National Environmental Monitoring Standards

Open Channel Flow Measurement

Measurement of Open Channel Flow

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Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.1	Jun 2013			Initial release
2.0.0	October 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

Table of Contents iii
The National Environmental Monitoring Standards vii
About This Standard x
Introduction x
Objective xi
Scope xi
Terms, definitions and symbols xi
Normative references xi
The Standard – Open Channel Flow xiii
Minimum requirements for the application of all Standards xiv
Requirements for open channel flow data irrespective of quality xv
Additional requirements for open channel flow data of good quality xix
Other requirements, guidelines, and recommendations xxii
Quality coding of open channel flow data xxiii
Quality coding of open channel flow data: velocity-area stationary meter methods xxiv
Quality coding of open channel flow data: velocity-area ADCP moving boat method xxvi
Quality coding of open channel flow data: surface velocimetry methods xxviii
Quality coding of open channel flow data: volumetric method xxxi
Quality Coding of Volumetric Methods xxxii
Quality coding of open channel flow data: indirect methods xxxiii
Quality Coding of Indirect Methods xxxiv
Quality coding of open channel flow data: dilution method xxxv
Quality Coding of Dilution Methods xxxvi
Application xxxvii
1 Method and Equipment Selection 1
1.1 Velocity-area stationary meter method 1
1.2 Velocity-area ADCP moving boat method 1
1.3 Velocity-area surface velocimetry methods 2
1.4 Index velocity method 2
1.5 Volumetric method 3

1.6 Indirect discharge methods 3
1.7 Dilution method 3
2 Site Selection 4
2.1 Sources of information 4
2.2 Risk management 4
2.3 Channel and flow characteristics 5
3 Velocity-Area Stationary Meter Method 12
3.1 Principles 12
3.2 Site selection 12
3.3 Measurement of cross-sectional area 13
3.4 Measurement of velocity 16
3.5 Instrument validation and calibration 18
3.6 Determination of mean velocity in a vertical 21
3.7 Discharge calculation methods 26
4 Velocity-Area ADCP Moving Boat Method 29
4.1 Principles 29
4.2 Site selection 31
4.3 Pre-measurement validation checks 32
4.4 Discharge measurement 37
4.5 Instrument validation and calibration 38
4.6 Discharge calculation methods 41
4.7 Calculation of measurement uncertainty 41
4.8 Ancillary equipment 42
5 Velocity-Area Surface Velocimetry Methods 45
5.1 Principles 45
5.2 Site selection 46
5.3 Measurement of cross-sectional area 47
5.4 Measurement of velocity 47
5.5 Instrument validation and calibration 53
5.6 Determination of alpha 53
5.7 Discharge calculation methods 54
5.8 Calculation of measurement uncertainty 54
6 Index Velocity Method 55
6.1 Principles 55

6.2 Site selection 56
6.3 Instrument selection 57
6.4 Installation and configuration 58
6.5 Discharge calibration 59
6.6 Stage–area rating 60
6.7 Index velocity rating 60
6.8 Continuous discharge calculation 62
6.9 Rating validation 62
7 Volumetric Method 64
7.1 Principles 64
7.2 Site selection 64
7.3 Measurement 64
7.4 Discharge calculation methods 65
7.5 Calculation of measurement uncertainty 65
8 Indirect Discharge Methods 66
8.1 Principles 66
8.2 Site selection 66
8.3 Data collection 67
8.4 Discharge calculation methods 67
9 Dilution Method 72
9.1 Principles 72
9.2 Site selection 72
9.3 Dosing 73
9.4 Equipment validation and calibration 78
9.5 Discharge calculation methods 79
10 Quality assurance 82
10.1 Quality assurance tools 82
10.2 Managing method changes 82
11 Requirements for Metadata, Calculation of Gauging Results and Archiving 84
11.1 Site details 84
11.2 Measurement details 84
11.3 Other metadata details 85
11.4 Quality coding 85
11.5 Comments 86

12 Data Management and Preservation 88
12.1 Original data 88
12.2 Preservation of data and records 88
References 91
Annex A – Application of Quality Coding Matrices 93
Annex B – Site Quality Matrix 94
Annex C – Velocity-Area Stationary Meter Method Matrix . 98
Annex D – ADCP Moving Boat Data Quality Matrix 100
Annex E – QRev Software Use and Explanation 102
Annex F – Salt Dilution Method Metadata 116
Checklist 116
Annex G – Example Salt Dilution Gauging Form 121
Annex H – Surface Velocimetry Method (Handheld SVR): Calculation of Cross-Sectional Area and Discharge 122
Annex I – Pressure Operated Electronic Meter (POEM) 134
Annex J – Moving Bed Test Correction 136
Annex K – Open Channel Flow Measurement Method Codes 138

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, Jo Martin, 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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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 provide information on flow at the time of measurement. Most open channel flow measurements (gaugings) are made to rate a water level station to enable derivation of continuous flow from the water-level record. 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 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 Public Works Department 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. 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 open channel flow until recent times has been the velocity-area method, which uses sounding devices and mechanical rotating-element current meters. Acoustic technology emerged in the 1990s, implemented as current meter devices using the velocity-area method. By the 2010s 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 river sections that are turbulent or difficult for the use of current meters or ADCPs. The dilution method has also benefited from technological advances, with the development of accurate real-time water quality sensors, and method is now included in this standard as a method.

This version of *Open Channel Flow Measurement* also incorporates further material on indirect flow measurement (slope-area and contracted opening methods), volumetric gauging, the index velocity method and surface velocimetry discharge measurement.

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 version of the NEMS *Open Channel Flow Measurement* results from a review of Version 1.1, undertaken by Alex Ring (Environment Canterbury), Phil Downes (Environment Canterbury), Evan Baddock (Earth Sciences NZ, formerly NIWA) and Jeff Watson (NEMS Technical Advisor). The document was restructured into the current NEMS format by Mike Ede (Environmental Data Experts), who also provided technical input into the final draft of this document. Constructive feedback received from Nick Holwerda (Basins Environmental Ltd), addressing a number of anomalies within the initial draft, is gratefully acknowledged.

Objective

The objective of this Standard is to ensure that single open channel flow 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

Dilution gauging utilising dye is excluded from this Standard due to the potential environmental impact that is perceived by the public.

No verification or calibration advice is provided in this document for 'calibrated' structures.

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 *Safe Acquisition of Field Data in and Around Fresh Water – Code of Practice*
- NEMS *Processing of Environmental Time-series Data*
- NEMS *Rating Curves: Construction of stage-discharge and velocity-index ratings*
- NEMS *Water Level: Continuous Measurement of Water Levels for Environmental Monitoring Purposes*
- *River discharge from surface velocity measurements: A field guide for selecting alpha* (Biggs et al. 2021)
- *National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021* (Australian Government Bureau of Meteorology 2021)
- *Hydrometry - Slope-area method* (ISO 1070:2018; International Organization for Standardization, 2018).
- *Measurement of fluid flow – Procedures for the evaluation of uncertainties* (ISO 5168:2005).
- *Hydrometry – Measurement of liquid flow in open channels Velocity area method using point velocity measurements* (ISO 748:2021; International Organization for Standardization, 2021).
- *Hydrometry – Rotating-element current-meters* (ISO 2537:2007; International Organization for Standardization, 2007a).
- International Organization for Standardization (ISO). (2007c). *Hydrometry – Calibration of current-meters in straight open tanks* (ISO 3455:2007; International Organization for Standardization, 2007b).
- *Evaluation of measurement data – Guide to the expression of uncertainty in measurement* (JCGM 100:2008; Joint Committee for Guides in Metrology, 2008).

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 relevant 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 initial 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 the 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 (pg. xi)	• Metadata recorded for all sites and measurements. • Permanently archived and discoverable.
	Identification of Standards (pg. xxxvii)	Standards and versions applied shall be tracked over time in time-stamped Stationarity Comments.
	Identification of data (11.2)	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 (pg. xxiii – xxxvii, and Annexes A, B, C and D)	All data shall be quality coded using the NEMS *National Quality Code Schema.*
Archiving	Original and final records (11, 12.2.3, also Annex C of NEMS *Data Processing*)	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 ± 50 ml/s.
Discharge calculation	Velocity-area stationary meter method (1.1, 3.7)	Mean-section method As calculated by QRevMS, where appropriate for the instrument type
	Velocity-area ADCP moving boat method (pg. xxvi, 1.2, 4.1.3, 4.6)	Moving boat method As calculated by QRevInt
	Velocity-area surface velocimetry methods (5.7)	As per supporting software packages
	Index velocity method (6.5, 6.6, 6.7. 6.8)	As per the methodology described for calculating continuous discharge using the index velocity method
	Volumetric method (7.4)	As per the methodology described for calculating discharge using the volumetric method
	Indirect discharge methods (8.4)	As per the methodology described in section 8.4

	Dilution method (9.5)	As per the methodology described in section 9.5
Uncertainty	Velocity-area stationary meter method (3.7.2)	± 8% (expanded uncertainty, 95% confidence) Calculated using the methodology described in ISO 748:2021 *Note: Not all flow measurement methods have an accepted form of calculating uncertainty.*
	Velocity-area ADCP moving boat method (4.7)	± 8% (expanded uncertainty, 95% confidence) Calculated as per OURSIN within the QRevInt software
	Velocity-area surface velocimetry (video) method (5.8)	Calculated using the methods supported in software packages *Note: A surface velocimetry (video) discharge measurement shall not be assigned a quality code greater than QC 500.*
	Velocity-area surface velocimetry (handheld radar or timed floats) method (5.8)	Calculated using the methodology described in Annex B and C of ISO 748:2021 *Note: A surface velocimetry (handheld radar or timed surface floats) discharge measurement shall not be assigned a quality code greater than QC 400.*
	Index velocity method (6.9.1)	N/A
	Volumetric method (7.5)	Calculated using the principles in ISO 5168:2005
	Indirect discharge methods (N/A)	N/A *Note: A slope-area or contracted opening discharge measurement shall not be assigned a quality code greater than QC 300.*
	Dilution method (9.5.5)	± 8% (expanded uncertainty, 95% confidence)

		Calculated using the SUNY ('Salt Uncertainty') software, or else quality code as QC 400
Gauging Frequency	All methods for which stage/discharge ratings are required	NEMS *Rating Curves:* (s. 4)
Quality assessment	Velocity-area stationary meter method (Annex C)	Classified using Annex C – Velocity-Area Stationary Meter Method Matrix
	Velocity-area ADCP moving boat method (Annex D)	Classified using Annex D – ADCP Moving Boat Data Quality Matrix
Timing of measurements	Discharge results (NEMS *Data Processing* Version 1.3.1, Annex C s.2.3)	Assign date and time of mean gauge height (where applicable) 1 min resolution
Supplementary instrument measurements	Temperature (4.1.2, 4.3, 6.1, 6.3)	± 2.0˚C Required for acoustic methods
	Salinity (4.1.2, 4.3, 4.3.1, 6.1)	± 5 ppt (parts per thousand) Required for acoustic methods in brackish, or potentially brackish, water only
	Bearing (compass) (3.5.5.2, 4.2.4, 4.3, 4.3.3, 4.3.5.2, 4.8.3.1)	Compass calibrated on site Local magnetic declination shall be entered Required for ADCP moving bed loop test and GPS-referenced boat velocity
	Water level (stage) for computed discharge (2.3.2, Annex H)	Required if result is to be used for stage–discharge rating. Discharge filed at the time of mean stage height Recorded at regular intervals over duration of discharge measurement
	Cross-sectional area (Pg. xxix, 3.3, 3.7, 5.3, 6.6, 6.7, Annex H)	To 3 decimal places (where applicable)
	Mean velocity (1)	To 3 decimal places (where applicable)

	Hydraulic radius (1)	To 3 decimal places (where applicable)
	Wetted perimeter (1)	To 3 decimal places (where applicable)
	Water surface slope (1)	To 3 decimal places (where applicable)
	Method code (Annex K)	In accordance with Annex K
	Unique gauging No./ID (11.2)	In accordance with documented organisational practice
Validation methods	Instrument tests: rotating element current meters (3.4.4.3, 3.5.2)	Required pre-deployment, and post-deployment for rotating-element current meters
	Instrument tests: ADP and AECV (3.4.4.3, 3.5.3.3, 4.5.3.3)	General instrument tests (instrument specific)
	Instrument tests: ADCP methods (4.3)	Temperature check Instrument diagnostics Compass calibration check Moving bed test
	Dilution method (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 QC 400
	Surface velocimetry (video) method (5.1, 5.5)	Stable cross-section Alpha value(s) established for the site Alpha value filed with the discharge measurement

	Surface velocimetry (radar and timed floats) method (5.1, 5.5)	Radar tilt angle validated annually Stable cross-section Alpha value filed with the discharge measurement
	Volumetric method (7.3.1, 7.3.2)	Measurement vessel volume validated to ± 2%
	Slope/-area and contracted opening methods (8.3)	Water levels surveyed to ± 3 mm
	Calibrated structures	While the use of calibrated structures is not specifically described in this document, where they are utilised they should be verified 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	Frequency (3.5)	Mechanical current meter: 2 years or 300 hours of use ADV: 5 years AECV: 5 years ADCP: 5 years POEM: 2 years or 100 hours of use Radar: 5 years Volumetric: current calibration of measurement vessel Dilution: conductivity sensor calibration check before each measurement Imagery: N/A Surface velocimetry: N/A

	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 (11)	Required metadata shall be recorded for all discharge measurements
Deployment	Site selection (4.2)	Use criteria within this Standard, method dependent
	Sampling: velocity-area stationary meter method (3.4)	≥ 40 s velocity measurement at ≥ 20 verticals, and each partial segment with < 10 % of the total discharge
	Width measurement: velocity-area stationary meter method (3.3.1, 3.4.2)	± 0.5% of total cross-section width
	Depth measurement: velocity-area stationary meter method (3.3.1.5)	≥ 22 verticals to ± 5 mm for depths ≤ 0.3 m, or ± 10 mm for depths > 0.3 m
	Sampling: velocity-area ADCP moving boat method (4.4)	≥ 720 s total sampling time, and reciprocal transect pairs
	Dilution method (9.3.2, 9.4.1, 9.4.5)	Temperature compensation of EC measurements completed using linear or non-linear functions and referenced to 25°C (EC_T) Complete mixing, indicated by the EC trace showing a single, smooth, well-defined salt curve Dry tracer salt weighed to ± 1% or better.
	Surface velocimetry (video) method (5.4.1, 5.4.2)	Video camera resolution at least 1080p or 4k A minimum video duration of 30 seconds Entire width of the channel is visible in the imagery

		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 velocimetry (radar and timed floats) method (5.4.3.3, 5.4.3.4, 5.4.3.5)	Radar: held parallel to the direction of the flow and at a vertical angle of $45^{o} \pm 10^{o}$ Radar: a minimum of 40 seconds exposure time for each velocity reading.
	Volumetric method (7.3.1)	A minimum of 10 observations of time to fill the measurement vessel.
	Slope-area method (8.2, 8.3, 8.4.1)	Slope/area: A minimum of 10 water levels surveyed along the observation reach Reach surveyed is a minimum of 5 times channel width No abrupt bends or change of gradient occur within the observation reach

Other requirements, guidelines, and recommendations

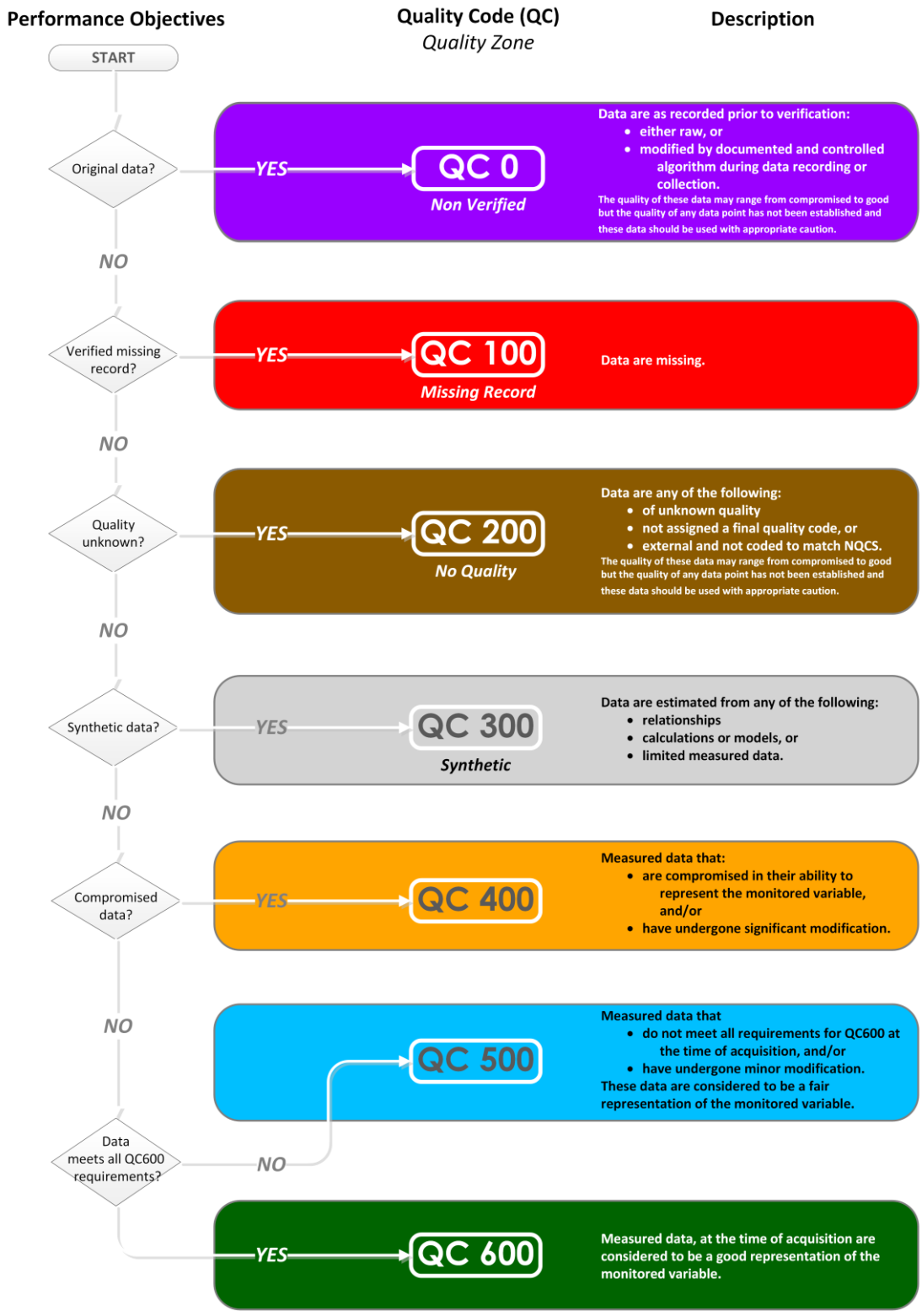
The following table summarises other requirements and guidelines (e.g. for quality assurance or lower quality codes), and additional recommended practices that are either not relevant to or not required for QC 600 but if implemented will enhance work practices and data quality.

Table 4 – Other requirements, guidelines, and recommendations.

Validation methods	Inspection of measurement devices (3.4.4.3, 3.5, 4.3, 4.5, 4.5.3.4, 5.4.3.5, 5.5, 9.4, 10.1.1)	Perform inspections at least annually to ensure calibration remains stable.
Archiving	Original and final records (11.2) (Also, see NEMS *Data Processing* Version 1.3.1, Annex C s. 6)	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 QC 100 has been deemed as not applicable because the measurement should be discarded and repeated.



Quality coding of open channel flow data: velocity-area stationary meter methods

The velocity-area stationary meter and ADCP moving boat 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.

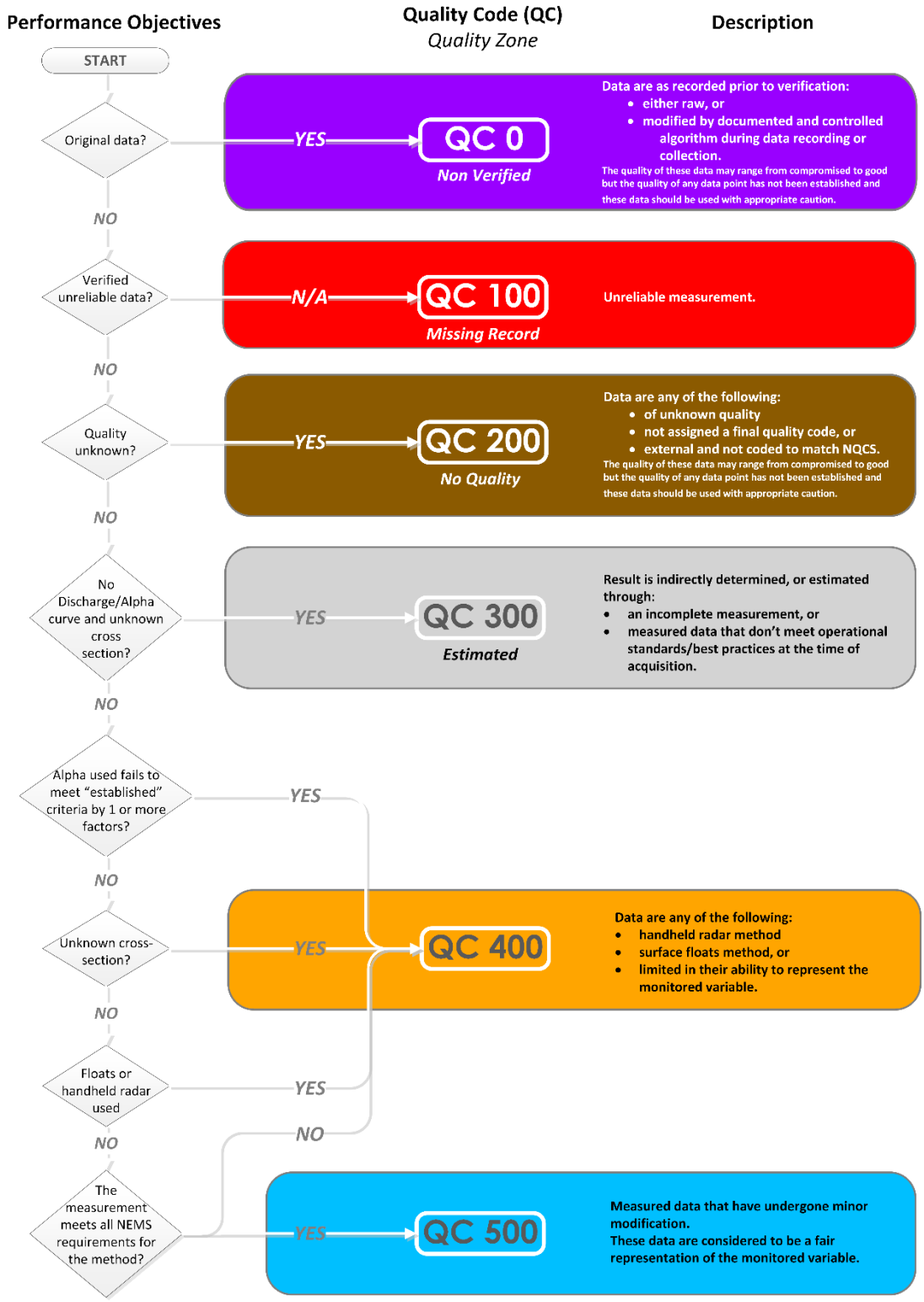
Refer to Annex C for the method-specific quality coding matrix, and the site quality matrix in Annex B, before using this flow chart.

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

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 applies to POEM measurements.

Quality Coding of Velocity-Area Stationary Meter Methods

Note: For this standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.



Quality coding of open channel flow data: velocity-area ADCP moving boat method

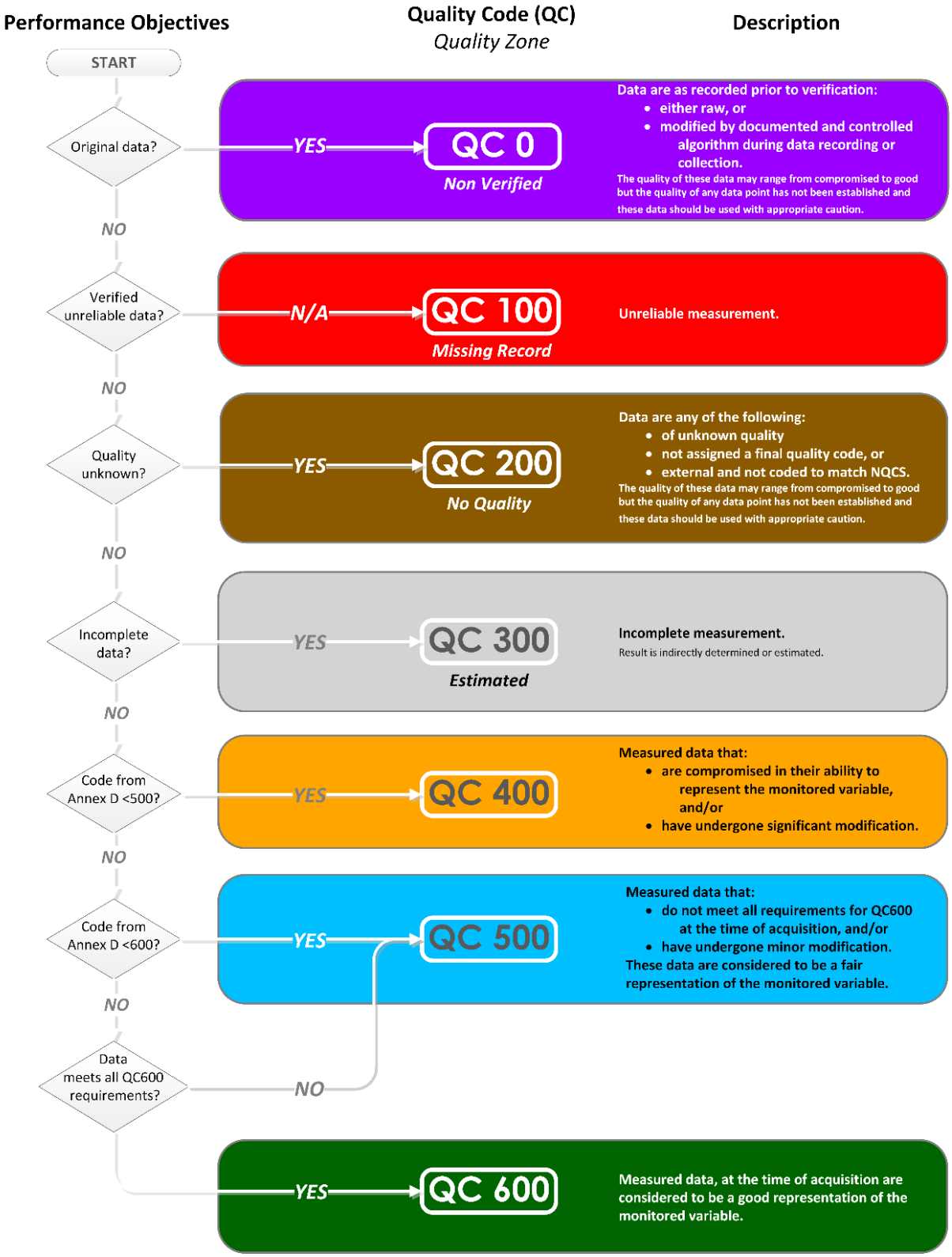
The velocity-area stationary meter and ADCP moving boat methods employ similar principles and are the most common means of measuring open channel flow for most agencies. With the large datasets and resources available for these methods, many QA/QC parameters have been identified beyond a simple statistical uncertainty.

Please refer to Annex D for a method-specific quality coding matrix, and the site quality assessment table in Annex B, before using this flow chart.

Powerful QA/QC software packages have been developed for discharge measurements utilising ADCP. The relevant software (QRev/QRevInt for moving boat) must be used to achieve a QC greater than 200. Refer to Annex E.

Quality Coding of Velocity-Area ADCP Moving Boat Methods

Note: For this standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.



Quality coding of open channel flow data: surface velocimetry methods

Surface velocimetry methods are:

- image velocimetry (STIV/LSPIV)
- surface floats
- handheld 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 Standard, 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 obtained by index velocity methods.

Surface velocimetry discharge measurements rely on assumptions and theoretical relationships, and often have data collected at different points in time, which makes them very difficult to accurately define the appropriate quality code. For this reason, the maximum achievable quality code for image velocimetry measurements is QC 500, as it is very difficult to define. The maximum achievable quality code for all other types of surface velocimetry is QC 400 unless the measurement is undertaken on a section/reach with an established alpha and known cross-section, in which case a maximum quality code of QC 500 may be achieved.

Definitions

Established alpha

Where alpha (the ratio between depth-averaged velocity and surface velocity, which is then applied to measured surface velocities to obtain depth-averaged velocity for computing discharge) has been measured and expressed as a decimal fraction (to 2 decimal places) it can then be plotted against discharge to construct a discharge–alpha rating curve for the site. The alpha value for any given discharge can then be read off the 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 determine alpha, the surface velocities are ideally measured concurrently with the full velocity profile, e.g. by flying a drone immediately 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:

- was constructed based on five or more measurements collected from the same gauging location
- a verification measurement of QC 600 standard must be completed every 12 months and following any 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
- 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 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 measurement) or known to be stable (e.g. lined water race) or measured 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 for current industry best practice and *River discharge from surface velocity measurements: A field guide for selecting alpha* (Biggs et al. 2021).

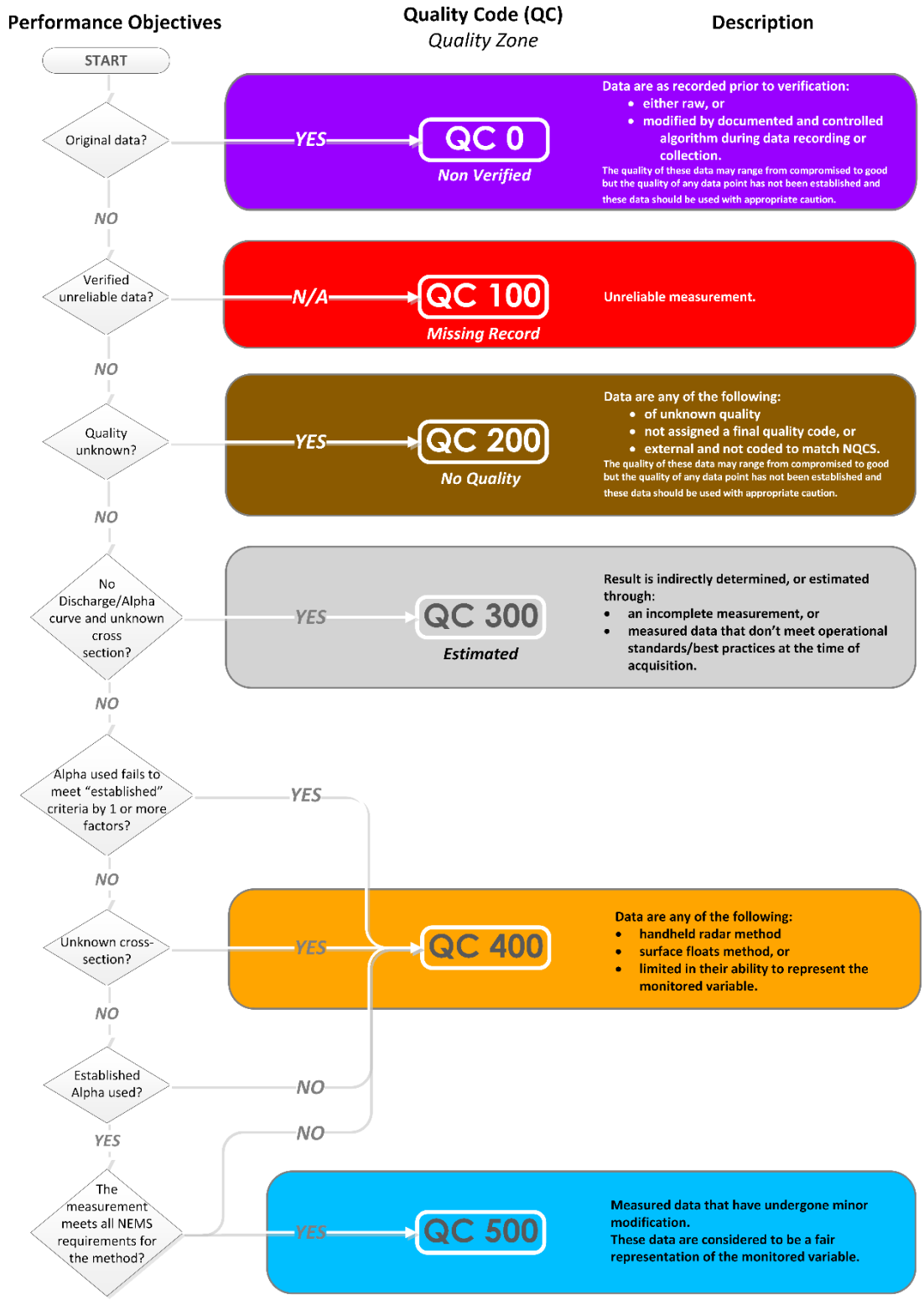
Guidance note:

> *To assist with implementation of quality coding surface velocimetry discharge measurements:*
>
> - *any surface velocimetry discharge measurement where a discharge–alpha curve and a known cross-section do not exist shall be quality coded no greater than QC 300*
> - *measurements using surface floats or handheld radar shall be quality coded no higher than QC 400*
> - *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 QC 400*
> - *surface velocimetry discharge measurements that fall within the range of an established discharge–alpha curve that has been defined by alternative discharge measurement methods and has a known stable cross-section may be quality coded no greater than QC 500.*

Quality Coding of Surface Velocimetry Methods

Note: For this Standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.

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Quality coding of open channel flow data: volumetric method

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 (Max. QC <=QC 200)
2. Container filled 5 times or less (Max. QC <=QC 300)
3. Mean filling time for container is less than 10 seconds (Max. QC <= QC 500)
4. Variation in filling times varies by more than 5% (Max. QC <=QC 500)
5. Container filled less than 10 times (Max. QC <=QC 500)
6. Uncertainty not calculated, or calculated and above 8% (Max. QC <=QC 500)

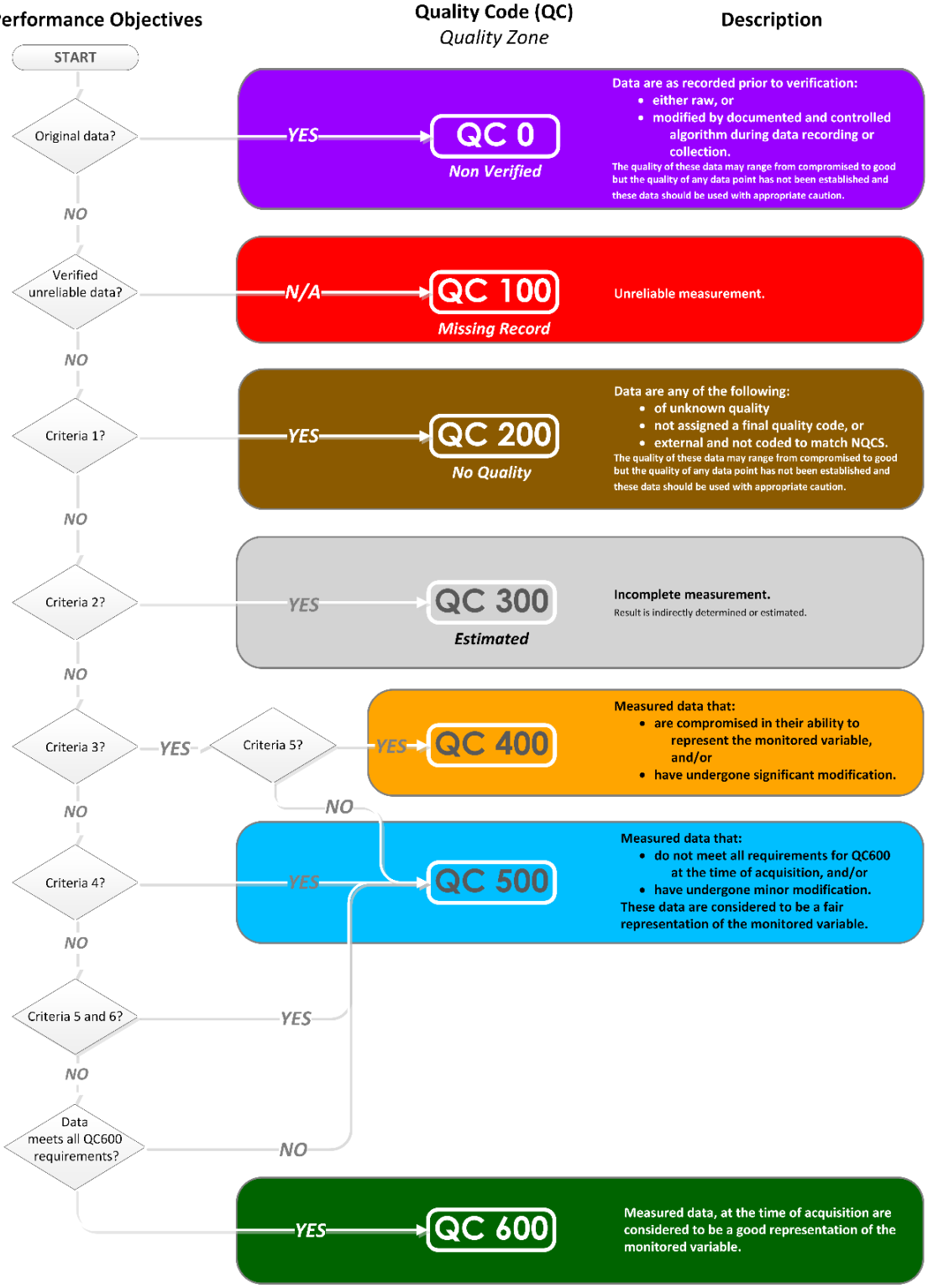
Guidance notes: To assist with implementation of quality coding of volumetric discharge measurements:-

1. If the volume of the container has not been calibrated/validated (i.e., criteria 1, above) to within 2% of a known volume, the measurement shall be quality coded no higher than QC 200.

2. If the uncertainty is not calculated, the measurement shall be quality coded no higher than QC 400.

Quality Coding of Volumetric Methods

Note: For this Standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.



Quality coding of open channel flow data: indirect methods

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 or 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 and theoretical relationships, and often use data collected at different points in time, which makes it very difficult to accurately quantify uncertainty.

For this reason, the maximum achievable quality code for most indirect measurements is QC 300.

Properly installed and maintained rated structures such as weirs can, however, achieve measurements of QC 500 when verified by gauging.

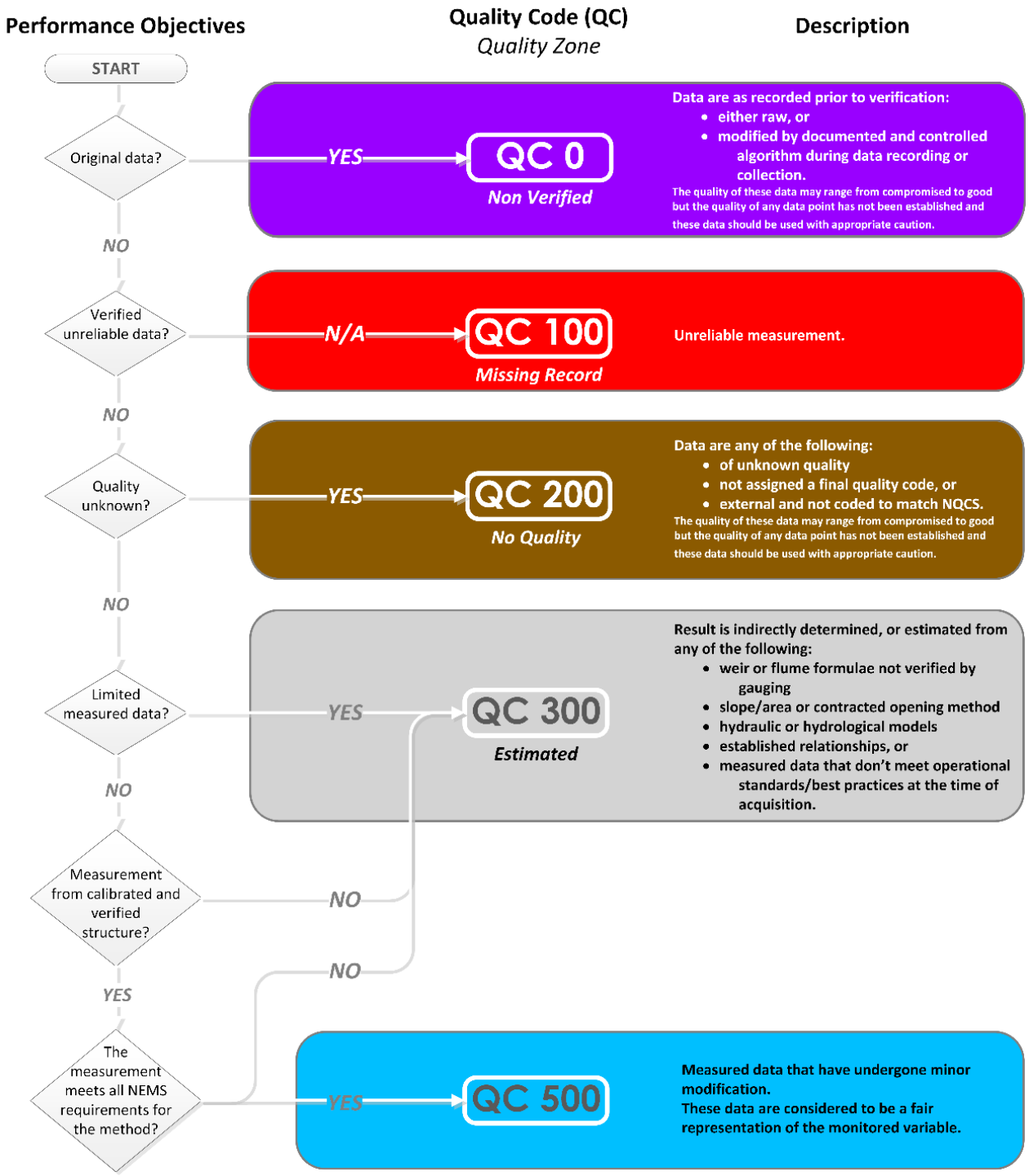
For the purposes of verifying the stage–discharge rating associated with a structure, an open channel flow measurement of QC 600 standard, undertaken using an alternate method, must be completed every 12 months and following an event of significance that has the potential to alter the slope of the reach or the effective cross-sectional area of the structure.

Guidance note: to assist with quality coding 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.*

Quality Coding of Indirect Methods

Note: For this standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.



Quality coding of open channel flow data: dilution method

SUNY Software (Hauet, 2020a) shall be used (unless it is not applicable to the dilution methodology 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.
3. Background EC returns to starting EC levels or, if not, the results are adjusted to account for the shift in background EC.

Guidelines

- For background EC below 200 µS/cm, the peak increase should be at least 50 µS/cm (absolute) and not in percent; this improves the influence of the signal-to-noise (SNR) ratio and probe accuracy.

  Example using percentages: for a background EC of 30 µS/cm, a peak increase of 30% = 40 µS/cm. An EC disturbance of 2 µS/cm is an error of 2 x (1/40 µS/cm) = 5%.

  Example using absolute values: if background EC is 30 µS/cm, a recommended peak increase of 50 µS/cm = 80 µS/cm. An EC disturbance of 2 µS is an error of 2 x (1/80 µS/cm) = 2.5%.

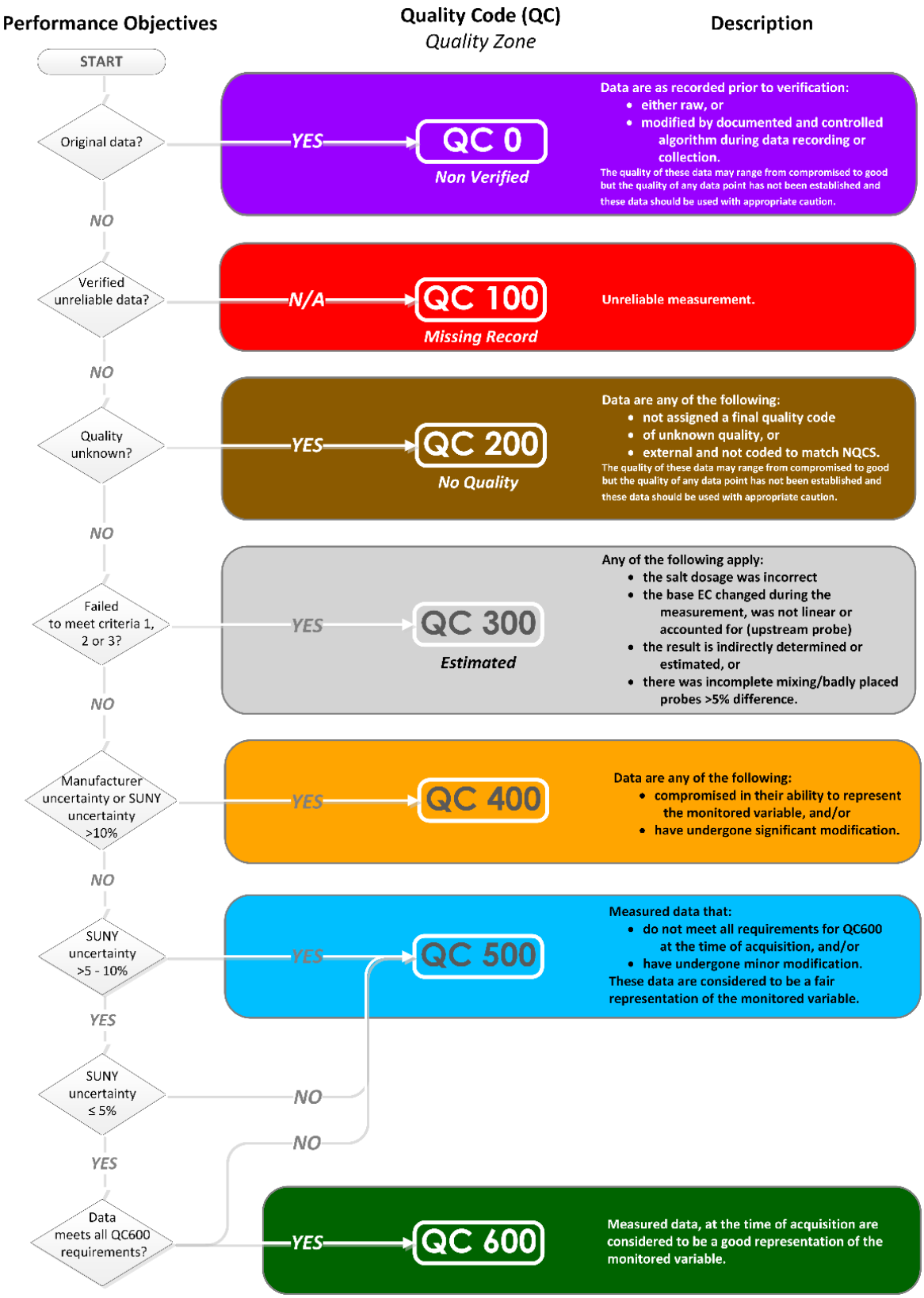
- For background EC above 200 µS/cm, use percentages; peak increase should be around 25% to 50%.

  Example: for a background EC of 200 µS/cm, peak increase is 25% = 250 µS/cm. An EC disturbance of 2 µS/cm is only an error of 2 x (1/250 µS/cm) = < 1%.

- If the background EC changed during the measurement by more than 15 uS/cm (if below 200 uS/cm) or 15% (if above 200 uS/cm), 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 to provide information for a correction or need to repeat the measurement.

Quality Coding of Dilution Methods

Note: For this Standard QC 100 has been deemed as not applicable as the measurement should be discarded and repeated.



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 10.1 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 that are appropriate to site conditions and flow characteristics, safety considerations, and data quality requirements, with the aim of producing reliable, comparable, and verifiable flow measurements over time.

The following parameters shall be recorded to three decimal places:

- Velocity
- Hydraulic radius
- Wetted perimeter
- Water Surface slope

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 locations and depths across the channel width, where it measures the velocity. By multiplying the measured average velocity by the corresponding area for each 'segment', and summing across all segments, the total discharge (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, 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 Velocity-area surface velocimetry methods

The surface velocimetry 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. 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

Index velocity methods are:

- side-looker ADCP
- fixed radar.

The index velocity method is similar to the surface velocimetry method described in Section 1.3, in that surface velocities are measured and converted to mean-channel velocity. However, the index velocity method is different in that it involves establishing two ratings for a site: a stage–area rating and an ‘index velocity’ rating.

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 continuous water level 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 derived from the hydroacoustic current meter into reliable estimates of mean-channel velocities over time.

When deployed at a water level station, the mean-channel velocities obtained through index velocity methods are then combined with the stage–area rating 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 (validated) 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 methods

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 or inaccessibility of the site during flood events.

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

Indirect methods always rely on assumptions and theoretical relationships, and often use data collected at different points in time, which makes it very difficult to accurately quantify uncertainty.

1.7 Dilution method

The dilution method is 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

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, and
- historical and current information about other extreme measurements. (flood and low flows)

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 Channel and flow characteristics

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

Laminar flow is when a fluid flows layer by layer (Figure 1). When a layer of a fluid gets mixed with other layers of the fluid, the flow is known as turbulent flow.

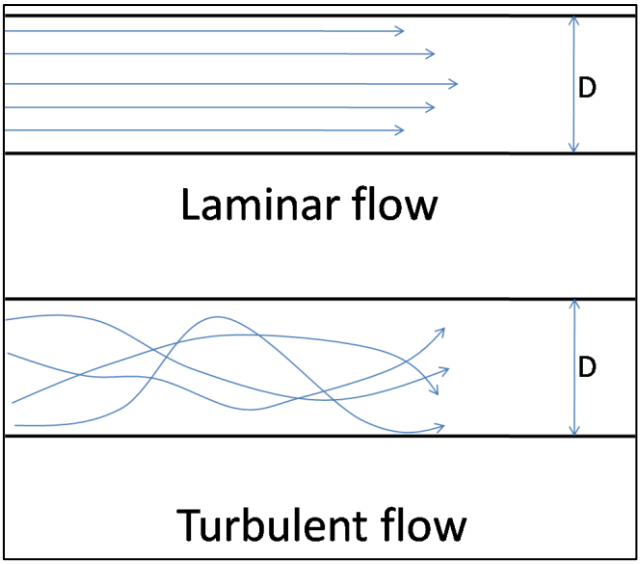


Figure 1 – Schematic of laminar and turbulent flow.

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.

When flow is not laminar, 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] (see section 3.6) will not approximate the mean velocity in the vertical.

Figure 2 shows the velocity distribution over the water depth in a vertical, that should occur in a gauging cross-section that has laminar flow.

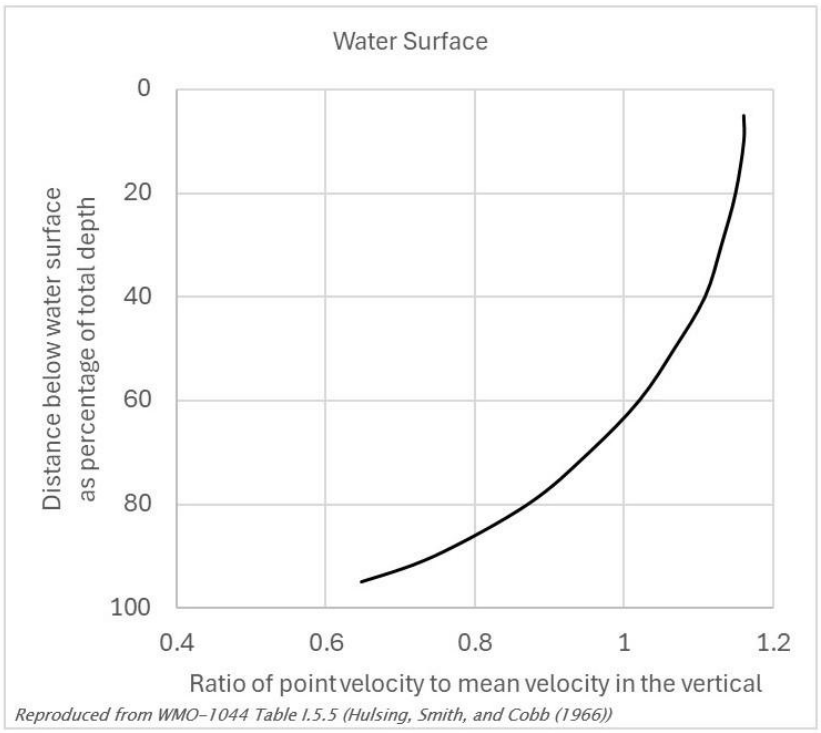


Figure 2 – Water depth versus the ratio of at-point velocity to mean velocity over the total depth at any point in a channel with laminar flow.

Figure provided by Hydronet Ltd.

Figure 3 shows a gauging being undertaken in a very good cross-section with laminar flow, where the reach also meets the criteria described above (i.e. reach length of 3-5 times channel width).



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 or weed growth within the channel. Figures 4 and 5 show streams where velocity observations taken at 0.6 of the 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 (3–5 times channel width) to result in the vertical velocity distribution shown in Figure 2. If weed growth is removed downstream of a water level 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 the weed clearance and consideration 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 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 shows a gauging reach where the use of a stationary current meter is inappropriate and salt dilution gauging is likely to provide a superior measurement of flow.



Figure 4 – 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 three to five 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:

1. Where weed is present (Figure 5), measuring velocities utilising the three-point method (section 3.6) will generally provide a better estimate of the mean velocity in the vertical (even in relatively shallow water) than just measuring the velocity at 0.6 of the 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 three-point method will generally provide a better estimate of the mean velocity in the vertical than just measuring the velocity at 0.6 of the depth (the one-point method).

3. Where boulders exist, or the depths are 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 three-point method at high flow to determine if the velocity at 0.6 of the 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.

Gaugings undertaken to test the validity of the one-point (0.6) method should be calculated twice: once using the 0.2, 0.6 and 0.8 depth velocities and then using just the

0.6 depth velocities. If these two calculations do not result in discharges within 2% of each other, the three-point method should be adopted and all future high stage gaugings should be undertaken using that method, or a boat-mounted ADCP, as these methods will provide a better representation of the velocities in gauging sections where a non-standard velocity distribution exists.

The 'gauging reach' is defined as the distance upstream and downstream the gauging section, The reach upstream of the measurement cross-section shall be at least 3 times greater than the width of the gauging section and the reach downstream of the measurement cross-section shall be at least 2 times the width of the measurement cross-section. For most situations, if this reach is clear, uniform, and free from obvious turbulence the velocity profile can be assumed to be reasonably laminar. For narrow, deep sections the above rule may not be adequate.

Using the length to width ratio of the reach as a guide to determine site quality is simple, useful and particularly relevant in the case of a sharp bend at higher velocities. 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 velocity to a normal distribution is dependent on many variables, such as the obstruction's height, roughness and shape, the proportion of the water column obstructed, the speed of the water, depth at the measurement site and bed roughness. A conservative method is to ensure that a horizontal distance of greater than twenty times the measurement depth exists between the vertical in which velocity is being measured and the nearest upstream obstruction (Figure 6). For the purposes of this Standard, an obstruction is anything that obstructs more than 30% of the water column but does not protrude above the water surface (at which point it becomes an island), e.g. a boulder that sits 100 mm off the bed in 290 mm of water.

In the Figure 6 example, if the gauging cross-section was 1 m wide and there were no upstream obstructions a 'clear' reach would only have to extend at least 3 m upstream. However, because there is an upstream obstruction, a requirement of a clear reach of at least twenty times the depth (i.e. 10 m) provides for better site quality assurance.

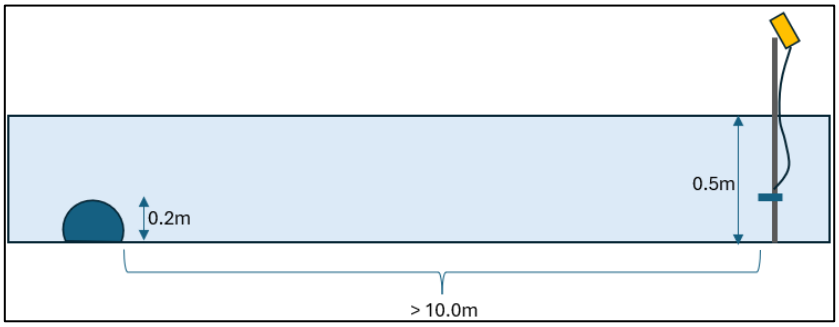


Figure 6 – Graphical example of the distance to obstruction vs depth ratio approach.

If a suitable site can be located and a unit is available, an ADCP (Acoustic Doppler Current Profiler) will produce more accurate results than either a mechanical current

meter or handheld 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 water level (stage) stations for the purpose of establishing rating curves to enable a continuous flow record to be produced.

See NEMS *Water Level* for details of site factors beyond those to be considered for open channel flow measurement.

2.3.2 Location

If a stage–discharge rating curve is to be established for the site, 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 gaugings must be undertaken in a different reach, account for conceivable inflows or outflows between the water level recording installation and the gauging location(s).

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.

Where a measurement of open channel flow is made at a site where water level (stage) is recorded, the flow (discharge) measurement shall be assigned a mean gauge height and be filed at the time at of mean gauge height rather than the time at gauging mid-point. Assigning the time of the discharge measurement, to the time of the mean gauge height, results in the gauging having the same stage height as the actual, or interpolated, filed stage record. If the water level record is adjusted during data processing, the mean gauge height assigned to the discharge measurement shall also be recalculated, and the gauge height filed with the discharge measurement adjusted accordingly.

2.3.3 Access and legal requirements

Consider the following, in addition to the requirements of 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:

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

- inflows and/or outflows between the measurement cross-section and the water level station, and
- channel storage between the measurement cross-section and the water level station at times of changing water level.

Note: These criteria may not be important for one-off spot measurements of flow but are important for measurements used to derive stage–flow rating curves 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 could be too low to determine velocity.

Note: This can be avoided by seeding the flow upstream with sufficient 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 at a resolution that will ensure width measurements can be made to an accuracy of ±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 measurement, 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. These markings shall be at a resolution that will ensure width measurements can be made to an accuracy of ±5% of the total cross-section width and have regular cumulative graduations (coded or digital). Measurement of depth:

Depth measurements:

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

3.3.1.5 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 for which 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.

3.3.1.6 Measurement instruments

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

- 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.

3.3.1.7 Pressure transducers, echo sounders and acoustic profilers

When using pressure transducers, echo sounders or acoustic profilers, one, or more depth reading shall be taken at each vertical. When undertaking discharge measurements in gravel, or sand bed, rivers during flood situations rapid changes in cross-section can occur and it is desirable to obtain a depth observation, prior to, and following velocity observations. The mean depth shall be applied to the discharge measurement.

Note: Software associated with these devices typically averages many depth readings taken during the time velocity is being measured at the vertical.

3.3.1.8 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.

3.3.1.9 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 where a staff gauge or water level recorder exists.

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.

3.3.1.10 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, or
- in the case of current meter measurements, a depth measurement at the beginning and end of the velocity measurement.

3.3.1.11 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 ISO 748:2021.)

- 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 Criteria

Velocity measurements shall be made to meet the following requirements:

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

3.4.2 Velocity vertical spacing

Velocity measurement verticals shall be made:

- at a minimum of 20 (preferably 25) verticals

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, and
- as close as practically possible for channels < 1 metre wide.

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

3.4.3 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: ISO 748:2021 sets the minimum exposure time at 30 seconds. Historical and recommended exposure time in New Zealand and current technique of the United States Geological Survey is 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 QC 600.

3.4.4 Sampling technique

3.4.4.1 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.

3.4.4.2 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 a correction for the angle of flow applied. 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 how particular instruments address angle of flow.

3.4.4.3 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 and for the required duration. (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.

3.4.4.4 Visual examination checks

The current meter shall be visually examined for signs of fouling or damage, generally after each vertical is completed.

3.4.4.5 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 meter's 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 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 types

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)
- Acoustic Echo Correlation Velocimeter (AECV).

Current meters shall be calibrated in an approved rating tank, 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.

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

3.5.2 Rotating-element current meters

3.5.2.1 Calibration

Rotating-element current meters shall be manufactured, calibrated in an approved rating tank and maintained according to AS 3778.6.3, ISO 2537:2007 and ISO 3455:2007.

Meters shall be recalibrated after two years of use or 300 hours of service, whichever is shorter. A recalibration in an approved rating tank shall be completed when a meter consistently fails its validation following routine cleaning, servicing or minimum spin test requirements.

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 undertaken since it failed validation.

3.5.2.2 Validation

Prior to each deployment, a spin test shall be undertaken to ensure that the meter rotates for at least the duration specified by the manufacturer.

3.5.3 ADV and AECV current meters

3.5.3.1 Calibration

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

Note: The NIVUS AECV is not supplied with a calibration certificate unless specifically requested by the purchaser.

3.5.3.2 Validation – ADV

The performance of an ADV can be validated by:

- placing the ADV in still water where the measured velocity should be near zero (≤ 0.01 m/s)
- checking correlation and signal-to-noise ratio (SNR) values. Typically, > 70% correlation and > 15 dB SNR indicate good data
- confirming the latest software version is installed and that the instrument communicates properly with the software, and
- taking multiple velocity readings at the same location; variation should be within ± 2%.

Validation of an ADV can also be achieved via:

- validation within a suitable ranking tank,
- deployment at a managed 'regatta' (section 10.1.1.1).

3.5.3.3 Validation – AECV

The manufacturer of the NIVUS AECV indicates that no validation tests are required prior to deployment. However, an annual check of the entire measuring system, by the user, is recommended, and a complete factory service every ten years is recommended.

Validation of an AECV can also be achieved via:

- validation within a suitable ranking tank,
- deployment at a managed 'regatta' (section 10.1.1.1).

3.5.4 Pressure-Operated Electronic Meters (POEM)

3.5.4.1 Calibration

Pressure-Operated Electronic Meters shall be calibrated in an approved rating tank initially, and then a calibration check undertaken every two years or 100 hours of service in an approved rating tank.

3.5.4.2 Validation

At the commencement of a discharge measurement (prior to immersing the instrument) 'PoemGauge' will attempt to initialise the POEM decoder and, if successful, will display a "System is ready to set zero values" message. Once the initialisation routine has completed, PoemGauge will then verify that stable depth and velocity zeros are being registered. If successful, the instrument is operating as expected and the discharge measurement may proceed.

3.5.5 ADCP Instruments

3.5.5.1 Calibration

An ADCP shall have a calibration check undertaken when first acquired and then every five years.

3.5.5.2 Validation

Validation requirements must be undertaken prior to commencing a discharge measurement; these involve carrying out:

- ADCP Test
- compass calibration (especially when using GPS), and
- moving bed test when using the moving boat method (loop method is preferred to stationary.)

3.5.6 Dilution conductivity sensors

3.5.6.1 Calibration

Calibration of conductivity sensors should be undertaken by the manufacturer if validation fails.

Note: Calibration of conductivity sensors can only be undertaken by the manufacturer.

3.5.6.2 Validation

Validation of conductivity sensors confirms the relationship between electrical conductivity measured by the sensors and the actual salt concentration. A sensor validation shall be undertaken prior to each discharge measurement (or set of discharge measurements).

To validate the conductivity sensors, a small subsample of the injection solution is diluted incrementally into distilled water, and the corresponding conductivity increase is measured. This produces a linear calibration curve that is used to convert the conductivity time series into a concentration time series. When you inject a known standard (i.e. 5 g NaCl in one litre of distilled water) into a sample of stream water, you then employ the distilled water correction to calculate the CF_T.

Temperature effects are accounted for, either through probe compensation or during validation. Accurate validation of conductivity sensors is critical, as errors propagate directly into the discharge estimate.

Sensor validation shall be undertaken at least once every 6 months and should be undertake prior to a measurement being taken. If a recent validation has been undertaken that may be utilised if there is confidence that the equipment has not suffered any damage in the intervening period.

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 holds 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.

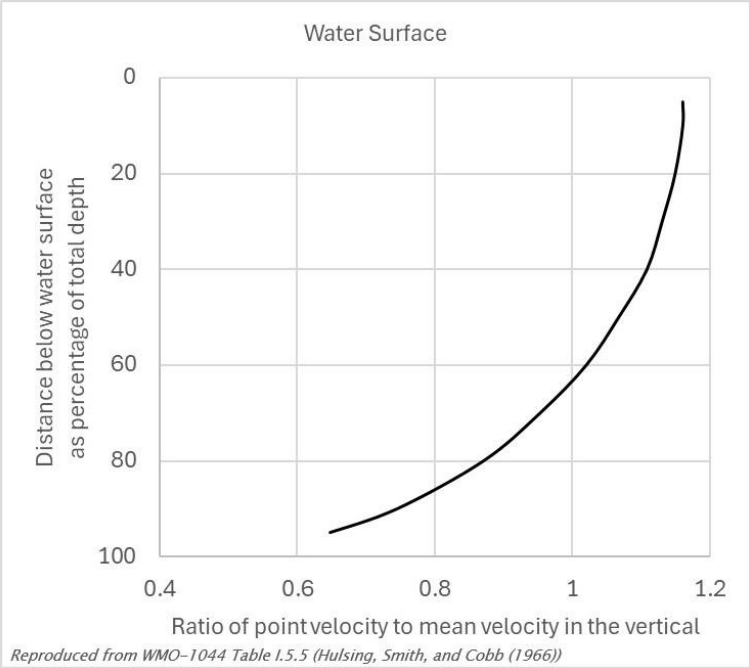


Figure 8 - Water depth versus the ratio of point velocity to mean velocity.
Diagram provided by Hydronet Ltd

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, or
- 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 the theoretical velocity profile shown in Figure 8.

It is recommended that the three-point method is utilised wherever practical, as this method can be expected to provide a robust representation of the velocity distribution in a vertical.

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

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 (> 0.5 m).

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 is 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.

Note: The three-point method is the preferred method where depth allows (> 0.5 m).

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 is determined from a graphical plot of the vertical velocity profile with a planimeter, or from the equation:

$$v_{mean} = 0.1(v_{surface} + 3v_{0.2} + 3v_{0.6} + 2v_{0.8} + v_{bed})$$

Where v_{mean} is the mean velocity in the vertical and v_x is the measured velocity at point *x*.

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 to the surface and the bed as possible. The mean velocity is determined from a graphical plot of the velocity profile with a planimeter, or from the equation:

$$v_{mean} = 0.1(v_{surface} + 2v_{0.2} + 2v_{0.4} + 2v_{0.6} + 2v_{0.8} + v_{bed})$$

Where v_{mean} is the mean velocity in the vertical and v_x is the measured velocity at point *x*.

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 water 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 can be used in most flood situations.

The 'surface' velocity is converted to the mean velocity in the vertical by multiplying it by a correction coefficient (alpha), which is 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 of the depth or the average velocity of measurements at 0.2 and 0.8 of the depth, obtained from other verticals of the same discharge measurement, or from previous discharge measurements at the site. 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 with stage).

Measurement of surface water velocities during medium - to high-stage gaugings will help to develop stage–mean velocity curves and mean velocity–maximum surface velocity curves, which can be used for higher stage extrapolations.

3.6.2 Integration method

The integration method involves lowering and raising the current meter 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 POEM is the standard instrument for this method, as it is capable of sampling velocity (at the front of the instrument) and depth at a very high rate. This instrument and the integration method best suited to flood flow measurement, as the POEM is not accurate 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 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.

At each vertical, the 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 using an ADCP and the stationary profiling method:

- 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.

Notes: 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.

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.*

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

3.6.4 Handheld AECVs method

Handheld AECVs 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 instrument's 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 for undertaking a traditional mechanical current meter gauging also apply to AECVs. These instrument 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.

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

3.6.4.1 Mean vertical velocity calculation

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

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

- checking field notes that record wind and current conditions at the time, and
- using specialised velocity extrapolation checking software, or
- using 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

The mean-section 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.

Cross-sectional area, at-point velocity, mean velocity, hydraulic radius, wetted perimeter, and water surface slope shall all be calculated to three decimal places.

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 for calculating total discharge

Discharge shall be calculated as follows:

- determine cross-sectional segments

- calculate the discharge of each segment, and then
- calculate total discharge.

3.7.1.1 Determine cross-sectional segments

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

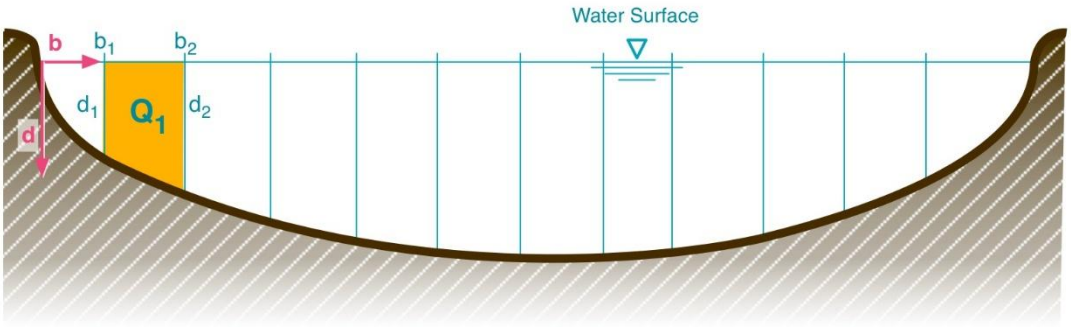


Figure 9 – Cross-sectional segments.
Illustrator: Chris Heath

3.7.1.2 Calculate segment discharge

If v_1 and v_2 are the mean velocities at the first and second verticals, respectively, and 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:

$$q_1 = (b_2 - b_1) \times \frac{(d_1 + d_2)}{2} \times \frac{(v_1 + v_2)}{2}$$

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

where:

- q_1 = discharge through segment 1
- b_1 = horizontal distance from initial point to vertical 1
- b_2 = horizontal 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 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, is estimated as a proportion of the velocity at the adjoining velocity vertical.

3.7.1.3 Calculate total discharge

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

3.7.2 Calculation of uncertainty

The uncertainty assigned to all discharge measurements that utilise the velocity-area stationary meter method and an electronic meter shall be that produced by OURSIN within QRev.

The uncertainty assigned to all discharge measurements that utilise the velocity-area stationary meter method and a mechanical meter shall be in accordance with ISO 748: 2021), Hydrometry - Measurement of liquid flow in open channels.

4 Velocity-Area ADCP Moving Boat Method

In this section

This section contains information about measuring discharge by moving boat in open channels using Acoustic Doppler Current Profilers (ADCPs).

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.

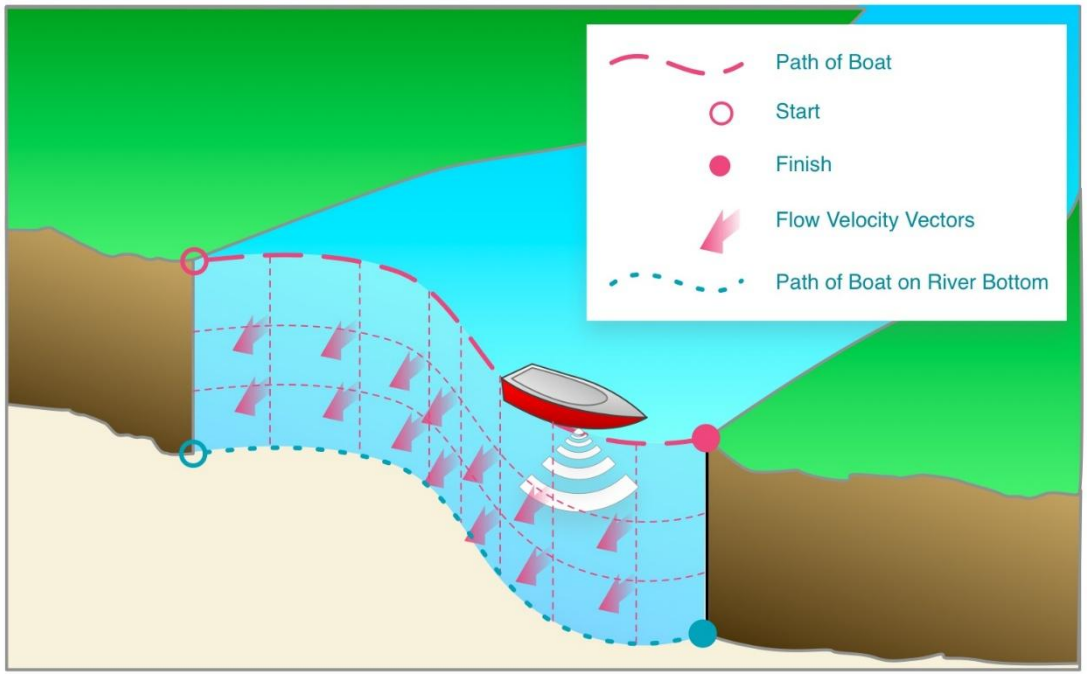


Figure 10 - An ADCP mounted on a boat measuring discharge of a river. Acoustic beams are directed down into the water as it guided across the channel.

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 the 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 can be found in Mueller and Wagner (2013).

Measurement of all these parameters continuously means that:

- transects do not need to be in a straight line, or at right angles to flow
- open channel flow measurements by this method are much faster than standard velocity-area stationary meter methods
- many data points can be measured across the river, as ADCPs measure velocities in many 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 (moving boat method) are very similar 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. The required depth is likely to vary between 0.35m and 0.40m depending on the instrument type being used.

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 water level station, and
- channel storage between the section and water level station at times of changing water level.

Note: These criteria may not be important for one-off spot measurements of flow but are important for measurements used to derive stage–discharge rating curves at a water-level station.

4.2.4 Sites to avoid

Where practicable, sites showing any 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 could 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 validation checks

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

- water temperature measurement
- salinity measurement (where applicable)
- instrument diagnostics
- compass calibration
- ADCP configuration, and
- moving bed tests whenever possible and mandatory for bottom track reference boat velocity.

The results of 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.

- Water temperature shall be checked prior to discharge measurement using a calibrated thermometer.
- It is important that the thermistor of an acoustic instrument be allowed to equilibrate prior to making a measurement. This is particularly important if there is a large difference between the air and water temperatures, assuming that the ADCP has not been in the water prior to the measurement.
- If an ADCP thermistor fails or is reporting temperatures inconsistent with the independent measurement (e.g. more than 2°C difference), the temperature or the speed of sound can be manually edited in the post-processing software, although is not desirable. Rather, it is best to identify and resolve such problems during or prior to data acquisition.
- Any modification of water temperature or speed of sound data shall be documented within the associated metadata.

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 20°C 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 prior to discharge measurement. 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 the instrument's 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 established by the recording authority.

- 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 New Zealand from https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination.

A number of phone apps are able to provide the current and previous magnetic declination (e.g. 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 wind speed and direction 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 a discharge measurement, a moving bed test should be conducted. If using bottom tracking 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:

- 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 stationary at a 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 against the thresholds Annex J 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 (Annex J).

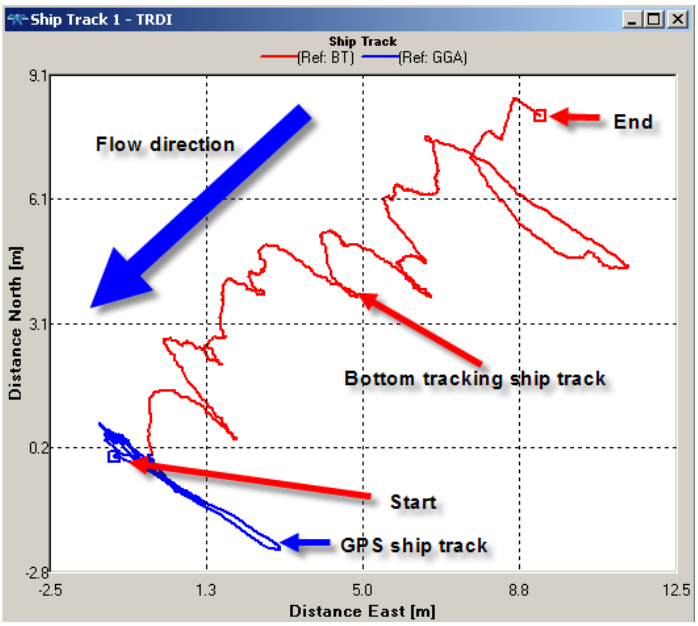


Figure 11 – Example of a stationary moving bed test carried out on an anchored boat with a GPS. The red ADCP bottom track has moved upstream 12 m over 10 minutes while the blue GPS ship track has not moved upstream, just swung sideways over time on the anchor. Moving bed velocity = 0.017 m/s.

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 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 (Annex J), or
- computed using ADCP manufacturer or USGS software for this purpose.

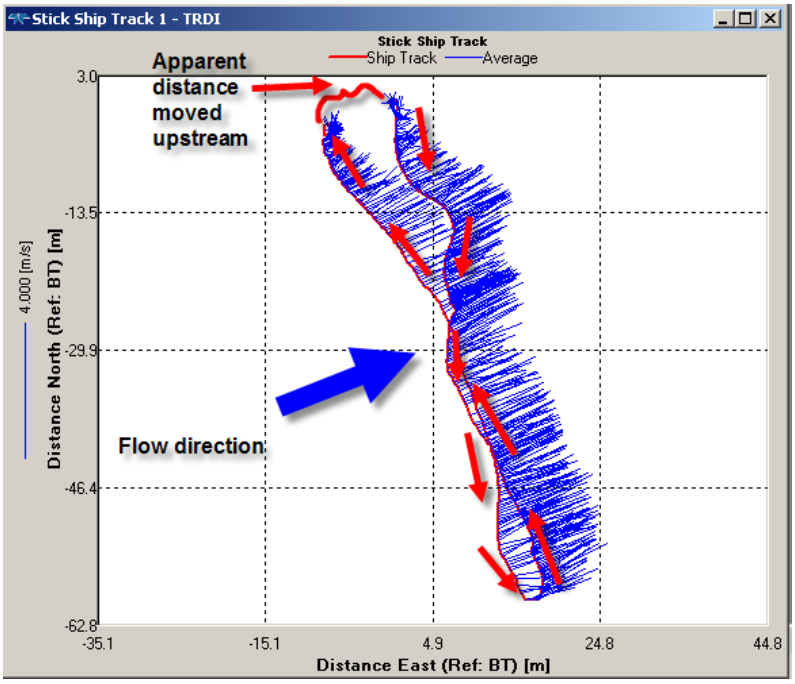


Figure 12 – Example of a loop test with a distorted ship track caused by a moving bed. Apparent distance moved upstream = 8.1 m, duration = 275 s, average moving bed velocity = 0.029 m/s.

Illustrator: Andrew Willsman.

4.3.5.3 When moving bed occurs

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, or
- 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 J.

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 with the ADCP moving boat method, the following rules apply:

- the edge distances from the start and stop positions to the water's edge shall be measured
- the draft/depth of the ADCP reference point must be accurately measured
- ≥ 2 bins/depth cells shall be obtained at the start and end postions
- 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, and

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 transects (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:

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

4.5.1 Number and configuration of transducers

Typically, four or eight transducers are used. Examples of transducer configurations are shown in Figure 13.



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.
Image sources, from left to right: 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 and conductivity sensors.

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, however, the potential for major changes that can affect the results, so the following practices 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 shall be used, and

Note: The USGS provide information on software versions at the OSW hydroacoustics web page https://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 instrument for routine data collection.

Note: Testing shall involve making comparison discharge measurements using another instrument, such as a rotating-element current meter or an ADCP utilising a previously approved version of the software.

4.5.3.2 Calibration

Each instrument shall have its calibration verified via a rating tank:

- when the ADCP is first acquired, and
- after factory repair or modification.

4.5.3.3 Verification checks

The purpose of verification checks is to verify that the ADCP is working in a manner that will enable accurate discharge measurements.

4.5.3.4 Validation checks

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

- conducting a beam alignment and distance made good test in a tow-tank
- 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 et al. (2013).

- comparing ADCP discharge results with concurrent measurements made using an independent method with the discharge measurements being undertaken over a known cross-section

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

- comparing ADCP discharge results with the discharge provided from a stable stage–discharge rating for the site. 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 stable stage–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 stage–discharge relationships that is not attributable to rating changes shall be investigated.

4.5.3.5 Gauging regattas

Gauging regattas (section 10.1.1.1) provide a means by which the equipment being deployed and the techniques associated with deployment can be validated.

Both instrument calibrations and field verifications are essential to instrument/method quality assurance. Regattas have been used to identify such things as bias errors introduced by factory calibrations, excessive random errors associated with a new instrument, compass errors associated with the instrument design, and other issues related to instrument performance or application. They also can be used to identify or revise measurement protocols and determine limitations associated with instruments and/or deployment methods.

Gauging regattas can be used to assess the performance of an instrument or method and, when properly designed and carried out, gauging regattas also allow for the acquisition of sufficient measurements for a robust statistical analysis. However, to be meaningful a standardised procedure for acquiring and processing the measurement results is necessary. For example, if the goal of an intercomparison is to assess the uncertainty of a specific velocity-measuring instrument, Le Coz et al. (2016), Estimating the Uncertainty of Streamgauging Techniques Using In Situ Collaborative Interlaboratory Experiments, suggest that at least four of the same kind of instrument should be deployed, usingthe same methodology during each measurement.

Ultimately, the more instruments and methods deployed in the regatta, the better the assessment. Therefore, for comparison of ADCPs, data should be collected from at least four different ADCPs to enable assessment of the uncertainties. If the objective is to assess the effects of differing site conditions, three or more measurements should be made at each site using the same methodology and instruments (Despax et al. 2019).

It is recommended that for all ADCPs, a comparison measurement be made at least once per year.

WMO (2016) *Guidance on Field-Based Intercomparison Events for Streamflow Measurement Instruments and Techniques (Draft)* provides very good guidance on how ADCP regattas should be undertaken. It can be found at:

https://community.wmo.int/site/knowledge-hub/programmes-and-initiatives/hydrology-and-water-resources/assessment-of-performance-of-flow-measurement-instruments-and-techniques-project-x

Note: On the above web page, the document appears with the title: "Guidance on In-Situ Inter-Comparison Events for Flow Measurement Instruments and Techniques – October 2016", which is the same draft.

Note: Much of the material contained within WMO (2016) is also applicable to intercomparison events for other types of discharge measurements devices.

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: Transects 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 (Annex D) is applied.

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

4.7 Calculation of measurement uncertainty

The measurement uncertainty assigned to a discharge measurement shall be derived by OURSIN within QRevInt.

The OURSIN method is designed as a trade-off between statistical accuracy and practical efficiency. The OURSIN method follows the framework of the *Guide to the Expression of Uncertainty in Measurement* (JCGM, 2008).

The OURSIN method combines uncertainties due to systematic and random errors to estimate the uncertainty of single- or multiple-transect ADCP discharge measurements. The discharge uncertainty in measured areas is estimated by propagating the uncertainty of elemental measurements (boat velocity, cell size, water velocity).

The uncertainty of discharges extrapolated in unmeasured areas (top, bottom, right/left edges, and invalid ensembles and cells) is estimated through expert-designed configurations varying meaningful parameters and assuming a rectangular distribution.

Note: Although further development is needed, the OURSIN uncertainty results have been successfully compared using empirical uncertainty estimates from large-scale repeated measures experiments with variable site and flow conditions.

4.8 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 can be utilised for ADCP measurements includes:

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

4.8.1 GPS instrument 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. VTG sentence 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 than would occur if using differentiated position (GGA sentence).

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

4.8.2 Echo sounders

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

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.

4.8.3 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.

4.8.3.1 Manned boats

An ADCP can be mounted on either side, off the bow, or in a well in the centre of a manned boat. There are advantages and disadvantages for each of these locations, and details of these can be found in Table 6 of Mueller et al. (2013).

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 not to 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.

4.8.3.2 Tethered boats

A tethered boat is a small, unmanned boat generally less than three metres long, attached by a tether or rope that enables it to be deployed from a bridge, cableway or temporary bank-operated cableway.

Tethered boats shall be:

- equipped with a mount that meets the criteria of the boat mount, and
- deployed using a method of towing, where the operator is not standing in the water upstream of the boat or 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 be positioned well downstream of the boat.

4.8.3.3 Remote controlled boats

Remote controlled boats allow deployments where a manned or tethered boat may not be feasible or ideal. Mounting and operational requirements are the same as manned boats. Regular maintenance of the boat and control radios is critical to ensure reliable operation and to avoid potential loss of the boat and equipment.

Note: Remote controlled boats that are utilised for environmental monitoring purposes (primarily utilised for, but not limited to, undertaking ADCP gauging and bathymetric surveys) may 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, 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 Velocimetry Methods

In this section

This section sets out the minimum requirements that shall be followed to allow discharge data collected via surface velocity measurement methods ('velocimetry') 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 section must be read in conjunction with *National Industry Guidelines for hydrometric monitoring Part 11 NI GL 100.11–2021* (Australian Government Bureau of Meteorology 2021).

5.1 Principles

Surface velocimetry is a non-contact method of open channel flow measurement, generally utilised when higher flows preclude the use of more accurate methods such as ADCPs or mechanical meters. Surface velocimetry is currently undertaken within New Zealand using surface velocity radar and video imagery.

The application of an alpha value (α, the correction factor to adjust to the surface velocity measurement to obtain depth-averaged velocity) is required to calculate discharge when using either surface velocity radar or video imagery. Alpha can be derived at a point from a single velocity profile, or by combining all data to obtain a cross-section averaged 'site' alpha. The most robust way to obtain a site alpha is to perform a reference ADCP discharge gauging (Q_{Ref}) and a surface velocimetry gauging at the same time. An initial discharge value $Q_{S,\alpha=1}$ is calculated from the surface velocimetry gauging with an initial alpha of 1. Site alpha is calculated as $\alpha = Q_{Ref} / Q_{S,\alpha=1}$.

The site alpha method is more robust than the point method because it is discharge weighted (i.e. area weighted). In contrast, the point method places equal weight on every measurement, where some may be from shallow areas with less flow and lower local alpha values.

Generally, the shallower, rougher, and steeper the channel (or measurement location) the lower alpha is (i.e. 0.7–0.86), whereas for deeper channels (or measurement locations) alpha tends to be higher (i.e. 0.86 – 1). An alpha value of 0.86 is typically used as a default value in the absence of any available measurements (which corresponds to a 1/6th power law used in Manning's equation). In some extreme cases with very deep flows, upstream surface wind, secondary currents, or drag near the surface from riparian vegetation or bridges, alpha may even be > 1 (i.e. 1–1.2); this is known as the 'surface dip' phenomena and can be a major source of uncertainty. Due to possible range of alpha values, direct measurements of alpha are important.

Another challenge with determining alpha is that it can vary with stage (and thus discharge), due to changes in the wetted portion of the cross-section, relative roughness (i.e. how much of the rough bed is submerged) and water surface slope (as this is likely to vary on the rising/falling limb). To overcome the issue, stage–alpha curves can be established for sites over the gauged range and then extrapolated to better estimate the alpha value during large floods when ADCPs cannot be used. For rectangular channels alpha will typically increase with stage (as depth increases). However, for some natural channels, an initial increase in stage will result in flow no longer being confined to deep channels but also passing over shallow rough bed areas or flood plains; in these cases, alpha may initially drop then increase again as depth further increases and the rough bed is more deeply inundated.

For more information, see Biggs et al. (2021, 2023).

Note: While a "default" alpha of 0.85 or 0.86 is often used for convenience, relying on it can introduce very significant error. Typically, alpha may range from 0.60 for channels with large boulders, up to over 1.0 for artificial concrete channels.

5.2 Site selection

The water at the site selected must have sufficient surface tracers to enable flow directions to be detected on the imagery. Natural tracers 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 piers or other flow disturbances should be avoided. If near a structure (such as a bridge pier) that produce a wake then the video should be taken looking upstream to eliminate the effects of the surface disturbance.

The river reach utilised for observations associated with surface velocimetry should ideally have a stable cross-section and not be subject to scour or sediment deposition. Given that stable cross-sections are not that common in New Zealand rivers, repeated surveys over a period of time and after major flood events will help to determine if the cross-section is stable.

Scouring or deposition of material in gravel bed rivers during flood events can result in very significant changes to cross-sectional area, causing significant inaccuracy in derived discharges at high flows. 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.

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.

5.3 Measurement of cross-sectional area

The cross-section can be surveyed at the time of measurement or, if measurement is during a flood, after the flood event. Cross-section bathymetry is typically surveyed after the event.

Peg the water's edge at the time of measurement (or take a photo of water's edge with visible fixed references visible).

- 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) and be visible in the collected and orthorectified imagery.

Refer to Annex H for the determination of cross-sectional area.

5.4 Measurement of velocity

5.4.1 Velocity derived from drone video

5.4.1.1 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. There should be no wide-angle lens or other distortions to ensure a good quality image.

A minimum video duration of 30 to 90 seconds is recommended with the target being 60 seconds.

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

5.4.1.2 Field of view requirements

The entire width of the channel must be visible in the imagery at the measured cross-section, including in a flood situation. Multiple videos may be required to cover the total wetted width.

5.4.1.2.1 Visible items (vertical imagery)

The fixed ground control 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 is advantageous to have a survey of the cross-section pre- and post-image capture, but this is not always possible.

A minimum of two ground control 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.

5.4.1.2.2 Visible items (oblique imagery)

The entire width of the channel must be visible in the imagery at the measured cross-section, including in a flood situation. Multiple videos may be required to cover the total wetted width.

The ground control points must be visible for section measurement.

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

Alternatively, four GCPs at water level, with two on each side of the channel (can be at water's 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.

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

5.4.1.2.3 Camera angle

For oblique imagery a high angle is best (should be 90° / vertical / Nadir). Look down on the water, as opposed to across it, and ensure that all the ground control points are visible in the fields of view.

If standing on the bank, ensure the 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.

5.4.1.2.4 Lighting

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

5.4.1.3 Ground Control Points

The correct placement of survey Ground Control Points (GCPs) for video imagery is fundamental to obtaining an accurate and useful discharge measurement. Survey stakes/pegs can be used, or rocks, trees, etc., can be used as these GCP's.

5.4.1.3.1 Number and location (vertical imagery)

A minimum of two GCPs (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 the water's edge (e.g. vegetation, boulders)
- reference pegs, or
- visible/identifiable 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 should be known or measured.

5.4.1.3.2 Number and location (oblique imagery)

A minimum of six GCPs on channel banks, with three on each side of the channel, is required; eight GCPs with four each side of the channel is best practice (NI GL 100.11-2021). These GCPs 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 four GCPs at water level with two on each side of the channel (can be at water's edge), that are visible in the imagery and are surveyed at the time (or could be surveyed 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 using four GCPs at water level, they do not need to form a perfect square.

5.4.1.3.3 Additional measurements

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

If using six (or more) GCPs on channel banks, a 3D survey of their locations is required using total station or RTK/PPK GPS.

5.4.2 Velocity derived from handheld video

5.4.2.1 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. There should be no wide-angle lens, or other distortions to ensure a good quality image.

A minimum video duration of 30 to 90 seconds is recommended, with the target being 60 seconds.

Ensure that the camera platform is as stable as possible by mounting it on a tripod or bracing it against a fixed object.

5.4.2.2 Field of view requirements

The entire width of the channel must be visible in the imagery at the measured cross-section, including in a flood situation. Multiple videos may be required to cover the total wetted width.

5.4.2.2.1 Visible items

The ground control 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 water's 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.

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

5.4.2.2.2 Camera angle

For oblique imagery a high angle is best (should be 90° / vertical / Nadir). Look down on the water, as opposed to 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.

5.4.2.2.3 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.

5.4.2.3 Ground Control Points

5.4.2.3.1 Number and location

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

Alternatively, you could use four GCPs at water level with two on each side of the channel (can be at water's edge), that are visible in the imagery and are surveyed at the time (or 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 four GCPs at water level, they do not need to form a perfect square.

5.4.2.3.2 Additional measurements

If using four GCPs at water level, the distances between each (including diagonal distances) need to be surveyed and recorded using RTK GPS or survey tape.

If using six (or more) GCPs on channel banks, a 3D survey of their locations is required using total station or RTK/PPK GPS.

5.4.3 Velocity derived from 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.

Some SVRs are not waterproof or rainproof. Take appropriate measures to protect the device from water damage.

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

5.4.3.1 Direction of flow

The radar can be set to measure velocity of flow towards the user or away from the user. For example, you could measure the velocities from the upstream side or 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.

5.4.3.2 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.

5.4.3.3 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.

5.4.3.4 Exposure time

The velocity should be measured at a minimum of 20 verticals across the measured cross-section and the exposure time for each velocity reading should be a minimum of 30 seconds (40 seconds recommended).

5.4.3.5 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 should be held at an angle of 45° ± 10°.

The tilt angle measurement should be verified annually using an angle measuring device, as the tiltmeters are sometimes inaccurate. However, velocity readings can be corrected if a more reliable tilt measurement is available.

The radar averages the point velocities measured within the target area, so care should be taken when taking velocity measurements close to the bank. Most radar devices are not accurate when velocities are less than 0.5 m/s.

For optimal performance, ensure that the height of the radar device above the water surface is within the manufacturer's recommended range (this is typically less than 10 metres for optimal performance).

Consideration needs to be given to the height above the water relative to 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 5 provides a reference for the sample size area depending on the angle of the radar and the height above the water.

Table 5 – Sample size area for an SVR gun with 12° beam angle. Data provided by Earth Sciences NZ

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

5.5 Instrument validation and calibration

At present there is no calibration or validation devices available for users and the device should be returned to the manufacturer every five years for recalibration. However, it is likely that calibration devices will be available for purchase, for some of the radar devices on the market, within the foreseeable future.

Calibration results shall be stored within the organisation's instrument data base.

5.6 Determination of alpha

In theory, the 'correction coefficient' (known as alpha, α) to convert the measured surface velocity to mean velocity in the vertical water velocity profile, where near laminar flow exists, is typically between 0.84 and 0.90. Due to variations in conditions at individual sites alpha can vary substantially depending upon a number of physical and hydrological factors (stage, channel width, depth, substrate, hydraulic control, approach, etc.). Gathering site-specific 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 surface velocimetry methods can be used.

During medium to high flow events, measuring discharge with an ADCP and measuring surface velocities by surface velocimetry methods at the same time can help determine alpha more accurately. This can be done by adjusting alpha until the surface velocimetry discharge result matches that derived by the ADCP measurement undertaken for a range of flows (also see Section 5.1).

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.

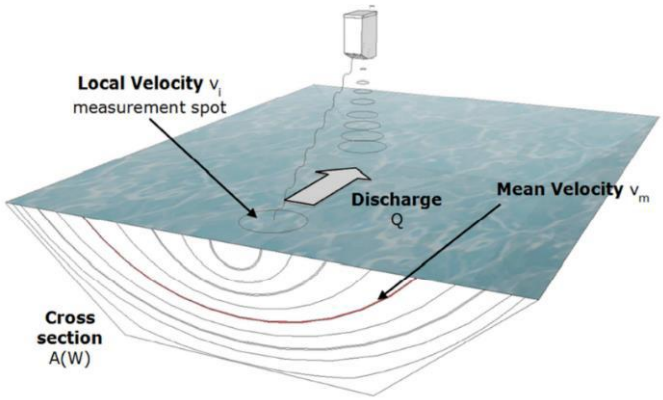


Figure 14 – The difference between observed surface velocity and mean velocity.

If it is not possible to carry out ADCP and surface velocimetry measurements at medium to high flows to derive a stage–alpha relationship, an alpha value of 0.85 should be used.

It is important that the alpha value utilised for a discharge measurement is filed with the measurement. The alpha value 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 velocimetry measurements and details of how to include the alpha value utilised are provided in Annex K.

Further information on the measurement and estimation of alpha can be found in Biggs et al. (2021).

5.7 Discharge calculation methods

The supporting software packages calculate surface velocities and convert these surface velocities (using alpha) to depth-averaged velocities. The depth-averaged velocities are then combined with a cross-sectional area to calculate discharge.

The alpha value utilised with a surface velocimetry gauging shall be stored with the discharge measurement.

5.8 Calculation of measurement uncertainty

At the time this document was produced there was no recognised method for the calculation of uncertainty associated with surface velocimetry open channel flow measurements.

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

6 Index Velocity Method

In this section

This section contains information relating to the continuous measurement of discharge in open channels using the index velocity method with Acoustic Doppler Velocity Meters (ADVMs). The section covers:

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

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 on this method of discharge measurement

6.1 Principles

The index velocity method of open channel flow measurement involves establishing two ratings for a site: a stage–area rating and an 'index velocity' rating. The index velocity rating describes the relationship between the measured ('index') velocity and mean channel (cross-section) velocity. The cross-sectional area and mean channel velocity derived from the ratings are then multiplied to obtain the discharge result. Stage records and index velocity are often collected continuously so that discharge can be calculated continuously.

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

The index velocity method can be used at locations where traditional stage–discharge methods can be used but are more commonly used where more than one discharge can occur for a specific stage (meaning stage–discharge methods are not accurate). Often this occurs due to tidal effects, variable backwater or unsteady flow conditions.

The USGS have implemented the most index velocity flow stations and have developed the best guidance for the method (Levesque and Oberg, 2012). For detailed information refer to this technical guide which can be found at:

Techniques and Methods 3–A23: Computing Discharge Using the Index Velocity Method

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.

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

Note: Manufacturers of ADVM 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%.

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. The site characteristics will determine instrument choice and potential accuracy of the method.

The criteria for a good (traditional) stage–discharge site are applicable to this method (refer to NEMS *Rating Curves*. 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, eddies), and
- 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 a length equal to 5 to 10 channel widths upstream and downstream
- there is a stable channel shape that is not subject to frequent scour or fill
- the total flow is confined to one channel, and
- 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 type.

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.

ADVMs can be orientated horizontally (referred to as a 'sidelooker') or vertically (referred to as an 'uplooker'). A horizontal orientation is more commonly used.

A horizontal ADVM is best suited when:

- channel water depths are sufficient in the representative section so that the beams do not impinge on the bed or surface
- there is a relatively uniform horizontal flow distribution and consistent vertical profile over a range of flows, and
- the region of maximum velocity in the cross-section can be sampled.

A vertical ADVM is best suited when:

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

For a vertical ADVM installation, 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 loss during flood events) 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 velocity measurement 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 the expected velocity range within the measurement volume, which is usually not in the full channel width or depth.

ADVMs 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 V_x) and parallel to the instrument axis (across river, referred to as V_y). 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 sufficient to capture the change in flow conditions and develop an accurate stage–area rating. Many ADVMs 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, and
- 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, and
- accessible during most flow conditions.

Positioning of an uplooker ADVM requires:

- a bottom mount that is sufficiently robust to withstand any potential bed changes and any heading changes
- be positioned to enable the full range of flow to be measured
- accessible during much of the flow range
- 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 (which can block the beams), and
- mounting hardware that will enable it to be accessible during most flow conditions

An ADVM emits several beams, and it is assumed that the velocity field measured by each beam is essentially the same. An ADVM must therefore be properly oriented to the primary flow direction and after installation individual beam velocity data can be evaluated for equal magnitude and opposite direction (see Figure 5 in Levesque and Oberg, 2012). This USGS document can be found at: - https://pubs.usgs.gov/tm/3a23/

After installation, an ADVM must be configured to account for flow characteristics at the site. Configuration involves setting:

- the measurement volume, by sending commands for the velocity range (minimum and maximum) 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 Levesque and Oberg (2012), and
- 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 (i.e. index velocity to mean channel velocity) over a range of expected flows. Discharge measurements should be conducted with an ADCP (see section 4) and require:

- synchronization of time clocks of the ADCP and the ADVM
- setting the ADVM to a 1-minute rapid sampling interval during discharge measurement, to relate the index velocity to the mean channel velocity derived from the discharge measurements. This 1-minute ADVM velocity data can then be averaged to match the respective mean channel 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 five 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, and
- calculation of a mean channel velocity by dividing the calibration discharge values by the respective area from the standard cross-section (from the stage–area rating, see section 6.6).

6.6 Stage–area rating

The stage–area rating is developed first, because cross-sectional area is required to compute the mean channel velocity from the calibration discharge measurements. Mean channel velocity is required for the calibration of the index velocity rating (section 6.7). 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 requires:

- 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 cross-sectional 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, and
- verification of stage-area rating is undertaken by repeat cross-section surveys over time to confirm that no changes to channel bathymetry have occurred. Verification 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, subject to no floods of a magnitude that will create scour, or deposition, of bed material.

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 (V_x and V_y) collected concurrently with discharge measurements
- stage data collected concurrently with the discharge measurements, and
- calibration discharge measurement data.

Note: 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. The index velocity rating is then developed using the following steps:

- range-averaging of the ADVM index velocity 1-minute interval data (V_x and V_y) from the 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 mean channel velocity
- time-averaging of the ADVM index velocity 1-minute interval data (V_x and V_y) collected concurrently with the duration of the discharge measurements
- averaging of the stage data collected concurrently over the duration of the calibration discharge measurements
- calculation of the cross-sectional area for each discharge measurement using the respective averaged stage value and applying the stage–area rating
- calculation of the mean channel velocity by dividing the measured discharge values by the respective calculated cross-sectional areas
- plotting the concurrent (paired) index velocity and mean channel velocity values. If site selection, instrument location, calibration and synchronization were properly performed then a linear relationship should be evident, and

Note: It is important to assign the index velocity to the x-axis, as this is the independent variable, and channel mean velocity to the y-axis, as this is the dependent variable.

- applying simple linear regression to calculate a best-fit relationship and compute statistical results for evaluation. This relationship is the index velocity rating.

Note: 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 is contained in the USGS techniques and methods document (Levesque and Oberg, 2012).

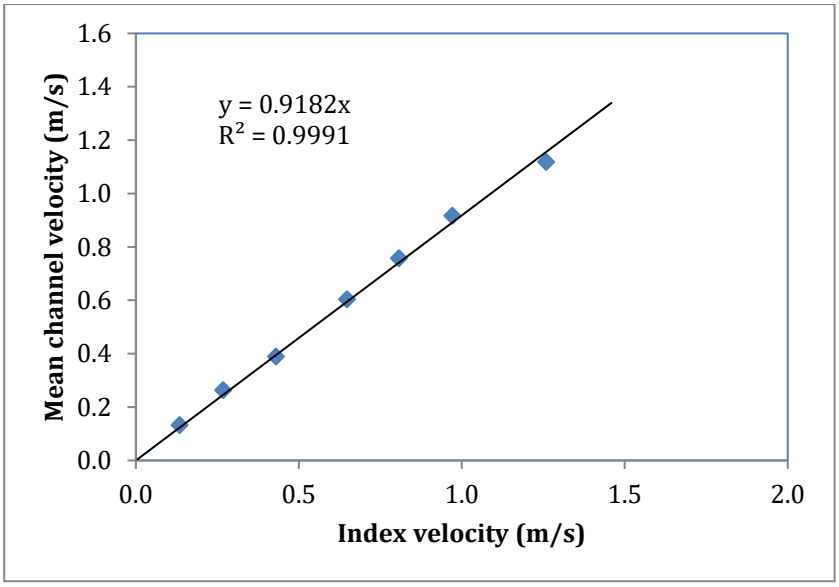


Figure 15 – Example of a linear index velocity rating.

6.8 Continuous discharge calculation

Continuous discharge (Q) is computed as the product of the outputs of the two ratings (area and velocity):

- area is derived from the stage–area rating, using the continuous stage time series as the input to calculate a continuous cross-sectional area time series, and
- velocity is derived from the index velocity rating, using the ADVM's chosen index velocity time series as the input to calculate a continuous mean channel velocity time series.

6.9 Rating validation

The stage–area and index velocity ratings need to be continually validated to check for any change over time. This validation requires ongoing calibration discharge measurements using an alternative method to check the stability of the rated discharge and the index velocity rating. If a significant change is detected, then the index velocity rating process and cross-section survey and stage–area rating process needs to be repeated.

'Significant change', in the context of the ratings, is not defined in this document as there are no international standards for this method. However, most organisations would consider a difference of greater than ± 5% between a single verification discharge measurement and rating-derived discharge with a consistent bias as 'significant'.

6.9.1 Measurement uncertainty

There is no accepted method for the calculation of uncertainty associated with index velocity discharge measurements. This Standard presents no options for Quality Coding other than assigning a Quality Code no greater than QC 400.

However, in relation to the rating uncertainty associated with index velocity discharge measurements, the USGS currently advises (unpublished memorandum) that:

- prediction intervals can be used to describe rating uncertainty when using linear regression. Prediction intervals characterise the likelihood that a new rating validation measurement is consistent with conditions represented by the measurements used to develop or calibrate the rating, and
- the use of 95% prediction intervals to describe index velocity rating uncertainty is required. The intervals must be calculated and plotted with the rating during rating development.

For example, by making some standard statistical assumptions, a new validation measurement made at an index velocity recording site has a 5% chance of plotting outside the 95% prediction intervals developed for a rating if the conditions (such as velocity distribution and channel characteristics) that were present during the validation measurement were the same during measurements used in rating development. In other words, validation measurements that plot outside a rating's prediction intervals indicate that site conditions have likely changed substantially from the site conditions that predominated during rating development.

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. It requires:

- sufficient fall to enable diversion of water into 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:

- Validated 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% then 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 and it is practical to divert the water to the larger container.

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.

Note: Volumetric measurements usually require two people to undertake the measurement – one person undertaking the filling of the container and one person undertaking the timing.

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.

7.5 Calculation of measurement uncertainty

The uncertainty associated with a discharge measurement undertaken using the volumetric method shall be calculated using the principles in ISO 5168:2005.

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

8 Indirect Discharge Methods

In this section

This section contains information on estimating discharge in open channels using indirect hydraulic methods. This method has requirements associated with:

- site conditions
- indirect discharge method utilised
- data collection, and
- calculation of discharge.

8.1 Principles

Indirect methods make use of the energy equation for computing discharge.

Indirect methods shall only be used to estimate flood flows, where it is*:*

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

8.2 Site selection

The reach chosen for the indirect discharge estimation should:

- 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 surveyed 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 reach of length equal to a minimum of five flood widths. However, the longer the reach surveyed (and the number of water levels surveyed within it) the better the derived surface slope will be
- 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, and
- be where significant backwaters, or tidal effects, do not occur.

8.3 Data collection

Data collected for the indirect methods include:

- surveyed high-water-levels at least 10 locations and elevations to an accuracy of ±3 mm
- cross-sections along the reach
- geometry of any structures relevant to the method, and
- a roughness coefficient for the reach (see sections 8.3 and 8.4.1.1).

The determination of maximum water level from flood marks is not as straightforward as it seems, and the USGS publication *Identifying and Preserving High-water Mark Data* (Koenig et al., 2016) provides excellent information relating to the identification and survey of high-water flood marks. This publication can be found at:

Identifying and preserving high-water mark data | U.S. Geological Survey

8.4 Discharge calculation methods

A number of indirect methods are available to calculate peak discharge. These methods make use of the energy equation for computing discharge.

The two most common methods are the:

- slope-area method, and
- contracted opening method.

8.4.1 Slope-area method

The slope-area method is one of the most commonly used techniques of indirect discharge determination. A complete description of the method is detailed in ISO 1070:2018, Hydrometry-Slope/Area Method and USGS Publication TWRI: 03-A2 (Dalrymple and Benson, 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 water surface slope. These values are calculated for the reach, rather than a single cross-section, with the values thus being averaged over 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 applied to these data points (with any obviously outlying observations being discarded prior to line fitting). Where possible a converging reach should be utilised for slope-area discharge measurements as the hydraulic factors are more correct than for a diverging reach.

The simplest version of the Manning's equation (Hicks and Mason, 1991) employed 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:

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

where:

- α is usually assumed to be 1
- g is the acceleration due to gravity
- v is 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 more effectively 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 New Zealand Ministry of Works (circa 1970).

The conveyance of the reach (K) is calculated using:

$$K = \frac{A R^{\frac{2}{3}}}{n}$$

where:

- K is the conveyance of the reach (m^3/s)
- A is the mean of the upstream and downstream cross-sections (m^2)
- R is hydraulic radius, and
- n is the Manning's roughness coefficient.

Then discharge in a converging 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: The above formula is for a converging reach. For a diverging reach, replace (2gL) in the above formula with (4gL).

where:

- Q is discharge (m^3/s)
- g the acceleration due to gravity (m/s^2)
- L is the length of reach (m)
- S is the slope (m/m)
- A_1 is the upstream cross-section area (m^2), and
- A_2 is the downstream cross-section area (m^2).

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 and hydraulic radius. The best way to define an appropriate *n* is to carry out a number of current meter gaugings at a site, at a range of flows, and calculate *n* from the transposed Manning equation, i.e.:

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

The derivation of *n* will require the cross-sectional area to be known, and the slope of the gauging reach surveyed at the time of the current meter gaugings. Alternatively, staff gauges (of known gauge 'zero') can be installed at the top and bottom of the reach and the slope determined from the difference in reduced level between the water level at the two gauges.

An alternative is to install benchmarks, and/or water level recording devices, at the top and bottom ends of the reach so that the water level at these locations can be recorded easily or quickly surveyed.

Often, it will not be possible to determine *Q* at high discharges. However, other, usually lower-stage, gaugings at a site can 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 derivation of *n* by calculation from observed slopes and measured discharge (with extension to the maximum expected gauge height) 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:

- using *n* values derived for similar rivers. Reference can be made 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 Barnes (1967) provides 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 and found to be adequate.

The metric version of this equation is:

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

Where:

n = Manning's "n" (the friction coefficient)

S_f = friction slope (also known as the energy slope, or slope of the energy grade line) which approximates the surface slope in uniform flow conditions

R = hydraulic radius

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, for bedrock channels.

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. The difference in the water-surface elevation can be used to estimate discharge. High water marks and the geometry of the bridge and channel are used in this method.

This method can be applied post-flood by pegging water levels during the 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.

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: Matthai (1967) is a US paper with formulae and examples in imperial units; coefficients, unless dimensionless, require conversion to metric units.

A variation of the formula for calculating discharge through a contracted opening was derived and applied in New Zealand by Mr A. C. Hopkins of the New Zealand Ministry of Works (circa 1969). This version of the formula removes the components that have no significant effect on the discharge and so simplifies the calculation.

First, velocity at the upstream cross-section is determined 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 drawdown 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

This section contains information on estimating discharge in open channels using the salt dilution method This method has requirements associated with:

- site selection and conditions
- channel and mixing reach properties
- tracer properties, dosing and tracer detection
- calculation of discharge.

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 (EC) 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 other methods of discharge methods due to high velocities, turbulence, or debris.

The tracer concentration needs to be completely mixed between the point of injection and the location at which the tracer mass is observed. However, for the slug injection method (where the entire quantity of tracer is introduced into the stream over a very short period, typically a few seconds), it is not the instantaneous concentrations that need to be uniform across the channel but the time-integral of the conductivity exceedance over background.

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 is 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 to ensure adequate stream channel conditions for minimising uncertainty in the discharge calculated using the dilution method.

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 location for which flow needs to be known is downstream of the tributary and is a sufficient distance downstream to ensure the tributary inflow is fully mixed with the main channel flow. Measuring background EC 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 upstream of an area of flow constriction, whereas measurement points should be in or downstream of 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 reaches 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 instream 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 to or further away from the injection 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 CF_T (calibration factor for mass balance method) are properly performed. Finally, field methods to control for potentially variable, and possibly shifting EC background 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 depending on the equipment used. Doses of 100 mg per m^3/s can achieve great results, reducing the impact on the stream environment.

At sites with previously constructed stage–discharge 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 (e.g. based on estimates of width, depth, and velocity).

A lower dose should be used for an initial trial, and 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 Breakthrough curve characteristics

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. The dose strength required is dependent on signal to noise ratio that in turn is a function of both EC sensor resolution and background EC (EC_{BG}) stability. A recommendation is to target 25–40 µS/cm over EC_{BG} (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.

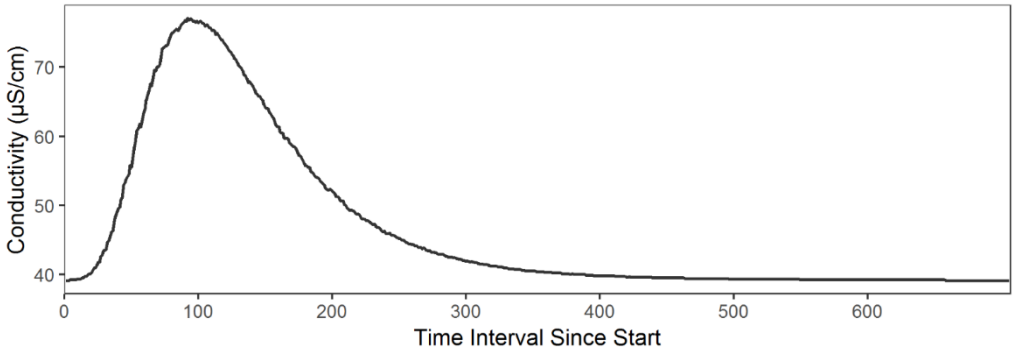


Figure 16 – Typical breakthrough curve, with 38 µS/cm exceedance over background. EC_{BG} = 39 µS/cm.

9.3.3 Derivation of CF_T

The CF_T (Calibration Factor, also sometimes referred to as the Concentration Factor) is used to convert measured temperature-compensated electrical conductivity (EC_T, also referred to as specific conductivity) to salt (NaCl) concentration. This process 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 EC instrument'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 CF_T 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. The steps to be followed are:

1) Place the probes in the stream to reach equilibrium. Note the EC_T value in the stream.
2) Place the probes in a sample flask containing 1000 mL of stream water. Note the EC_T value; if it is any different to that obtained in step 1, repeat step 1, clean flask and repeat step 2 until the EC_T measurements are equal.
3) Inject 1.00 mL of salt standard into 1000 mL of stream sample in the flask, mix thoroughly without spilling any water.
4) Place probes in the sample. Note change in EC_T value; probe traces should follow each other and plateau out.
5) Set this on the device or in the software.
6) Inject a further 1.00 mL of salt standard into the sample in the flask, mix thoroughly.
7) Place probes in the sample. Note change in EC_T value; probe traces should follow each other and plateau out.
8) Set this on the device or in the software.

Repeat three more times to give five points in total; i.e. until a total of 5.00 mL of the salt standard has been added to the 1000 mL of stream water. Typical graphed results are shown in Figure 17.

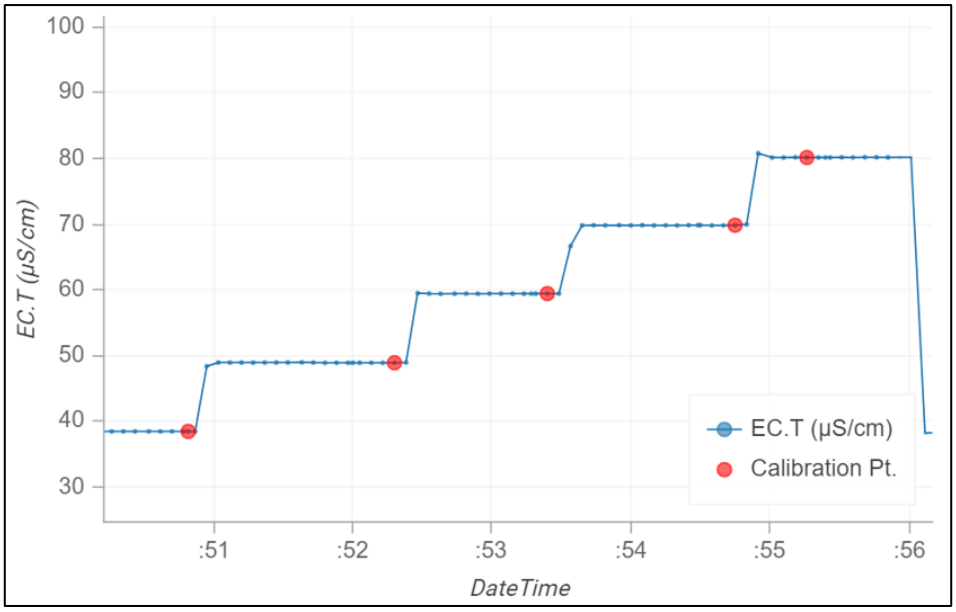


Figure 17 - Typical graph of on-site CF_T calibration, showing measured EC_T for each calibration point.

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, 10-25 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 sensor 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 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 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.

EC Results should not vary by more than 7% between measurements when the probe is moved between salt runs. Alternatively, 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 interval between consecutive EC_T and temperature measurements is no longer than 5 seconds (1 second preferred), and for runs with very short-duration salt pulses (i.e. less than 3 minutes), be no longer than 1 second.

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 return to EC_{BG}. When EC_T is changing by less than ± 0.1% it can be assumed to have reached EC_{BG}. If time constraints prevent waiting for EC_T to return to background (e.g. if accessing the site by helicopter) 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 EC_T - control in the field

For all methods, EC_T must return to the pre-injection background conductivity (EC_{BG}) at the end of the breakthrough curve. In instances where the EC_{BG} is changing (via snow melt, rain, or glacial melt, etc), measurement of EC_{BG} upstream of the injection is the

preferred method to control for shifting background (point or continuous). Control of shifting background can also be compensated for in the office (see section 9.5.1) 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 to minimise instrumentation and salt tracer uncertainty.

9.4.1 Temperature compensation of electrical conductivity 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; the result is called temperature-compensated temperature (EC_T). Temperature compensation is a standard option on most electrical conductivity sensors.

9.4.2 Conductivity sensor resolution

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

- for EC_{BG} measurements < 200 µS/cm, the minimum instrument resolution is 0.1 µS/cm, and
- for EC_{BG} measurements > 200 µS/cm, the minimum instrument resolution is 1 µS/cm.

Both sensor resolution and background conductivity noise affect the injection ratios (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 EC_{BG} > 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 or returned to the manufacturer for calibration;

Temperature measurements from other 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 and water softeners are not permitted as they contain added chemicals. Consistency in tracer composition is important; hence, metadata on brand and make of table salt should be tracked, 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 (e.g. 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 metadata.

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 CF_T calibration 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 four 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 discharge is the final step where uncertainty in salt dilution measurements can be minimised. Discharge shall be calculated using the SUNY software.

Most of the recommendations in this section encourage good metadata practices and data processing procedures that are transparent and reproducible.

9.5.1 Shifting background EC_T – control in the office

Application of appropriate algorithms to address changing EC_{BG} (no return to pre-injection level) is an acceptable alternative to use of measurements upstream of injection (section 9.3.7), provided it can be shown that the maximum potential error only increases measurement uncertainty in the final discharge values by less than 5%.

For example, suppose EC_{BG} exhibited an increasing trend prior to injection, and following injection EC_T 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 EC_{BG} exhibited an approximately linear increase through time. 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 EC_{BG} from the observed EC_T 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 (Figure 19). Filtering and filling of such values should affect fewer than five instances per salt run.

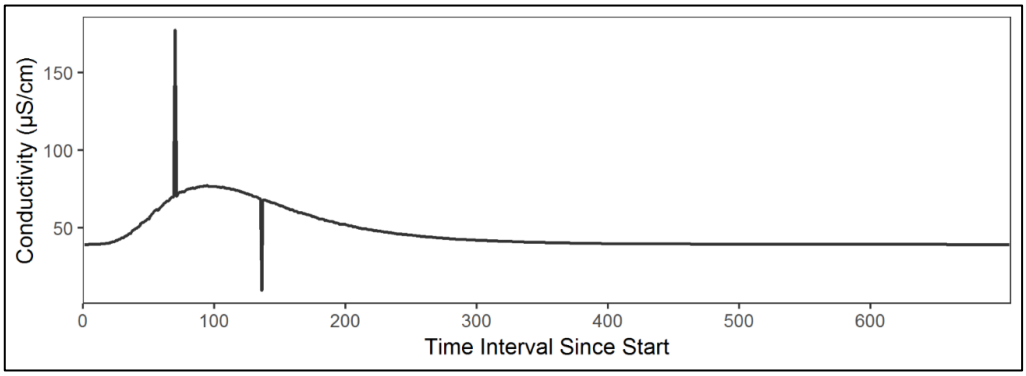


Figure 19 – Breakthrough curve with outliers.

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 metadata for each measurement:

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

9.5.4 Data output and filing

The gauging output (usually a csv, pdf or xml file) is to be treated 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.

9.5.5 Calculation of uncertainty

The uncertainty associated with the discharge measurement shall be that provided by the SUNY software (Hauet, 2020a; see also Hauet, 2020b).

The WMO is currently preparing a document on deriving discharge using dilution methods. At the time of publication, this WMO document is still a "Draft" and not

available for download. However, when the WMO document becomes available, users should refer to it for further information in relation to dilution discharge measurements.

10 Quality assurance

In this section

This section describes quality assurance tools 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

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

10.1.1.1 Regattas

The most effective approach for 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.

Note: To be considered an instrument validation, the measurements performed at a regatta must be undertaken on a known cross-section with a known flow and have the discharge calculated using the same software (including version). In addition, as far as practical, common versions of instrument firmware should be utilised.

When a gauging regatta is used as an instrument verification tool, all results obtained from the 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 instrumentation and methods assessed during the regatta.

For more detailed guidance on conducting field comparisons of instruments used for discharge measurement, refer to WMO: *Guidance on field-based intercomparison events for streamflow measurement instruments and techniques* (Draft 16 March 2026).

Note: A link to this WMO document will be added when WMO publishes the final version.

10.2 Managing method changes

Significant change to measurement methods can disrupt stationarity of the record. Examples of changes that could affect stationarity of record include:

- a change of site and/or sensor location
- instrumentation type
- methodology change

- firmware change, or
- software used for the calculation of discharge.

Care needs to be taken when any of the above changes occur. Checks of measured discharge should be undertaken, at a stable site, before and after the change is made, or by the use of an alternative measuring device, or method, to ensure that the measured discharge is as expected.

11 Requirements for Metadata, Calculation of Gauging Results and Archiving

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. The majority of the requirements and guidance are contained within the NEMS *Data Processing and* are not reproduced within this document.

11.1 Site details

Site metadata includes the following site details:

- the site identifier (site name or number)
- 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.

Original measurement records form part of the site metadata and include:

- a unique measurement identifier
- date and time
- site name and/or identifier, and
- the verification checks if undertaken during the measurement.

11.2.1 Original records

(See NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* – Section 1.2.2)

11.2.2 Deployment/Verification tests and checks

(See NEMS *Data Processing Version 1.3.1: Annex C Processing of Gauging Results* – Section 2.2)

11.2.3 Gauging Register

(See NEMS *Data Processing Version 1.3.1: Annex C Processing of Gauging Results* – Section 1.2.1)

11.2.4 Further metadata requirements

Further metadata requirements are contained within NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results*, and these requirements are not reproduced within this document.

11.3 Other metadata 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 Version 1.3.1: Annex C - Processing of Gauging Results*) includes:

- data acquisition records (see NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* – Sections 1.2 - 2.1)
- quality codes (see NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* - Section 4.1)
- data records and filed comments (see NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* – Section 2 and Section 4.2)
- data access agreements and/or waivers (Section 2.2.1).

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 open channel flow 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 simplified quality coding matrices (see Annexes A–D) 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
- available when the data are processed (see NEMS *Data Processing Version 1.3.1* – section 4.1), and
- retained indefinitely as part of the site metadata.

11.4.1 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.

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. 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 time-stamped 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.

Filed comments are intended for end users of the data. They have a formal structure and text format (see NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* – Section 4.2). 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* Version 1.3.1 *Annex C - Processing of Gauging Results – Section 4.2)* 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

(See NEMS *Data Processing Version 1.3.1: Annex C - Processing of Gauging Results* - Section 1.2, Section 2.5, Section 2.6, Section 3, Section 6 and Appendix C.3.)

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 due to manual changes to the collected data, such as water's edge adjustments or velocity extrapolations that have been made to ADCP discharge measurements.

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, and
- 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:

- all required site and measurement metadata
- all other original records
- the original data, as defined by the recording agency
- quality assurance records (see NEMS *Data Processing Version 1.3.1* – Section 7), and

- supplementary and/or complementary data used in the production of the final verified measurement.

12.2.1 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 to be stored in a format that is:
  - universally readable (e.g. text)
  - migrated as systems change, or
  - stored with the software to open and read them.

12.2.2 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.

12.2.3 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 open channel flow 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 – Application of 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 the 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 this 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 **type of site being** assessed. Where different **site types** have different criteria, strike through 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, as defined by 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 Matrix

This matrix is to be used for assessing adverse factors within the gauging reach that are ≤ 3 x width upstream and ≤ 2 x width downstream. (Section 2.3 – channel and flow characteristics)

Note: This Matrix does not apply to dilution gaugings

Criteria		QC 600	QC 500	QC 400	QC 200
Channel characteristics	**Straight channel**	No discernible flow angles or ADCP ☐	☐	20–45 degree flow angle ☐	☐
	Change in depth	< 100% or ADCP ☐	☐	> 300% ☐	
	Undercut banks	None ☐	☐	25–50% ☐	☐
Total number of channel characteristics not achieving QC 600		0 ☐	☐	≥ 1 in QC400 or ≥2 in QC 500 ☐	☐
In-flow obstructions	**Benthic weed**	< 10% or ADCP ☐	value? ---------- ☐	25–50% ☐	☐
	Riverside/surface vegetation	< 10% ☐	value? ---------- ☐	25–50% ☐	☐
	Submerged obstructions (>1/3 of depth)	None or ADCP ☐	value? ---------- ☐	25–50% ☐	☐
	Partially submerged obstructions	None or ADCP ☐	value? ---------- ☐	25–50% ☐	☐
Total percentage of in-flow obstructions		<10% or ADCP ☐	value? ---------- ☐	25–50% ☐	☐
Quality Code					

The results of this site quality matrix then feed into the method specific matrices in Annexes C and D.

Where ‘or ADCP’ is stated, this means the channel characteristic is not applicable when an ADCP instrument is being used for the open channel flow measurement.

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 0.3 m increasing to a depth of 0.6 m at the cross-section would equate to a 100% change. A depth upstream of 0.3 m increasing to a depth of 1.2 m at the cross-section would equate to a 300% change.

Often the bed is not visible for part of, 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 B 1 and B 2.



Figure B 1 – The left image shows a site with excessive bankside/surface vegetation in the flow.



Figure B 2 – A QC 600 site. (Left photo looking downstream, right photo looking upstream).

Submerged obstructions

Are there any obstructions, e.g. logs, rubbish, boulders, 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 200 mm.

Partially submerged obstructions

These are obstructions to flow that extend all the way to the surface, e.g. islands, bridge piles, power poles and trees. Are there any islands within the reach? If so, what are their nature? Steep-sided islands are to be particularly avoided. 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? One example is where 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 and assess only once. Use either the width or depth ratio method, whichever is greatest (see Section 2.3).

Other considerations

Avoid reaches with 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

Note: This matrix shall also be used for discharge measurements made using a POEM.

Criteria			QC 600	QC 500	QC 400	QC 200
Instrument calibration valid (3.5)			Yes ☐			No ☐
Instrument used within calibrated velocity/depth range (3.4.4.5)			Yes ☐			No ☐
Pre-deployment test (3.4.4.3)			Completed with no errors ☐			Not completed or completed with error/failed ☐
Oblique flow (3.4.4.2)			Not present or ADCP/ADV used ☐		Present, but not measured and accounted for ☐	
Depth measure-ment (3.3.2)	**ADCP**		☐			
	Cable	**Firm bed**	No mobile bed and Wet/air-line angles absent, or Wet/air-line angles present measured and applied, or POEM ☐		Mobile bed known/likely or Wet/air-line angles present and not applied ☐	
		Soft bed	Bed visible across entire section ☐	☐	Bed not visible across entire section ☐	
	Rod	**Firm bed**	No mobile bed ☐	Mobile bed ☐		
		Soft bed	Bed visible across entire section ☐	☐	Bed not visible across entire section ☐	
Maximum segment discharge (3.4.2)			≤ 10% ☐		> 10% but < 15% ☐	

Velocity profile (3.6.1)	**ADCP, or** **POEM**	☐			
	Proven regular velocity profile	Single-point method, < 0.5 m deep or ≥ 3-point method ☐	Single-point method, > 0.5 m deep ☐		
	Known irregular or unknown velocity profile	≥ 3-point method or Single-point method, < 0.2 m deep ☐	☐	Single-point method, > 0.5 m deep ☐	
QC warnings: Poor Boundary, Low SNR and Spikes only		None or ADCP used ☐	☐	25–50% of verticals contain warnings ☐	☐
QC derived from the Site Quality Matrix (Annex B)		☐	☐	☐	☐
95% uncertainty (3.7.2)		≤8% ☐	☐	10–20% ☐	☐
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 QC 400 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	QC 200
Instrument calibration valid (4.5.3.2)	Yes ☐			No ☐
Compass calibration (if applicable) (4.3.3)	Completed without error and manufacturer threshold met or N/A ☐		Completed with error(s) and/or manufacturer threshold not met ☐	Not completed ☐
Moving bed test BT-referenced boat speed only (4.3.5)	Completed without warnings or N/A ☐		Completed with red warnings ☐	Not completed ☐
Even number of transects in opposing directions (4.4)	Yes ☐		No ☐	
GPS-referenced boat speed (only) (4.8.1)	VTG with avg. boat speed > 0.24 m/s or RTK/DGPS or N/A ☐	VTG with avg. boat speed < 0.24 m/s ☐		
Total exposure time (4.4)	> 12 min ☐	☐	3–8 min ☐	☐
Edge data Min. for any transect (4.4)	≥ 2 bins/cells for all used transects and Distance measured ☐	☐	< 2 bins/cells for any transect and Distance not measured ☐	
95% uncertainty Using QRev default settings and Oursin method (4.7)	≤ 8% ☐	☐	10–20% ☐	☐
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 QC 400 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

The USGS Office of Surface Water developed a computer program known as QRev, for the calculation of discharge and uncertainty for discharge measurements undertaken with acoustic instruments. This software has been subsequently enhanced for the international community as QRevInt (for Moving Boat measurements) and QRevMS(for stationary mean section measurements) with ongoing development and funding by many countries worldwide including New Zealand. This annex describes the use, and features of both QRevInt and QRevMS.

QRev Moving Boat

The use of acoustic Doppler current profilers (ADCPs) from a moving boat is a common 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 manufacturers 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. 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 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 backfilled 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 boat velocity of zero. If the boat velocity reference is set to GGA or VTG (both satellite receiving options, only VTG is available in New Zealand) 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 E 1 – What the QRevInt software uses for the calculations associated with the various parameters for various instrument types.

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 on the downstream side of a bridge using a tethered boat during a flood. 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 E 1, 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 E 2, 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 m^3/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 computed 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

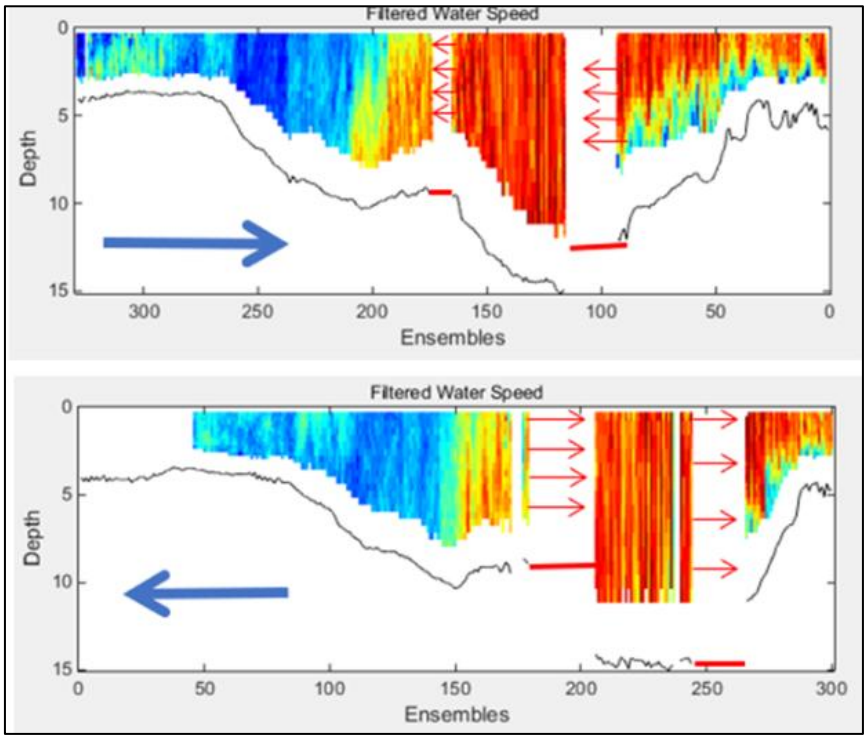


Figure E 1 – Example of TRDI ADCP data collected during a flood and processed with WinRiver II.

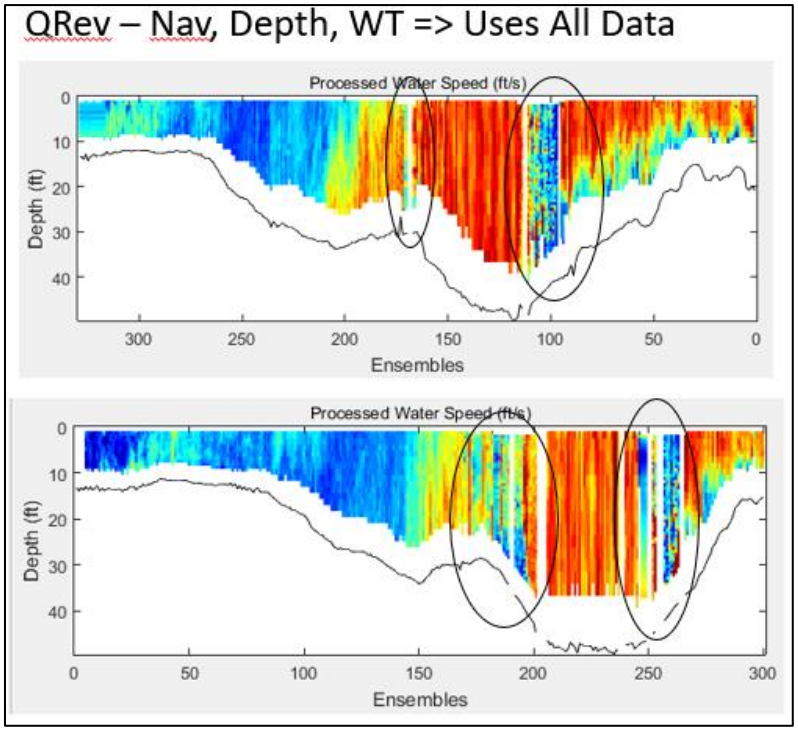


Figure E 2 – Same TRDI data processed with QRevInt.

Using 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 pre-measurement steps first. Navigation reference, depth, and water velocity 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 velocity 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.

QRevInt access, version documentation and updates

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.

'Tricks' of usage

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 shortcut keys available and right-clicking on any graph will display the following context menu which 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 analyse 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.

QRevMS - 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 computation for the mean-section measurement has a fixed edge coefficient of 0.5 in RiverSurveyor Stationary Live and a pull-down menu option that 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. QRevMS must be utilised for the calculation of all Flowtracker gaugings and every gauging should have a new edge factor implemented in QRevMS that is between 0.0 and 1.0, and therefore aligned with the field observations (not just a standard 0.5 or 50%). Also, each discharge measurement must be checked when it is loaded into an organisation's time series management (TSM) software, to ensure that the edge factors assigned have remained correct following the data import. This is because some TSMs (especially Hydstra) import the edge factors as 1.0, not the observed factor, which results in an incorrect discharge being filed.

3. RiverSurveyor Stationary Live and RSQ define the velocity correction factor as an adjustment of the velocity of a measured profile, which is not consistent with the common definition of velocity correction factor.

4. RiverSurveyor Stationary Live and RSQ do not provide access to the sample or ensemble data for a vertical. Accessing these data within Section-by-Section Pro requires the measurement to be split into individual pd0 files and loaded into WinRiver II.

5. The methods used to compute the mean profile can be different.

6. Filtering of potentially invalid data is either not available or not automatically adjusted to the collected data.

7. The application of the ice exponent for ice cover situations is limited to an exponent of 0.1667 in Section-by-Section Pro.

8. 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 manufacturers' 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 example in Figure E 3, 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 (Figure E 4).

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 E 3 – Cell sizes from QRevMS, showing only one ensemble with 0.02 m cell size.

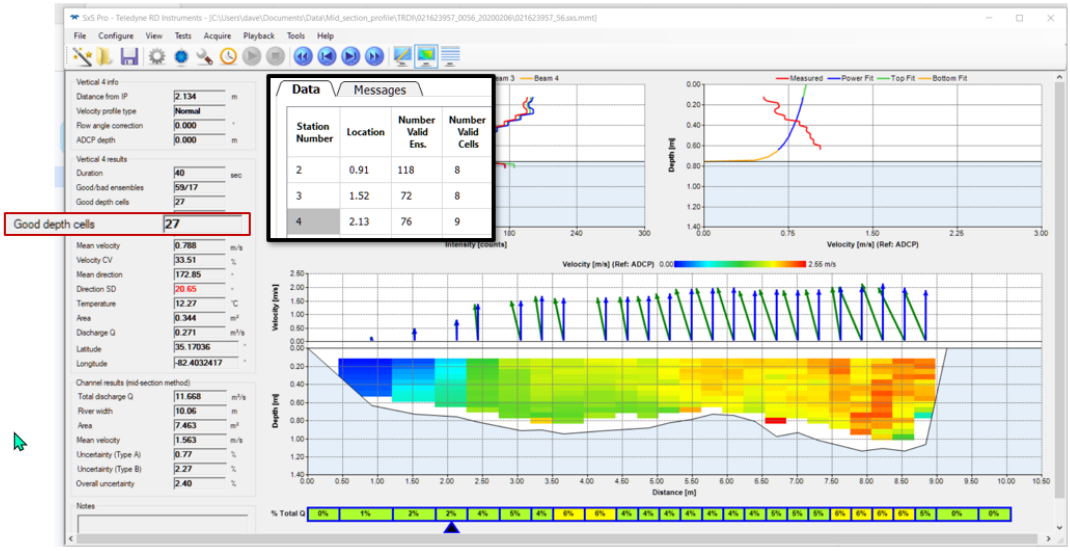
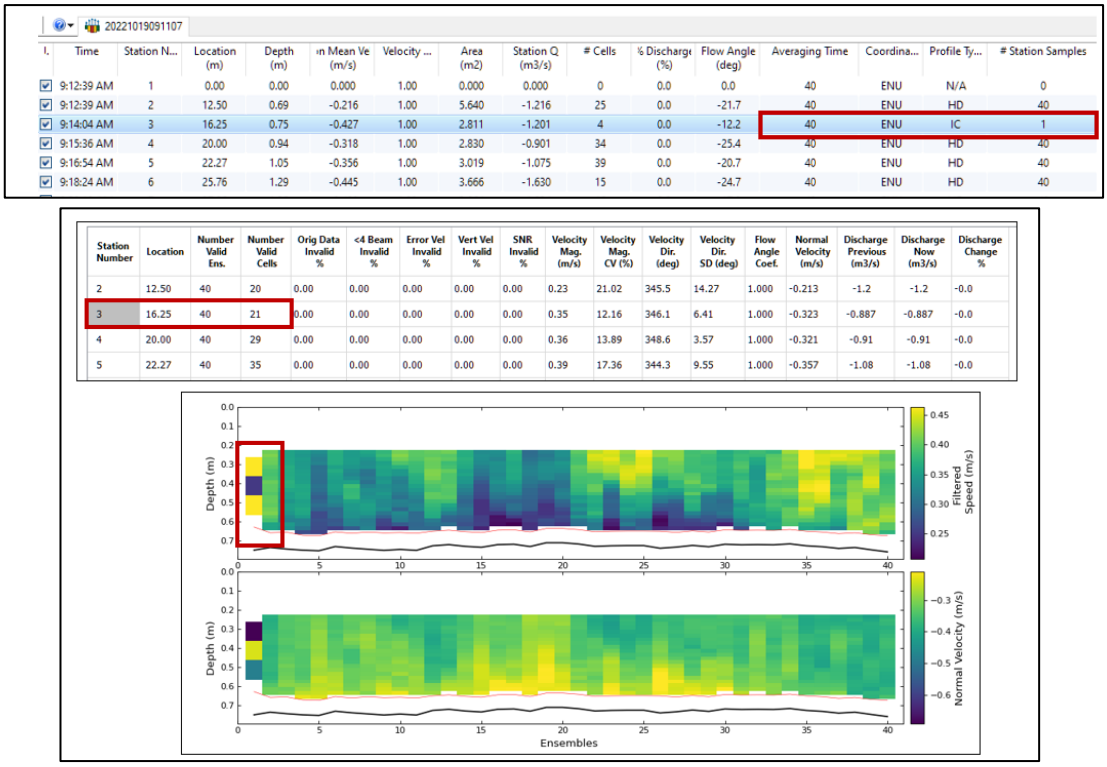


Figure E 4 – Section-by-Section Pro reporting 27 good depth cells, while QRevMS (inset) reported 9.

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 (Figure E 5).



	Time	Station N...	Location (m)	Depth (m)	›n Mean Ve (m/s)	Velocity ...	Area (m2)	Station Q (m3/s)	# Cells	% 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 E 5 – 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 vertical's 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.

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 E 6 – An explanation of the no-slip method from the Section-by-Section Pro User's Guide.

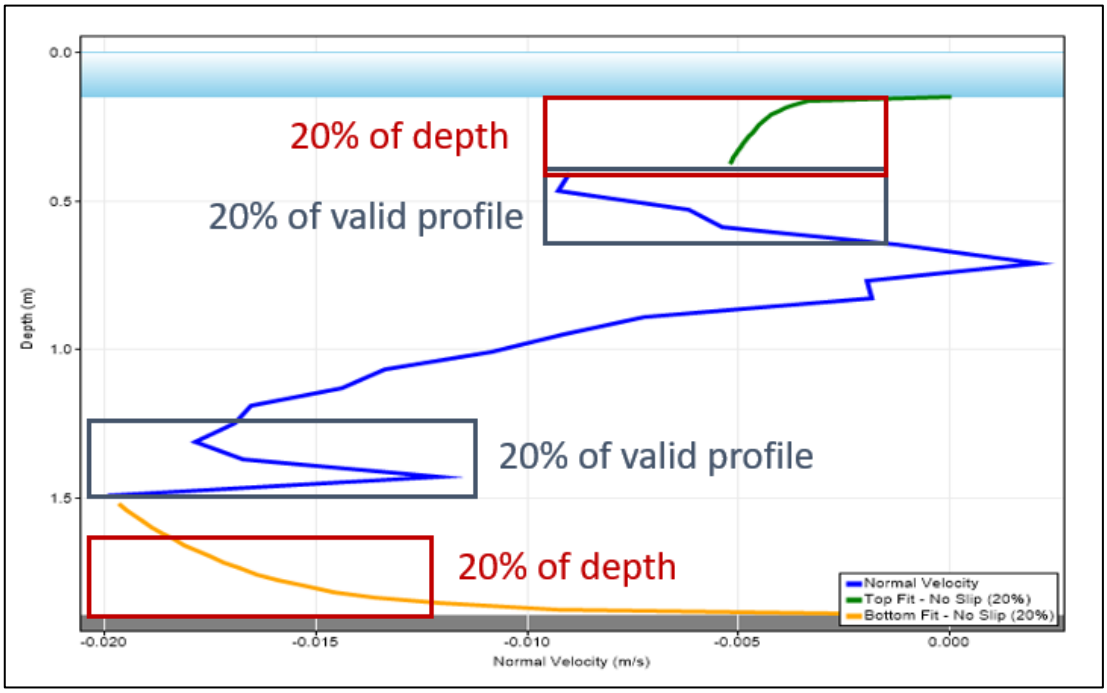


Figure E 7 – Diagram illustrating the difference between 20% of depth and 20% of valid profile.

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 (Figure E 8).

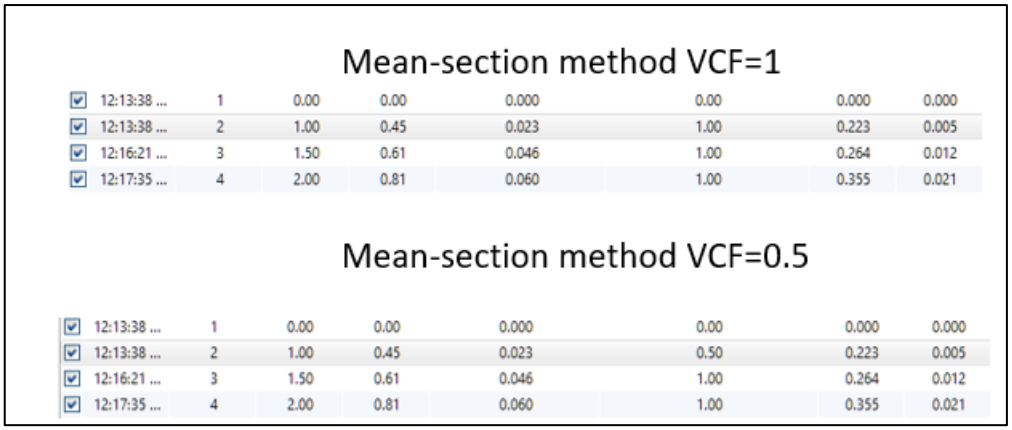


Figure E 8 – Illustration of the lack of effect of changing the velocity correction factor of the edge discharge for a mean-section measurement in RiverSurveyor Stationary Live.

What QRev does to solve these problems

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 apply consistent algorithms for the computation of discharge independent of the manufacturer of the ADCP (or Flowtracker 1 & 2 ADVs). 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 ADCPs and Flowtracker instruments:

- automatic quality assurance checks
- automated filtering of data based on statistical properties
- access to view the ensemble data used to compute the average profile for a vertical
- automatic extrapolation settings for each vertical
- computational methods consistent with ISO 748:2021 *Measurement of liquid flow in open channels*
- user modification of velocity correction factor at edge for mid-section measurements
- user modification of edge coefficient at edge for mean-section measurements, and
- traditional use of velocity correction factor.

And additionally, for ADCPs QRevMS provides:

- 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 averaging and the resolution is representative of the data collected, and
- 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.

The interface is designed for the user to work from left to right along the major tabs. 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 QRevMS easier to use on a touchscreen 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.

Accessing, updating and documenting QRevMS

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.

‘Tricks’ of usage

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 – Salt Dilution Method Metadata

The following table identifies the minimum metadata required for the salt dilution method of discharge measurement. Some of this metadata is required as input into the SUNY software, which calculates the discharge and uncertainty associated with the measurement.

Checklist

Instrumentation				
Sensor ID:	Make:	Model:	Serial:	Metadata
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 _____ ºC Manual reading _____ ºC	Temp verified < 6 months Date: _____		

Tracer data			
Maker:	Brand:	Lot #:	Metadata
Tracer composition	Is salt tracer of food-grade quality?		Y☐ / N☐
Tracer weight	Scale recently calibrated (<1 year)? Scale calibration date: _____ Measured to _____ % or +/- _____ g		Y☐ / N☐
Tracer volume (relative concentration method)	Measured with _____ rated to +/- _____ ml		

Field Procedures for Determining Channel Reach Properties			
Stream:	Stage (m):	Date:	Metadata
Mixing reach properties	Pictures: ☐ _____		
	Are there additional water inputs (streams, ditches, groundwater) within the measurement reach? Describe: _____ _____		Y☐ / N☐
	Do the channel characteristics facilitate lateral mixing and enhance turbulence at the stage measured? Describe: _____ _____		Y☐ / N☐
	Is substantial storage, pool volumes and re-circulating present within the channel Describe: _____ _____		Y☐ / N☐
	Does the channel contain any vegetation or other features that could affect the storage and release of the tracer? Describe: _____ _____		Y☐ / N☐
	Are there at least two constrictions or other mixing features to promote lateral mixing? Describe: _____ _____		Y☐ / N☐
Injection point properties	Pictures: ☐ _____		
	Is the injection point 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:_____		
	Pictures: ☐ _____		

Measurement point properties and sensor placement - constant rate	Were all measurement points located in areas lacking back eddies, recirculating flow and aeration: Describe all locations measured and approximate distances from injection point _____ _____ _____ 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	Y☐ / N☐ Y☐ / N☐

Field Procedures	Run #		
Stream:	Stage:	Date:	Metadata
Tracer dose: general	Are permissions or consents required? Are any sensitive species present? Was dosing designed to meet the requirements of the local consenting authority?		Y☐ / N☐ Y☐ / N☐ Y☐ / N☐
Tracer dose: mass balance method	Estimated flow _____ m^3/sec Estimated flow(2) _____ m^3/sec Dose ratio _____ kg/m^3/sec Mass injected _____ kg		
Tracer dose: relative concentration method (salt in solution)	Batch # _____ Estimated flow _____ m^3/sec Estimated flow(2) _____ m^3/sec Solution concentration _____kg /____ L Dose ratio _____L/m^3/sec Volume injected _____L		
Tracer dose: relative concentration method (constant rate)	Batch # _____ Estimated flow _____ m^3/sec Estimated flow2 _____ m^3/sec Dose _____ L/m^3/sec Solution Concentration ____kg / ____ L Injection 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 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 measured stream temperatures >2°C and electrical conductivities >3 µS/cm?	Y☐ / N☐
Background EC_T sensor (*optional if data correction method applied*)	Placed above injection point or measured above point of injection before and after salt run?	Y☐ / N☐
Measurement sensor(s) placement	See *Channel Reach Properties* 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:	Metadata
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/s, Probe 2_____ m^3/s Probe 3 _____ m^3/s, Probe 4_____ m^3/s		Y☐ / N☐
	Is the % difference between sensors (per run) >7% ?		Y☐ / N☐
Number of salt runs per discharge measurement	Were two or more runs used per derived discharge value? Run 1 _____ m^3/s, Run 2_____ m^3/s Run 3_____ m^3/s, Run 4 _____ m^3/s		Y☐ / N☐
	Is the % difference between the runs > 7%?		Y☐ / N☐

Annex G – Example Salt Dilution Gauging Form

Site. No. ..... Form GADCP201902005

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 Mariotte vessel

Measuring sensors: Sommer/QiQuac/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 .....°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 >0.99007 **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 .....°C
Salinity (saline water only) ..... ppt / mg/l
Turbidity ..... NTU / other

Annex H – Surface Velocimetry Method (Handheld SVR): Calculation of Cross-Sectional Area and Discharge

This annex provides a worked example of how to calculate the cross-sectional area of a waterway

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.

An SVR gauging is comprised of two transects. Each transect is comprised of alternate halves of the 20 measurement points (less measurement points are used for smaller rivers or under flood conditions): 10 evenly spaced measurements moving in one direction across the bridge, then the alternative 10 evenly spaced interspersed measurements moving in the other direction (Figure H 1). 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.

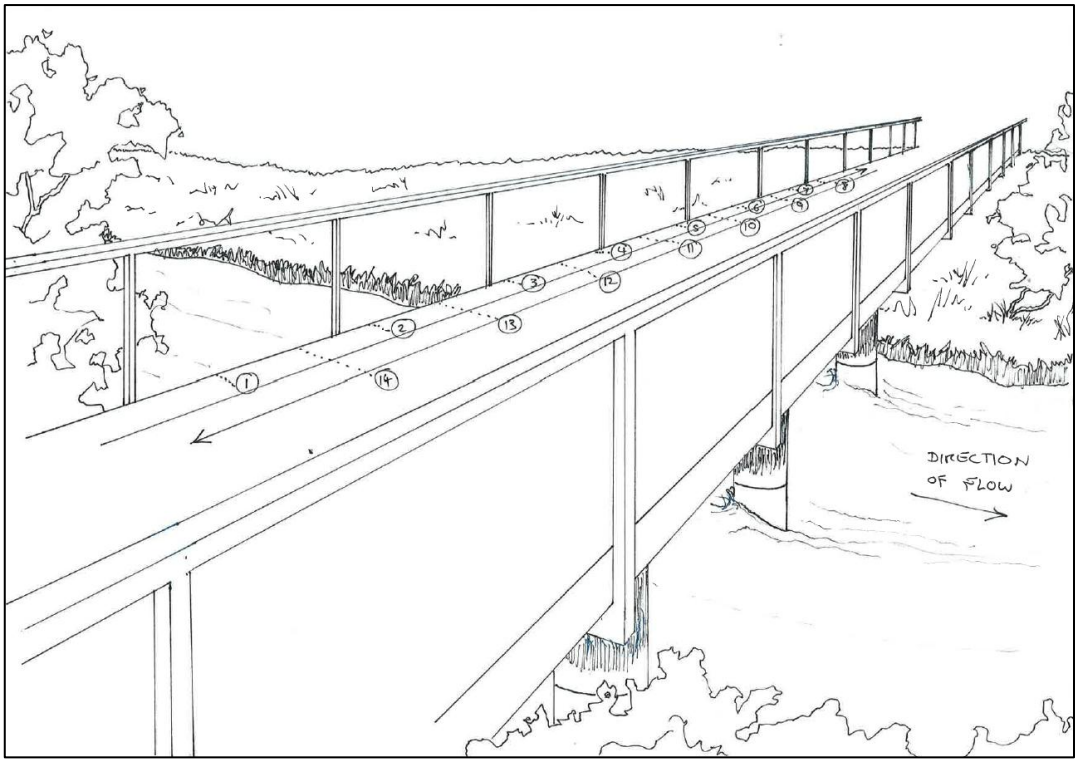


Figure H 1 – Interspersed velocity observation points along a bridge for an SVR gauging. Note, this example shows a smaller river with 14 measurement points – 7 observations in each direction.

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 and then subtracting this distance from the known bridge datum RL. For example, if the bridge datum RL is 12.291 m and the distance from the bridge datum point to the water surface is 3.142 m:

$$\text{RL of water surface} = 12.291 - 3.142 = 9.149 \text{ m}$$

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. Continuing the previous example, if the reduced level of the bed (from cross-section survey) is 8.486 m:

$$\text{Depth of water} = 9.149 - 8.486 = 0.663 \text{ m}$$

See the bridge cross-section shown in Figure H 2.

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. The example cross-section in Figure H 2 is tabulated in Table H 1.

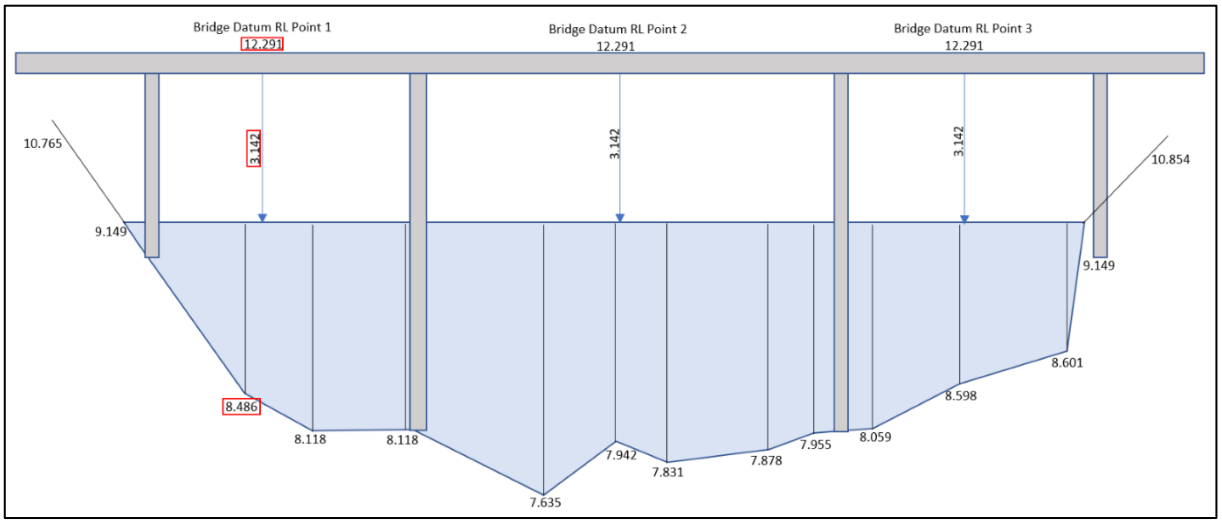


Figure H 2 – Example bridge cross-section with bed elevation.

The above cross-section is tabulated below in Table H 1.

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

Distance (m)	Bed RL (m)
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 the following section. This method uses the NIWA Surface Velocimetry Discharge Calculator available on the NEMS website 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 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.

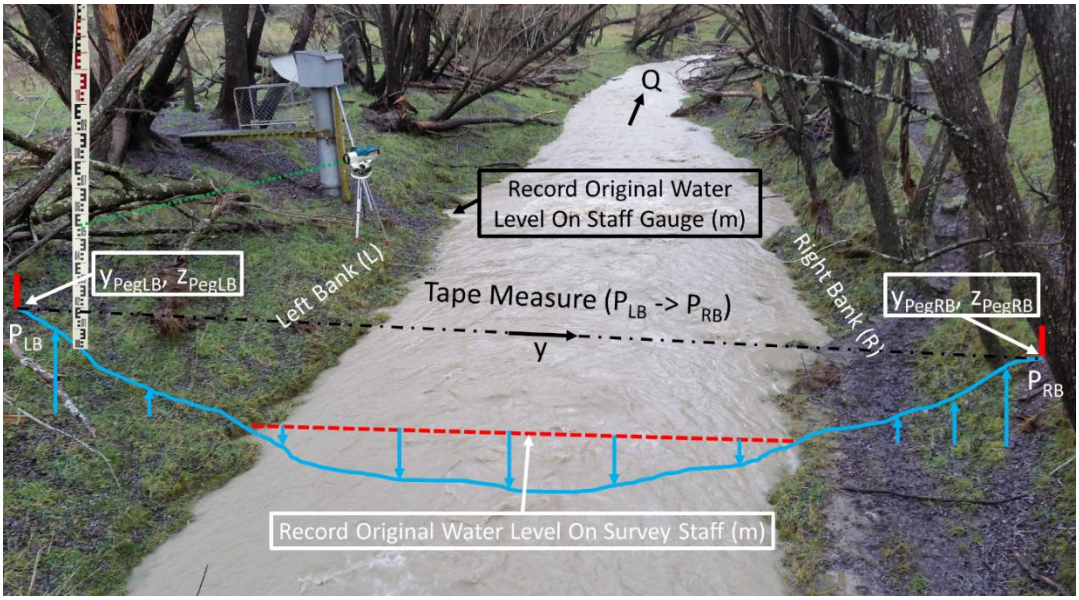
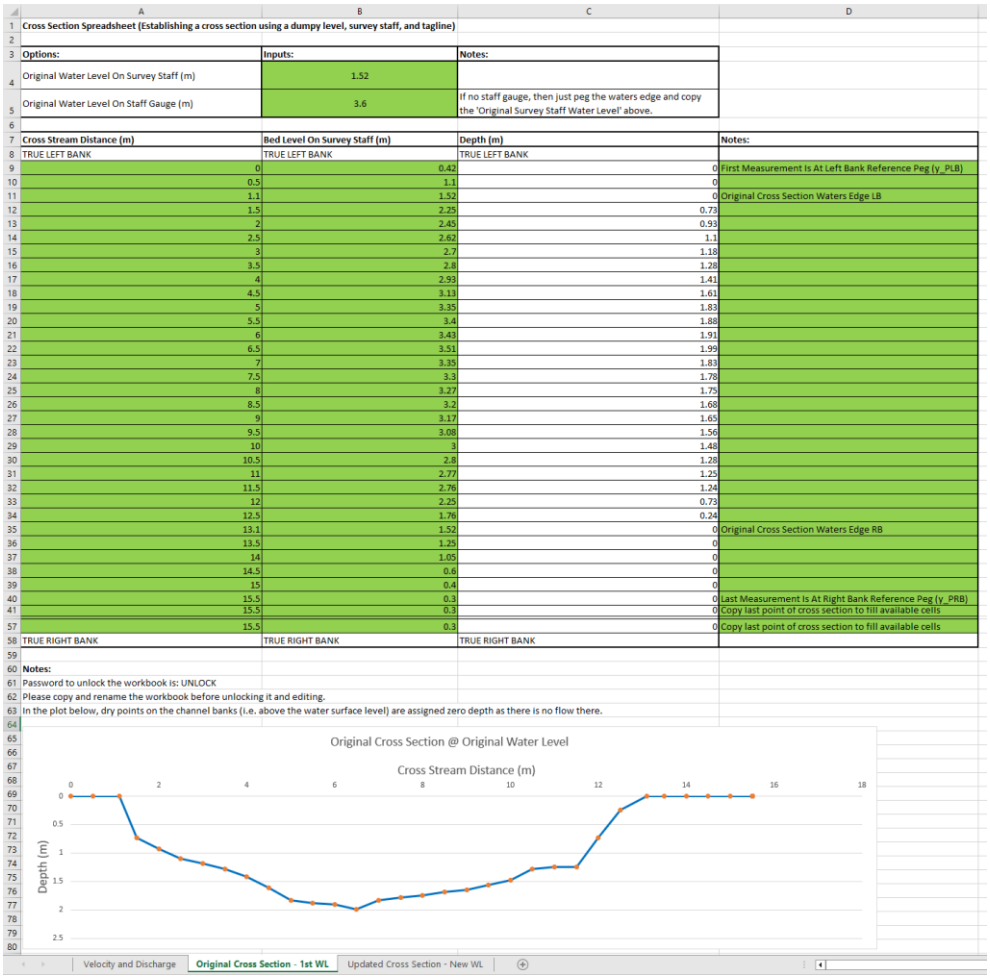


Figure H 3 – Cross-section measurement using a dumpy level, survey staff and tag line (or tape measure).

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	

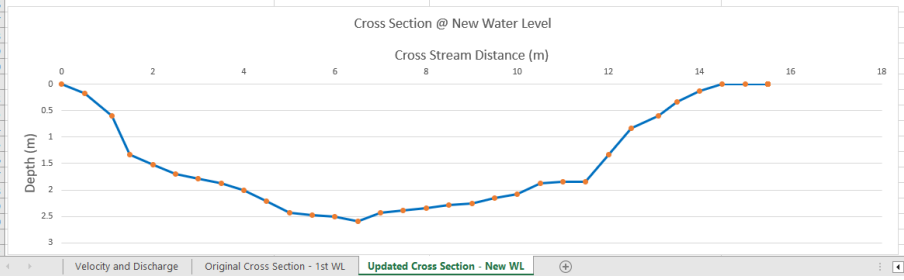
Notes:
Password to unlock the workbook is: UNLOCK
Please copy and rename the workbook before unlocking it and editing.
In the plot below, dry points on the channel banks (i.e. above the water surface level) are assigned zero depth as there is no flow there.

Velocity and Discharge | Original Cross Section - 1st WL | Updated Cross Section - New WL

Figure H 4 – Example cross-section spreadsheet.

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.

	A	B	C	D
1	**Options:**		**Notes:**	
2	Option to use	Option 1	Type: "Option 1" or "Option 2"	
3	Option 1: New Water Level On Staff Gauge (m)	4.2		
4	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)	
5	Calculated Water Level On Original Survey Staff (m)	0.92	Lower values on the original survey staff are deeper (less distance to waters surface)	
6				
7	**Cross Stream Distance (m)**	**Bed Level On Survey Staff (m)**	**Depth (m)**	**Notes:**
8	TRUE LEFT BANK	TRUE LEFT BANK	TRUE LEFT BANK	
9	0	0.42	0	First Measurement Is At Left Bank Reference Peg (y_PLB)
10	0.5	1.1	0.18	
11	1.1	1.52	0.6	Original Cross Section Waters Edge LB
12	1.5	2.25	1.33	
13	2	2.45	1.53	
14	2.5	2.62	1.7	
15	3	2.7	1.78	
16	3.5	2.8	1.88	
17	4	2.93	2.01	
18	4.5	3.13	2.21	
19	5	3.35	2.43	
20	5.5	3.4	2.48	
21	6	3.43	2.51	
22	6.5	3.51	2.59	
23	7	3.35	2.43	
24	7.5	3.3	2.38	
25	8	3.27	2.35	
26	8.5	3.2	2.28	
27	9	3.17	2.25	
28	9.5	3.08	2.16	
29	10	3	2.08	
30	10.5	2.8	1.88	
31	11	2.77	1.85	
32	11.5	2.76	1.84	
33	12	2.25	1.33	
34	12.5	1.76	0.84	
35	13.1	1.52	0.6	Original Cross Section Waters Edge RB
36	13.5	1.25	0.33	
37	14	1.05	0.13	
38	14.5	0.6	0	
39	15	0.4	0	
40	15.5	0.3	0	Last Measurement Is At Right Bank Reference Peg (y_PRB)
41	15.5	0.3	0	Copy last point of cross section to fill available cells
57	15.5	0.3	0	Copy last point of cross section to fill available cells
58	TRUE RIGHT BANK	TRUE RIGHT BANK	TRUE RIGHT BANK	
59				
60	**Notes:**			
61	Password to unlock the workbook is: UNLOCK			
62	Please copy and rename the workbook before unlocking it and editing.			
63	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.			
64	This plot shows the cross section at the new water level, which will be used in the 'Velocity and Discharge' calculations.			



Velocity and Discharge | Original Cross Section - 1st WL | Updated Cross Section - New WL

Figure H 5 – Updating cross-section measurements with a new water level 'Updated Cross-section – New WL' tab. Green shading 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 at Earth Sciences New Zealand if you require modification of this tool.

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 instrument 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 upstream (preferably), directly perpendicular to the cross-section.



Figure H 6 – A radar gun at 45-degree vertical angle (LHS) and velocity reading of 1.2 m/s (RHS).

The horizontal angle should be set to 0 degrees in all cases and the device held at a vertical angle of 45° +/- 10°.

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 alpha, the correction coefficient to convert from surface velocity to depth-averaged velocity,
- u_n is 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:

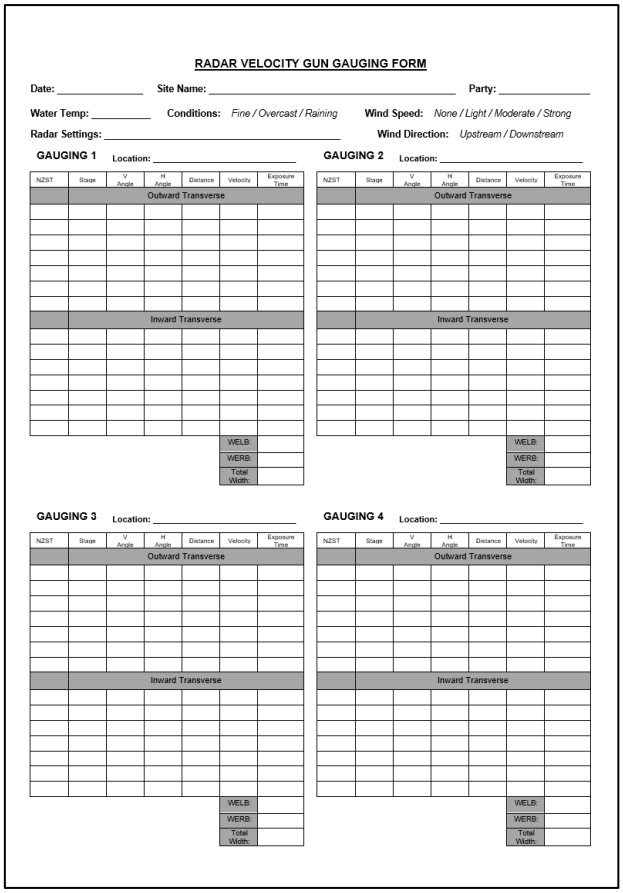
https://www.nems.org.nz/tools/niwa-surface-velocimetry-discharge-calculator

This discharge calculator enables cross-sections 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, and
- area bins 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 6.



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 H 7 – Radar Velocity Gauging Form

Setting up the radar gun (SVR)

Options menu

Press the MENU key and then 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.

Table H 2 – Radar gun settings.

Menu item	Preferred setting		Range	Description
Sensitivity	4		1 to 4	4 is sensitive (reduced measuring range)

				2,3 sets gun to a medium range
				1 is 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 is 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 WERB 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 obtain a minimum exposure time of 40 seconds for each measurement.

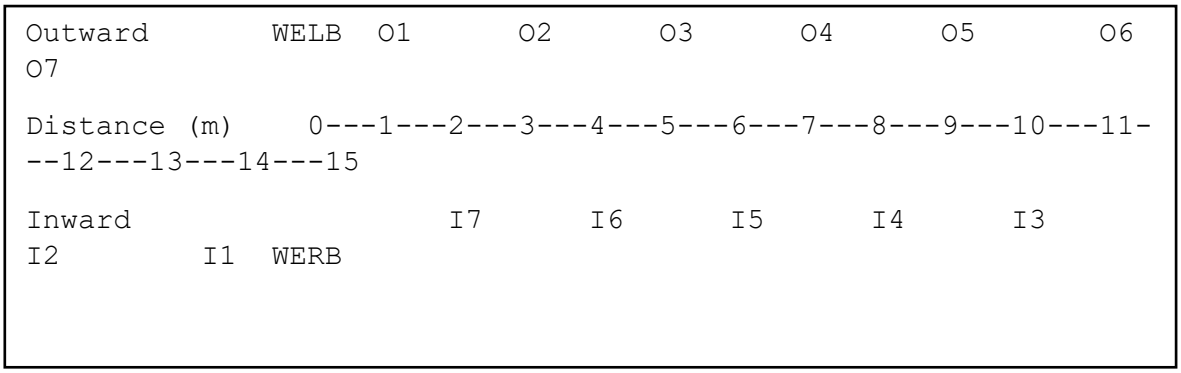


Figure H 8 – Example transect for an SVR measurement.

Set up angle

Press MENU until ANGLE is displayed. This will change as you TILT the gun. Set for 45° (45° preferred but +/- 10° is acceptable). Lock gun in place. Write down the 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

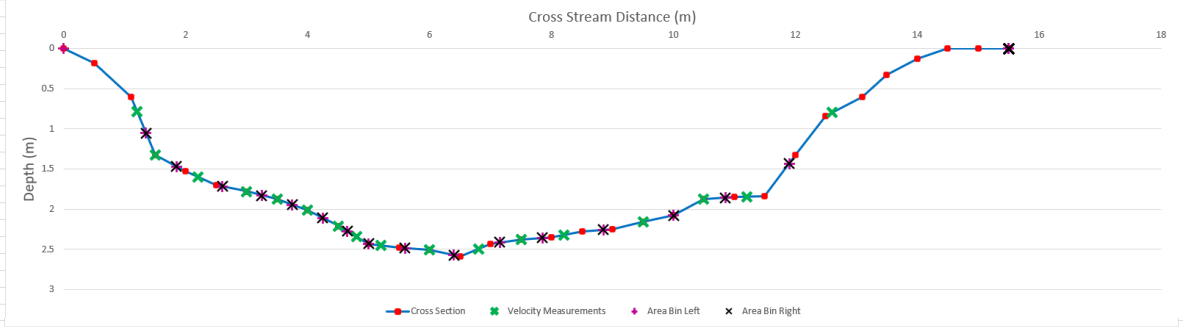
Pressing and releasing the trigger initiates Measurement Mode. The time is displayed in the top right and should start to increase. The velocity is displayed on the bottom right.

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 to re-initiate Measurement Mode.

	A	B	C	D	E	F
1	**NIWA Surface Velocimetry Discharge Calculator**					
2						
3	**Options:**		**Notes:**			
4	Cross Section Water Level To Use	New WL	Type: "Original WL" or "New WL"			
5						
6	**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:**
7	TRUE LEFT BANK	TRUE LEFT BANK			TRUE LEFT BANK	
8	1.2	0.1	0.857	0.48603125	0.041652878	
9	1.5	0.15	0.857	0.66896875	0.085995933	
10	2.2	0.22	0.857	1.2033	0.226870182	
11	3	0.32	0.857	1.15045	0.315499408	
12	3.5	0.45	0.857	0.941875	0.363234094	
13	4	0.58	0.857	1.009375	0.501719938	
14	4.5	0.65	0.857	0.87645	0.488226473	
15	4.8	0.68	0.857	0.82355	0.479931998	
16	5.2	0.62	0.857	1.4758	0.784151572	
17	6	0.58	0.857	2.016	1.00207296	
18	6.8	0.52	0.857	1.876575	0.836276883	
19	7.5	0.45	0.857	1.66845	0.643437742	
20	8.2	0.35	0.857	2.305	0.69138475	
21	9.5	0.25	0.857	2.500675	0.535769619	
22	10.5	0.15	0.857	1.644325	0.211377979	
23	11.2	0.05	0.857	1.855075	0.079489964	
24	12.6	0.03	0.857	1.4461	0.037179231	
25		0	0.857	0	0	
26		0	0.857	0	0	
47		0	0.857	0	0	
48	TRUE RIGHT BANK	TRUE RIGHT BANK			TRUE RIGHT BANK	
49						
50	**Total Discharge (m^3/s):**	**7.324271602**				
51						
52	**Notes on calculations:**					
53	Surface velocity measurement locations can be irregularly spaced.					
54	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.					
55	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.					
56	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.					
57	Password to unlock the workbook is: UNLOCK					
58	Please copy and rename the workbook before unlocking it and editing.					



Velocity and Discharge | Original Cross Section - 1st WL | Updated Cross Section - New WL

Figure H 9 – 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 shading 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 at Earth Sciences New Zealand.

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 to 9 m/s.

Note: This instrument is designed for velocities above 1 m/s, and accuracy falls away rapidly at velocities less than 1 m/s or, when velocities exceed 9 m/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, decrease in gauging times and increase in 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 are decoded and buffered by the POEM Interface, ready for RS232 transmission to a PC or datalogger.

Plots of rapid, instantaneous depth/velocity data as measured by the POEM show scatter caused by flow turbulence (Figure I 1). 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. The software output example (Figure I 2) shows the individual verticals and overall results of area, mean velocity and discharge.

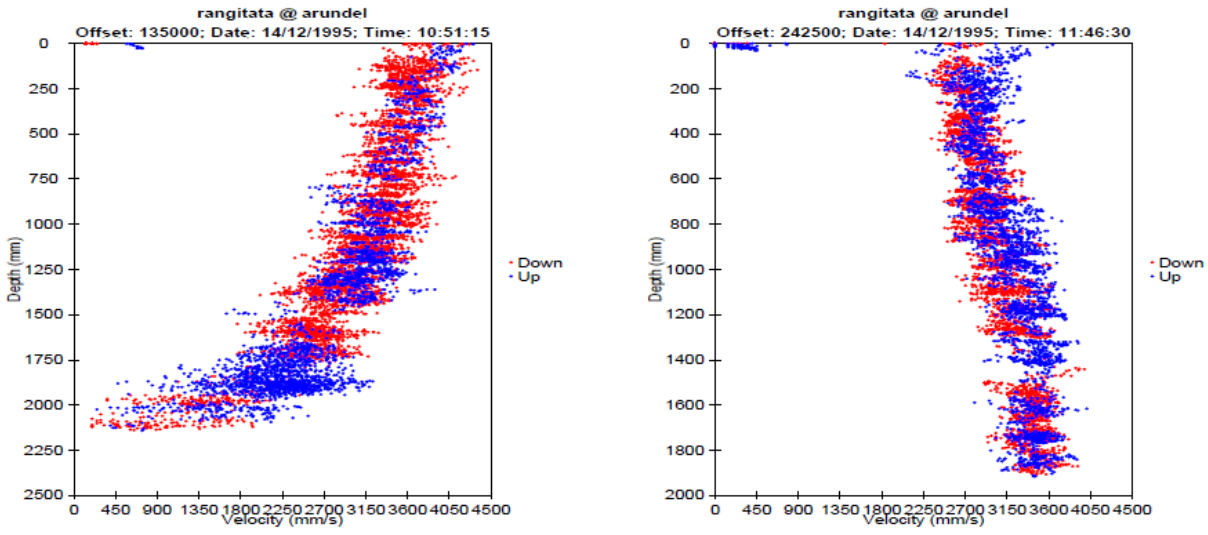
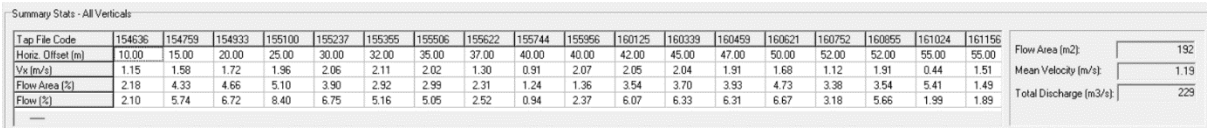


Figure I 1 – Example of POEM depth / velocity data.



Summary Stats - All Verticals

Tap File Code	154636	154759	154933	155100	155237	155395	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

Figure I 2 – Example POEM output

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 Velocity-Area Stationary Meter Method Matrix provided in Annex C.

In the absence of calibration within 24 months, the maximum quality code achievable is QC 200.

Annex J – 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 $V_{\text{mb}}/V_{\text{w}}$ ratio is greater than 0.01

where V_{w} is the mean water velocity.

Then calculate the area of section with moving bed:

A_{mb} (usually) = Total Area – Right Area – Left Area

Note: How you calculate the area of section (A_{mb})will depend on the section and what you know about the flow.

Then:

$$Q_{\text{corrected}} = Q_{\text{measured}} + (V_{\text{mb}} \text{ x } A_{\text{mb}})$$

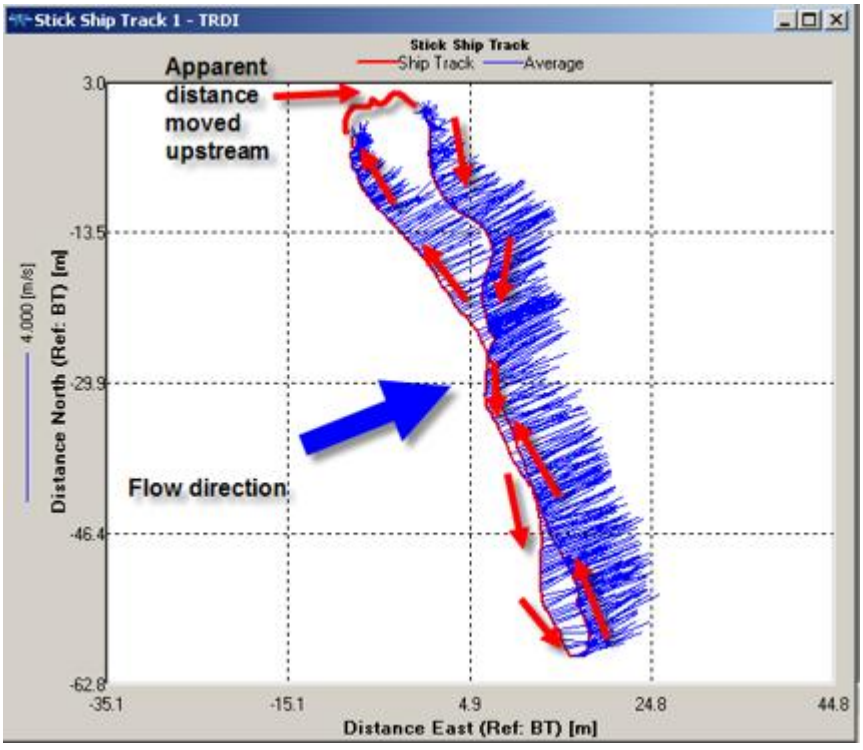


Figure J 1 – Example of a loop moving bed test with a distorted ship track caused by a moving bed. Distance moved upstream = 8.1 m, duration = 275 s, average moving bed velocity = 0.029 m/s.
Illustrator: Andrew Willsman

Carry out a series of normal measurements and calculate the 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.

Annex K – Open Channel Flow Measurement Method Codes

The Method Codes for the gauging methods and instruments that are used in New Zealand are shown in Table K 1.

Table K 1 – Method Codes for gauging instruments and 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			
Surface Velocimetry Methods *(Radars)*			**Fixed** 60[1]	**Handheld** 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. (For example, 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).*