolation settings for each vertical

5. Computational methods consistent with *ISO 748*
6. User modification of velocity correction factor at edge for mid-section measurements
7. User modification of edge coefficient at edge for mean-section measurements
8. Traditional use of velocity correction factor.

And additionally, for ADCP's:

1. Mean profile based on interpolation of data to the most used cell size for that vertical. This ensures all data get the appropriate weight in the average and the resolution is representative of the data collected.
2. Magnitude computational method that is dependent on whether the ADCP has a compass. This avoids the potential bias introduced in Section-by-Section Pro when only one method is used in both situations

How we use it

QRevMS is intended to be used both in the field and in the office. In the field, the measurement should be processed with QRevMS so that any issues identified by the automated quality checks can be addressed before leaving the site.

In the office, the QRevMS user interface provides nearly everything a reviewer needs to see in a single window. QRevMS is designed to be logical and tablet friendly. The information available from the opening tab provides the user an overview of the measurement quality and totals. The colour highlighting and messages alert the user to any potential issues detected by the automated data quality assessment. Other tabs allow the user to explore the data or change the processing settings.

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Where to get QRevMS from and how to keep versions up to date and document (metadata) which version that you are using at any point in time

QRevMS is available for download from the Genesis HydroTech LLC website (https://www.genesishydrotech.com/qrevms).

The website provides a table showing the latest released versions with associated changes and bug fixes. A user can sign up for email notifications of new versions using the provided link (https://docs.google.com/forms/d/e/1FAIpQLSfG75PwE97i0G8uOPHNBhrLghCgyHKs6Ok24ZOc72wDVLnsXA/viewform).

The version of QRevMS used to process the measurement is saved in the processed file *_QRevMS.zip and in the associated *_QRevMS.xm file.

“Trick’s” of usage that people should be aware of

The agency can control the options available to the user in the Options dialog using the available settings in the QRevMS.cfg file. This file is an ASCII JSON formatted file and can be edited with any text editor.

QRevMS can read the raw data file (*.rsqst) from RSQ. Do not use the Matlab output from RSQ for stationary measurements. The Matlab output is required for RiverSurveyor Stationary Live.

QRevMS and the measurement being processed should be available on the local drive. Using QRevMS with a network drive can result in extremely slow operation.

Users should make frequent use of the comments to document that they have reviewed any issues highlighted by the ADQA or any changes made to the automatic settings.

ANNEX F - Metadata list required for salt dilution methods

and for quality coding purposes

Instrumentation				
Sensor ID:	**Make:**	**Model:**	**Serial:**	**Meta-data**
Temperature Compensation	Non-Linear (25°C) Linear (25°C)	☐ ☐		☐
EC Sensor Resolution	EC_T measurements <_____µS/cm EC_T measurements >_____µS/cm	Resolution: _______ µS/cm Resolution: _______ µS/cm		☐
EC Sensor Calibration	Standard: ____________ µS/cm Expiry Date: ____________	Calibration Date < 6 months Date: ______________		☐
Temperature Verification	Sensor Reading ________ °C Manual Reading ________ °C	Temp Verified < 6 months Date: ______________		☐

Tracer Data			
Maker:	**Brand:**	**Lot #:**	**Meta-data**
Tracer Composition	Are salt tracers of food grade quality?		Y☐ / N☐
Tracer Weight	Scale recently calibrated (< 1 year)?		Y☐ / N☐
	Scale Calibration Date: ___________ Measured to __________ % or +/- _______ g		☐
Tracer Volume (Relative Concentration)	Measured with _________________ rated to +/- ______________ ml		☐

Field Procedures – Channel Reach Properties			
Stream:	**Stage (m):**	**Date:**	**Meta-data**
Mixing Reach Properties	Pictures: ☐ ______________________________		☐
	Is there a lack of additional water inputs (streams, ditches, groundwater) within measurement reach? Describe: ______________________________ ______________________________		Y☐ / N☐
	Channel properties that facilitate lateral mixing and enhance turbulence at the stage measured are present? Describe: ______________________________ ______________________________		Y☐ / N☐
	Channel does not contain substantial storage, pool volumes and re-circulating streamflow? Describe: ______________________________ ______________________________		Y☐ / N☐
	Channel does not contain any vegetation or other features that could affect the storage and release of the tracer? Describe: ______________________________ ______________________________		Y☐ / N☐
	Are there at least 2 constrictions or other mixing features to promote lateral mixing? Describe: ______________________________ ______________________________		Y☐ / N☐
	Pictures: ☐ ______________________________		☐

Injection Point Properties	Injection point is located above a feature (e.g., constriction) that promotes lateral mixing? Description:____ ____ ____	Y☐ / N☐
Measurement Point Properties and Sensor Placement - Slug Injection	Pictures: ☐ ____________________________________	☐
	Were all measurement points (sensors) located in areas lacking back eddies, recirculating flow and aeration:	Y☐ / N☐
	________ m from Point of Injection (estimate) (probe 1) ________ m from Point of Injection (estimate) (probe 2) ________ m from Point of Injection (estimate) (probe 3)	☐
	Was complete mixing confirmed and mixing length > 7 wetted channel widths?	Y☐ / N☐
	Average Reach Width ________m Wetted Channel Width Equivalent ________m Description:_____________________________________	☐
Measurement Point Properties and Sensor Placement - Constant Rate	Pictures: ☐ ____________________________________	☐
	Were all measurement points located in areas lacking back eddies, recirculating flow and aeration:	Y☐ / N☐
		☐

	Describe all locations measured and approximate distances from injection point ______________________________ ____ ____	Y☐ / N☐
	Were each of these points measured at least 3 times to confirm a stable exceedance level over background? If no, describe why _____________________________ ____ Average Reach Width ________m Wetted Channel Width Equivalent ________m	☐

Field Procedures	**Run #**			
Stream:		**Stage:**	**Date:**	**Meta-data**
Tracer Dose: General	No permissions or consents were required? No sensitive species were present? Was dosing designed to meet the requirements of the local consenting authority			Y☐ / N☐ Y☐ / N☐ Y☐ / N☐
Tracer Dose: Mass Balance	Estimated Flow ______________ m^3/sec Estimated Flow(2) ______________ m^3/sec Dose Ratio _______________ kg/m^3/sec Mass Injected _______________ kg			☐
Tracer Dose: Relative Concentration – Salt in Solution	Batch # ___________________________ Estimated Flow ________________ m^3/sec Estimated Flow(2) _______________ m^3/sec Solution Concentration ______kgs /_____ L			☐

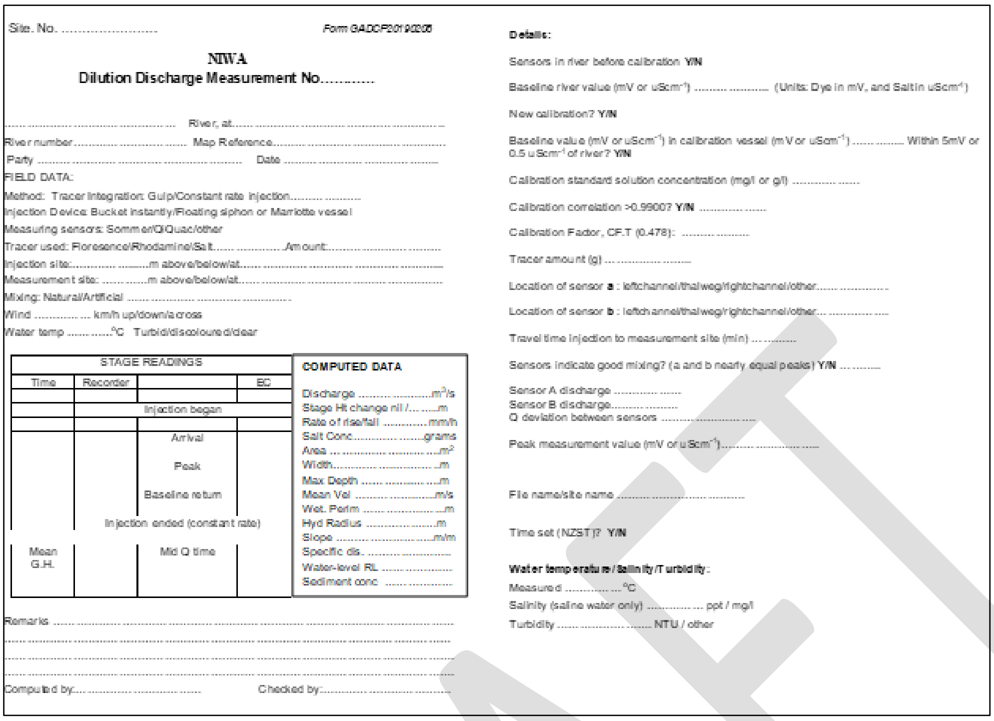
	Dose Ratio ________________L/m^3/sec Volume Injected : __________________L	
Tracer Dose: Relative Concentration – Constant Rate	Batch # ___________________________ Estimated Flow _______________ m^3/sec Estimated Flow2 _______________ m^3/sec Dose ________________ L/m^3/sec Solution Concentration _____kgs / _____ L Injected Rate: _____________________ml/s	☐
Derivation of *k* Constant for Relative Concentration Methods	In Situ ___________________________ ☐ Were separate *k* constants developed per EC sensor, per injection solution batch? Site Specific (automatic salt injection) ____________ ☐ Were site specific *k* constants developed per EC sensor, per site that were confirmed > 2 times (i.e., start and end of injection solution batch?	☐ Y☐ / N☐ ☐ Y☐ / N☐
Derivation of *CF_T* Constant for Mass Balance Method	In Situ ___________________________ ☐ Were separate *CF_T* constants developed per EC sensor? Site Specific ______________________ ☐ Were site specific *CF_T* constants developed per EC sensor, per site that were confirmed > 5 times? Lab Derived:______________________ ☐ Were all EC sensors recently calibrated (< 6 months) and demonstrated to produce a value that was close to the lab derived *CF_T*?	☐ Y☐ / N☐ ☐ Y☐ / N☐ ☐ Y☐ / N☐
Sampling Interval	Manual: every ______ secs	☐

	Automatic Data Logging: _____________ sec Point (constant rate only) ____ locations, ____ times Breakthrough Curve Duration ________________Mins	
EC_T Measurements (outside of range)	Were all stream temperatures > 2ºC and electrical conductivities measured > 3 µS/cm	Y☐ / N☐
Background EC_T Sensor (*optional if data correction method applied*)	Placed above injection point or measured above POI before and after salt run?	Y☐ / N☐
Measurement Sensor(s) Placement	See *Stream Channel Condition* form	☐
Shifting Background/ Variable Background Exceedance Over Background /	Water Level Start: ______ m Start EC_{BG}___ µS/cm Water Level End: _______ m End EC_{BG}___ µS/cm Level Change _______m/hr EC_{BG} Change ___ µS/cm Max. Exceedance Over Background_______ µS/cm Was the EC_{BG} steady? If no, list range: _______ µS/cm to _______ µS/cm	☐ Y☐ / N☐

Data Calculations and Assessment			
Stream:	**Stage:**	**Date:**	**Meta-data**
SUNY software used?	Was the uncertainty result from SUNY < or equal to 5%? If not, note major areas of uncertainty__________________________ ____		Y☐ / N☐
Shape of Break-through Curve	Image/ File Name: ______________________________		☐
Shifting Background	Were corrections for a shifting EC_{BG} applied? Method description: ______________________________ ____		Y☐ / N☐

	____	
Variable Background: Breakthrough Curve Detection and Separation	Were methods applied to define the start and end of the breakthrough curve due to a variable EC_{BG} ? Method description: ____________________________ ____ ____	Y☐ / N☐
Difference Between EC Probes per Runs	Were two or more EC Probes used per tracer run? Probe 1 ___________ m^3/sec, Probe 2___________ m^3/sec Probe 3 ___________ m^3/sec, Probe 4___________ m^3/sec Is the % difference between sensors, per run > 7% ?	Y☐ / N☐ Y☐ / N☐
Number of Salt Runs per Discharge Measurement	Were two or more runs used per derived discharge value? Run 1:_____________ m^3/sec, Run 2_____________ m^3/sec Run 3_____________ m^3/sec, Run 4 _____________ m^3/sec Is the % difference between the runs > 7%?	Y☐ / N☐ Y☐ / N☐

Annex G – Example Salt Dilution Gauging Form



Site. No. …………………… *Form GADCF20190205*

NIWA

Dilution Discharge Measurement No…………

……………………………………… River, at……………………………………………………

River number………………………… Map Reference………………………………………

Party ………………………………………………… Date ……………………………………

FIELD DATA:

Method: Tracer Integration: Gulp/Constant rate injection………………

Injection Device: Bucket instantly/Floating siphon or Marriotte vessel

Measuring sensors: Sommer/Q/Quac/other

Tracer used: Floresence/Rhodamine/Salt………………Amount:……………………………

Injection site:……………………m above/below/at……………………………………………………

Measurement site: …………m above/below/at……………………………………………………

Mixing: Natural/Artificial ……………………………………………

Wind …………… km/h up/down/across

Water temp …………$^{\circ}$C Turbid/discoloured/clear

STAGE READINGS			
Time	Recorder		EC
	Injection began		
		Arrival Peak Baseline return	
	Injection ended (constant rate)		
Mean G.H.		Mid Q time	

COMPUTED DATA

Discharge ………………………m^3/s

Stage Ht change nil /………m

Rate of rise/fall …………mm/h

Salt Conc……………………grams

Area ……………………………m^2

Width……………………………m

Max Depth ……………………m

Mean Vel ………………………m/s

Wet. Perim ……………………m

Hyd Radius …………………m

Slope …………………………m/m

Specific dis. …………………

Water-level RL ………………

Sediment conc ………………

Remarks ……………………………………………………………………………………………

……

……

……

Computed by:……………………………… Checked by:………………………………

Details:

Sensors in river before calibration **Y/N**

Baseline river value (mV or $uScm^{-1}$) ……………… (Units: Dye in mV, and Salt in $uScm^{-1}$)

New calibration? **Y/N**

Baseline value (mV or $uScm^{-1}$) in calibration vessel (mV or $uScm^{-1}$) …………… Within 5mV or 0.5 $uScm^{-1}$ of river? **Y/N**

Calibration standard solution concentration (mg/l or g/l) ………………

Calibration correlation >0.9900? **Y/N** ………………

Calibration Factor, CF.T (0.478): ………………

Tracer amount (g) ……………………

Location of sensor **a** : leftchannel/thalweg/rightchannel/other………………

Location of sensor **b** : leftchannel/thalweg/rightchannel/other………………

Travel time injection to measurement site (min) …………

Sensors indicate good mixing? (a and b nearly equal peaks) **Y/N** …………

Sensor A discharge ………………
Sensor B discharge………………
Q deviation between sensors ……………………

Peak measurement value (mV or $uScm^{-1}$)……………………

File name/site name ……………………………

Time set (NZST)? **Y/N**

Water temperature/Salinity/Turbidity:

Measured ……………$^{\circ}$C

Salinity (saline water only) …………… ppt / mg/l

Turbidity ……………………… NTU / other

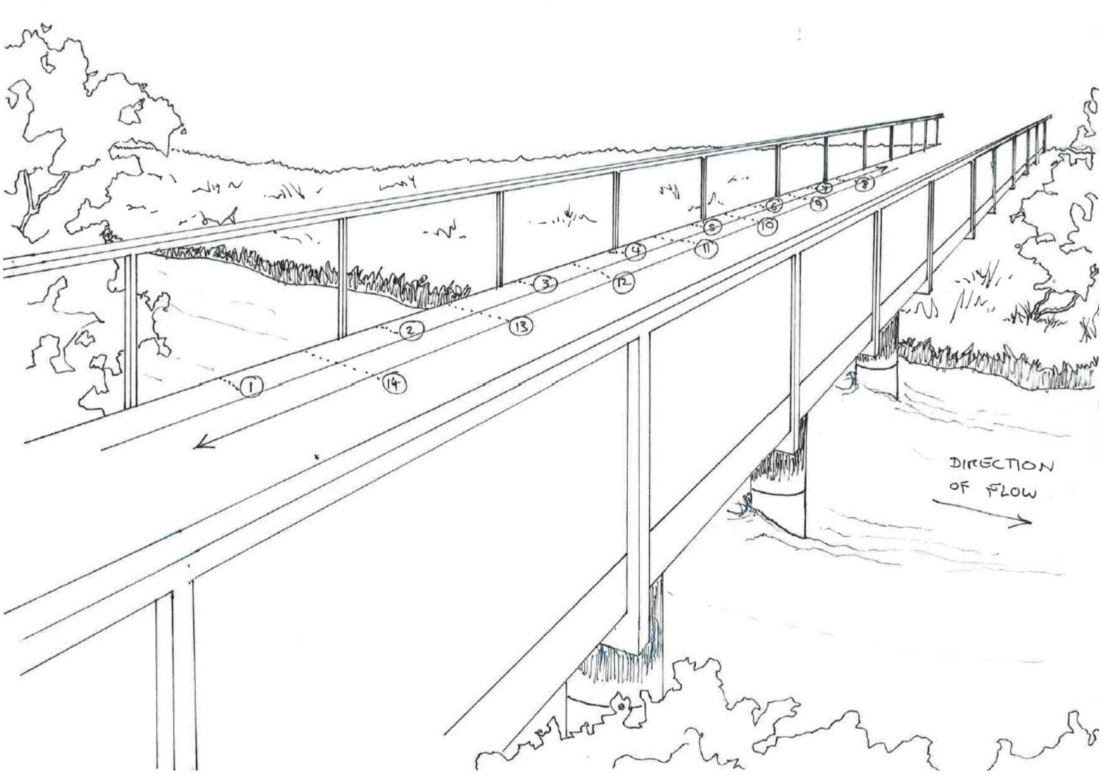
Annex H – Surface Velocity - Handheld Radar and Calculation of cross-sectional area and Discharge

This annex provides a worked example of how to calculate the cross-sectional area of a waterway utilising the information shown in below.

Establishing the cross-sectional area

Run the tagline along bridge on the side that the gauging will be carried out. Secure both ends and ensure the tagline is straight and tight. The looser it is, the less accurate any width measurement will be. Record the positions of the right and left water edges. From the measured section width, mark out up to 20 evenly spaced points on the tagline for SVR measurements to be taken at.

A SVR gauging is comprised of two transects. Each transect is comprised of alternate halves of the 20 measurement points. So, 10 evenly-spaced measurements moving in one direction across the bridge, then the alternative 10 evenly-spaced interspersed measurements moving in the other direction. This way if the flow is changing rapidly, each transect can be considered a gauging. See diagram below for example, where the numbers represent the order in which measurements are taken



The above example is for a smaller river with 14 points where velocity will be measured, 7 observations each way across the river.

Stage should be recorded at the start and end of each transect, either by staff gauge or by measuring water level height below/above a reference point (bridge) that can be levelled after the gauging or at a later date. If stage height is quickly and easily obtainable, then stage recorded for each (or every couple of) measurement points would be most useful for the determination of mean water level over the measurement.

To enable the calculation of the cross-sectional area, firstly determine the reduced level (RL) of the water surface. This is done by measuring the distance from the bridge datum point to the water surface. This distance is then subtracted from the known bridge datum RL. This is shown in the example below:

RL of water surface = 12.291 – 3.142 = 9.149

Once you have established the reduced level of the water surface, determine the depth of the water. The reduced level of the bed is obtained from the cross-section survey and is subtracted from the water surface RL. As shown below:

Depth of water = 9.149 – 8.486 = 0.663

See the bridge cross-section shown in Figure H -1

Once you have established the reduced level of the bed this and the running distance can be entered into a spreadsheet, that resembles that shown in Table H -1

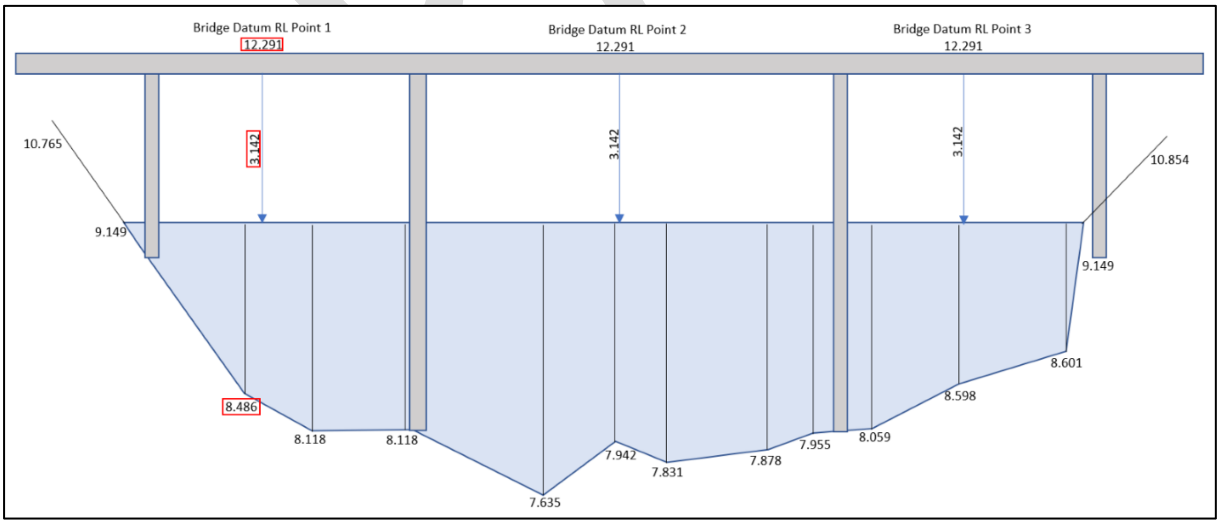


Figure H-1: Example bridge cross section with bed elevation.

The above cross-section is tabulated below in Table H1.

Table H-1: Example of Cross section with distances and the reduced levels of the bed.

Distance (m)	Bed RL (m)
0.000	10.765
1.490	9.149
2.790	8.486
2.930	8.118
3.960	8.118
5.100	7.635
6.380	7.942
7.480	7.831
8.270	7.878
9.210	7.955
11.210	8.059
12.010	8.598
15.130	8.601
18.520	9.149
23.510	10.854

An alternative method for surveying cross sections using a dumpy level, survey staff, and tagline (or tape measure) is provided in. This method uses the NIWA Surface Velocimetry Discharge Calculator available on the NEMS web site (https://www.nems.org.nz/tools/niwa-surface-velocimetry-discharge-calculator), which can also be used for inputting the cross-section data above.

Establishing a cross section using a dumpy level and survey staff

Cross sections can also be established by using a dumpy level, survey staff, and a tag line (or tape measure). This can be achieved by pegging out the cross section from the true left bank PLB to the true right bank PRB

Pegs should be placed above the high water (flood) level and installed robustly, so that they do not wash away during floods. It is also useful to peg the ‘water's edge’ (i.e. water level) at the same time that the cross section was measured. The tag line (or tape measure) can be stretched from PLB to PRB to provide horizontal distance measurements.

Measurements of bed level are then made across the cross section with the survey staff and dumpy level. Measurement points are usually evenly spaced; however, they can also be unevenly spaced, with more points being used where bed elevation is changing rapidly, and fewer where it is consistent.

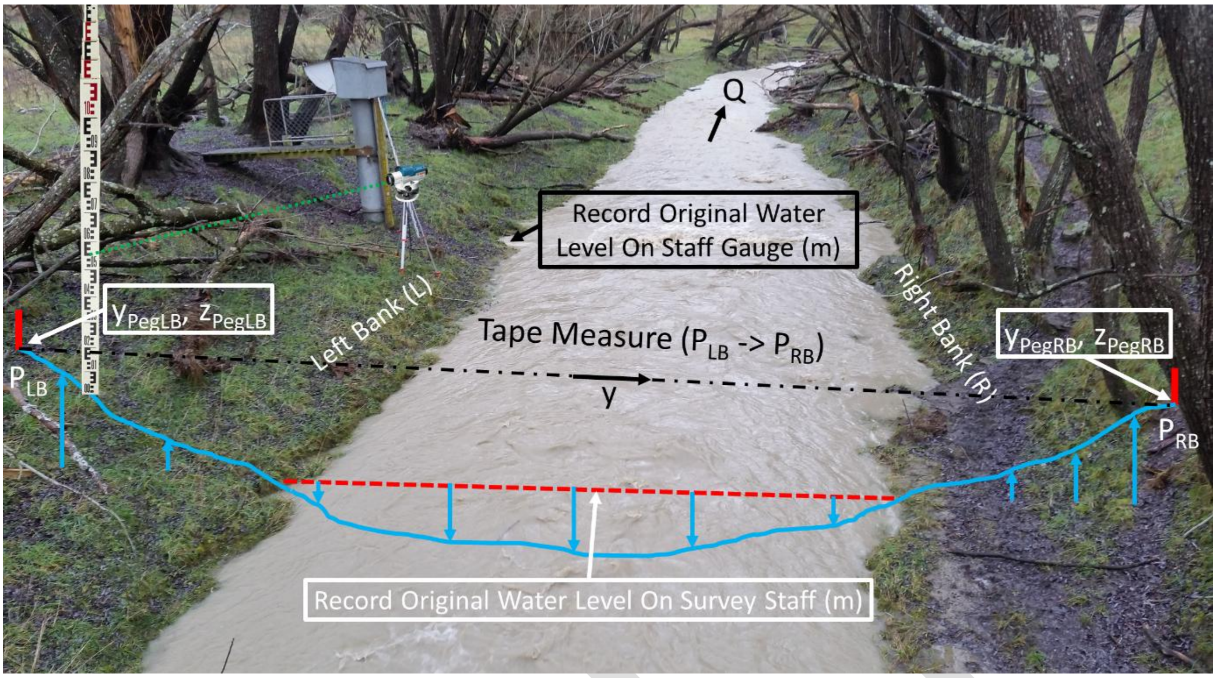
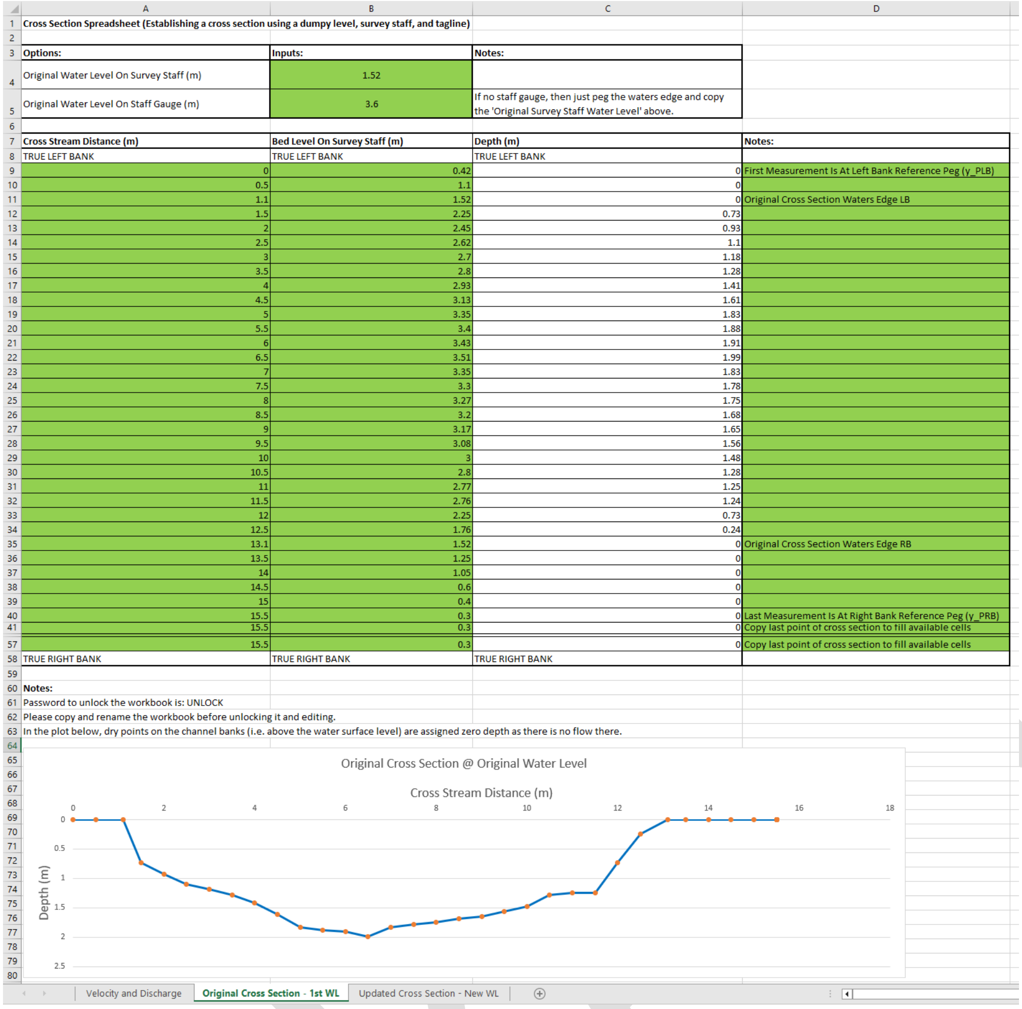


Figure H-2: Cross section measurement using a dumpy level, survey staff, and tag line (or tape measure).

Measurements can be entered into the “NIWA Surface Velocimetry Discharge Calculator - V1.3.xlsx” (see above for link) in the ‘Original Cross Section – 1st WL’ tab If a staff gauge is present at the measurement site then this gauge height can also be entered.



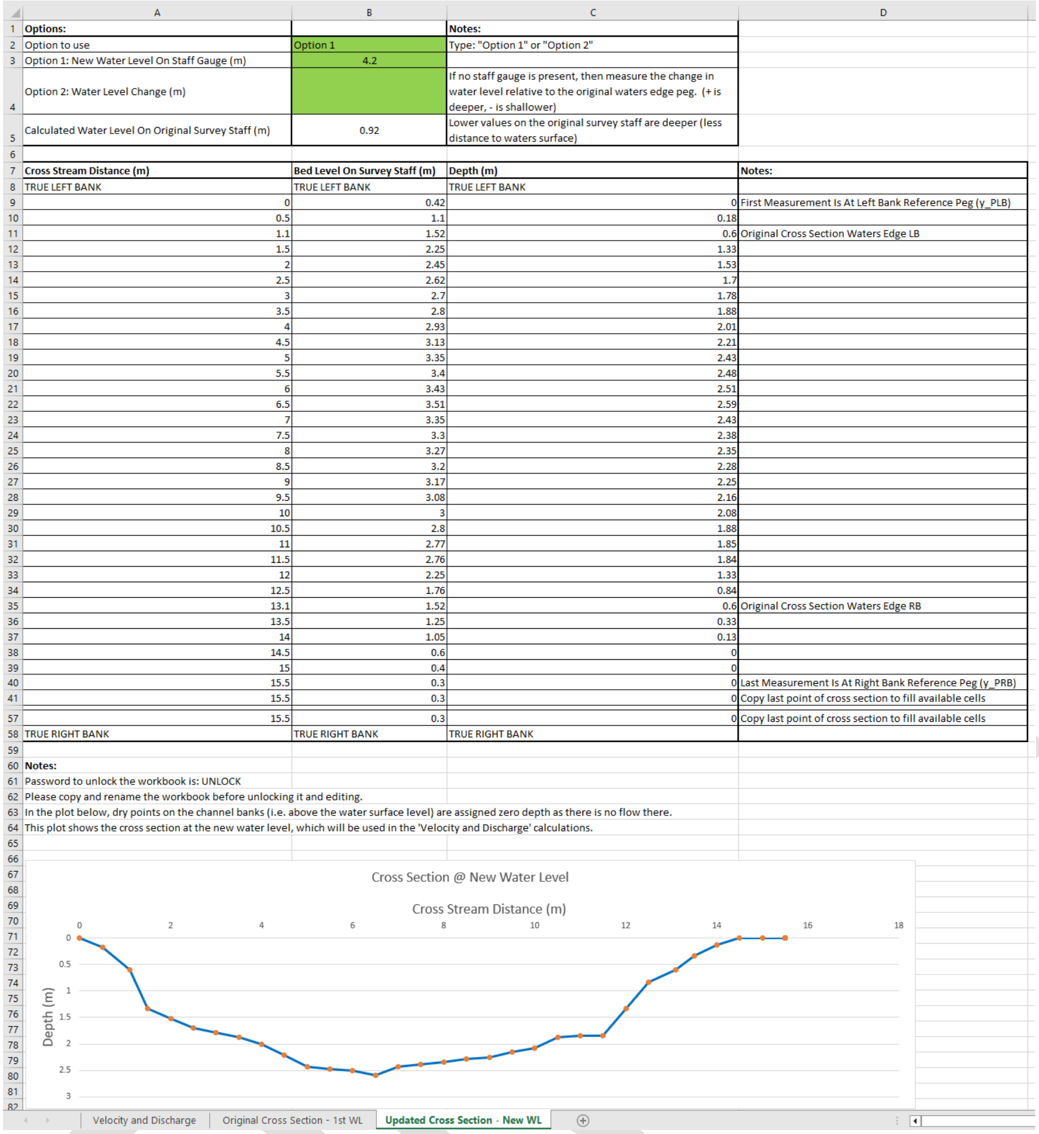
Cross Section Spreadsheet (Establishing a cross section using a dumpy level, survey staff, and tagline)

Options:	**Inputs:**	**Notes:**
Original Water Level On Survey Staff (m)	1.52	
Original Water Level On Staff Gauge (m)	3.6	If no staff gauge, then just peg the waters edge and copy the 'Original Survey Staff Water Level' above.

Cross Stream Distance (m)	**Bed Level On Survey Staff (m)**	**Depth (m)**	**Notes:**
TRUE LEFT BANK	TRUE LEFT BANK	TRUE LEFT BANK	
0	0.42	0	First Measurement Is At Left Bank Reference Peg (y_PLB)
0.5	1.1	0	
1.1	1.52	0	Original Cross Section Waters Edge LB
1.5	2.25	0.73	
2	2.45	0.93	
2.5	2.62	1.1	
3	2.7	1.18	
3.5	2.8	1.28	
4	2.93	1.41	
4.5	3.13	1.61	
5	3.35	1.83	
5.5	3.4	1.88	
6	3.43	1.91	
6.5	3.51	1.99	
7	3.35	1.83	
7.5	3.3	1.78	
8	3.27	1.75	
8.5	3.2	1.68	
9	3.17	1.65	
9.5	3.08	1.56	
10	3	1.48	
10.5	2.8	1.28	
11	2.77	1.25	
11.5	2.76	1.24	
12	2.25	0.73	
12.5	1.76	0.24	
13.1	1.52	0	Original Cross Section Waters Edge RB
13.5	1.25	0	
14	1.05	0	
14.5	0.6	0	
15	0.4	0	
15.5	0.3	0	Last Measurement Is At Right Bank Reference Peg (y_PRB)
15.5	0.3	0	Copy last point of cross section to fill available cells
15.5	0.3	0	Copy last point of cross section to fill available cells
TRUE RIGHT BANK	TRUE RIGHT BANK	TRUE RIGHT BANK	

Notes:
Password to unlock the workbook is: UNLOCK
Please copy and rename the workbook before unlocking it and editing.
In the plot below, dry points on the channel banks (i.e. above the water surface level) are assigned zero depth as there is no flow there.

After establishing the cross section at the site, different water levels can then be used for calculating cross sectional area and discharge. In the 'Updated Cross Section – New WL' tab a different staff gauge water level can be added, if a staff gauge is not present, then the water level change from when the original survey was undertaken can be entered. For this reason, it is prudent to peg the water's edge when the original survey occurs.



Options:		Notes:
Option to use	Option 1	Type: "Option 1" or "Option 2"
Option 1: New Water Level On Staff Gauge (m)	4.2	
Option 2: Water Level Change (m)		If no staff gauge is present, then measure the change in water level relative to the original waters edge peg. (+ is deeper, - is shallower)
Calculated Water Level On Original Survey Staff (m)	0.92	Lower values on the original survey staff are deeper (less distance to waters surface)

Cross Stream Distance (m)	Bed Level On Survey Staff (m)	Depth (m)	Notes:
TRUE LEFT BANK	TRUE LEFT BANK	TRUE LEFT BANK	
0	0.42	0	First Measurement Is At Left Bank Reference Peg (y_PLB)
0.5	1.1	0.18	
1.1	1.52	0.6	Original Cross Section Waters Edge LB
1.5	2.25	1.33	
2	2.45	1.53	
2.5	2.62	1.7	
3	2.7	1.78	
3.5	2.8	1.88	
4	2.93	2.01	
4.5	3.13	2.21	
5	3.35	2.43	
5.5	3.4	2.48	
6	3.43	2.51	
6.5	3.51	2.59	
7	3.35	2.43	
7.5	3.3	2.38	
8	3.27	2.35	
8.5	3.2	2.28	
9	3.17	2.25	
9.5	3.08	2.16	
10	3	2.08	
10.5	2.8	1.88	
11	2.77	1.85	
11.5	2.76	1.84	
12	2.25	1.33	
12.5	1.76	0.84	
13.1	1.52	0.6	Original Cross Section Waters Edge RB
13.5	1.25	0.33	
14	1.05	0.13	
14.5	0.6	0	
15	0.4	0	
15.5	0.3	0	Last Measurement Is At Right Bank Reference Peg (y_PRB)
15.5	0.3	0	Copy last point of cross section to fill available cells
15.5	0.3	0	Copy last point of cross section to fill available cells
TRUE RIGHT BANK	TRUE RIGHT BANK	TRUE RIGHT BANK	

Notes:

Password to unlock the workbook is: UNLOCK

Please copy and rename the workbook before unlocking it and editing.

In the plot below, dry points on the channel banks (i.e. above the water surface level) are assigned zero depth as there is no flow there.

This plot shows the cross section at the new water level, which will be used in the 'Velocity and Discharge' calculations.

Figure H 3: Updating cross section measurements with a new water level ‘Updated Cross Section – New WL’ tab. Green colour denotes cells to edit.

If needed, the “NIWA Surface Velocimetry Discharge Calculator - V1.3.xlsx” can also be modified to accommodate more convenient methods for measuring cross sections, such as with RTK GPS, total stations, or ADCPs. Please contact: Hamish.Biggs@niwa.co.nz

Re-checking the Cross-section

If the cross section was surveyed prior to a flood and was found to have changed post flood, the user must decide which cross section data to use for calculation of the flood-gauging depths. If the section is deeper, i.e., scour has occurred, it is likely that the change occurred before the peak.

Velocity Measurement Using Handheld Radar

At each measurement point the SVR tripod should be in a stable position, set at a vertical inclination of approximately 45°. Where possible, keep the inclination angle consistent throughout the gauging. The inclination angle can be changed to avoid obstacles, edge or vegetation, but bear in mind that while a steeper angle yields an increase in backscatter it also increases velocity projection errors (less accuracy). Aim the SVR preferably upstream, directly perpendicular to the cross-section.

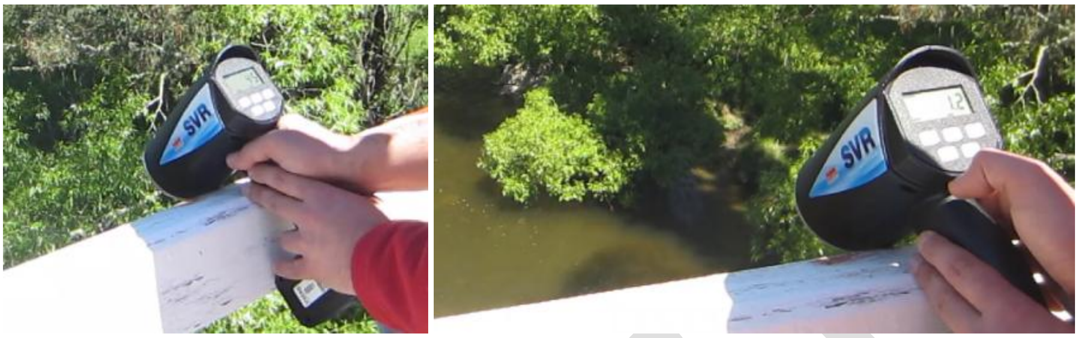


Figure H4: Shows a radar gun at 45 degree vertical angle (LHS) and velocity reading of 1.2m/s (RHS)

The horizontal angle should be set to 0 degrees in all cases and the device held at a vertical angle of 45°.

For each measurement, note the time (NZST), SVR angle, tagline position, stage if possible and operational time taken for measurement. Before taking readings with the SVR, ensure the settings are correct (downstream/upstream, rain compensation, horizontal/vertical angles, etc.).

Refer to the instrument manual for details relating to the operation of particular makes and models of SVR.

Calculating Flow

Total flow is calculated as

$$Q = \sum_{n=1}^{N} \alpha * u_n * A_n$$

which is a summation of flow in each of the SVR sections,

Where:

- Q is total flow (m^3/s),
- N is the number of SVR sections,
- n is the SVR section index,
- α is the velocity index (i.e. 'correction coefficient' to convert from surface velocity to depth averaged velocity), u_n
- U_n s the stream-wise SVR surface velocity (m/s) in section n and
- A_n is the area of section n.

To perform these calculations the “NIWA Surface Velocimetry Discharge Calculator - V1.3.xlsx” can be used. This tool can be downloaded from:

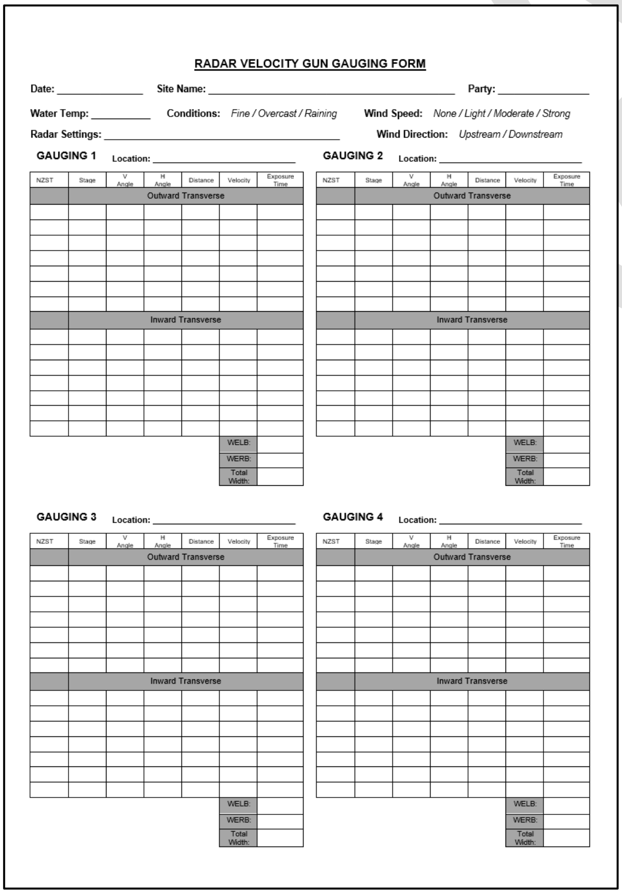
(https://www.nems.org.nz/tools/niwa-surface-velocimetry-discharge-calculator)

This discharge calculator enables cross sections to be and SVR surface velocities to be entered into the ‘Velocity and Discharge’ tab.

This calculator has multiple useful features:

- Cross sections are surveyed once, then water level adjusted during floods.
- Irregularly spaced cross sections are supported.
- Irregularly spaced SVR measurements are supported.
- Area bin edges are placed halfway between SVR measurement locations.
- Area bins A_n are accurately computed by trapezoidal integration following the bathymetric profile along the cross section between the bin edges.

An example radar velocity gun gauging field form is provided in Figure H -3.



RADAR VELOCITY GUN GAUGING FORM

Date: ______ **Site Name:** ______ **Party:** ______

Water Temp: ______ **Conditions:** *Fine / Overcast / Raining* **Wind Speed:** *None / Light / Moderate / Strong*

Radar Settings: ______ **Wind Direction:** *Upstream / Downstream*

GAUGING 1 **Location:** ______

NZST	Stage	V Angle	H Angle	Distance	Velocity	Exposure Time
	Outward Transverse					
	Inward Transverse					
					WELB:	
					WERB:	
					Total Width:	

GAUGING 2 **Location:** ______

NZST	Stage	V Angle	H Angle	Distance	Velocity	Exposure Time
	Outward Transverse					
	Inward Transverse					
					WELB:	
					WERB:	
					Total Width:	

GAUGING 3 **Location:** ______

NZST	Stage	V Angle	H Angle	Distance	Velocity	Exposure Time
	Outward Transverse					
	Inward Transverse					
					WELB:	
					WERB:	
					Total Width:	

GAUGING 4 **Location:** ______

NZST	Stage	V Angle	H Angle	Distance	Velocity	Exposure Time
	Outward Transverse					
	Inward Transverse					
					WELB:	
					WERB:	
					Total Width:	

Figure H5: Radar Velocity Gauging Form

Setting up the Radar Gun

Options Menu

Press the MENU key and the press MENU again and hold down to enter the Options Menu

*Set VTILT to Auto. Press MENU again and set Unit to M/S

Do not change anything else in the Options menu. Press the gun trigger to exit the menu at any time

Operator Menu

Briefly press the MENU key to enter the Operator Menu and press MENU key again to step through features

Menu Item	**Preferred Settings**	**Ranges**	**Description**
Sensitivity	**4**	1 to 4	4 is sensitive (reduced measuring range)
			2,3 sets gun to a medium range
			1 Decreased sensitivity and distance. Useful for objects close to the gun
Horizontal Angle	**0**	0 to 60	0 is perpendicular to the flow as in a bridge gauging
Vertical Angle *	**See Note Above**	0 to 60	Doesn't appear in menu when Tilt Sensor set to AUTO in Options Menu
View Auto Tilt Angle		0 to 360	Displays angle you have the gun tilted at
Backlight On/Off	**OFF**	On-Off	
Rain Setting	**116**	64 to 127	64 for very Wet, 127 for Dry

Set up Transects

It’s best to aim the gun upstream so try to set up on the upstream side of a bridge if possible. Pointing the gun downstream is acceptable if this suits best for safety/obstacles/cross-section.

You need to collect at least 7 verticals on the Outward and 7 on the Inward traverse. Divide the total width by 15 to get 14 evenly spaced verticals and note WELB and WELB on the form. Start measurements at the first vertical and every alternate one after that for the Outward traverse and note the distances on the form.

On the Inward traverse use the vertical farthest away from the start and take measurements at the alternate verticals moving back to the start. Note stages at Start and End time and be sure to get a minimum exposure time of 10 seconds for each measurement, preferably 20 seconds.

Example:

```
Outward       WELB  O1      O2      O3      O4      O5       O6
O7

Distance (m)    0---1---2---3---4---5---6---7---8---9---10---11---
12---13---14---15

Inward                  I7      I6      I5      I4      I3         I2
I1  WERB
```

Set Up Angle

Press MENU three times until ANGLE is displayed. This will change as you TILT the gun. Set for 45 (45 preferred but 30 to 60 is acceptable to avoid obstacles). Lock gun in place. Write down angle on the form and start the measurement. When in AUTO mode, the reported velocity takes the angle into account (no need to do any further calculations to correct this velocity). After the measurement is finished, check the angle again in case the gun has moved.

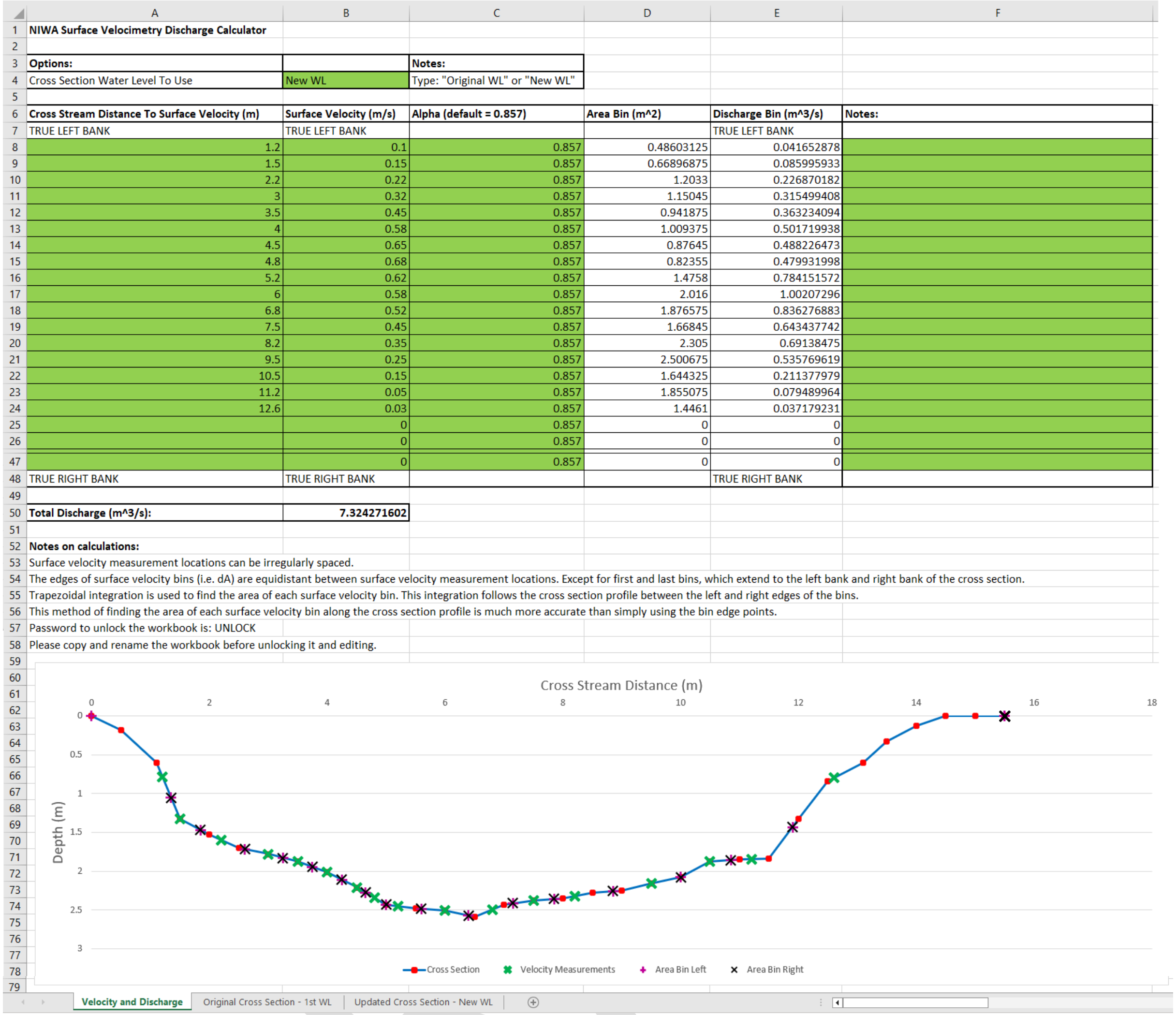
Measurement Mode

Press and releasing the trigger initiates Measurement Mode. The time is displayed in the top right and should start to increase. The velocity is displayed on the bottom tight

Press the trigger a second time to stop and store the current measurement. Write the values down immediately

Press the RECALL button to scroll though the stored measurements

Press and release the trigger re-initiates Measurement Mode



NIWA Surface Velocimetry Discharge Calculator

Options:		Notes:
Cross Section Water Level To Use	New WL	Type: "Original WL" or "New WL"

Cross Stream Distance To Surface Velocity (m)	Surface Velocity (m/s)	Alpha (default = 0.857)	Area Bin (m^2)	Discharge Bin (m^3/s)	Notes:
TRUE LEFT BANK	TRUE LEFT BANK			TRUE LEFT BANK	
1.2	0.1	0.857	0.48603125	0.041652878	
1.5	0.15	0.857	0.66896875	0.085995933	
2.2	0.22	0.857	1.2033	0.226870182	
3	0.32	0.857	1.15045	0.315499408	
3.5	0.45	0.857	0.941875	0.363234094	
4	0.58	0.857	1.009375	0.501719938	
4.5	0.65	0.857	0.87645	0.488226473	
4.8	0.68	0.857	0.82355	0.479931998	
5.2	0.62	0.857	1.4758	0.784151572	
6	0.58	0.857	2.016	1.00207296	
6.8	0.52	0.857	1.876575	0.836276883	
7.5	0.45	0.857	1.66845	0.643437742	
8.2	0.35	0.857	2.305	0.69138475	
9.5	0.25	0.857	2.500675	0.535769619	
10.5	0.15	0.857	1.644325	0.211377979	
11.2	0.05	0.857	1.855075	0.079489964	
12.6	0.03	0.857	1.4461	0.037179231	
	0	0.857	0	0	
	0	0.857	0	0	
	0	0.857	0	0	
TRUE RIGHT BANK	TRUE RIGHT BANK			TRUE RIGHT BANK	

Total Discharge (m^3/s):	7.324271602

Notes on calculations:

Surface velocity measurement locations can be irregularly spaced.

The edges of surface velocity bins (i.e. dA) are equidistant between surface velocity measurement locations. Except for first and last bins, which extend to the left bank and right bank of the cross section.

Trapezoidal integration is used to find the area of each surface velocity bin. This integration follows the cross section profile between the left and right edges of the bins.

This method of finding the area of each surface velocity bin along the cross section profile is much more accurate than simply using the bin edge points.

Password to unlock the workbook is: UNLOCK

Please copy and rename the workbook before unlocking it and editing.

Figure H-3: Recording SVR surface velocities and cross stream distances in the 'Velocity and Discharge' tab of the "NIWA Surface Velocimetry Discharge Calculator - V1.3.xlsx". Green colour denotes cells to edit.

This calculator (https://www.nems.org.nz/tools/niwa-surface-velocimetry-discharge-calculator) is the recommended method for discharge calculations from SVR surface velocities. Alternatively, MATLAB code for SVR discharge calculations can also be provided upon request from Hamish.Biggs@niwa.co.nz

Annex I – Pressure Operated Electronic Meter (POEM)

The POEM 1000 Flood Gauging Meter is used to measure high velocity open channel flows.

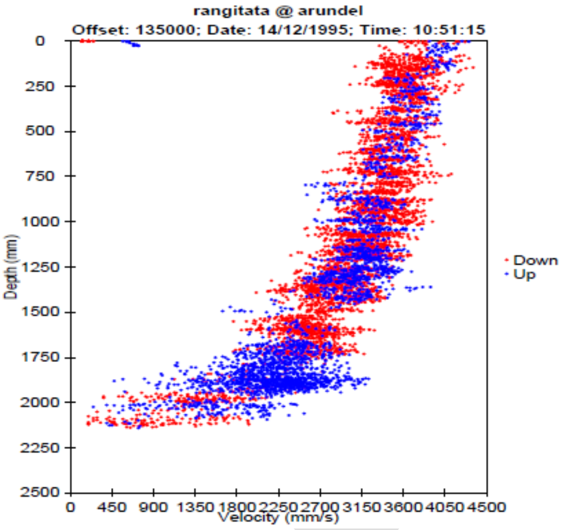
The POEM utilises Pitot tube principles and electronic sensing to provide rapid sampling of flow depth by hydrostatic pressure, velocity and turbulence from 1 – 9 m/s.

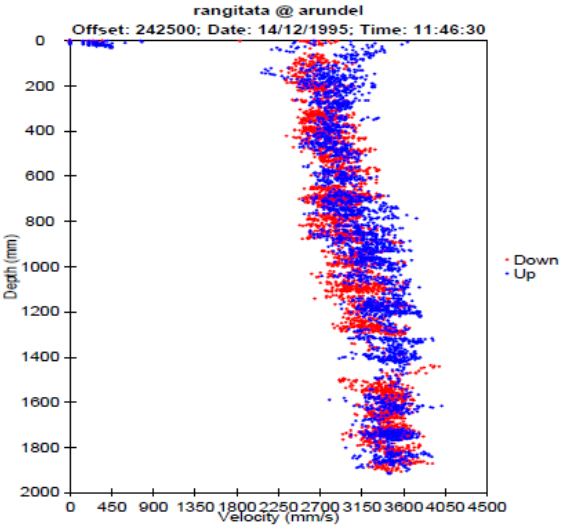
Note: This instrument is designed for velocities above 1 m/s and accuracy falls away rapidly at velocities less than 1m/s, or greater than 9m/s.

The POEM overcomes many of the limitations of other instruments and methods. It transmits 112 velocity and depth readings every second, giving a significant increase in overall gauging accuracy, decreasing gauging times and increasing the resolution of available information about the velocity profile.

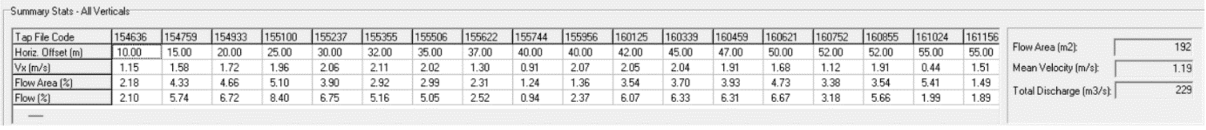
The depth and velocity information is continuously transmitted to the operator via standard suspended meter gauging equipment. The data is decoded and buffered by the POEM Interface, ready for RS232 transmission to a PC or datalogger.

Example of POEM Depth /velocity data





Plots of rapid, instantaneous, depth/velocity data as measured by the POEM show scatter caused by flow turbulence. The complete vertical profile of velocity is measured and more accurate flow gaugings are achieved, especially where anomalous velocity profiles occur as shown in the right-hand plot above.



Summary Stats - All Verticals

Tap File Code	154636	154759	154933	155100	155237	155355	155506	155622	155744	155956	160125	160339	160459	160621	160752	160855	161024	161156
Horiz. Offset (m)	10.00	15.00	20.00	25.00	30.00	32.00	35.00	37.00	40.00	40.00	42.00	45.00	47.00	50.00	52.00	52.00	55.00	55.00
Vx (m/s)	1.15	1.58	1.72	1.96	2.06	2.11	2.02	1.30	0.91	2.07	2.05	2.04	1.91	1.68	1.12	1.91	0.44	1.51
Flow Area (%)	2.18	4.33	4.66	5.10	3.90	2.92	2.99	2.31	1.24	1.36	3.54	3.70	3.93	4.73	3.38	3.54	5.41	1.49
Flow (%)	2.10	5.74	6.72	8.40	6.75	5.16	5.05	2.52	0.94	2.37	6.07	6.33	6.31	6.67	3.18	5.66	1.99	1.89

Flow Area (m2): 192
Mean Velocity (m/s): 1.19
Total Discharge (m3/s): 229

The software output example above shows the individual verticals and overall results of area, mean velocity and discharge.

Uncertainty is not calculated per gauging by the software but the calibration results from the Swiss and NIWA rating tanks show the POEM can be used for measuring velocities from 1.0 m/s to 9.0 m/s with an error of ≤ 1%

Quality coding of POEM discharge measurements can be obtained using the mean-section matrix provided in Annex B

A maximum quality code of QC500 can be achieved for a POEM discharge measurement if the device has been calibrated in a rating tank or with a portable pressure calibrator (which in-turn must have a valid calibration) within 24 months of the measurement being undertaken.

In the absence of calibration within 24 months, the maximum quality code achievable is QC400.

Annex I – Moving Bed Test Correction

The average moving bed velocity is found from:

V_{mb} = distance upstream/duration in seconds

It is significant if:

- it is greater than 0.012 m/s, and
- the Vmb/Vw ratio is greater than 0.01

  Where V_w is the mean water velocity.

Then calculate the following:

- Area of Section with Moving Bed

  A_{mb} (usually) = Total Area – Right Area – Left Area

Note: How you calculate this will depend on the section and what you know about the flow.

Then:

$$Q_{corrected} = Q_{measured} + (V_{mb} \times A_{mb})$$

Carry out a series of normal measurements and calculate this moving bed discharge correction for each one. Alternatively, in rapidly changing flows or flood situations, the loop test can be sub-sectioned into two transects later in the office using the recorded edge offsets.

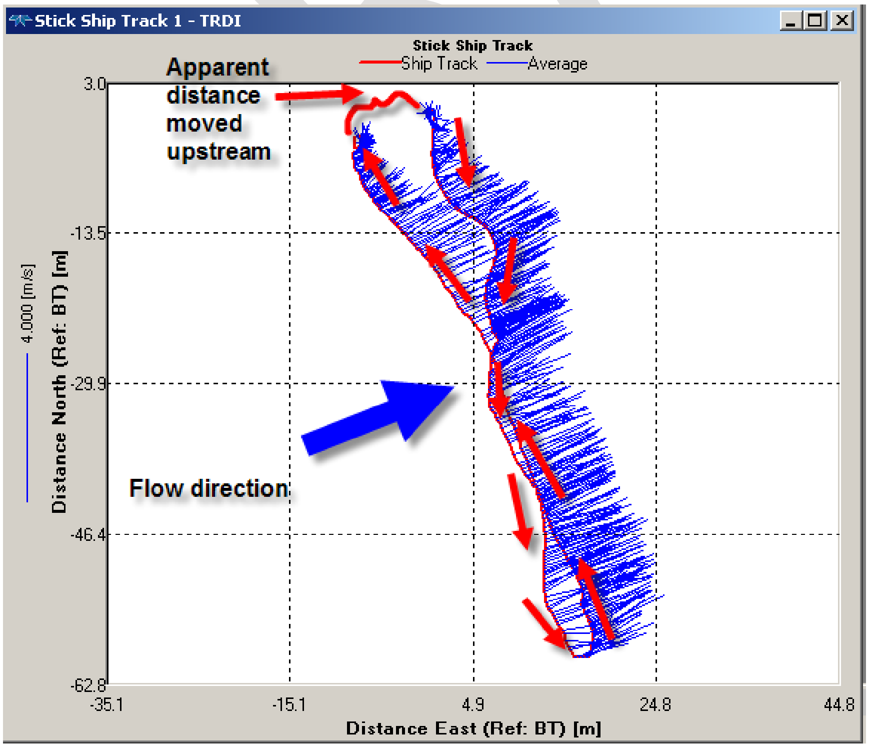


Figure I14 – Example of a Loop Test with a Distorted Ship Track caused by a Moving Bed

Distance moved upstream = 8.1 m, duration = 275 s, average moving bed velocity = 0.029 m/s.

Illustrator: Andrew Willsman

Annex J – Discharge Measurement Method Codes

The Method Codes for the gauging methods that are used in New Zealand are shown below in Table C2.

Table C2 – Method Codes for Gauging Methods used in New Zealand

Instrument/method	**Code**	**Rod-Mounted**	**Cable-Mounted**	**Combination Rod & Cable**
Pygmy		01	07	34
Gurley (Price AA)		02	08	35
Watts (Watts Price)		03	09	36
Amsler		04	10	37
Large Ott or Oss		05	11	38
Small Ott or Oss		06	12	39
Braystoke or other directional current meter			13	
Two different current meters	40			
Volumetric	14			
Portable weir or flume	15			
Continuous current meter	16			
Rated value (from rating curve)	17			
Velocity head rod	18			
Floats	19			
Slope-area	20			
Miscellaneous formula	21			
Chemical tracer velocity method	22			
Estimation	23			
Pitot tube	24			
Ripple meter	25			
Dilution gauging methods		***Constant rate***	***Sudden injection***	

Instrument/method	Code	Rod-Mounted	Cable-Mounted	Combination Rod & Cable
Conductivity		26	29	
Fluorometry		27	30	
Other		28	31	
Miscellaneous	32			
Miscellaneous current meter	33			
Cross-section only	41			
Sediment sample only	42			
Electromagnetic	43			
ADCP (RDI) + RiverRay	44			
ADP (Sontek)	45			
ADV including Flowtracker	46			
ADCP StreamPro	47			
POEM	48			
ADCP stationary Section by Section	49			
AECV Instruments	50			
			Fixed	**Handheld**
Surface Velocimetry Methods *(Radars)*			60[1]	61[1]
Surface Velocimetry Methods (Cameras)			70[1]	71[1]
UAV Camera			80[1]	

[1] *It is intended that the Alpha value used for each Surface Velocimetry measurement will be applied as*

a suffix to the method code. (I.e. A handheld radar surface velocity observation that utilised an Alpha of

0.78 for the calculation of discharge would have a method code of 6178, and a UAV surface velocity observation that utilised an Alpha of 0.82 for the calculation of discharge would have a method code of 8082).

Annex K - Initial Quality Coding of Discharge Measurements Undertaken in Open Channels

Quality coding matrices determine an initial quality code for the data based on site factors and field visit actions, observations, and verification checks.

If this initial quality code is QC 400 or above, it is then the maximum achievable final quality code for the data. The final quality code may subsequently be lowered from the maximum achievable by further data verification and subsequent actions during data processing, which are the subject of NEMS *Data Processing*.

For any quality code to be assigned, including QC 0, the requirements of Tables 1, 2 and 3 of the Standard must also be met.

Use of the matrices follows the concept of hierarchy in the NEMS National Quality Code Schema. Tick one of the boxes in every row applicable to the measurement being assessed. Where different measurement types have different criteria, strikethrough those that do not apply. For each applicable row in each matrix:

- Start with the QC 600 column and if the performance threshold is achieved, put a tick.
- If not QC 600, then consider the QC 400 column:
    - If the QC 400 performance description applies, put a tick.
    - If performance is between the QC 600 and QC 400 thresholds, or there is no QC 400 performance description, tick QC 500.
    - If performance is below (poorer than) the lower bound of a QC 400 performance band, tick QC 200.

      Note: QC 200 may not be available if there is no sensible concept of "poorer than" the relevant QC 400 performance requirement.
    - Action may be required instead, either immediately or subsequently, to resolve the performance issue and/or recheck.

The initial quality code to be assigned to the data is the lowest of all the boxes ticked.

- Initial quality code cannot be higher than QC 500 if any one QC 600 performance threshold is not achieved, by definition of Table 3 of the Standard.
- Data are considered to be of poor quality if any one QC 400 performance description applies.
- QC 200 indicates data quality is unknown until the affected data are processed and fully verified. Data processing may elevate or reduce an

initial quality code of QC 200 depending on additional tests, other available evidence, and subsequent editing actions.

Note: Original data may retain quality code QC 0 until they are altered or fully verified and processed.


NEMS