National Environmental Monitoring Standard

Processing of Environmental Time-series Data

Version 1.0.0

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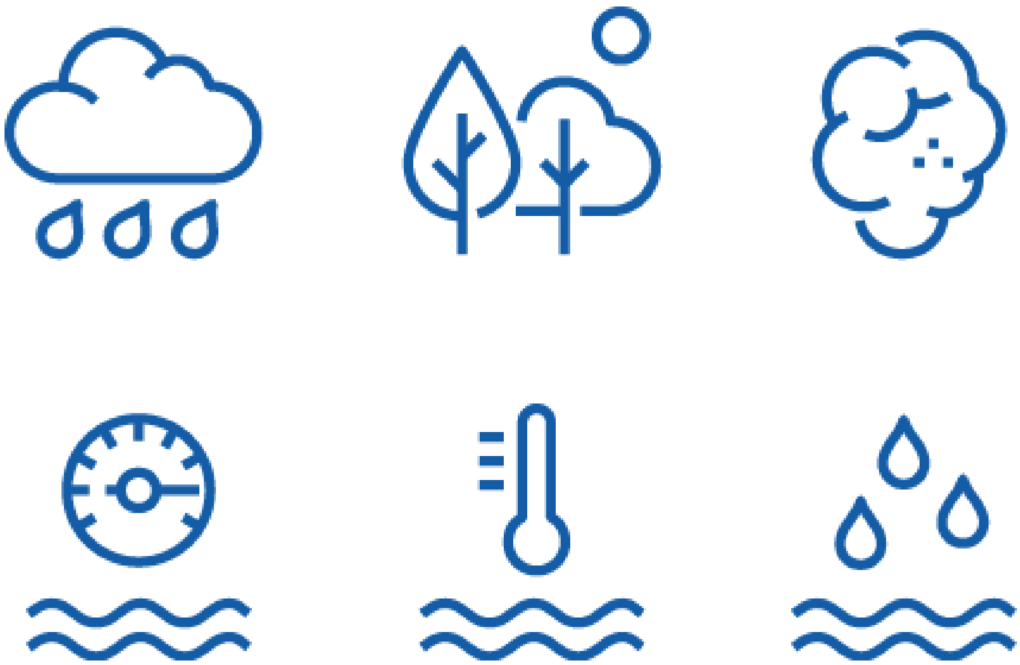

The National Environmental Monitoring Standards

The current suite of National Environmental Monitoring Standards (NEMS) documents, Best Practice Guidelines, Glossary and Quality Code Schema can be found at www.NEMS.org.nz.

Implementation

When implementing this Standard, current legislation relating to health and safety in New Zealand and subsequent amendments and the NEMS Best Practice Guidelines shall be complied with.

Limitations

It is assumed that as a minimum, the reader of these documents has undertaken industry-based training and has a basic understanding of environmental monitoring techniques. Instructions for manufacturer-specific instrumentation and methodologies are not included in this document.

The information contained in these NEMS documents relies upon material and data derived from a number of third-party sources including the World Meteorological Organization's Guide to Hydrological Practices (WMO, 2008) and technical manuals of the various contributing agencies in New Zealand.

The documents do not relieve the user (or a person on whose behalf it is 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 this document has been or is to be applied.

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Development

The National Environmental Monitoring Standards (NEMS) Steering Group has prepared a series of environmental monitoring standards on authority from the regional chief executive officers (RCEOs) and the Ministry for the Environment (MfE).

The NEMS initiative has been led and supported by the Local Authority Environmental Monitoring Group (LAEMG), now known as the Environmental Data Special Interest Group (ED SIG), to assist in ensuring the consistency in the application of work practices specific to environmental monitoring and data acquisition throughout New Zealand.

The strategy that led to the development of these Standards was established by Jeff Watson (Chair) and Rob Christie (Project Manager), and the current Steering Group comprises Phillip Downes, Martin Doyle, Michael Ede, Glenn Ellery, Jon Marks, Charles Pearson, Jochen Schmidt, Abi Loughnan, Ged Shirley, and Raelene Mercer (Project Manager).

The development of this Standard involved consultation with regional and unitary councils across New Zealand, industry representatives and the National Institute for Water and Atmospheric Research Ltd (NIWA).

These agencies are responsible for the majority of continuous environmental-related measurements within New Zealand. It is recommended that these Standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately to facilitate data sharing. The degree of rigour with which the Standards and associated best practice may be applied will depend on the quality of data sought.

This document was prepared by Marianne Watson (Hydronet Ltd), with project oversight by Jon Marks (NEMS Steering Group representative), building on the earlier work of John Fenwick and previous working group members Mike Gordon, Brent Watson, Peter Stevenson, and Nicholas Holwerda. The input of NEMS Steering Group members, lead writers of other NEMS documents, Regional and District Council staff working with data, and industry irrigation specialists is gratefully acknowledged.

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- National Institute of Water and Atmospheric Research Ltd (NIWA)
- Ministry of Business, Innovation and Employment – Science and Innovation Group
- GNS Science
- Genesis Energy
- StatisticsNZ
- Contact Energy
- Meridian Energy
- Mercury New Zealand Limited

Review

This document will be assessed for review by the NEMS Steering Group within one year of its release and thereafter will be assessed for review approximately once every two years. Further details on the review process can be found at www.nems.org.nz.

Control Table

Section	Topic	Revision summary	Carried out by	Date
		Version 1.0.0 release	Lead writer	Jul 2022

Table of Contents

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*

and any additional normative references specific to the measured variable as listed in the Annex for that variable.

About this Standard

Introduction

Time-series data are collected from field measurements and instrumentation in order to quantify temporal and spatial variations in environmental phenomena. Following recording on some medium, whether on paper and/or an electronic digital device, time-series data are converted to a form suitable for archiving and retrieval. In addition, data undergo a range of checks to determine their accuracy and reliability, and may be corrected, edited or adjusted to improve their useability. Data processing in environmental monitoring refers to the quality control procedures that time-series data are subjected to before they can be stored and made available for analysis. Data processing is therefore a significant intermediate task between data collection and delivery of verified data for use.

This document sets out an overall process that includes the types of data and issues that may be encountered, the necessary and recommended quality control actions, and the types of operations that might need to be applied to the data. However, the various time-series management systems in use in New Zealand differ in their structure, implementation, available tools, and application and operation of those tools; therefore, for data processing to be efficient and effective at an organisational level, data producers must know how their system is configured, how it works, and how to use it.

Objective

The objective of this Standard is to ensure that environmental time-series data, and their associated metadata, are processed and stored in a consistent way to facilitate regional and national analyses. This document is made up of two parts. The first part describes the generic requirements and methods for processing environmental time-series data. The second part is a series of Annexes (which will be added to over time) describing procedures specific to particular variables.

Scope

This Standard applies to the processing of environmental time-series data before they are permanently stored in, and made available for analysis from, a recognised time-series management system (TSM). It includes common data types, methods of quality control, data editing techniques, and requirements for associated metadata.

The environmental time series covered by this Standard include at-point numeric time series, vector data for wind, and 'less than' or 'greater than' censored time-series data.

This Standard recognises that data may be used in near real-time with minimal and/or some automated processing, and that automated quality control and editing of data intended for permanent archiving is desired and becoming more prevalent.

Scope Exclusions

For the purposes of this document, data processing does not include analyses of the data, except where analysis is required for quality control.

Two and three-dimensional time series (e.g. time series of cross-sections or lake profiles), and non-numeric time series other than censored (< or >) data and metadata, are not covered by this Standard.

Requirements for site and station metadata, including preservation of these records and ensuring their availability as and when required for data processing, are the domain of the relevant normative reference for each variable and are not repeated in this Standard.

A time series may be calculated by transforming the time series of a surrogate variable. An example is a flow series, which is most often obtained from a water level series by applying stage–discharge relationships that are derived from discrete open-channel flow measurements. This document does not cover developing the relationships between surrogate and target variables, or the process of transformation of surrogates, which is usually automatic as the data is accessed. These processes may be covered by other NEMS, for example in the case of flow, NEMS *Rating Curves*.

This Standard is designed for application to environmental data, and it does not address industrial applications (although many of the principles may apply).

About this Version

This document includes a number of annexes that are identified alphabetically, each specific to a variable measured.

When reference is made to an appendix, section, figure, or table in the main document, only the appendix, section, figure, or table number is used in the reference.

When reference is made to a section within an annex its number is prefixed by the Annex letter, although section numbering within the annex does not carry the letter. Appendices to, and figures and tables within the annexes carry the annex letter.

The Standard

Requirements

The following table summarises best practice for environmental time-series data processing, and includes requirements for:

- appropriate storage of data
- documenting and managing data processing procedures
- verifying data collected, including assessing its quality and reliability
- improving usability of the data, as required
- ensuring modifications are necessary, appropriate, and traceable, and
- preserving required forms of the data and its associated metadata.

Note: Modifying data to improve its usability may reduce its quality code because the quality coding schema incorporates data provenance.

Reference in the table, and elsewhere in this Standard, to 'an (or the) organisation' means one or more of the agencies responsible for the recording, collection, verification, processing, and/or archiving of a time series of environmental data.

Data Types	The data type used to store data shall ensure correct representation, interpretation, analysis, and reporting of the measured values. If storing data as censored, an organisation must develop, document, and implement their own protocols if not available elsewhere in NEMS.	Section 1.1
Units of Measurement	Units must conform to requirements of the relevant NEMS normative references. Dates and times shall be fully specified in DMY order to 1-second resolution of a 24-hour clock in Standard Time for New Zealand or the Chatham Islands.	Section 1.2
Management of Data and Processing Systems	An organisation shall establish and implement procedures to achieve the following: • All data records shall be clearly identified with at least the site name/identifier and date and time of the record. • Multiple data streams and/or versions of data for the same variable and period must be uniquely identified, tracked, and managed to ensure integrity is preserved and all data stored are traceable to source.	Section 2 and Section 3

Management of Data and Processing Systems (cont.)	• All verification information must be securely stored, permanently retained, retrievable, and referred to during processing of the time series. • Define and formally document what constitutes the original data for each time-series record, and the source of data to be processed, and the pathways to data publication and final archiving. • Identify periods of data at the various stages of processing, and identify the provenance and status of data, and track timeliness of data processing. • Maintain backups of data in its original (as defined) and subsequent forms.	
Quality Control	Quality control must be applied to all data collected using, but not limited to, the relevant procedures described in this Standard. Records of all quality control inspection and testing must be compiled and retained. Anomalies identified in data must be investigated to establish cause, edited appropriately, and recurrence prevented where possible. Data known to be faulty shall not be archived, other than in an original record. Machine algorithms used for quality control must be documented, changes to them controlled and tracked, and be regularly reviewed with outcomes documented and retained.	Section 3.6 and Annexes
Control of Editing	An organisation shall control the amount and type of editing that can be performed and the authorisation to do so. Editing and adjustments applied must adhere to the principles, procedures and operations described in this Standard. Evidence of modifications to, or discarding of, time-series data or verification information, and justification of these actions, must be recorded	Sections 3.8 and 3.9 Section 4 Section 5 and Annexes Section 6.2

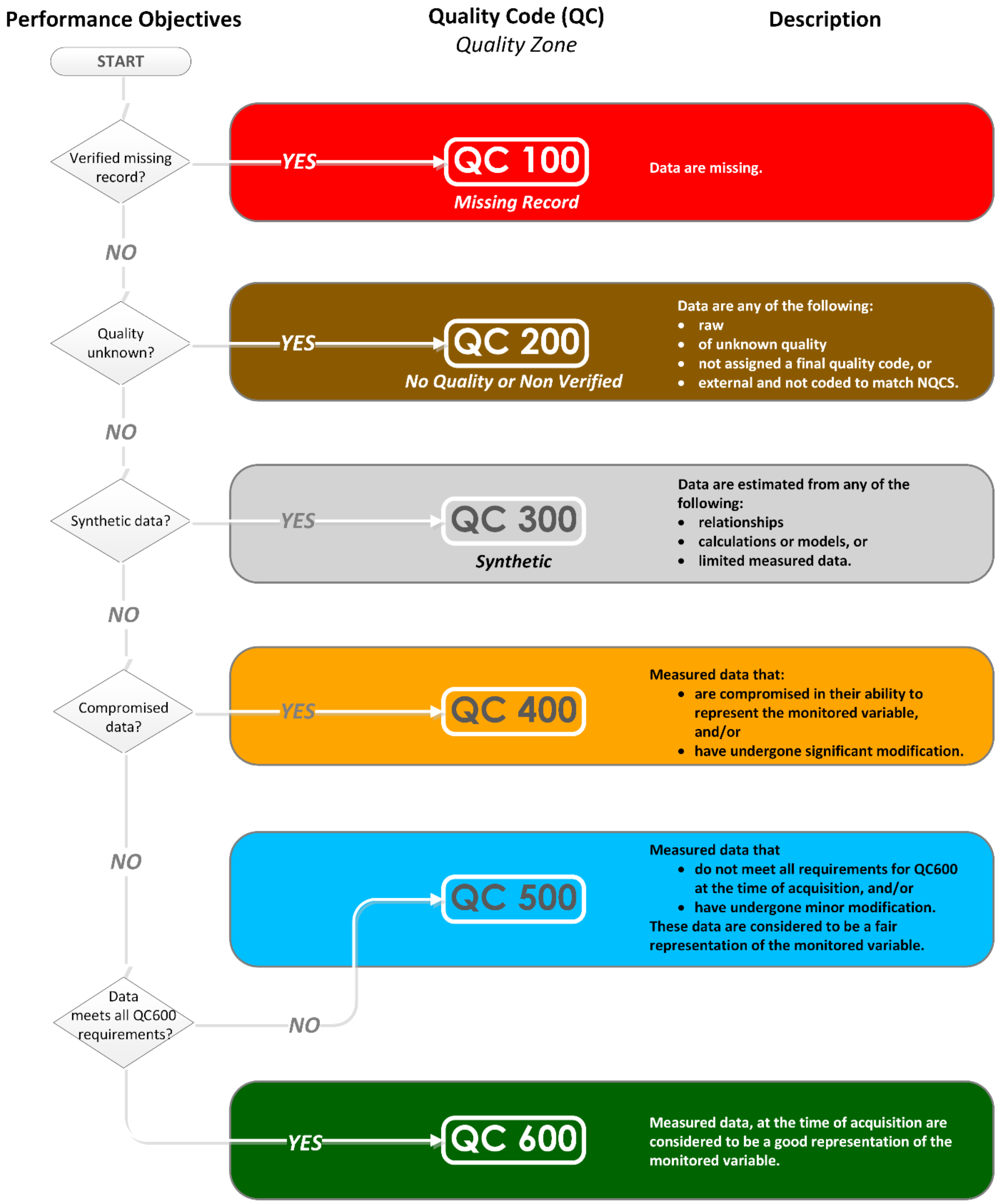
Control of Editing (cont.)	and retained, including those performed in the field or automatically by a data acquisition system.	
Missing Data	Gaps in continuous time series shall be avoided whenever practicable. Gaps shall be closed, marked, or infilled using the most preferred method(s) possible selected from this Standard, as is appropriate for the variable, the duration of the period missing, and the availability of supporting information. Infill with synthetic record is permitted, with some cautions and exclusions, but each period must be identified to data users via a Data Comment and quality code of QC 300.	Section 5.4 and Annexes
Stationarity	All information contributing to assessment of stationarity must be securely stored, permanently retained, and summarised for data users. Stationarity shall be preserved as much as is reasonably practicable. Processing methods and editing actions shall not unduly disturb stationarity already achieved. Any known or suspected changes in stationarity shall be recorded in the metadata.	Section 3.7
Metadata	All required metadata, comprising site and instrument information (site metadata) and time-series metadata, must be created, collected, and/or collated, then verified and permanently archived. Site metadata and data acquisition records relevant to the time series must be readily available when the data are processed. A quality code shall be assigned to all data according to: • the national quality coding schema, and • the normative NEMS for that variable, and • the guidance in this Standard, and • the extent of modifications to the data.	Section 6

Metadata (cont.)	Timestamped and time-bound comments, conforming to the minimum requirements of this Standard, shall be filed to identify the data, and to inform a data user so they may determine the data's fitness for purpose. An organisation shall develop and implement policy to distribute relevant quality codes and comments with the time-series data.	
Quality Review and Audit	All agencies shall implement standard methodologies for quality review and for periodic more formal audit of archived data. All editing, and metadata compiled during processing, shall be routinely peer reviewed prior to archiving using, but not limited to, procedures described in this Standard. Periodic audit of archived data is recommended. A minimum of biennial audit of machine-processed data is required if they were not reviewed prior to archiving by a suitably trained and experienced person. An audit must address, but is not limited to, the minimum requirements set out in this Standard. Information resulting from an audit about reliability, accuracy, and utility of the data shall be collated into a formal report. Further alteration of data that have passed an audit shall be formally controlled.	Section 7
Preservation of Record	An organisation shall develop, maintain, and implement policies, procedures, and systems for the permanent archiving of records, including those needed for traceability of the data, and the assessment of stationarity and fitness for purpose. The following shall be stored, retained indefinitely, and (if electronic) backed up regularly: • original data as defined • final data as verified	Section 8 and Annexes

Preservation of Record (cont.)	• supplementary data • all required metadata • additional time series and/or metadata as specified by an Annex. Physical records that must be retained indefinitely should be stored in conditions suitable for their preservation and efficient retrieval.	

Quality Codes

All data shall be quality coded in accordance with the NEMS *Quality Code Schema*. The schema permits valid comparisons within and across multiple data series. The following flowchart is a generic example from which more specific charts for each variable are derived. Guidance on selecting and applying suitable quality codes during data processing is included in this Standard and the relevant normative references.



1 Environmental Time Series Characteristics

In the context of this Standard, the time-ordered observations forming the time series are of environmental variables such as water level, water temperature, and most of the other variables that make up the suite of National Environmental Monitoring Standards (NEMS).

1.1 Time-series data types

There are several types (kinds) of time-series data. The purpose of these different types is to ensure stored values are correctly interpreted. The types differ by how the data are interpolated (or not interpolated) in the time intervals between stored values, and by what the stored values represent and therefore how the data are to be treated. In other words, the same series of numbers can be stored as any one of a range of data types, but which type determines the information derived from those numbers.

A time series may be one of the following types (OGC, 2016):

- instantaneous (continuous)
- discrete (discontinuous)
- instantaneous (discrete) total
- value in preceding interval, where the value may be:
  - a statistic summarising samples in the interval (usually an average, maximum or minimum), or
  - a constant (e.g. a pump rate), or
  - a total (that is continuous, i.e. interpolating)
- value in succeeding interval, where the value may be:
  - a statistic summarising samples in the interval (usually an average, maximum or minimum), or
  - a constant (a form of 'event' or 'status' data, e.g. a gate setting), or
  - a total (that is continuous, i.e. interpolating).

There are other data types available in many time-series management systems. Most are variations on the above, for example:

- 'quasi-continuous', which plots data as if it were an instantaneous continuous (and therefore interpolating) data type but analyses the data as discrete values
- cumulative totals
- other statistical methods of representing the measured values and/or controlling interpolating between the stored values. These are not discussed further unless relevant within a specific annex to this Standard.

Time-series management software may specify interpolation method separately from data type. This provides more options for data storage but usually, although not exclusively, an individual time series remains restricted to one combination of type and interpolation method that is set when the time-series is defined and does not change during the record.

The data type used to store data must be consistent with how the values in the time series were obtained, what they were intended to represent, and the validity of any interpolation permitted between the stored values.

For example, logged values that are the average of more frequent sampling in the recording interval up to each timestamp, should be stored as type 'average in preceding interval'. These data will then be aggregated as averages and not totals and interpolating at any time between adjacent timestamps will return a value equal to the value stored at the end of the interval, being the average for that interval.

Data may be converted from one data type to another (see Section 4.14).

1.1.1 Instantaneous (continuous)

Instantaneous data are the most common type in environmental monitoring and originate from recorders that take observations at instants (usually regular intervals) of time, e.g. water level measurements at a recording site. The values are intended to represent a continuous signal, i.e. the data are assumed connected and it is valid to interpolate linearly with time between them. Therefore, for the data to be representative of the variable, values need to be collected sufficiently frequently to adequately follow the rate of change in the phenomenon being measured.

1.1.2 Discrete

Discrete data are values that are known, suspected, or assumed to be discontinuous. Interpolation between the stored values is not valid, i.e. no assumptions are made about how the variable behaved between samples. Examples are spot values of water quality variables and measurements of open channel flow (i.e. gaugings).

If the data type is discrete totals, values can be accumulated. An example is rain gauge tip counts where each tipping bucket is assumed to have filled instantly and therefore interpolation between tips is not valid and not supported, but total rainfall in a period can be calculated from the sum of the tips recorded in the period.

1.1.3 Value in preceding interval

If the value stored is the average of more frequent samples in the interval it may be known as histogram data.

The value may also be a constant, such as a rate per unit time (e.g. of a pump), or a total (e.g. rainfall).

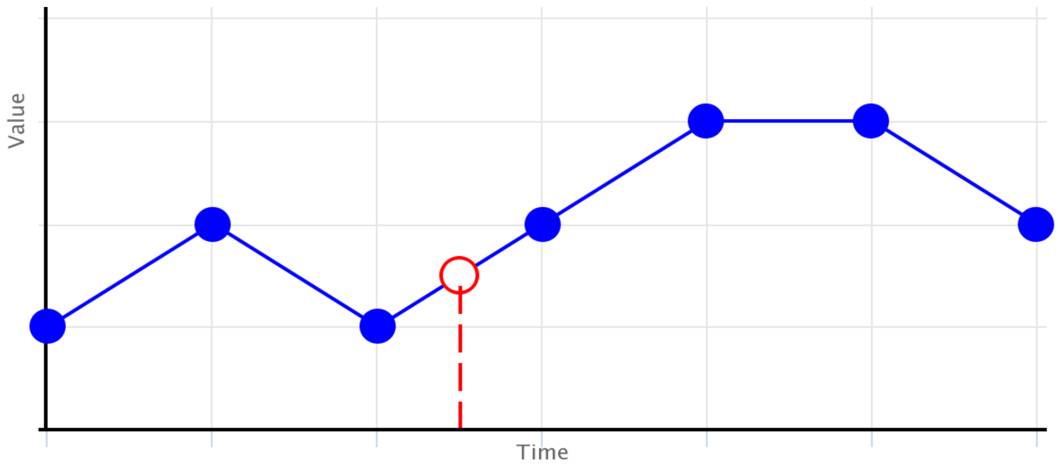


Figure 1 – A depiction of instantaneous time-series data. A value at any time (e.g. the red circle) can be interpolated linearly with time from adjacent recorded values (blue dots).

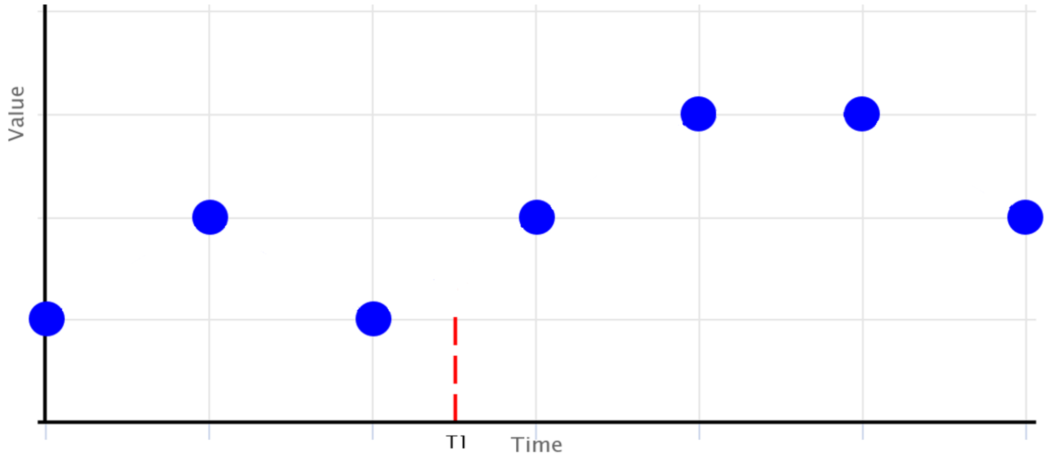


Figure 2 – A depiction of discrete time-series data. Interpolation between values is not valid. Values at times other than those stored (e.g. at T1) cannot be inferred.

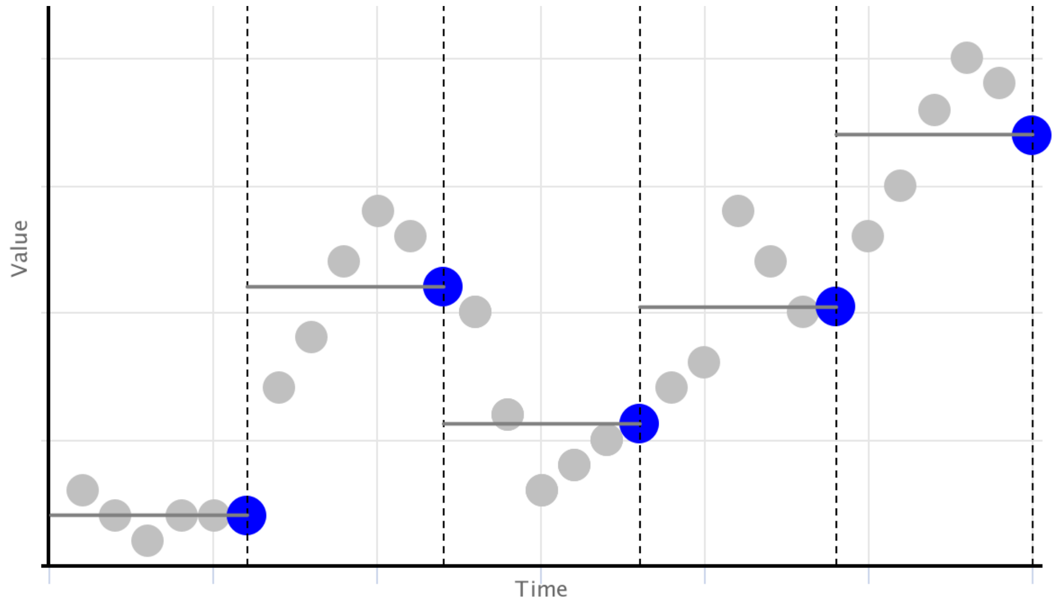


Figure 3 – A depiction of average in preceding interval (histogram) time-series data (blue dots) that are the average of samples (grey dots) within each preceding time interval.

1.1.3.1 Incremental data

Incremental data are values intended to be totalled over any specified period of time. Totals are aggregated for periods spanning multiple recording intervals. Incremental series can be presented using a bar chart (with totals at regular or irregular intervals) or as a cumulative trace.

In New Zealand, data that are incremental refers more specifically to values representing a total in the preceding interval where the interpolation method is continuous and linear. Rainfall data have traditionally been stored this way, whether the rain gauge bucket tips are recorded as they occur or are counted into set (fixed) intervals. Use of a discrete (non-interpolating) incremental data type is rare but should be considered.

The continuous linear interpolation method assumes each stored total has accumulated at a constant rate within the interval, as shown by the dashed lines in Figure 4. Because the data type refers to an interval and the data are intended to be continuous, the end of one interval also sets the start of the next, i.e. the previous timestamp is essential to interpretation of the current value. Any values of zero incorporated into the time series are interpreted as periods of no rain in the preceding interval.

To interpolate values at intermediate times (e.g. the red value in Figure 4), the average rate of accumulation (represented by the dashed line) is used to calculate the portion of the stored total assumed to have accumulated in the new (shorter) interval.

Incremental totals that are continuous and interpolating can be aggregated into multiples of the recording interval (e.g. hourly or daily totals from 15-minute data), or apportioned, by way of the average rate of accumulation, into smaller or different intervals (e.g. from daily totals at midnight to daily totals at 9 a.m.). A total for any period of time is obtained from a combination of aggregation and apportioning.

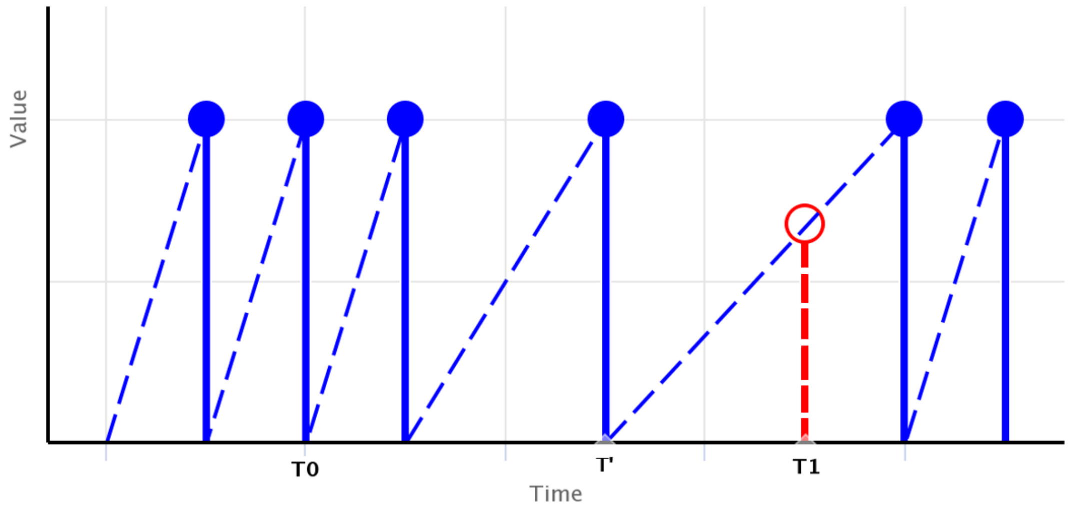


Figure 4 – A depiction of 'total in preceding interval' incremental time-series data (blue dots). Dashed lines show the average rate of accumulation in each interval. Total for the period T0 to T1 is the sum of the value after T0 and the value at T' plus the value interpolated at T1 (red circle).

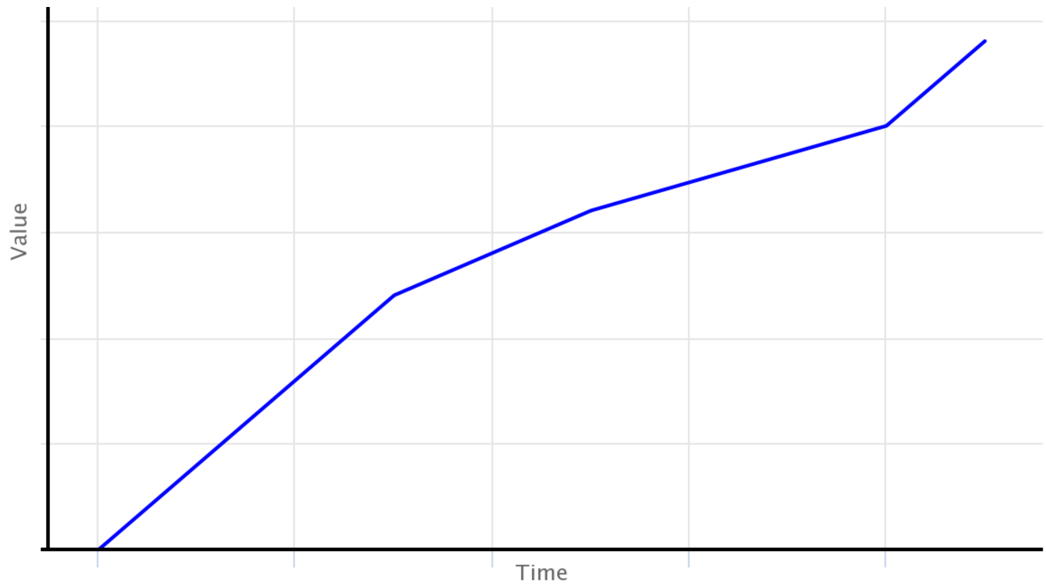


Figure 5 – A depiction of incremental time-series data plotted as a cumulative trace (using the same data as in Figure 4). Slope of the line is the average rate of accumulation in each interval.

1.1.4 Value in succeeding interval

This data type is used when values that represent measurement(s) over intervals of time are stored at the beginning of the interval, rather than at the end.

In some time-series managers the values may be any of the forms available for 'preceding interval' data type (i.e. an average, maximum, total etc.), including choice of interpolation method, but others are more restrictive. Some systems support transformation between the two, either in the database or when reporting from it.

1.1.4.1 Event (step) data

If the value is a constant in the succeeding interval, it may be known as event or step data (not to be confused with event rainfall data; see Appendix B.2).

Event data are only captured at a change of state, and that state expressly remains the same until another change of state is recorded. This means that each event is represented by a single value at the start of each period. Thus, for this type of event data there is no apportioning between data points, as there is for incremental data, nor linear interpolation with time as there is for instantaneous (continuous) data. An example of event data is the changing settings of a hydraulic gate.

Special cases of event data are 'switch status', where the values are restricted to 0 ('off') and 1 ('on'), and the Hilltop implementation of quality coding.

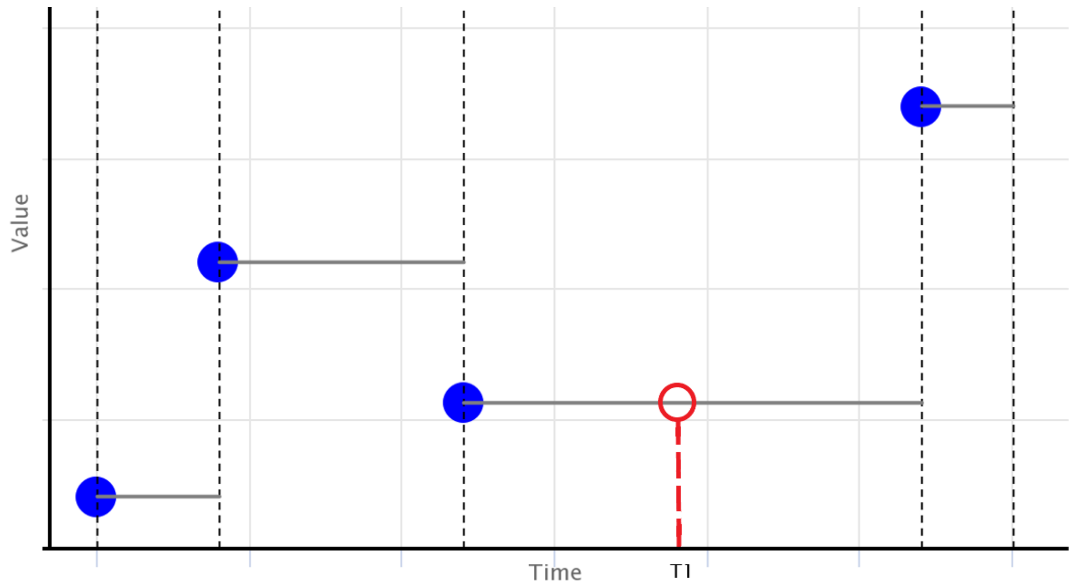


Figure 6 – A depiction of event time-series data. Each event is represented by a single value at the start of the relevant period. The value interpolated at time T1 is the same as is stored at the beginning of the interval.

1.1.5 Censored data

Censored values are those that are only partially known and are recorded as being greater than (>) or less than (<) a limit or threshold, or within a range.

Censored values are often found in discrete water quality data, either as greater than the maximum value of the calibrated range of the meter or test, or less than its method detection limit (MDL). These censoring thresholds may change over time.

A laboratory's official result may be a validated but censored value. Laboratories may also be asked to supply an 'uncensored' (i.e. raw unrounded) measurement result and the associated uncertainty of measurement (UoM), in accordance with either the relevant NEMS normative reference or JCGM (2008).

Continuous sensors may return values outside their calibrated range, in which case a decision must be made whether to trim, censor, reduce quality code, comment, or some combination of these actions.

Censoring real time publication of data may be an initial temporary step prior to verification and decision on the final form of the data to be archived.

If policy for a specific variable's censored data is not provided within the relevant NEMS normative reference an organisation must develop, document, and implement their own protocols, giving due consideration to the purpose of the data collection and maintaining consistency of treatment within and across datasets.

As a minimum, an organisation's data processing system shall include the following:

- the ability to differentiate censored data from uncensored data
- methods for storing, editing, and reporting censored data to ensure correct interpretation of the values

- methods for storing, editing, and reporting the associated uncertainty of uncensored data that would otherwise be reported as censored, and
- protocols for treatment of values that are out of calibration range, if not included in the relevant NEMS normative reference for that variable.

1.1.6 Vector data

Vector data within the scope of this NEMS are restricted to wind direction, which will usually be measured in conjunction with wind speed.

The purpose of the specific data type is so that graphing and analysis tools take account of the values ranging between 0 and 360 degrees with 0 and 360 being the same 'north' direction, and therefore present wind roses rather than plots that 'run off the edge' as direction goes through north.

1.1.7 Multi-item data

The most common time series of multi-item data is gauging results (see Appendix C.1); however, not all time-series managers store gauging results as a time series. Some store gauging data in relational database tables with the results queried as needed for quality control, reporting, and ratings work.

Although multi-item data as a time series is supported in some systems their use is discouraged. The main disadvantage is that all items must be populated, which leads to use of default or substitute values in the instance of an item being missing. An example is the historic use of a value of -1 to indicate an item was 'not measured' (or not calculated from the measurements).

1.2 Units of measurement

Measurement units of all variables must conform to requirements of the NEMS normative reference for each variable. Generally, units are metric in accordance with the SI system of measurement.

1.2.1 Formats for date and time units

Date and time format requirements are:

- a fully specified (i.e. 4-digit) year
- DMY or YMD (i.e. not American-format dates)
- 24-hour clock
- time resolution of 1 second, and
- conventional DD-mon-YYYY (with dashes or spaces) or DD-MM-YYYY and hh:mm:ss (with or without colons) in filed comments (see also Section 6.2.4.1).

Conformance with ISO 8601 (ISO, 2004) is desirable to facilitate data exchange, but may be achieved either directly or by facility for conversion of date and time format(s).

1.2.2 Time zones

Coordinated Universal Time (UTC) is based on the time at Greenwich, England. New Zealand Standard Time (NZST) is UTC + 12 hours, and New Zealand Daylight Time (NZDT) is UTC + 13 hours.

In New Zealand, data shall be archived in NZST, except for in the Chatham Islands (CHAST), which is 45 minutes ahead of NZST.

1.2.2.1 Daylight saving

NZDT (and CHADT) is in common use in the summer months but, for reasons of continuity and standardisation, time-series databases shall use NZST (or CHAST). Data collection should record in NZST (or CHAST) unless there are overwhelming reasons to use NZDT (or CHADT).

To avoid confusion, it is normal that field notes record both standard time and daylight time when applicable, and that the time references are stated when data are provided.

Policy on daylight saving periods has changed over time since it was first introduced in 1927. For historic NZDT (and CHADT) periods in New Zealand refer to https://www.govt.nz/browse/recreation-and-the-environment/daylight-saving/history-of-daylight-saving-in-nz/

Daylight saving periods since the mid-1940s are as follows:

from:	1946	NZST established, with no daylight saving
	1974/75	first Sunday in November to last Sunday in February
	1975/76	last Sunday in October to first Sunday in March
	1989/90	second Sunday in October to third Sunday in March
	1990/91	first Sunday in October to third Sunday in March
	2007/08	last Sunday in September to first Sunday in April (i.e. current)

2 Data Capture

The term 'data capture' refers to the processes of recording data in written, graphic, punched media, analogue or digital electronic forms and converting, if necessary, to a medium whereby it can be further processed, stored, and analysed.

2.1 Electronic recording

Electronic recording is by far the most common method of capturing time-series data. Electronic data loggers began to be used to store values from sensors in the 1970s and their use expanded significantly in the 1980s. Ongoing developments in technology now provide a diverse range of options for data capture and collection, including:

- data logging at site, either on-board the sensor or to a separate, often multi-purpose data logger from which the captured data are then either periodically manually downloaded and/or polled by a telemetry or SCADA system
- transmission of measurements via hard-wire or wireless communications from a sensor or intermediate electronic device to a central collection point such as a data logger servicing a network of nearby sensors, or a cloud server, or a mobile device
- transmission of measurements via hard-wire and/or wireless communications from a sensor or intermediate electronic device to a dedicated centralised data acquisition system, such as a telemetry or SCADA base, or client-server portal.

Capture to electronic form is inherent to electronic recording so this step of data processing has become simpler. At the same time, the technology has made it easier for errors to be more serious and widespread, so that quality control needs to be rigorous and quality assurance (in terms of error prevention) is more important.

Transmission of measurements can be prone to timing and intermittent communication issues causing data loss that is difficult to detect. For this reason, a data logger at site is recommended, and is required for some variables, e.g. rainfall (see Section 3.6 of NEMS *Rainfall* v2.1). Two records are therefore possible from the same sensor that must be carefully identified, tracked, and managed (see Section 3), then possibly combined, while preserving traceability of the contributing data.

2.2 Punched tape recording

A significant amount of historical water level and rainfall record was produced by punched-tape analogue-to-digital recorders. These electro-mechanical instruments were widely used from the 1960s to the 1980s and were the first commonly used machine-readable recorders. They usually punched binary-coded decimal (BCD) measurement values at each time interval or the time of an event as lines of holes in a roll of paper tape and could be read relatively rapidly by an optical tape reader and translated to computer files.

Data processing operations were similar to those used for the later solid-state data logger, and verification processes developed for them are the basis of those used today for electronic data.

2.3 Chart recording

Analogue (chart) records of variables such as water level and rainfall were commonly collected in the past, and in a few places this technology may still endure due to its advantage of rapid interpretation by lay people and/or for historical reasons. On occasions, chart data may need to be reprocessed to improve a historical record.

Capture to digital form can be done by manual reading and key entry, which normally involves a person reading the series of values at an appropriate time interval and writing these to a form from which the values are later keyed into a computer file (see Section 2.4).

More commonly, digitising is carried out from either a digitising tablet or a scanner. Tablet or flat-bed digitising is the most common method and relies to some extent on the skill of the operator to not introduce errors of precision or interpretation into the record. The use of a scanner with software to interpret the trace is a more recent development, particularly for 'data rescue', and while this process can also have errors of precision, or of interpretation if the trace is obscured in some way, it can be an improvement over methods used in the past.

2.4 Manual recordings

Examples of data that may be recorded manually include:

- verification data (see Section 2.5)
- discrete water quality data obtained by field measurement and observation, and/or laboratory analysis of samples
- ad hoc at-site observations, such as
    - current meter streamflow measurements (gaugings)
    - climate observations that are not logged
    - battery voltage
    - surveyed levels, e.g. datum checks
- 'citizen science' observations
- regular 'self-monitoring' observations by consent holders or their agents, e.g. daily water meter or staff gauge readings
- river or lake cross-sections
- values read by eye from a chart or punched tape.

Manual recordings may be captured directly to an electronic file or manually typed (keyed) in after capture to paper via a form, chart, level book or field station logbook.

2.5 Verification data

When visiting a recording station or measurement site, for servicing or any other reason, it is standard practice to record:

- manual observations of the relevant variables:
  - readings of a primary reference gauge
  - water quality observations using a handheld device
  - intermediate observations, i.e. at times between logged values
  - values read by eye from a logger display
  - weather conditions, e.g. presence of snow at a rainfall site
  - flood levels
- the date and time of the observations, recorded unambiguously (in particular, using NZST and noting NZDT), and
- any other information that may assist in the verification and interpretation of the data (see Section 3.2 and the relevant NEMS normative references).

Verification data may also include results for samples collected at site but analysed off-site in a laboratory, for example for water quality variables, suspended sediment, or soils.

These records must be permanently retained, and available and referred to during processing of the time series for the purposes of verification and/or adjustment of the data (see Sections 3 and 5), compiling of metadata (see Section 6), and for quality assurance (see Section 7).

Electronic secure storage of these records is recommended. This can be achieved by implementing electronic field sheets or by scanning and indexing paper records as they arrive in the office, then maintaining regular backups.

3 Elements of a Data Processing System

This section focuses on the components and procedures that need to be included in a data processing system in order for data integrity and processing traceability to be assured.

Time-series and related data are valuable in that they are relatively expensive to collect, are usually irreplaceable, and have the potential to have very high use value. To realise and maintain their value, there must exist a means of verifying their integrity and accuracy and giving assurance that errors are largely absent. The data must be traceable in a readily followed form.

Data processing is best done as soon as practical following data capture, otherwise some opportunities for verification may be lost.

A data processing system shall include provisions to:

- store multiple versions of the data (see Section 3.1)
- keep backups of the data in its original and subsequent forms (see Section 3.1)
- file all field observations, results, and other information used to verify the data, track activities at site, and monitor conditions that are affecting or may in future affect reliability and/or stationarity of the data (see Section 3.2)
- identify periods of data at the various stages of processing (see Sections 3.3 and 3.4)
- identify the provenance and status of data (see Section 3.5)
- track the timeliness of data processing (see Sections 3.3 and 3.5)
- present the data in a number of ways for checking and reviewing (see Section 3.6)
- identify anomalies in data and provide a means of identifying issues that need correcting in order to prevent recurrence (see Sections 3.6 and 3.7)
- control the amount and type of editing that can be performed and the authorisation to do this (see Section 3.8)
- present and store evidence of any modifications to the data (see Section 3.9)
- assign quality codes, in accordance with the NEMS normative references for the variable, and having regard to any editing and transformations that have been applied (see Section 4 and the respective Annexes to this document).

The following sections enlarge on the above requirements.

3.1 Versions of data

It is common to have multiple versions of a time series and/or copies of the same data. For example, there may be:

- one or more raw versions (see Section 2.1), preferably as originally logged and not modified on-site and/or during data collection (see Section 3.1.1)
- possibly one or more versions with quality tags and/or flags and/or automatic editing or adjustments applied as sent to a user or website, in real or near-real time, or as a first step to verification and processing of the data for archiving
- possibly one or more versions at various stages of editing (which may include cleaning the data to remove recording errors and/or adjusting the data, with or without verification control, to eliminate bias)
- possibly one or more versions at various stages of review, if pre-processed and/or partially or fully verified and processed by machine
- the final processed, verified data (cross-checked with independent readings, edited if necessary, and metadata attached)
- an audited and possibly 'certified' version, and
- backup and/or shared copies of any of the above.

Different time-series managers have different architecture and different degrees of management of multiple versions and copies of data. Versioning and copies may be provided by way of multiple files, multiple time series within a file, multiple time series and/or versions within a central database, or as a series of transactions on a file or database.

Good housekeeping of all versions and copies is essential to maintain integrity of the data. If the time-series manager does not provide sufficient housekeeping services, they must be achieved by way of office procedure (see Section 8).

3.1.1 Raw (original) data

An organisation shall define and formally document:

- what is regarded as the raw (original) data taken into their data verification and editing processes (see Section 8.2.1)
- where the data to be processed for final archiving are drawn from, and
- how data travel through their system(s) from data logger to the various forms of publication, including near real-time web services and final archive.

For publication of raw data see Section 3.5, 'Data provenance and status'. For archiving of raw data without processing see Section 8, 'Preservation of Record'.

The following conditions apply to telemetered data:

- the data shall be quality coded as QC 200 (raw) until processed
- implemented automatic functions that modify the data captured and/or collected must be described, and changes to those functions controlled, tracked in the station history, and summarised in the metadata (see Section 5)
- performance of the automatic functions shall be regularly checked and the outcome of those checks documented (see Sections 5 and 7)
- ad hoc changes applied at, or initiated from, the telemetry base, e.g. rescaling a sensor or changing a sampling method, must be controlled and documented in a manner equivalent to making the change on site.

The 'first write' to the time-series management system that will be used to process and store the data may be regarded as the raw (original) version in the context of data processing (see Section 8.2.1), but if the measured values arriving at the data logger have been censored, aggregated and/or altered in some way on the logger or by the data collection system (e.g. auto-filtering by a telemetry system) this 'first write' is not unmodified data.

If all operations on the data are not fully traceable throughout the process (i.e. from measured values before any modification, to the final archiving of the data) the archived data must retain a quality code of QC 200 (not verified, quality unknown).

Fully traceable means that either:

- the measured values are able to be obtained, retained, referred to during data verification, and retrieved at any time in the future, or
- all modifications that have been made to the measured values during data capture and collection are known, documented, able to be confirmed as valid during data verification, and able to be reversed if necessary.

3.2 Verification information

All information that enables tracking and verification of the data and activities at site must be stored securely, permanently retained, and be readily retrievable. Typically, this information will include:

- calibration certificates
- results of instrument validations (pre-deployment and at-site)
- verification data, such as reference readings or laboratory test results
- supplementary data, if any
- backup or adjacent site data, if any
- field station logbooks, electronic field sheets, or equivalent, recording:
    - site and variable name(s)

- date and time of visit
  - date, time, and result of inspections
  - conditions at the time of inspections
  - instrument serial numbers
  - equipment installation/removal records
  - details of software and/or configuration changes to instrument and/or data logger
  - manual observations and measurements
  - status of power supply and communications
  - notes of maintenance carried out
  - comment on issues and possible interferences
  - name of the person making the logbook entry
- completed checklists and forms (e.g. level checks, annual site survey)
- photographs, and possibly video.

All information contributing to assessment of stationarity must be stored securely, permanently retained, and be summarised for users of the data. This information will include information from field visits but may also include other related records, such as imagery over time and results of trend analyses of conditions at site and/or deviations in the data.

If the measured data are used as a surrogate for another variable, data collected to calibrate the relationship between the variables become part of the verification information, for example, the discharge measurements and observations of control conditions when water level is being measured to derive flow.

3.3 Data registers and tracking

Periods of data between two or more physical on-site observations, whether time-series, point or sample data, need to be tracked and their processing managed.

- Earlier data records in chart, tape, or paper form are tangible, unique, and permanent so they are easily identified, tracked, secured, and able to show evidence of what has been done to them.
- Datapaks (now obsolete) and storage cards are also tangible, but not unique or permanent if reused. Data may be inadvertently overwritten before they are permanently stored if not suitably tracked and managed.
- Electronic data with no tangible presence must be tracked and managed to ensure the same traceability and security as is provided by physical records. If multiple versions of raw data are collected, e.g. primary and backup, or telemetered and manually downloaded, procedures must also ensure the integrity of each version and allow the source of data subsequently published and/or processed and archived to be traced.

Agencies shall establish data processing procedures aimed at:

- achieving traceability of data files and data verification status, and
- efficient processing of the data while preserving and verifying its integrity.

In one or more registers designed for the purpose:

- track data as it arrives in the office
- update the register as further periods of data arrive
- identify any missing periods
- include the start and finish times of the period of data being processed
- update the register(s) as data progresses through the various steps, confirming that the editing, checking, quality coding, and updating to archive as final verified data, has been done
- sign off each step with at least the staff member's initials and date, or a more formal approval system may be used.

  Note: Sign-off encourages staff to take responsibility for and gain 'ownership' of their work and its progress.

Registers may be paper-based, spreadsheet-based and/or part of a database or automated data collection system.

If more than one register is used there must be continuity in traceability of data between them. The register(s) will thus contain a complete chronological record of the passage of data from logged raw to verified archived forms.

3.4 Identification of records

All data records shall be clearly identified and must at least include the site name/identifier and the date and time of the record.

3.5 Data provenance and status

Organisations must document the provenance of datasets, encompassing their origin, subsequent modification, and changes in status. Their current status (e.g. whether they have been verified as fit for use) also needs to be readily known.

The NEMS quality codes provide information about status, degree of modification, and reliability of data. Filed comments further identify dataset origin, details of any modifications, and alert to other relevant factors such as legal constraints on dissemination, limitations of the data and cautions about use. These are designed and intended primarily for users of the data.

Some time-series software packages also include approval facilities to convey status of any period of data and help manage dissemination of data. These facilities are designed and intended primarily to assist data producers. If a more manual approach is necessary, the organisation's data processing procedures must provide for adequate tracking of the progress of any period of data through the process and should define the conditions for release of data from the various steps within the process.

For example, the following may be defined:

- raw data published automatically to a website:
    - quality coded QC 200 (provisional, raw)
    - available to the public but with disclaimers as to accuracy, and advice on how it should and should not be used
    - data subject/likely to change.
- data that have had initial checks but not verified by field check(s) and detailed inspection:
    - quality coded QC 200 (provisional, non-verified)
    - if available for release will have disclaimers,
    - data subject to change.
- data that have been checked by a field visit, edited, and marked as verified, but not yet passed a quality (peer) review:
    - quality coded as QC 400 or QC 500 (verified and graded) as applicable
    - available for release with quality code changed to QC 200 (provisional, not assigned a final quality code), and applicable metadata including explanation of quality codes, and disclaimer
    - data subject to confirmation.
- data that have been checked by a field visit and marked as final and verified but not yet passed an audit review:
    - quality coded as QC 400, QC 500, or QC 600 (verified and graded) as applicable
    - available for release with applicable metadata, including explanation of quality codes
    - data might be modified in future.
- verified final data that have passed the organisation's audit review process:
    - quality coded as applicable
    - available for release with applicable metadata, including explanation of quality codes
    - possibly 'certified' or 'locked', i.e. a formal process of approval must be followed to change the data in future.

3.6 Quality control

Quality control comprises inspection and testing of the data and is the purpose of the data verification process. A number of routine checks must be applied to all data collected.

Some checks may be applied as part of near real-time data publication (see Section 3.1), and some may be repeated more than once throughout the full process, including during quality review after processing is completed (see Section 7).

For data that are laboratory results, rigorous quality control is carried out by the laboratory, and data processing need only be concerned with spurious errors, usually of human origin, and ensuring correct identification, transcription, documentation, and storage of results.

For other time-series data, rigorous quality control is an essential part of data processing that must be able to also identify anomalies within the data that arise from measurement and/or recording errors, and measurement and/or recording system faults and failures. Necessary capability includes:

- comparing recorded values with field checks and verification data, and assessing tolerance within the context of conditions at site during the visit (e.g. the greater uncertainty of a staff gauge reading during a flood)
- detecting possible anomalies (such as steps, spikes, gaps, poor resolution, out of range values, noisy periods, or unusually flat or straight segments) that may occur, and possibly resolve, between site visits
- identifying missing timesteps in fixed interval data that may indicate a system fault or reset and possible data corruption or loss
- comparing the data to one or more other datasets that would be expected to show some correlation (e.g. backup or supplementary data, associated variables, adjacent or nearby station(s), adjacent catchment(s), modelled data for the same variable and period)
- access to all relevant site and time-series metadata (see Section 6 and the relevant Annex as applicable), and
- ability to review the chronological history of the above four points to identify persistent faults or failures, and bias or trend in deviations from reference values that may not necessarily be outside verification tolerances (see Appendix 1).

Problems identified must be investigated to establish plausible cause then a suitable remedy formulated and applied. Feedback must be provided where necessary to prevent recurrence (see Section 3.6.5). Editing of data must be controlled (see Section 3.8).

3.6.1 Methods

Inspection and testing for quality control may be:

- manual, carried out by skilled personnel using data plots, quality charts and/or tables, and statistical tests, or
- pre-set and/or automated, or
- implemented using some combination of manual, pre-set and/or automated functions.

Method selection should be commensurate with the:

- nature and inherent variability of the data
- frequency of site inspections
- range, frequency, and reliability of reference measurements
- availability of other reliable datasets for comparison
- available resources and skills, and
- scope and reliability of available and/or possible automation.

There is a trade-off between:

- the skills required to manually inspect and verify a record
- sufficient prior data collection and/or knowledge to establish pre-set thresholds, and
- sufficient redundancy of data collection to provide reliable comparators for automated inspection and test.

  For example: simultaneous measurements from a second instrument at the same site, or of a closely correlated variable at the same site, or of the same variable at a closely correlated nearby site.

Comparisons can be made using:

- allowable percentage deviation
- range and uncertainty bounds, and
- allowable deviation for the relevant quality codes.

Inspection for anomalies, whether automated or manual, should evaluate the data giving consideration to:

- the characteristic behaviour of the variable
- the instruments and installation, when performing well and poorly
- the nature of the location, site, and measurement environment, and
- events known or suspected to have occurred.

Machine algorithms may be used:

- to identify anomalies, and

- to generate alerts for later manual review and processing, or
- as a first step to auto-processing of the data (see Section 5).

Machine algorithms must be:

- described in the organisation's data processing procedures,
- detailed in the site file and/or station history for each site, as applicable,
- controlled and tracked, with respect to changes of function and/or application, and
- subjected to regular review with outcomes documented and retained (see Section 7).

Records of all quality control inspection and testing must be permanently retained as part of the site and/or time-series metadata (see Section 6).

For illustration purposes, examples in this Standard are graphical as would be used for manual inspection and test. This does not imply that automated methods cannot be used.

Further examples and guidance specific to each measured variable may be found in the relevant Annex.

3.6.2 Data plots with time

To be effective for verification purposes, plots of data with time must display at a resolution sufficient to see all the features of the data as collected.

- Use a 1-month time scale for all initial plots, including comparison plots. Anomalies noticeable at this scale will tend to be those requiring further attention.
- Zoom and pan sufficiently to check range and continuity of shorter-term features and cycles such as peaks, recessions, drawdown and recovery, daily sine curves and tide cycles.
- Zoom to the time of each site visit to check for anomalies introduced by inspection, sampling, cleaning, sensor replacement, and other maintenance activities.
- Plot the full period of processing at full range to check for outliers and time faults, trends that may indicate drift, and changes in pattern that may be due to poor and/or declining sensor performance.
- For incremental data use bar and cumulative plots. Cumulative plots are the most useful for comparisons. Use bar plots at resolutions of:
    - the maximum recording interval, e.g. 5 minutes, to check for spurious or invalid data, unmarked gaps, and unusually erratic or similar rates, and
    - intervals consistent with expected norms and thresholds, e.g. hourly, daily, weekly, to check data range and timing of events, and trends that may be due to calibration drift.

- For comparison plots of the same variable, use:
    - a common axis to check for data range anomalies, and
    - separate axes with auto-scaling to assess patterns and detail without range of the data confusing or clouding perspective.

Note: Some graphical tools (mainly those intended for publication graphics) compress and/or resample data and may not display all features such as steps and spikes. These are not suitable displays for quality control.

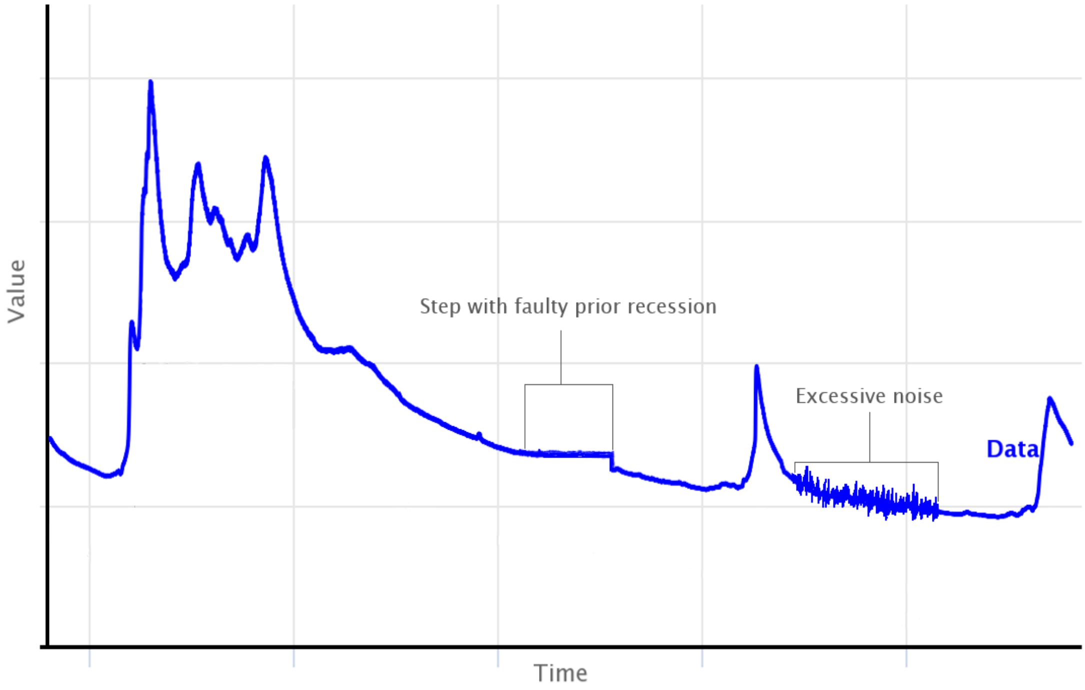


Figure 7 – A plot of stream water level showing anomalies in the data.

3.6.3 Comparisons with time

Comparisons with time are useful to identify anomalies, but they are equally useful to confirm data are reliable if there is some doubt. They are especially useful when the data collected do not conform to a typical pattern for some reason, e.g. a record of water levels below a hydro-electricity generator or downstream of a control gate.

Time of travel and attenuation must be accounted for when comparing record from stations some distance apart on the same river network.

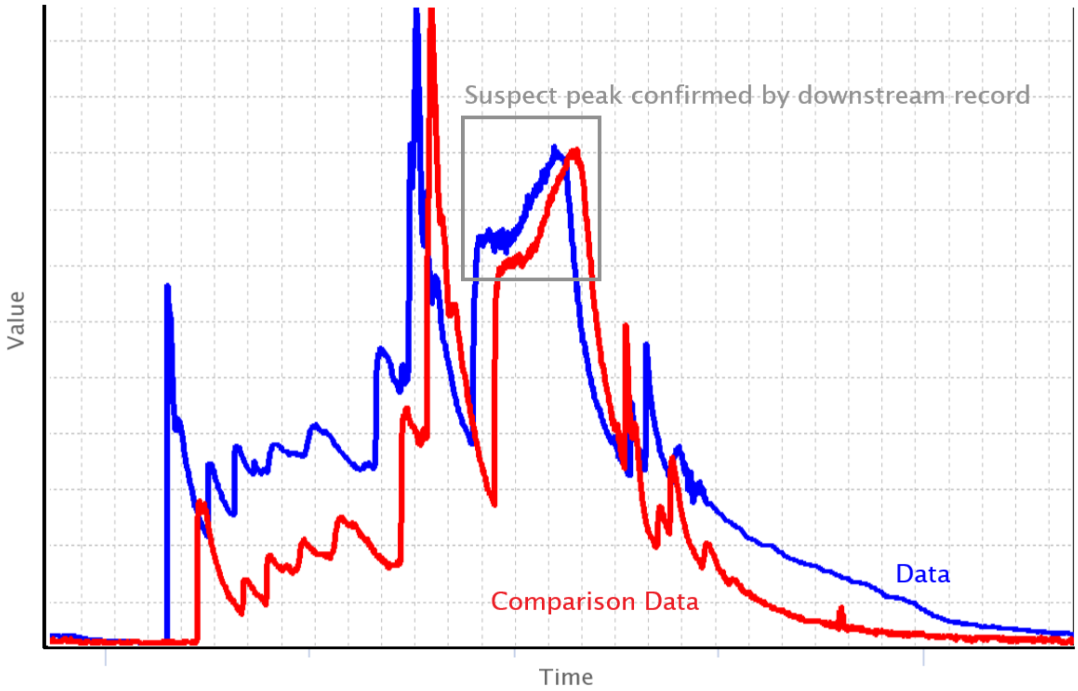


Figure 8 – A comparison with time of water levels from stations on the same river confirming that a peak suspected to be faulty record has been captured correctly.

3.6.3.1 Use of models

Output from calibrated models running in near-real time for the same site or an adjacent or a nearby site, possibly for prediction purposes, can be compared with incoming actual data for rapid quality control.

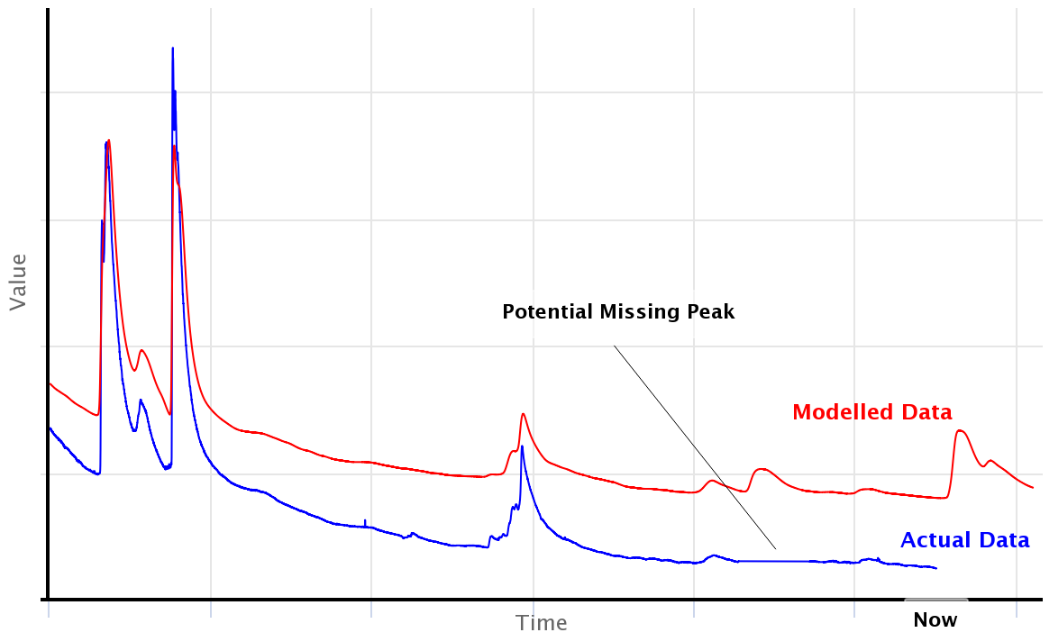


Figure 9 – Comparison plot of modelled and actual flow, for quality control purposes.

3.6.4 Examples of deviation tests

Tests of deviation of logged values from corresponding verification data include:

- direct comparison of simultaneous values (e.g. a scatter or x-y plot)
- monitoring a simplified chronological sequence of deviations (e.g. control charts, run charts, or equivalent tabulations)
- assessing deviation with time and value, to diagnose time- and range-dependent drift, respectively.

Other tests that may be useful are:

- tracking cumulative departures (e.g. cusum charts)
- mass and/or double mass analysis (more useful for investigating longer-term issues, such as stationarity, than day-to-day quality control).

Uncertainties can be incorporated if known.

Deviation tests may also usefully be compiled using the logged data from two sites.

Quality plots in the following sub-sections illustrate some of the more common tests.

3.6.4.1 Scatter plot (X–Y plot)

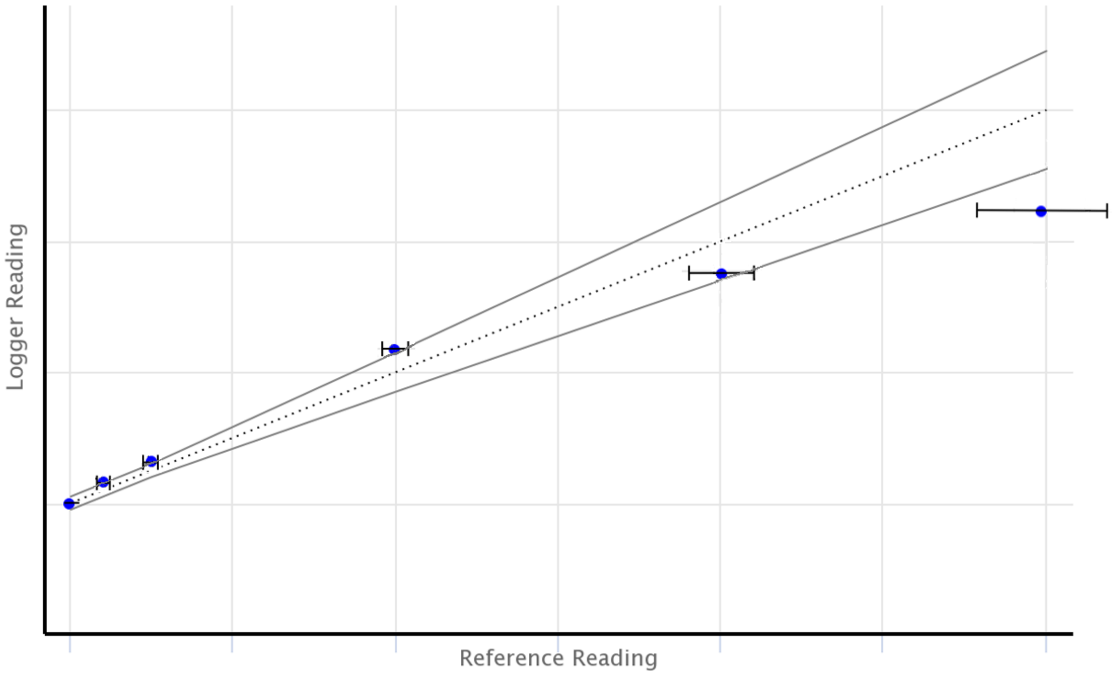


Figure 10 – Scatter plot of manual reference observations (with their uncertainty bounds) vs logged values. The allowable tolerance envelope is shown by the solid grey lines and agreement is shown by the dotted line.

3.6.4.2 Control chart

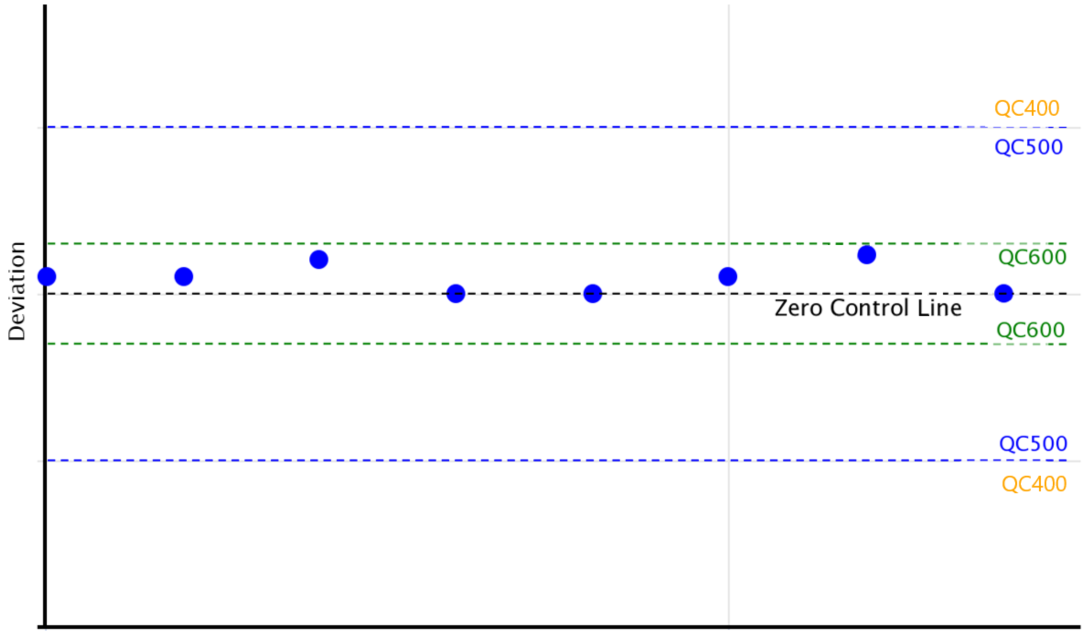


Figure 11 – A control chart for assessing the deviation of logged values from simultaneous manual reference observations. The dotted lines represent the tolerance thresholds for the various quality codes.

Control charts are a simplified form of deviation with time presentation, used to monitor a process and alert when the process may be out of control; in the case of collecting environmental time-series data that is when the variable measurement system does not return logged values that are within defined agreement of corresponding reference values.

A control chart is chronological but does not have a true time x-axis.

Indications of a process out of control are deviations outside limits and any trends, cycles, or bias whether within or outside limits. Limits may be set by Standards or by statistical thresholds such as standard deviation.

A control chart can indicate offset and drift problems but cannot inform whether drift is linear or non-linear because the chart does not use a true time axis.

For guidance on how to interpret a control chart see Appendix 1.

3.6.4.3 Run chart

A run chart is a simpler form of control chart. It does not have threshold lines and may only display the sign of the deviation, thus providing for non-parametric assessment of variation (e.g. the greater the number of changes of sign in a sequence of differences the less bias is present in the data).

Run charts may be presented as tabulations or print-plots.

3.6.4.4 Deviation with time

These can be a simple plot of differences with time or a modified control chart where the x-axis is true time.

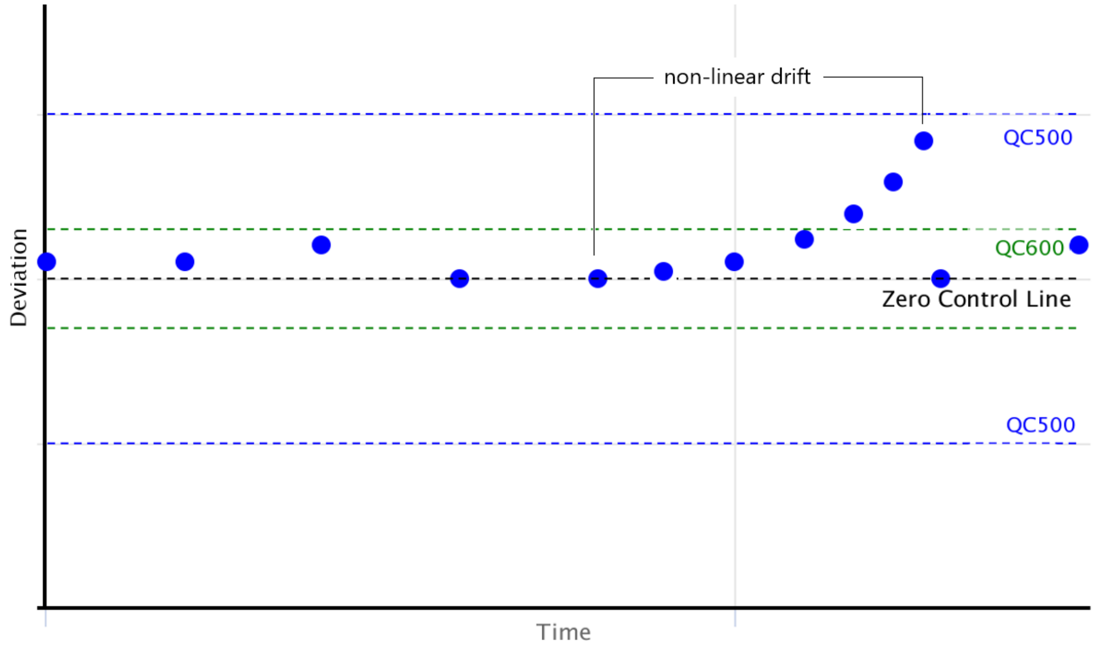


Figure 12 – Deviation with time adapted from a control chart and showing a period of non-linear drift, able to be ascertained because the x-axis is true time.

3.6.4.5 Deviation with range

This test detects range-dependent bias or drift. Deviation is calculated as sample minus reference and the sign of the difference indicates the direction of the deviation.

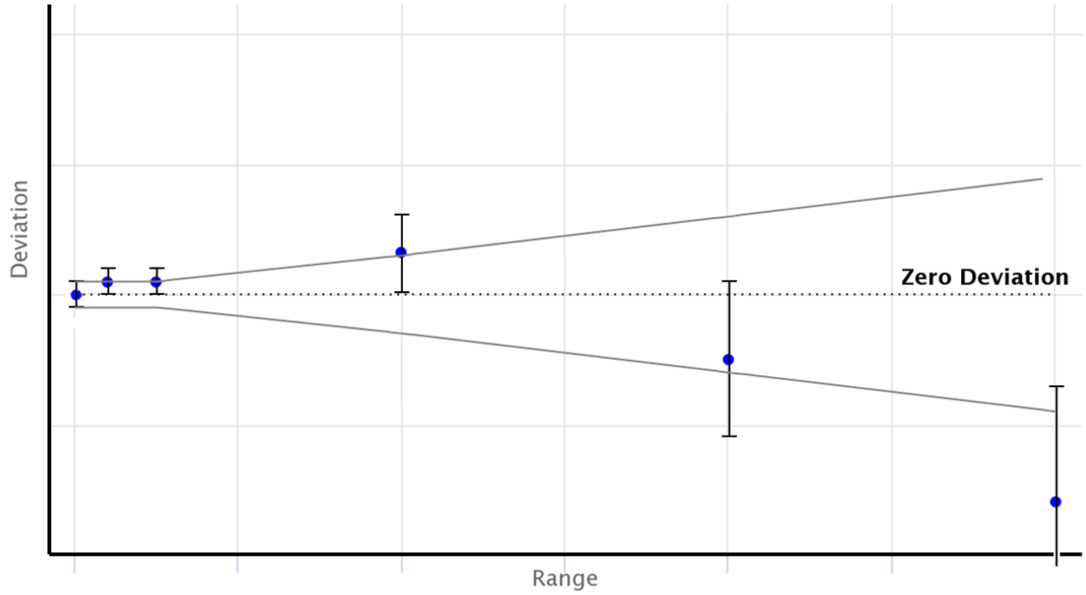


Figure 13 – Deviation of logged values from corresponding reference values (with uncertainty bars) versus the range of values. The allowable tolerance envelope is shown by the solid grey lines and agreement is shown by the dotted zero deviation line.

3.6.5 Reporting

To prevent problems recurring, feedback to the field operation must follow discovery of significant or persistent issues during data processing that have not already been identified.

Feedback may be achieved by:

- having the same staff member responsible for both site operation and processing the data collected from it, or
- team meetings, and/or
- adopting a more formal quality assurance non-conformance reporting framework.

Feedback may include:

- requests for additional checks and information (e.g. validating an instrument) before current data processing can be completed
- recommended changes at site
- recommended changes to field procedure for future data collection.

If errors are discovered in verification (field inspection) data (e.g. a wrong inspection date, survey origin, etc.) refer to Section 3.9.2.

3.7 Non-stationarity

Non-stationarity may cause discontinuities that compromise a long-term record but are difficult to quantify. Avoidance is preferred. Stationarity is formally evaluated during data audit (see Section 7.3) but should be monitored and managed during data processing.

Data collection and processing practices must record all known influences and events that may affect stationarity.

Editing actions must not disturb or disrupt stationarity already achieved. For example, undesirable practices are:

- routine adjusting of data to reference readings (see Section 5)
- unduly varying method(s) of deriving synthetic data (see Section 5.5)
- applying different methods to the same problem for different periods within the same time series (e.g. swapping between stage adjustments and rating change(s) to compensate for weed growth).

When non-stationarity is detected, the issue and its likely effects on the data must be described in a Stationarity Comment (see Section 6.2.4.9). Response to identified non-stationarity might also include:

- field actions to resolve the issue (e.g. removing obstructions or reversing instrument changes)

- transforming data to compensate for, or minimise, the effect.

If an above action has been taken, cross-reference the Stationarity Comment from the relevant Operational (see Section 6.2.4.5) and/or Transformation Comments (see Section 6.2.4.8).

3.8 Control of editing

The amount and type of editing that can be performed, and the authorisation to do this, shall be controlled within an organisation. Editing and adjustments applied to data must adhere to the principles, procedures, and operations described in Sections 4 and 5 and the relevant Annex.

The organisation's procedures shall make personnel aware that:

- a conservative approach is required, including deciding when and how much to edit data
- editing of data is controlled
- data editing needs to be done
  - in a conservative fashion, and
  - according to principles and requirements of this Standard, and
  - following the organisation's procedures
- the procedures may limit an individual's authority as to what editing they may carry out without explicit approval, and
- significant changes to data must be peer reviewed.

An organisation's data processing procedures will likely change over time. Some aspects of data provenance may be related to the version of the procedures and NEMS documents being used at the time of processing. Therefore, version control of such procedures should be maintained, and which version of procedures and Standards applied at the time of processing the data should be tracked in the time-series metadata (see Section 6.2).

3.9 Evidence of modifications to data

Evidence of, and justifications for, any modifications to data collected shall be recorded in the metadata so that the entire process from raw to final verified data can be tracked and justified.

3.9.1 Modifications to the time-series data

The organisation's processes shall include, as a minimum, the following steps and records:

- a record of any modifications and transformations applied within the data logger program and, if applicable, the telemetry data software

- a record of diagnosis and description of any errors found in the data, any assumptions made when editing that data, and a description of the editing process
- timestamped comments filed as part of the metadata attached to the time-series, which summarise issue(s) identified with the data and resolution of them in a standardised format and vocabulary so that meanings are clear, and
- the filed comments about data editing must include the period to which the comment applies in addition to its timestamp, the reason for making the change to the data, a summary of the evidence that confirms the validity of the change, the identity of the person carrying this out, and the date that this was done (see Section 6.2.4).

3.9.2 Modifications to verification information

It is possible for verification information to contain errors. If verification information is suspect, altered, or disregarded:

- seek confirmation of the information whenever practicable (e.g. by repeating a survey or validating an instrument)
- ensure assumptions are defensible
- record the decision in the processed time-series metadata, and with the original verification information
- ensure changes to the verification information are:
  - noted on, or included in, the original record, but not in a way that obscures or deletes the original information, and
  - annotated with date of the change and name of the person responsible for making the change
- record and store full explanation with the verification information in question, and summarise the explanation in the time-series metadata
- consider downgrading the time-series quality code for the period that would otherwise be verified by the information.

4 Types of Operations

In this section, the usual types of data manipulations performed after data collection and before final archiving, their potential benefits, and the possible risks in applying them are described. For further details specific to a particular variable, refer to its relevant Annex.

4.1 Interaction with quality code

Manipulating the data has the intended purpose of improving its reliability and usability; however, within the NEMS quality coding framework, doing so may require a reduction of quality code if the recorded data have been altered on the basis of assumptions that cannot be fully verified.

Data may be corrected for a known and fully traceable recording fault. In this case quality code is usually unaffected.

Data may be adjusted to minimise the effect of a detected recording fault, wherein assumptions are made about cause of the fault and/or what the values would have been had the fault not occurred. Minor adjustments reduce quality code to a maximum of QC 500; significant adjustments to a maximum of QC 400. Refer to Section 6.2.3 for explanation of 'minor' and 'significant'.

Operations may change the way data are stored and/or represented to better suit system limitations or desired use of the data. If value or time resolution of data is reduced, its quality code may be affected, depending on the requirements of the Standard for each variable.

4.2 Offset shift

An offset shift adds a constant positive or negative value arithmetically to every data value in a specified period.

It can be regarded as a correction if applied in response to:

- a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt. In this case it is often also associated with a scaling error that must be corrected at the same time, or
- an intended, persistent, and traceable change of datum and/or recording zero.

It is an adjustment when applied to compensate for a deduced constant difference between recorded and expected values, usually associated with a spontaneous shift of physical instrument position, or a spontaneous reset to, or change of, instrument zero.

4.2.1 Potential benefits

Potential benefits of applying an offset shift are:

- eliminating an introduced error, for example, by having the sensor or logger set to the wrong recording zero, or perhaps a more convenient zero for field operations
- making the data more meaningful for a user; for example, changing stage above assumed datum to Mean Sea Level
- minimising suspected constant bias in a period, revealed by verification of the data.

4.2.2 Possible risks

Possible risks of applying an offset shift are:

- the offset applied is inaccurate because:
  - it is inferred rather than directly and independently measured
  - associated scaling error is not properly resolved
  - verification data are uncertain, unreliable, or incomplete
  - assumptions about the cause, extent, duration and/or effect of the fault are wrong
- an offset shift is inappropriate because the observed bias is not a result of a step change in the relationship between instrument and primary reference zero.

4.2.3 Effect on quality code

A correction has no effect on the quality code for most variables. An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.2.4 Guidance for use

- Use when a constant bias between recorded and expected values is detected or assumed to exist. Residual variation may persist, but it should be random and within expected tolerance.
- The basis for correction should be at least as accurate as the data itself.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.2.5 Mathematics

Function: $Y' = Y + C$

Where Y' is the corrected data, Y is the original value and C is the constant (positive or negative) to be added.

4.2.6 Example

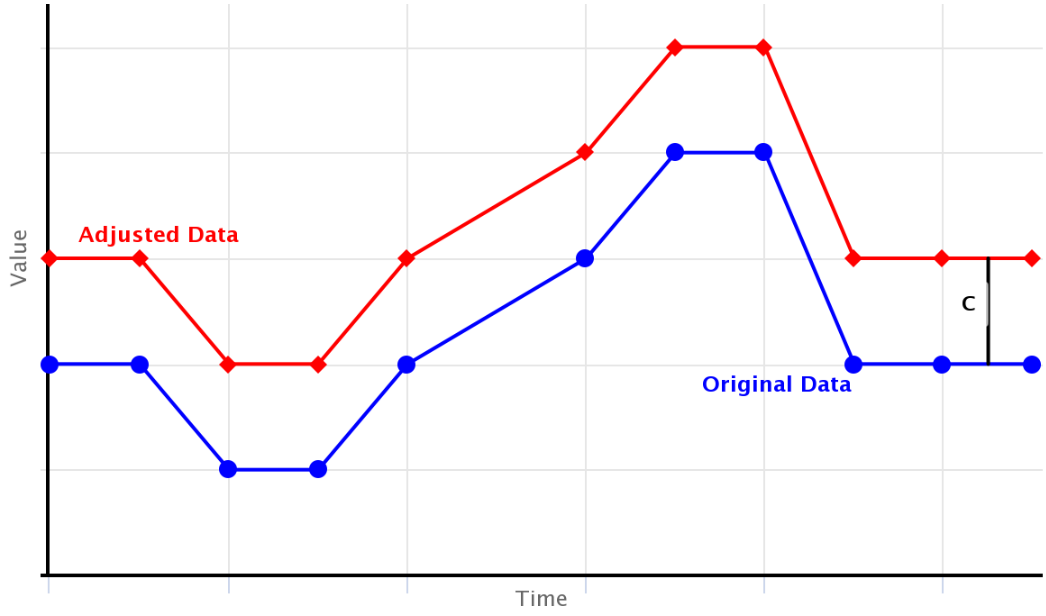


Figure 14 – Example of offset shift, where an offset, *C*, has been added to an entire dataset.

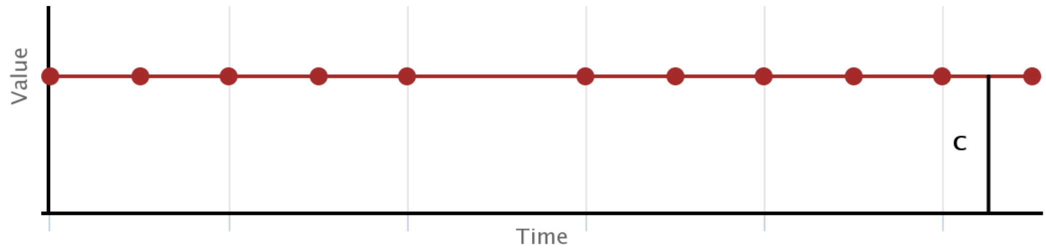


Figure 15 – Graph showing the value of the offset, *C*, for the shift applied in Figure 14.

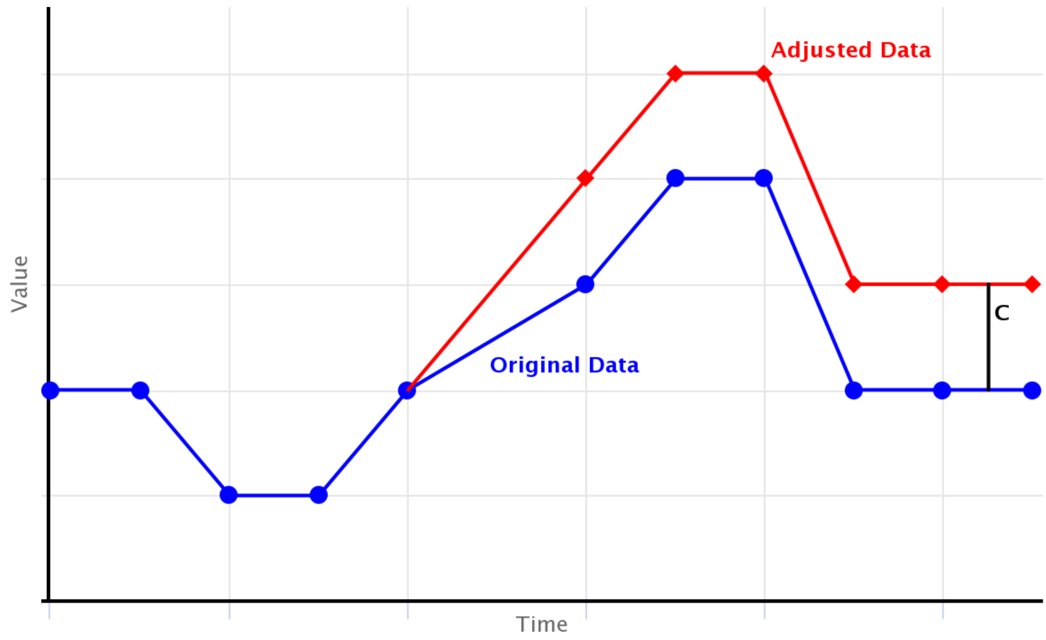


Figure 16 – Example of offset shift, where an offset, *C*, has been added to part of a dataset.

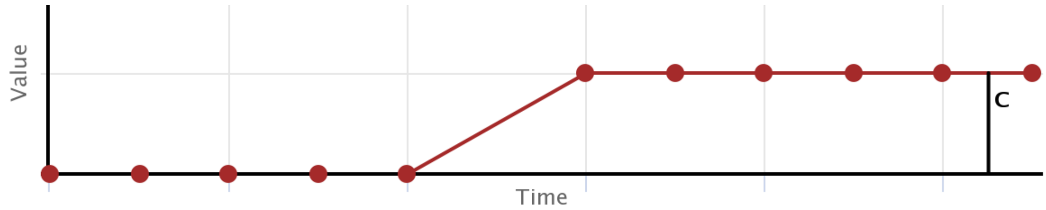


Figure 17 – Graph showing the value of the offset, *C*, for the shift applied in Figure 16.

4.3 Time shift

A time shift moves a period of data backward or forward in time without disturbing the duration of the data or the timesteps between the stored values.

The shift may be necessary because of:

- a change of time zone
- an incorrectly set logger start date and/or time, or
- a logger reverting to a default 'initial' date and time.

Shifts between daylight saving time and standard time are a special case because of the hour 'lost' when clocks move forward and the hour 'repeated' when clocks move back. The consequent overwriting of the hour of data recorded prior to the move back at the end of a period of daylight saving is one of the main reasons for recording all continuous time-series data in Standard Time.

4.3.1 Potential benefits

Potential benefits of applying a time shift are:

- assigning values their correct sampling dates and times
- making the data more meaningful for a user, for example, shifting from UTC to NZST.

4.3.2 Possible risks

Possible risks of applying a time shift are:

- inadvertently stretching or contracting time by, for example, not accounting properly for leap years or transitions into and/or out of daylight-saving periods
- inadvertently overwriting other data.

4.3.3 Effect on quality code

A time shift has no effect on quality code.

4.3.4 Guidance for use

- Data collected with the wrong time period assigned must be shifted to its correct time period.
- The amount of shift required must be determined from evidence that should be unequivocal.
- File a comment explaining the change and reason(s) for it.
- Suitably identify the raw data as possessing wrong times (in case it is required again in the future).
- If the times needed correcting prior to import, record in the metadata that the raw data were changed prior to import, the time shift that was applied, and the reason(s) for it.

4.3.5 Mathematics

Function: $T_n = T_x + C$

Where T_n is the new timestamp, T_x is the original timestamp at time x, and C is the constant amount of time to be added (or subtracted).

4.3.6 Example

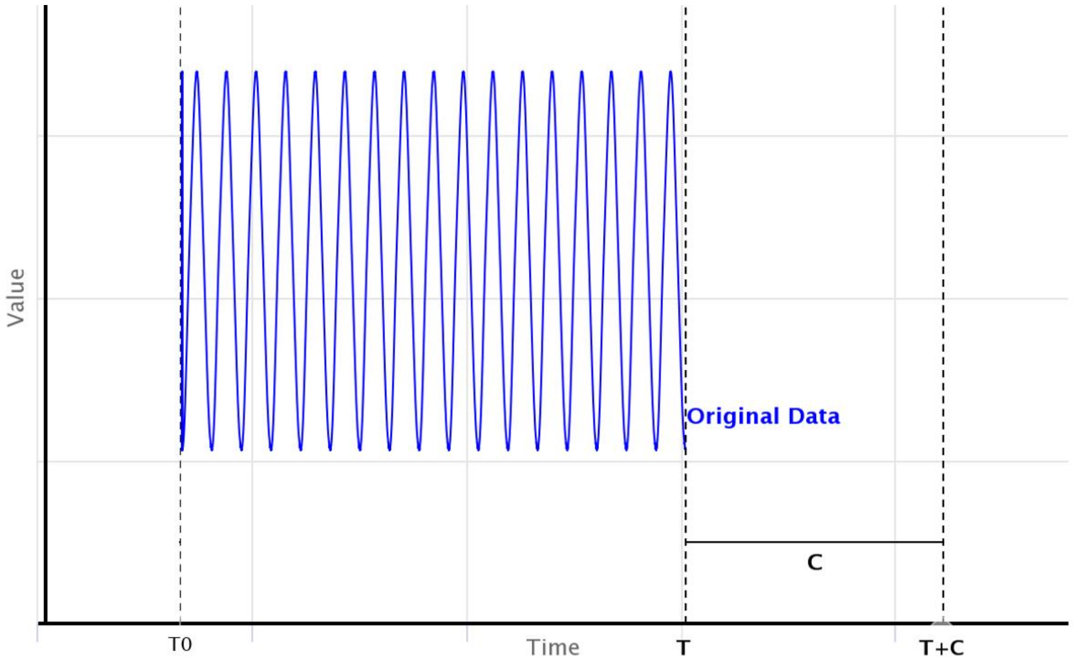


Figure 18 – Example of a time shift where the entire dataset is to be moved forward by an amount of time, *C*.

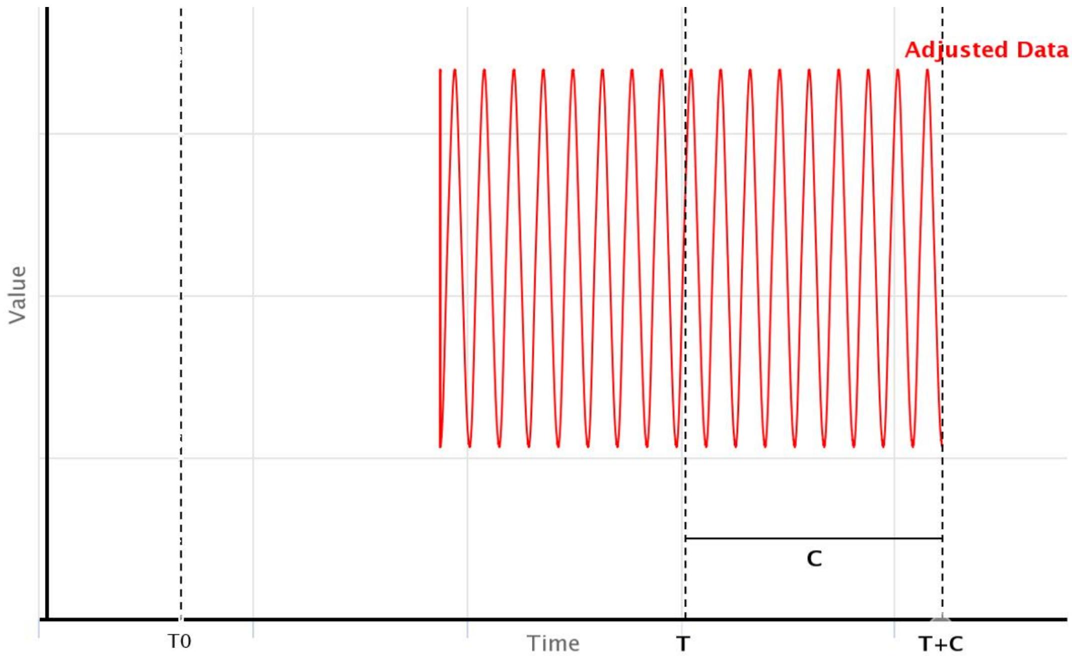


Figure 19 – Example of the result of a time shift where the entire dataset shown in Figure 18 has been moved forward by the time period, *C*, with all timesteps preserved.

4.4 Linear drift adjustment

A linear drift adjustment applies a progressive offset shift, where the amount of shift varies linearly with time over the period of the adjustment. The adjustment may be one- or two-tailed. A one-tailed adjustment begins or ends with zero change. The difference between original and adjusted values may increase or decrease through the adjustment period.

4.4.1 Potential benefits

Potential benefits of applying a linear drift adjustment are:

- minimising gradual apparent errors related to sensor performance, such as:
  - calibration drift
  - biofouling
  - silting
  - gradual change of base level, for example, due to deterioration of an optical sensor's lens
- compensating for periods of gradual interference, for example, weed growth affecting a flow site's control.

4.4.2 Possible risks

Possible risks associated with applying a linear drift adjustment are:

- the amount of offset applied to any value may be inaccurate because:
  - it is inferred rather than directly and independently measured
  - verification data are infrequent, uncertain, unreliable, or incomplete
  - assumptions about the cause, extent, duration and/or effect of the fault are wrong, for example, the drift is actually non-linear or the period assumed affected is wrongly identified
- while the method is used to distribute 'corrections' over a time period, it can also be considered as distributing errors
- successive adjustments to reference may distort the data due to the influence of:
  - the random uncertainty in the reference values, or
  - a large uncertainty in a single reference value due to measurement conditions, e.g. a high stage staff gauge reading.

4.4.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of adjustment. If the adjustment is significant, maximum quality code is QC 400 over the period of adjustment.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.4.4 Guidance for use

- Drift adjustments should be used with caution.
- Adjustment of data within tolerance should only be necessary if a step of some significance is created when the cause of the drift is resolved. For data used as a surrogate, significance is determined by the effect on the subsequent variable.
- Linear drift can be compensated for using rating curves, but only one method (rating curves or linear drift adjustment) should be used in a record, with the decision a balancing of efficiency and effectiveness.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.4.5 Mathematics

Function: $Y' = Y + C_0 + (C_1 - C_0)\left(\frac{T_n - T_0}{T_1 - T_0}\right)$

Where Y' is the adjusted value, Y is the original value, C_0 and C_1 are the offsets to be added at the start and finish times, respectively, T_0 is the start time of the adjustment, T_1 is the finish time and T_n is elapsed time since T_0.

4.4.6 Example

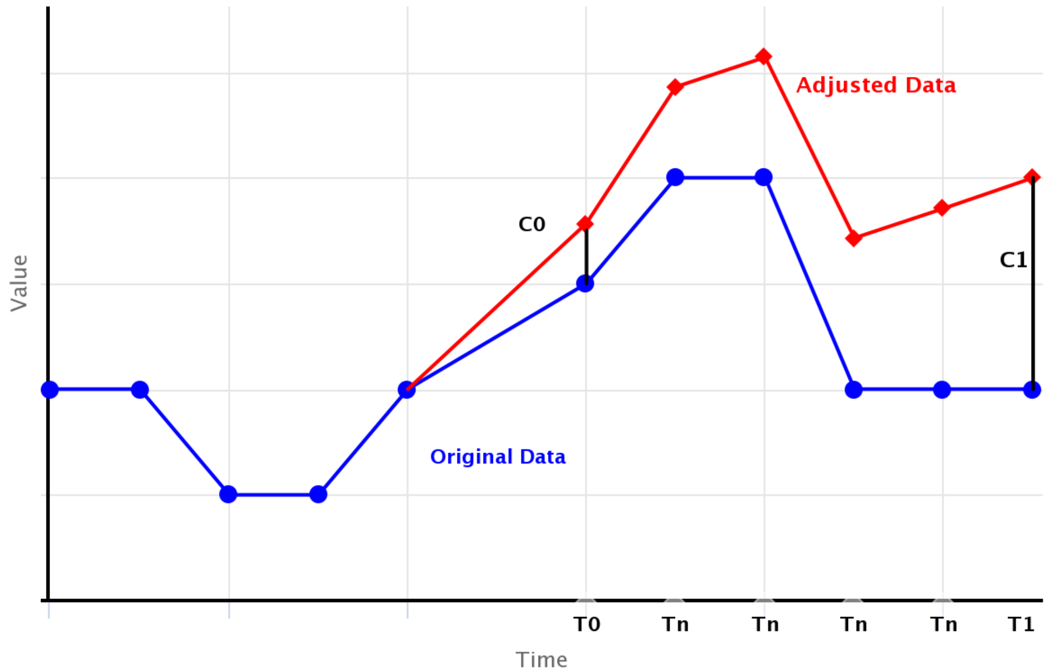


Figure 20 – Example of a two-tailed linear drift adjustment of C_0 to C_1 applied over the time period T_0 to T_1.

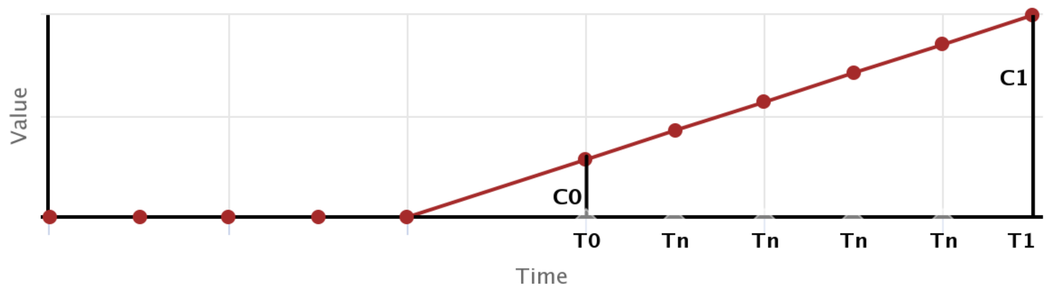


Figure 21 – Graph showing the gradually changing offset applied by the linear drift adjustment in Figure 20.

4.5 Non-linear drift adjustment

Non-linear drift with time may take many forms depending on cause and the tools available to adjust for non-linear drift differ between the time-series software used in New Zealand.

A simple but effective form of non-linear drift adjustment can be achieved by applying a progressive shift where the amount of shift is a linearly increasing or decreasing percentage of each value in the period of the adjustment (a 'percent linear' adjustment). The adjustment may be one- or two-tailed. A one-tailed adjustment begins or ends with zero change. The difference between original and adjusted values changes through the adjustment period in proportion with elapsed time and each original value, so the scale of the data is also changed.

4.5.1 Potential benefits

A non-linear drift adjustment may be more suitable for issues with some water quality sensors, and forms of biofouling or interference caused by growth of vegetation, than a linear drift adjustment.

4.5.2 Possible risks

The possible risks associated with a non-linear drift adjustment are essentially the same as for a linear drift adjustment (see Section 4.4.2).

4.5.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of adjustment. If the adjustment is significant, maximum quality code is QC 400 over the period of adjustment.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.5.4 Guidance for use

- Drift adjustments should be used with caution.

- Adjustment of data within tolerance should only be necessary if a step of some significance is created when the cause of the drift is resolved. For data used as a surrogate, significance is determined by the effect on the subsequent variable.
- While rating curves can apply non-linear relations, transition between ratings is linear with time so they are not a recommended alternative.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.5.5 Mathematics

Function: $$Y' = Y + (C_0/100)Y + ((C_1 - C_0)/100)\left(\frac{T_n - T_0}{T_1 - T_0}\right)Y$$

Where the function is the 'percent linear' example, Y' is the adjusted value, Y is the original value, C_0 and C_1 are the percentages of Y to be added at the start and finish times, respectively, T_0 is the start time of the adjustment, T_1 is the finish time and T_n is elapsed time since T_0.

4.5.6 Example

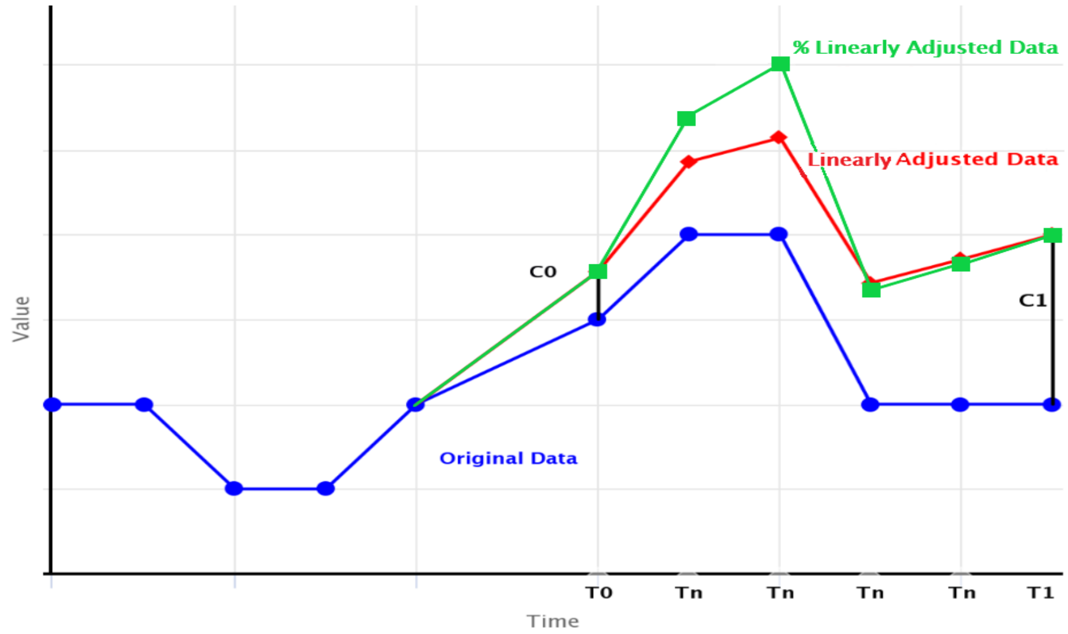


Figure 22 – Comparison of examples of two-tailed linear drift (red trace) and % linear drift (green trace) adjustments of C_0 to C_1 applied over the time period T_0 to T_1. For linear drift C_0 and C_1 are constants. For % linear drift they are percentages of the original value.

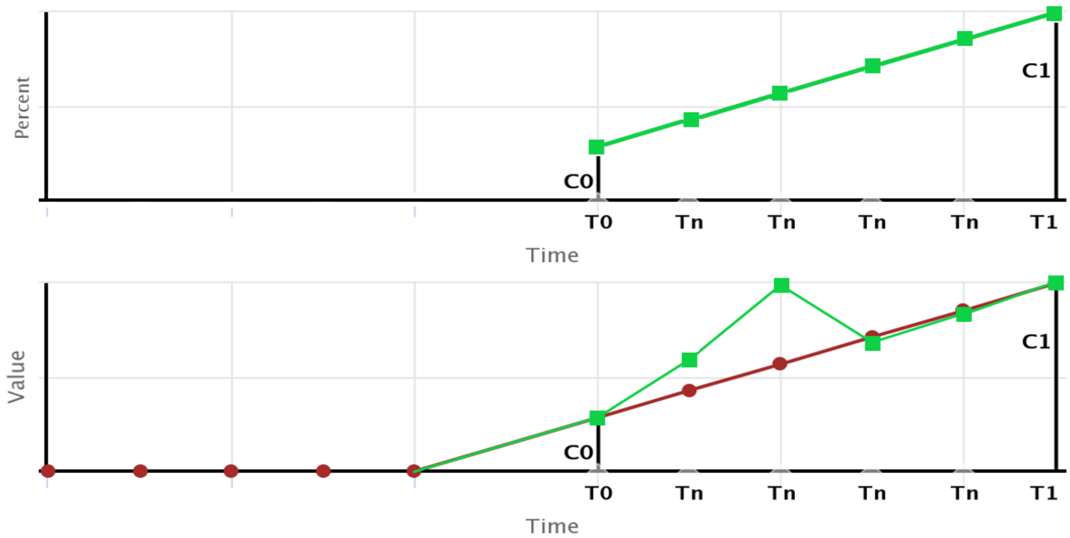


Figure 23 – Graphs showing the linear change in percentage (top) of the % linear adjustment (green trace), and its effect in terms of offset added (bottom) compared with the linearly increasing offset of the linear drift adjustment from Figure 202 (red trace).

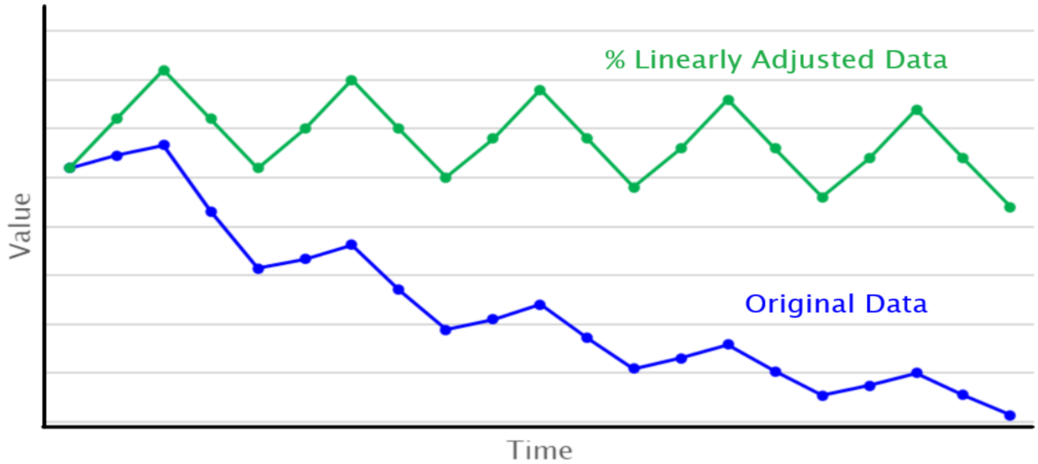


Figure 24 – Example of a one-tailed % linear drift adjustment of 0 to 200% applied over the entire dataset and showing the recovered range of the cycle.

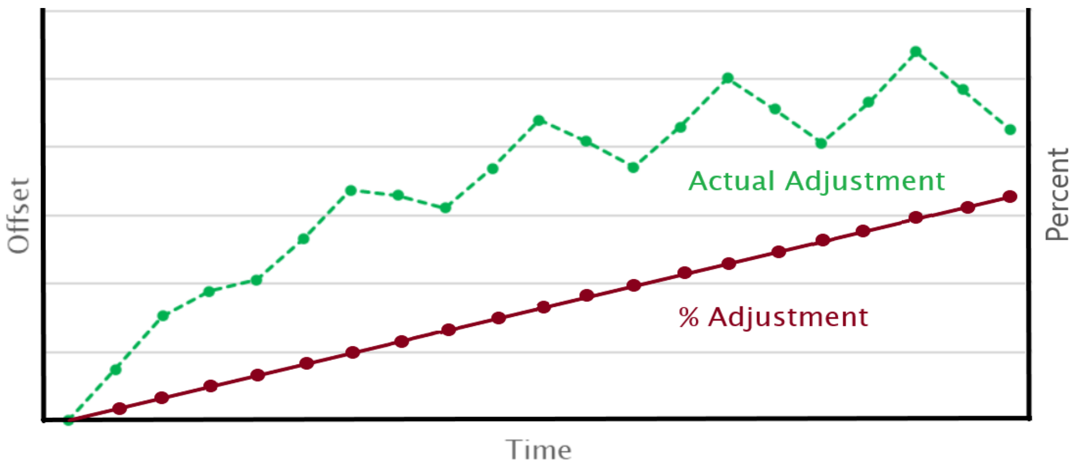


Figure 25 – Graph showing the proportional increase in the amount of actual offset applied to the original data in Figure 24 by the 0 to 200% non-linear drift adjustment.

4.6 Time drift adjustment

The time range of a dataset may be stretched or contracted. Time is altered progressively through the affected period, i.e. the amount each timestep within the period is stretched or contracted is prorated in proportion with its elapsed time since the start of the adjustment.

4.6.1 Potential benefits

'Elastic' time adjustment minimises error resulting from an instrument clock having lost time (run slow) or gained time (run fast) over the period.

4.6.2 Possible risks

Possible risks associated with time drift adjustment are:

- clock drift is rare with modern devices; it is more likely for a solid-state clock to have stopped or reset
- the method assumes the rate of drift is constant when it may not be
- if the evidence (including accuracy of reference observations) is in any way uncertain, errors may be introduced of the same order as, or greater than, the adjustment.

4.6.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of resulting actual time. If the adjustment is significant, maximum quality code is QC 400 over the period of resulting actual time.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.6.4 Guidance for use

- Time adjustments should be applied with caution.
  Note: NEMS requirements for accuracy of timing of measurements varies with the variable and environment. However, practically, adjusting fixed interval data for a period of clock drift that has accumulated to a discrepancy of less than one recording interval is rarely justifiable. Consequently, the need for time adjustments is effectively governed by the frequency of clock resets if a clock's timekeeping is relatively poor.
- Confirm, by comparison with another suitable record:
  - that the clock has drifted, and not stopped or reset, and
  - the period to be adjusted is correctly identified.
- Review, and revise, if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.6.5 Mathematics

Function: $T_n = T_x + C * \left(\frac{T_x - T_0}{T_1 - T_0}\right) \quad T_0 \leq T_x \leq T_1$

Where T_n is the new timestamp, T_x is the original timestamp at time x, T_0 is the start time of the period to be adjusted, and T_1 is the original finish time. C is the amount of time correction required between the actual and original finish times.

Note: In the Figure 26 example, the value of C is negative, thus the original finish time is brought back by the value C to the actual finish time.

4.6.6 Example

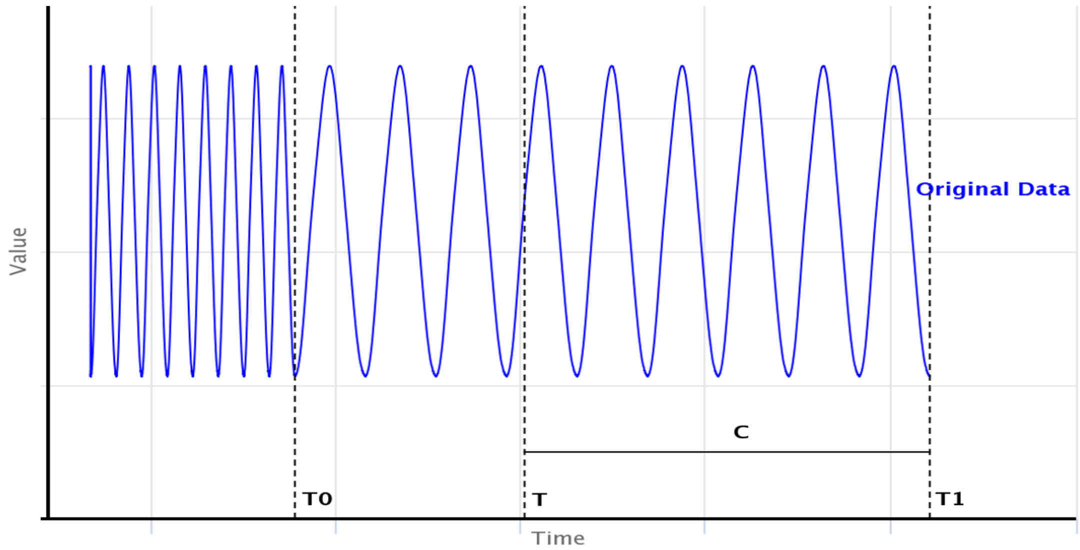


Figure 26 – Example of time drift where a clock has run fast between T0 and T so the apparent end time is T1, or when part of a dataset has been erroneously stretched. The period T0 to T1 needs to be contracted by the overall amount of time *C*.

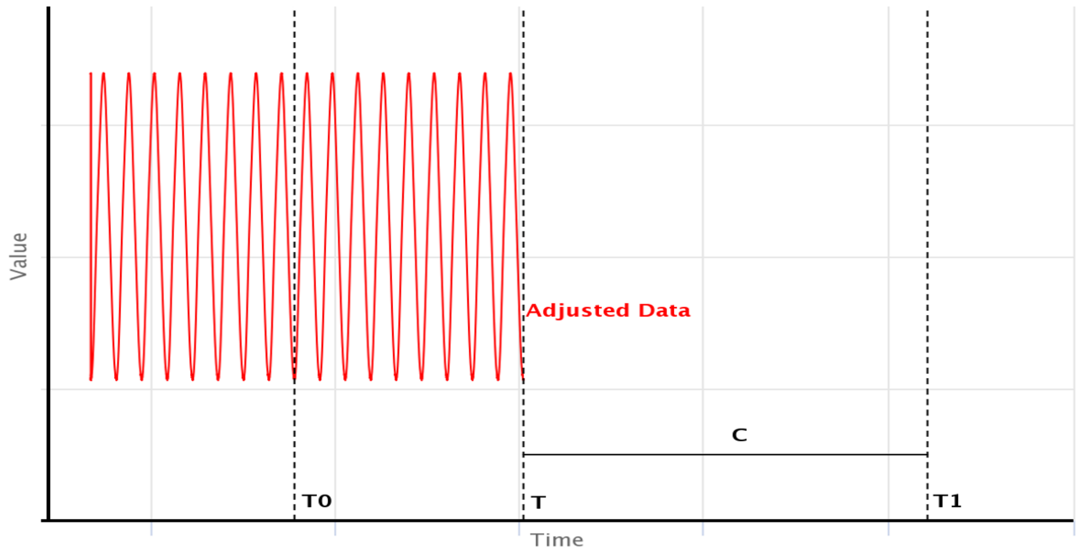


Figure 27 – Example of a time drift adjustment where the stretched data in Figure 26 have been contracted by the overall amount of time *C*.

4.7 Linear transformation

Linear transformation alters each value in a specified period according to a linear relationship that is applied to every value in the series.

It can be regarded as a correction if applied:

- in response to a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt. In this case it is often also associated with an offset error that must be corrected at the same time, or
- to convert between units or variables where there is a direct physical relationship that is not subject to assumptions and/or approximations.

4.7.1 Potential benefits

Potential benefits of and situations for applying a linear transformation are:

- rescaling data, such as to recover data collected from an incorrectly configured sensor
- converting data units, e.g. from imperial to metric
- reducing errors introduced by a shift in a sensor's calibration that has not also resulted in a loss of its linear response
- converting from a surrogate variable to the variable of interest, e.g. water pressure to water level, or resistance to conductivity.
  Note: this conversion may be done within an 'intelligent' logger or sensor.

4.7.2 Possible risks

A linear transformation may introduce error if:

- the relationship applied is in any way approximate
- the underlying relationship is actually non-linear, and/or
- the relationship is transferred as rating curve point-pairs between different time-series management systems (see Section 5.2.2, 'Exchanging a Rating between Software' in NEMS *Rating Curves*).
  Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.7.3 Effect on quality code

- A correction has no effect on the quality code for most variables.
- An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.

- If the Rating Curve engine is used, the quality code of the transformed data is the lesser of the input series and the quality code(s) assigned to the relation.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.7.4 Guidance for use

- The basis for correction should be at least as accurate as the data itself.
- In the case of a wrong instrument configuration the offset (constant C in Section 4.7.5) will also usually be affected by the scaling error and require recalculation in terms of the new data range.
- A linear transformation may be applied using the Rating Curve engine in some software and is often the best method for 'best fit' relations and/or those required continuously but that may vary over time.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.7.5 Mathematics

Function: $Y' = mY + C$

Where Y' is the new value, Y is the original value, m is the multiplier (slope of the line), and C is the constant to be added, if applicable.

4.7.6 Example

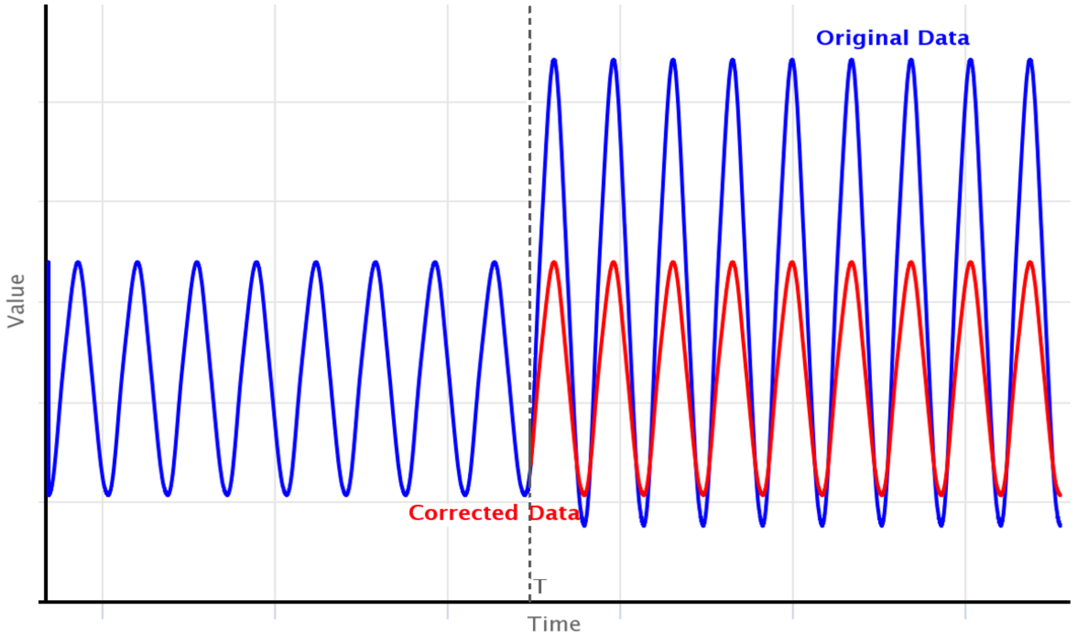


Figure 28 – An example of a linear transformation applied to data where the sensor was configured with an incorrect multiplier (and offset) at time T. The red line is the corrected data.

4.8 Change of data increment

This is a special case of a linear transformation specific to incremental (total in interval) quantities, where only the scale of the data is changed, usually to adjust the total recorded in a specified period to a corresponding primary reference gauge total.

This transformation changes the nominal resolution of the data.

4.8.1 Potential benefits

Potential benefits of and situations for applying a change of data increment are:

- compensating for factors that affect recording but are not addressed by instrument calibration, e.g. orifice height of a rain gauge
- rescaling data, e.g. if a tipping bucket gauge pulses only on one side
- minimising the effect of an incremental sensor's loss of calibration.

4.8.2 Possible risks

Possible risks of applying a change of data increment are:

- it assumes instrument calibration issues affect all data in a period the same way and to the same extent
- it has the potential to transfer unidentified error in a reference gauge total to the time-series record.

4.8.3 Effect on quality code

Quality codes for variables to which this transformation is applied are determined by the deviation of recorded from reference. Transformation of the data to compensate for the deviation does not subsequently change that quality code.

Refer to the relevant normative references and individual annexes for further guidance on code selection.

4.8.4 Guidance for use

This adjustment is required for all rainfall records where associated primary reference gauge totals are available and reliable.

4.8.5 Mathematics

Function: $Y' = mY$

Where Y' is the adjusted increment value, Y is the original value, and m is the multiplier to be applied to each increment. Usually, the multiplier is a factor equal to primary reference gauge total divided by recorded total.

4.8.6 Example

Table 1 – Example of change of data increment.

Period		Total Rainfall (mm)		Increment (mm)	
From	To	Recorded	Reference	Nominal	As filed
1/01/2011 17:15:00	19/03/2011 19:00:00	291	270	0.5	0.464
19/03/2011 19:00:00	17/10/2011 16:00:00	1561	1630	0.5	0.522
17/10/2011 16:00:00	31/12/2011 19:00:00	474	450	0.5	0.475

Also see Annex B 'Rainfall Data Processing', Figure B 5.

4.9 Non-linear or multi-variable transformation

Non-linear transformation alters each value in a specified period according to a non-linear relationship that is applied to every value in the series. Variable conversions described by power equations and complex equations to minimise the effect of non-linear calibration drift are examples of non-linear transformations.

Multi-variable transformations include secondary measurements as input to the function(s) applied to the time series. A common application in environmental data processing is compensation of a record for temperature and/or pressure.

Transformation can be regarded as a correction if applied:

- in response to a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt, or
- to convert between units or variables where there is a direct physical relationship that is not subject to assumptions and/or approximations.

4.9.1 Potential benefits

Potential benefits of applying a non-linear or multi-variable transformation are:

- recovering data collected from an incorrectly configured sensor
- converting data units, e.g. dissolved oxygen (DO) concentration to saturation
- reducing errors introduced by the loss of a sensor's calibrated linear response
- converting from a surrogate variable to the variable of interest, e.g. absolute to gauge pressure, then to head of water.

Note: These conversions may be done within an 'intelligent' sensor or logger and may be multi-variable, such as conversion of DO concentration to DO% saturation, which involves temperature and pressure, or barometric compensation of absolute pressures to obtain gauge pressures.

4.9.2 Possible risks

A transformation may introduce error if the relationship is:

- inappropriate
- in any way approximate
- multi-variable and/or multi-step, with each additional variable or calculation step adding its uncertainty to the overall uncertainty, and/or
- transferred as rating curve point-pairs between different time-series management systems (see Section 5.2.2 'Exchanging a Rating between Software' in NEMS *Rating Curves*).
  Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.9.3 Effect on quality code

- A correction has no effect on the quality code for most variables.
- An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.
- If the Rating Curve engine is used the quality code of the transformed data is the lesser of the input series and the quality code(s) assigned to the relation.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.9.4 Guidance for use

- The basis for correction should be at least as accurate as the data itself.
- Non-linear transformation is often relatively complex and not obvious from comparison of the transformed data with the raw version, so data provenance and traceability are crucial and must be fully documented in the data processing records.
- A non-linear transformation may be applied using the Rating Curve engine and is often the best method for 'best fit' relations and/or those required continuously but that may vary over time.
- Transformations should be applied carefully and checked, preferably by a peer.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.9.5 Mathematics

Function: often power equations of the form $Y' = cY^m$

or of rational form, for example $Y' = cY/(1-Y)$

Where Y' is the new value, Y is the original value, m is an exponent, and c is a constant, if applicable.

or multi-variable, for example $P_g = P_{abs} - P_{atm}$

Where P_g is gauge pressure, P_{abs} is absolute pressure and P_{atm} is atmospheric pressure.

4.9.6 Example

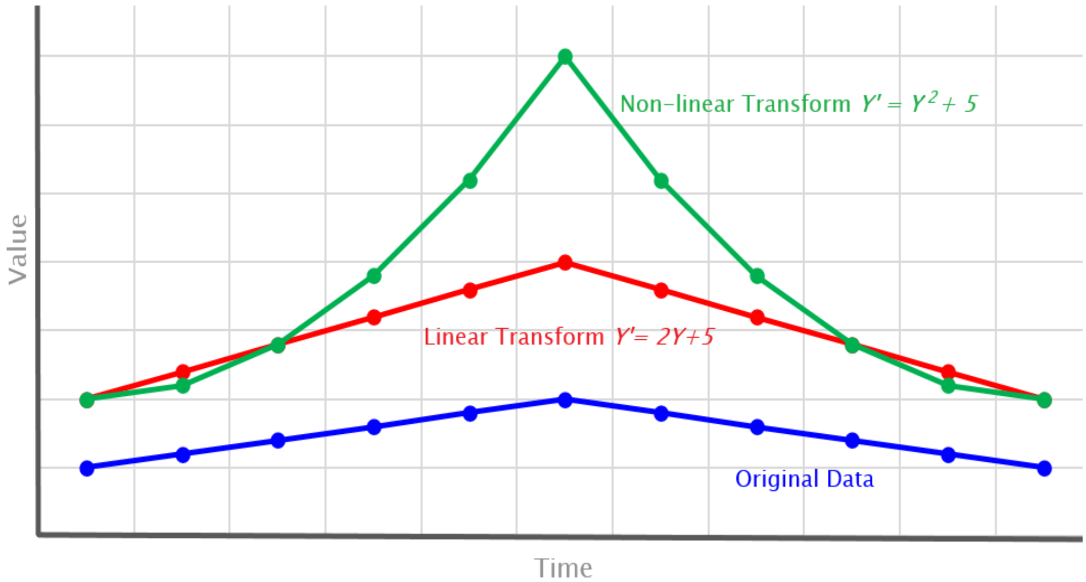


Figure 29 – An example of the difference between a linear and non-linear transformation applied to data. A linear transformation alters the scale of data but preserves its 'shape'.

4.10 Transitioning between transformations

The transformations required, for example to adjust for calibration drift or to convert a surrogate variable, may themselves vary with time, in which case it will be necessary to apply a new transformation at some time. If this is done at an instant in time it may create a step in the transformed data. To avoid this, a gradual transition between each successive transformation may be applied. This is most efficiently and effectively achieved using the Rating Curve engine, or similar functionality where that is provided in the software.

Refer to the NEMS for the variable, and/or NEMS *Rating Curves*, and software manuals and user guides as applicable.

4.10.1 Potential benefits

Transitioning between transformations:

- allows gradual transition between different transformations over time where they must be applied continuously
- avoids a sudden change between successive transformations, which may create a step in the transformed data.

4.10.2 Possible risks

Beyond the risks associated with the transformations themselves (see Sections 4.7 and 4.9):

- selection of the time period for transition and duration of the transition has a large influence on the resulting transformed time-series
- the transitions are complex to calculate and are error prone if not implemented using the Rating Curve engine (or similar functionality where that exists in the software)
- the Rating Curve engine transition method is pro-rata with time, which may not be appropriate or accurate in every instance
- transitioning between ratings can be configured to act the same way in any of the time-series management systems used in New Zealand but interpolation of curves may differ, so exchanging ratings between systems may produce different results (see Section 5.2.2, 'Exchanging a Rating between Software' in NEMS *Rating Curves*).
  Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.10.3 Effect on quality code

Maximum quality code for periods in transition is the lower of the quality code assigned to the transformed data or QC 500.

4.10.4 Guidance for use

- The basis for transitioning should be scientifically defensible.
- Periods of transition should be selected with care, and based on sound assumptions such as whether the new relationship is the consequence of continual drift or an identifiable event.
- Transformations should be applied carefully and checked, preferably by a peer.
- The method applied should be consistent throughout the time series.
- All periods of transition must be identifiable to an end user beyond assignment of quality code, e.g. provision for listing the dates and times of transition periods, or filing of a comment for each period.

- Review, and revise if necessary, the quality code of the transition period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

4.11 Spike removal

Spikes are values that are implausibly high or low compared with the values either side.

If due to fault or failure of electronics they will often be zero, the value of the sensor's current offset or full range default, or the null value assigned to a loss of signal (e.g. a NAN), but other causes will not be so definitive.

4.11.1 Potential benefits

Potential benefits of spike removal are:

- eliminating values that would otherwise skew the results
- minimising the effects of instrumentation faults
- minimising the effect of sporadic interferences in the environment, e.g. drifting debris catching on a sensor
- making the data more sensible and usable.

4.11.2 Possible risks

Possible risks associated with spike removal are:

- if assumptions about values not being 'real' are incorrect, valid values may be removed
- data of significance may be discarded
- significant amounts of data may be, possibly unjustifiably, discarded
- automatic spike filtering may delay identification of a developing instrument failure, or mask persistent interference that could be mitigated or eliminated at site.

4.11.3 Effect on quality code

- Removing known spurious data, such as values logged during a validation, has no effect on quality code.
- Replacing values, if the editing is minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.
- Deleting values with subsequent interpolation must be assigned a quality code of QC 300 for the modified period if:
  - duration is more than a few recording intervals (i.e. considered to be a synthetic record)

- the frequency of spikes removed is high compared with data retained (i.e. considered to be ‘estimated from limited measured data’).

Refer to Section 6.2.3 for explanation of ‘minor’ and ‘significant’, and the individual annexes for further guidance on code selection.

4.11.4 Guidance for use

Whether to delete or replace the value(s) depends on:

- the variable and data type
- knowledge of the recording system,
- the need to retain regular timesteps, and
- frequency of occurrence of the spikes.

If deleted, it is usually valid and sufficient to allow interpolation across the interval between the valid values either side. However, if preservation of the timestep is integral to the data, such as for a ‘value in interval’ data type, or if frequent users of the data require it at regular fixed intervals (e.g. if exported to spreadsheet or served to a website), edit the value to retain its timestamp.

If the spikes are very frequent, treatment as for noisy data is required.

Spike removal can be tedious and is often semi- or fully automated. If future reference to unmodified data is possible it may be sufficient to keep a count of the spikes removed in a period. If future reference to unmodified data is not possible then spike removal must be fully traceable, for example by maintaining a log of values removed that is compiled and included with the permanent processing metadata.

- Review, and revise if necessary, the quality code of the transition period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

Comments may be aggregated if repetitive to avoid overwhelming the comment file.

4.11.5 Example

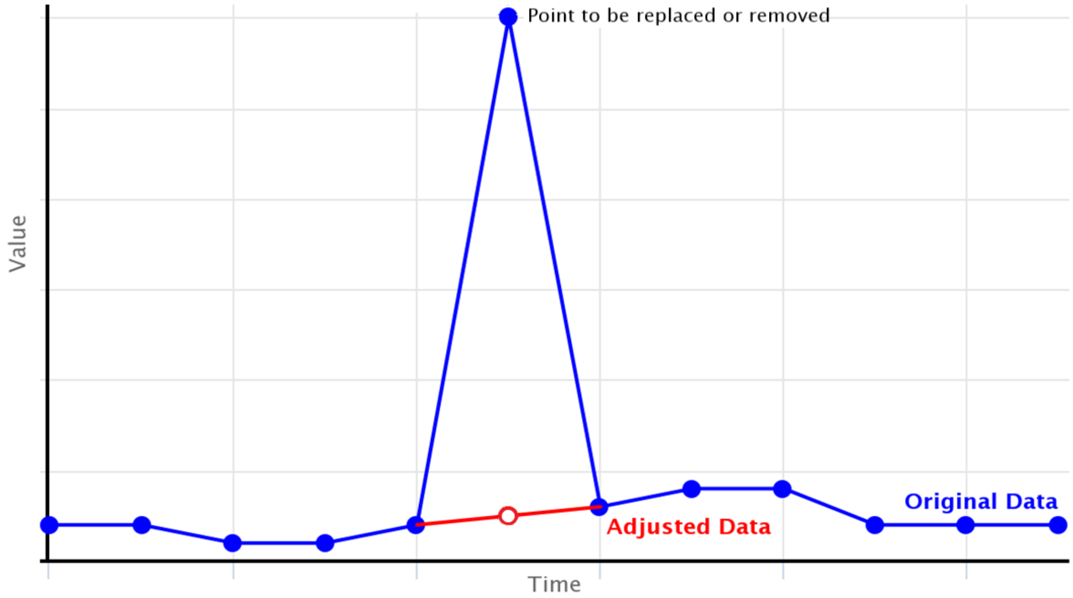


Figure 30 – Example of a spike that may be replaced (by the red circle) or removed with interpolation then connecting the values either side (red line between blue dots).

4.12 Filtering or resampling noise

Some datasets exhibit unacceptable noise that obscures the meaningful data. All or part of a time series may be filtered or resampled to reveal a signal more representative of the measured variable.

Noisy data, when graphed, appear 'furry' or have a 'fatter' trace than unaffected periods. Noise can arise from a variety of situations, including the actual behaviour of the quantity being measured, i.e. it may be 'real' but still be an undesirable feature of the record. Understanding the cause(s) of the noise, the normal behaviour of the quantity being measured, and the purpose of the data is essential to deciding if, when, and how to edit it.

4.12.1 Potential benefits

Potential benefits of filtering or resampling noise are:

- improving presentation of the data, i.e. the data look more sensible when graphed, especially to a person unfamiliar with the measurement process
- avoiding incorrect conclusions being drawn about what the variability represents
- minimising the effects of noise caused by interference or faulty equipment, e.g. electrical or radio interference, insufficient power supply, accumulation of debris, or instrumentation about to fail

- not transferring and possibly amplifying noise in a surrogate variable's measurements to the target variable's time series. For example, to be reliable, determination of flow using rating curves requires a static water level free from the influence of wind, waves, and pressure variations.

4.12.2 Possible risks

Possible risks associated with filtering or resampling noise are:

- the modified data appear to have greater accuracy than is real
- masking certain values may disguise errors that could otherwise be detected
- moving averages can induce significant hysteresis in the modified data
- removing information that may be useful for other purposes, e.g. wave lap in a water level record may compromise determination of volume or flow but be useful for erosion or hazard studies
- wrong assumptions about cause of the noise leading to inappropriate, and possibly biased, editing
- loss of resolution.

4.12.3 Effect on quality code

- Quality code applied cannot be QC 100 or QC 600.
- Unless the modification can be considered 'minor', quality code cannot exceed QC 400 for the altered period.
- In the case of biased noise (see Section 4.12.4) it should be kept in mind that the minima or maxima selected may still be compromised, and hence the maximum quality code achievable is QC 400.
- Data producers must exercise responsible discretion as to when QC 300 may be more applicable than QC 400. That is, the filtering or resampling applied may have removed enough of the original resolution for the data to be more truthfully described as 'estimated from calculations, or limited measured data' rather than 'measured data that have undergone significant modification'.
- QC 200 (of unknown quality) may be applied if a 'higher' code cannot be settled on.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.12.4 Guidance for use

Whether to suppress the noise, and which method to apply, depends on:

- the variable
- cause of the noise, and

- the purpose of the data.

If the affected variable is a surrogate, consider the effect on the target variable.

If the noise is random, such as wave action affecting a surface reflection water level sensor, a moving average (or median) filter, centred on the averaging interval, is appropriate. Results of applying the moving average must be carefully assessed, especially if the underlying signal is changing rapidly, e.g. at onset and over the course of a river fresh, tide or diel cycle.

If the noise is biased high, such as may be due to electrical interference or burial of a pressure sensor, minimum values should be retained and higher values discarded.

If the noise is biased low, such as may be due to insufficient power supply to a sensor, maximum values should be retained and lower values discarded.

Results are sensitive to the filtering or resampling interval. The minimum interval to achieve the desired suppression should be used. This may require some trials. Centring on the interval may not prevent induced hysteresis.

A consistent approach should be taken for noise due to the same cause.

Filtering or resampling must not be applied again on the results of a previous attempt.

Often the results of filtering or resampling noise should technically be stored as a different data type, e.g. a period of noise in a water level record that is smoothed using a fixed interval average should also be changed from instantaneous (continuous) to 'average in interval', but a time series cannot contain both types (see Sections 1.1 and 4.14). This means the final filed result is often yet another approximation.

Results must be graphed with the unmodified data and with a comparison site to confirm the transformation has not introduced other problems and is an acceptable representation of the variable.

A cautionary approach is recommended with conservative principles, particularly if the normal behaviour of the variable is not well understood; however, in such cases the metadata should be clear to a user of the data where such uncertainty exists.

- Review, and revise if necessary, the quality code of the filtered period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

4.12.5 Mathematics

Function: A statistical algorithm such as a fixed or moving interval average or median, or

A resampling filter, for example, selecting each maximum or minimum in a specified interval or discarding values according to some threshold rate of change rule.

4.12.6 Example

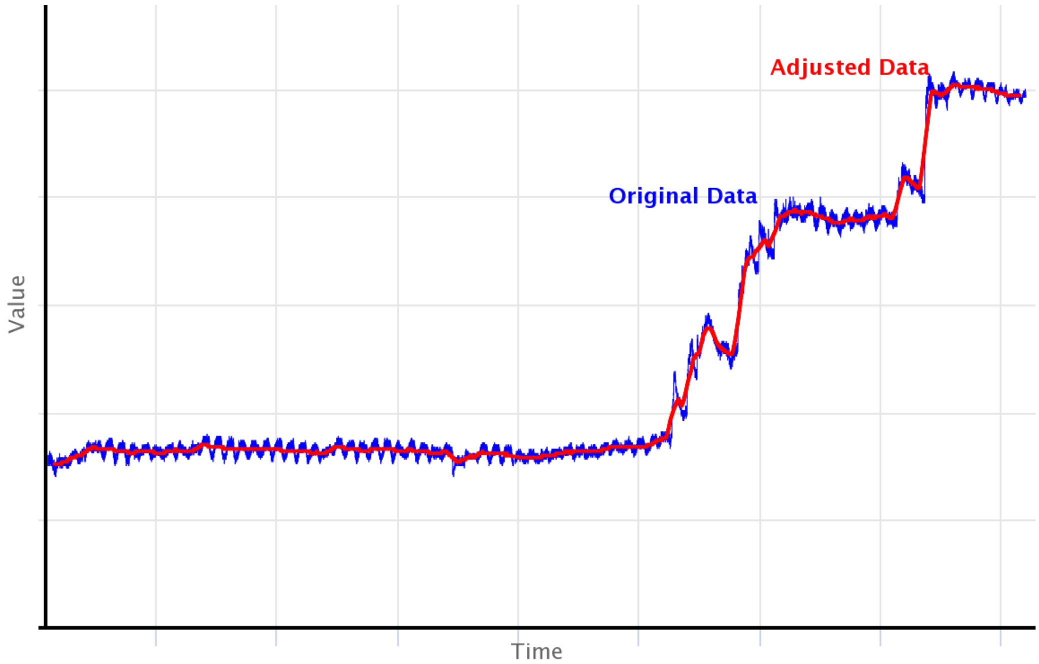


Figure 31 – Example of noisy data smoothed using a moving average centred on the interval, i.e. shifted back by half the averaging interval.

4.12.7 Noise induced by data collection method

4.12.7.1 Multiple data streams

Noise can arise when values from more than one data source for the same measurement are collected then merged into a single time series. Examples are:

- readings from two turbidity sensors at the same site, each with different range (to obtain range coverage while preserving low end resolution), and thus two different values are captured for the same recording interval
- data collected from a sensor via two paths using different and unsynchronised clocks, e.g. direct transmission of values via satellite and radio polling of at-site logged data, so that the same value may be assigned two slightly different timestamps.

Managing the successful merging of the data requires policy about which data source takes precedence and when. The policy must be documented, implemented as required, and summarised in one or more relevant comments.

4.12.7.2 Supervisory Control and Data Acquisition (SCADA) systems

Noise and data loss are both possible in a time series collected by SCADA systems due to disparities between remote device clocks and the base clock. The issues have most impact on the recording of incremental (totalling) data, so further detail is provided in Annex B, 'Rainfall Data Processing' and Annex F, 'Water Meter Data Processing'.

4.13 Repacking data

Repacking is when a time series of interpolating data type is recalculated or resampled at regular intervals. The new interval may be different from the original timesteps, whether regular or irregular. Examples are:

- values aggregated and/or apportioned into regular intervals of a different duration, or
- values interpolated at a regular and/or different timestep.

Repacking is known as resampling in some time-series management systems.

4.13.1 Potential benefits

Potential benefits of repacking are:

- may reduce data file size if the new timesteps are larger
- may make the data more useful for a particular user, for example:
    - providing a series of daily means instead of 15-minute samples
    - converting irregular timesteps to fixed interval data for use in systems that do not have a true time facility, or do not support irregularly spaced samples
    - synchronising samples across multiple series, e.g. values at noon.

4.13.2 Possible risks

Possible risks associated with repacking are:

- apportioning assumes a constant accumulation rate that may be untrue
- loss of definition if new timesteps are larger
- extra values could give the impression of providing more definition than is real if new timesteps are smaller.
  Note: Repacking data to smaller intervals usually has no advantage except to establish regular intervals or match other datasets.

4.13.3 Effect on quality code

The quality code of repacked periods shall be downgraded.

- Quality code applied cannot be QC 100 or QC 600.
- Quality code cannot exceed QC 400 for the altered period unless the modification can be considered 'minor'.
- Data producers must exercise responsible discretion as to when QC 300 may be more applicable than QC 400. That is, when the repacked or

resampled data are more truthfully described as ‘estimated from calculations, or limited measured data’ rather than ‘measured data that have undergone significant modification’.

- QC 200 (of unknown quality) may be applied if a ‘higher’ quality code cannot be settled on.

Refer to Section 6.2.3 for explanation of ‘minor’ and ‘significant’, and the individual annexes for further guidance on quality code selection.

4.13.4 Guidance for use

Repacking data should only be part of a process for data analysis or preparation for export. However, with respect to data processing, data analysis may include:

- comparing two or more ‘value in interval’ time series for quality control purposes, or
- preparing synthetic data to fill a gap.

A change of data type may be necessary to ensure proper subsequent treatment and interpretation of the resulting series (see Section 4.14).

Repacking should not be necessary after processing and before archiving the verified processed data (e.g. to re-establish the recording interval in edited data). The same interpolation engine usually performs this function on demand as data are subsequently read from the archived series. However, there are two exceptions:

- it may be more efficient to repack data to regular intervals during data processing if it is routinely exported or served to systems that do not support irregular intervals in continuous data
- some time-series software can deliver data at any desired interval as part of the export/delivery process so there is no need to repack data in these systems prior to archiving. However, others export the data exactly as archived, so if fixed interval data are required, the data must be archived at fixed intervals and repacking may be needed as the final data processing step before archiving to ensure this.

Repacked data cannot be quality coded QC 600 (see Section 4.13.3) and periods repacked must be explained in a Data Processing Comment (see Section 6.2.4.7).

4.13.5 Example

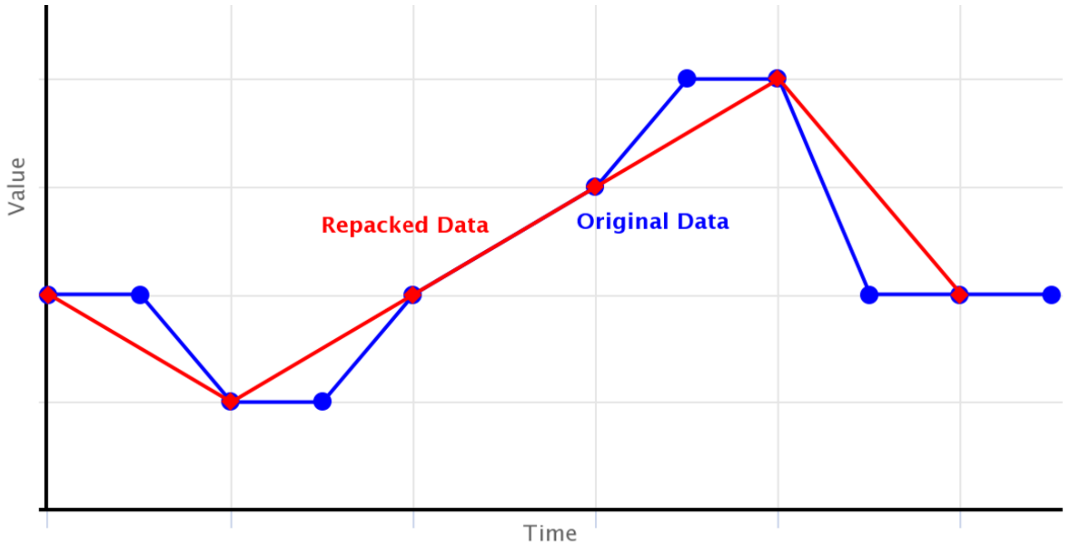


Figure 32 – Example of an instantaneous (continuous) dataset before (blue) and after (red) it has been repacked (resampled) to intervals twice the original timesteps.

4.14 Changing the data type

Data types are explained in Section 1.1. The data type of a time series can be changed, which will change the 'kind' of data, i.e. how the data are to be interpolated (or not) and what the values represent.

In some systems the interpolation method can be changed independently of other characteristics. For example, totals (in preceding interval) can be interpolating, where portions of totals can be assigned to different intervals (apportioning), or discrete, where values can be tallied (aggregated) into larger intervals but not 'spread' (apportioned) across smaller intervals.

Some systems allow interpolation method to vary within a time series so that discrete samples and continuous data can be combined in the one dataset, with each interpreted and treated appropriately without further manipulation.

Reasons for changing the data type and the methods to do so are therefore also dependent on the system and software used to store and manipulate the data.

4.14.1 Potential benefits

Changing the data type may:

- better represent the data
- make the data better suited for analysis, or
- correct a mistake made at set-up of the data type definition for the time series.

4.14.2 Possible risks

Changing the data type of a time series has far-reaching effects on how the values are interpreted and treated, some of which may be unanticipated and significant.

4.14.3 Effect on quality code

It is unusual for the data type of verified data to be changed for the purpose of archiving unless to correct a mistake with the initial data type specification. Quality codes should not be affected but should be reassessed against the requirements for the variable in question to confirm.

If the data type is changed in conjunction with repacking the data, quality code is determined by the repacking (see Section 4.13.3).

4.14.4 Guidance for use

Unless a mistake was made with the initial data type definition for the time series, the data type should be kept as originally defined, for the purpose of archiving verified data. This has implications for data that have been filtered, resampled, repacked or created to fill a gap (see Sections 4.12, 4.13 and 4.20) in that the values filed may ultimately be interpolated differently to how they were obtained and what they therefore represent.

If some arithmetic is performed on the data or a transformation applied, and the results are to be written to a new time series, a change of data type may be necessary to ensure proper subsequent treatment and interpretation of the resulting series. Change of data type may be done automatically by the time-series software as part of the calculation process but other software requires the user to specify how the results are to be stored.

Common examples are:

- a time series of daily mean flows calculated from 5-minute instantaneous (continuous) data that should be written to a time series with data type ‘average in preceding interval’
- a series of cumulative totals calculated from incremental totals, or vice versa.

4.15 Compressing data

The various time-series managers offer different types of data compression and different levels of system and user control. In the context of this NEMS, compressing data refers to the lossy process of removing redundant values from a time series by virtue of them being on or close to a straight line between adjacent points. Definition and implementation of ‘on’ and ‘close to’ also differs between the software.

Historic data may be heavily compressed, partly due to data storage and computation constraints, but often too as a crude method of suppressing noise. A time series of historic data may contain periods with different levels of compression applied.

4.15.1 Potential benefits

Potential benefits of compressing data are:

- removing unnecessary values; for example, there is a significant amount of redundant data in a fixed interval rainfall series during dry periods
- reducing file size, and potentially machine computation time
- reducing the number of values to be transmitted.

  Note: Compressing data may become an important consideration again as more systems migrate to the cloud because of the costs and limitations of internet services in New Zealand.

4.15.2 Possible risks

Possible risks associated with compressing data are:

- using a non-zero range compression can smooth data unnecessarily and reduce its resolution
- the various software differ as to how compression range is specified into the process; some apply the specified range as ± and others as a band that is halved to achieve a ± range. For example, a 3 mm compression in some systems is the equivalent of 6 mm compression in others (see Figure 35)
- removing redundant values with a range zero compression poses no risk to integrity or accuracy of the data, and the uncompressed data are fully recoverable if repacked to recording interval using the same software, provided the compression has been performed only once on the data
- because data type and number representation also play a part, repacking data compressed to range zero by another system, in an attempt to recover the initial uncompressed series, may not be straightforward and may result in different, although possibly no less accurate, values to those in the initial uncompressed series.

  Note: Most historic data in New Zealand were processed and archived originally in TIDEDA. Because it is limited to storing data as integers, TIDEDA adds 0.5 to the specified compression range when the process runs, so TIDEDA's 'zero compression' removes more than just duplicated values, unlike other systems. If data compressed in TIDEDA to a specified range of zero are migrated then repacked using one of the other time-series managers, the results may not be identical to the values originally stored in TIDEDA but may be no less accurate because the other systems can store values in floating point form that TIDEDA had to round up or down.

4.15.3 Effect on quality code

The quality code cannot be QC 600 if a non-zero compression is applied.

The quality code to be applied to the compressed series must take into account:

- the descriptions of what constitutes 'minor' and 'significant' modification of the data (see Section 6.2.3), and
- the relative size of the compression range applied, compared to the quality code data resolution thresholds for the variable.

Refer to the individual annexes for further guidance on code selection.

4.15.4 Guidance for use

Compression to remove only redundant duplicate values may be applied if desired, without need for change of quality code or commenting of each instance, to:

- any instantaneous (continuous) time series
- any run of zero values in an incremental time series.

Non-zero compression is not recommended when preparing verified data for archiving.

If compression is used:

- data producers must understand how their system applies the specified range, in order to choose an acceptable range
- compression must not be applied again to the results of a previous attempt, i.e. no data should be compressed more than once
- results must be graphed with the unmodified data to confirm the compression has not removed an unacceptable amount of detail and the data remain representative of the behaviour of the variable
- a cautionary approach is recommended with conservative principles, particularly if the normal behaviour of the variable is not well understood
- review, and revise if necessary, the quality code of the compressed period
- file a comment for the period that records the software used, the compression range applied, what the range means in terms of C or C' in Figure 35, and the reason(s) for compressing the data.

4.15.5 Example

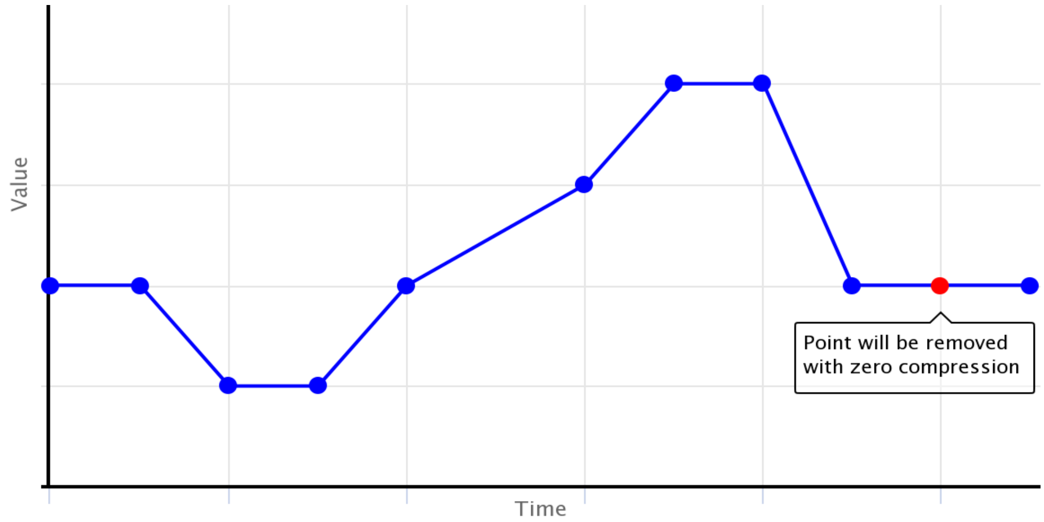


Figure 33 – Example of a time series with a redundant point that would be removed if range zero compression were applied.

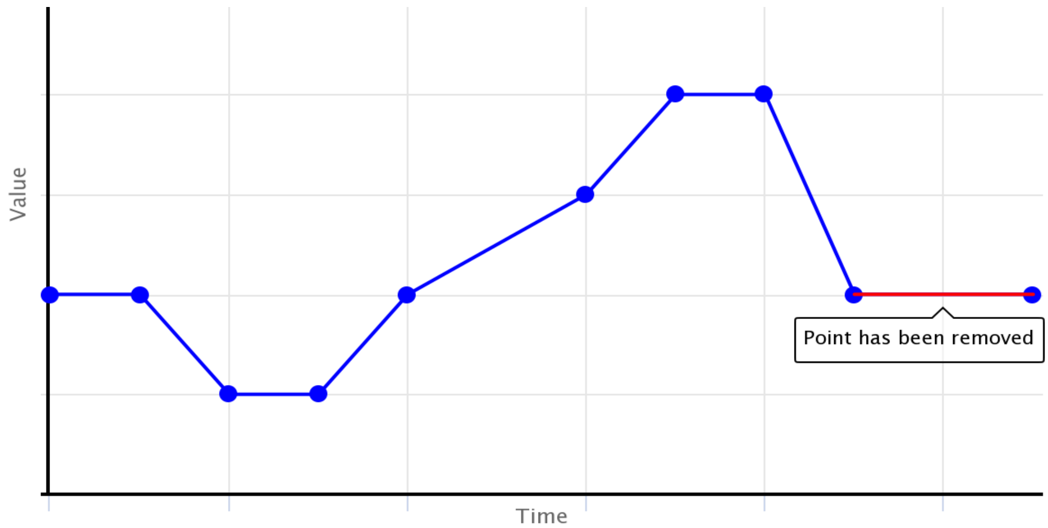


Figure 34 – Example of the time series in Figure 33 where the redundant point has been removed by range zero compression.

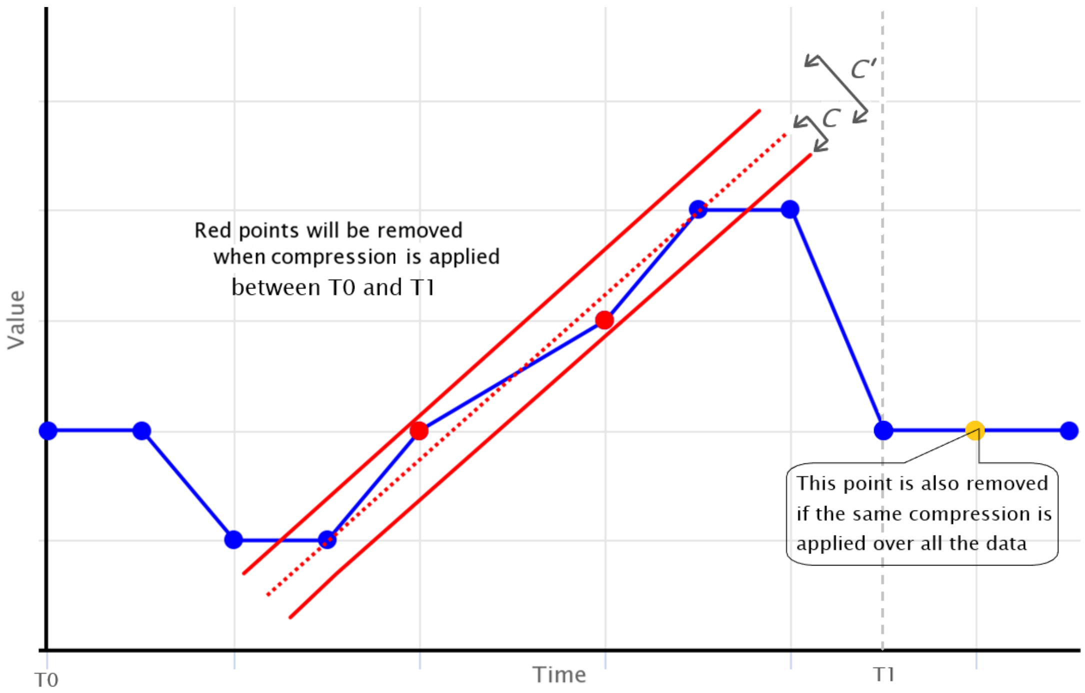


Figure 35 – Example of a time series with two redundant points (red dots) if non-zero compression is applied between T0 and T1. If applied over all the data, the orange point is also removed. Range specified to the process is *C* or *C'*, depending on the software used.

4.16 Marking gaps

If the time-series data type is interpolating, any gap in the data series must be identified to prevent interpolation over the relevant period. This is achieved in the software by some form of flag or marker or 'valid data' period boundary in the series and shows in a plot of the data as a break (empty space) in continuity of the trace.

An interpolating data series must be inspected for any periods of missing data that have not been marked as gaps. If the data are fixed interval, search for timesteps that exceed that interval. Otherwise, search for timesteps that exceed some suitable nominal interval and/or inspect the trace of a plot of the data for any unusual pattern that may indicate data are missing, e.g. a straight line where you would expect to see a curve.

Where a gap flag or marker should be present but is absent, and the gap is not to be closed or filled prior to final archiving, it must be manually applied. The period of the gap must be assigned quality code QC 100 and be accompanied by a Data Comment (see Section 6.2.4.6).

Gap markers are not applicable to discrete data types, but data may still be missing. Relevant periods must be quality coded QC 100 and be explained by a Data Comment (see Section 6.2.4.6).

If infilling is attempted but fails, the Data Comment filed should include explanation of what methods were attempted and why they failed. Future methods, technology or data may permit these gaps to be filled at a later date and such guidance will be valuable.

If the gap is for an extended period, and especially if it is a result of significant site maintenance or change of location, consider whether the gap should instead be treated as a temporary or permanent site closure.

4.17 Closing gaps and interpolation

A gap in a time series that is stored with an interpolating data type can be closed by removing the gap flag, gap marker, or gap period boundary, and thus re-enabling interpolation between the adjacent values.

If the time interval is short, and/or linear interpolation at constant rate with time is valid between the adjacent values, this may be all that is required; commonly when a logger or sensor is shut down briefly for servicing and personnel can observe that it is valid to interpolate the missed data.

If the interval is longer or the data type is discrete, extra values can be inserted by interpolating manually between adjacent values using the equation given in 4.17.5.

Note: If the series is of interpolating data type and linear interpolation at constant rate with time is valid, it is not necessary to add values into the interval regardless of its length; the interpolation engine of the time-series manager will derive values as and when required at any time in the interval.

4.17.1 Potential benefits

Interpolation is usually valid if the time between the adjacent values is short compared with the time taken for the variable to change under the natural processes occurring at the time, and the reason for the gap is known. Interpolation avoids small, unnecessary gaps in the data record, which may interfere with data analyses.

4.17.2 Possible risks

The validity of interpolation depends on the time period filled in relation to changes in the variable, and evidence that no change occurred that is not reasonably represented by the interpolation. There is risk that an important event or unexpected change was missed and thus this action should only be done if there is corroborating evidence that no such event or change occurred during the gap.

4.17.3 Effect on quality code

The interpolated period shall be QC 300 (as synthetic data) if duration is more than a few recording intervals.

An exception is when personnel on site were able to observe and note that the variable did not change or it changed uniformly over the period, such as during equipment maintenance. In this case, given that the behaviour was observed, the quality code can remain unchanged from the adjacent record.

4.17.4 Guidance for use

Interpolations of longer than a few recording intervals should be allowed with caution, considering the above points. Should the verified data have this method of data correction applied, then this must be documented in the associated comments. Comments may be aggregated if repetitive to avoid overwhelming the comment file.

4.17.5 Mathematics

The following is a simplistic depiction to determine the interpolated point Y':

Function: $$Y' = \left(\frac{Y_2 - Y_1}{T_2 - T_1}\right)(t' - T_1) + Y_1 \quad \text{if } T_1 \leq t' \leq T_2$$

Where Y_1, Y_2, are the original series values and Y' is the value interpolated.

4.17.6 Example

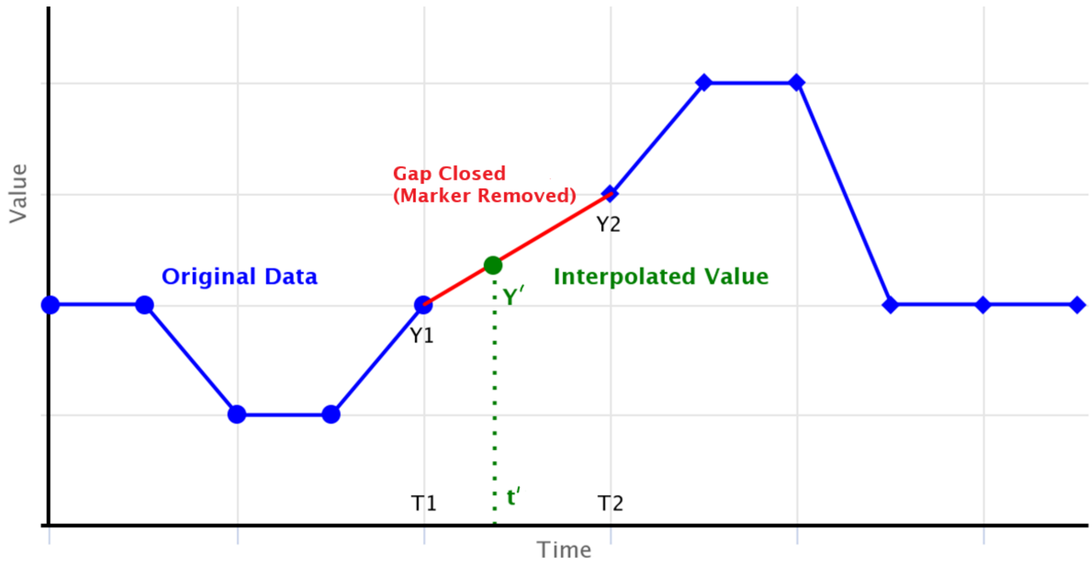


Figure 36 – Example of closing a gap between Y_1 and Y_2 so that values may be interpolated at any time t' between T_1 and T_2.

4.18 Infilling a gap with observations

Some or all of a gap in a data series may be filled by inserting values observed or measured while on site, most commonly from the primary reference and when the gap either immediately precedes (due to recording fault), or is caused by, activities during a site visit.

If the time interval is short and the observations are adequately representative of the behaviour of the variable, this may be all that is required. Otherwise, other methods of infilling must be employed.

Available periodic actual observations and/or retrospective measurements such as a surveyed peak flood level must be used to verify synthetic data generated by other infill methods and be incorporated into the final record.

4.18.1 Potential benefits

Infilling a gap with observations is valid for the duration over which the behaviour of the variable is observed with sufficient time resolution to be representative of that behaviour. Doing so minimises the number and extent of gaps in the record that may interfere with data analyses.

Periodic observations and/or retrospective measurements enhance the reliability of results of other infill methods by providing some certainty, for example, to the estimation of a significant event such as a peak flood level.

4.18.2 Possible risks

Validity of the infill is dependent on frequency and timing of observations in relation to changes in the variable. If observations are sparse there is a risk that the actual variation is under-represented in the data.

4.18.3 Effect on quality code

If the observations provide a suitably complete record, quality code for the relevant period can be one of QC 400, QC 500 or QC 600 depending on assessed accuracy of those observations. Otherwise, quality code must be QC 300, either by way of the infill being largely synthetic data or estimated from limited measured data.

4.18.4 Guidance for use

Each period infilled with observations must be explained with a comment. Use of the data should be guided by the general implications of the assigned quality code and the information provided in the relevant comment(s).

4.19 Infilling a gap with a curve

A gap in a data series may be filled by inserting values that:

- complete the curve that can be reasonably inferred from the trace when a short period of data surrounding and including the gap is plotted, and/or
- mimic the curve evident in a comparison plot of the simultaneous period of reliable data for the same variable from a nearby site, or
- follow the curve evident in a reference plot of a similar period of reliable data for the same variable at the same site.

4.19.1 Potential benefits

Infilling a gap with a curve is usually valid if the duration of the gap is short, the behaviour of the variable under the natural processes occurring at the time is well understood, and the reason for the gap is known. Doing so avoids small, unnecessary gaps in the data record, which may interfere with data analyses.

4.19.2 Possible risks

The validity of infilling a gap with a curve is dependent on the time period filled in relation to changes in the variable and whether fitting a curve is appropriate. There is risk that an important event or unexpected change was missed and thus this action should only be done if there is corroborating evidence that no event or deviation from the curve occurred.

4.19.3 Effect on quality code

The inserted data values shall be quality coded QC 300 (as synthetic data).

4.19.4 Guidance for use

Use with caution, considering the above points. Each period infilled with a curve must be explained with a comment.

4.19.5 Example

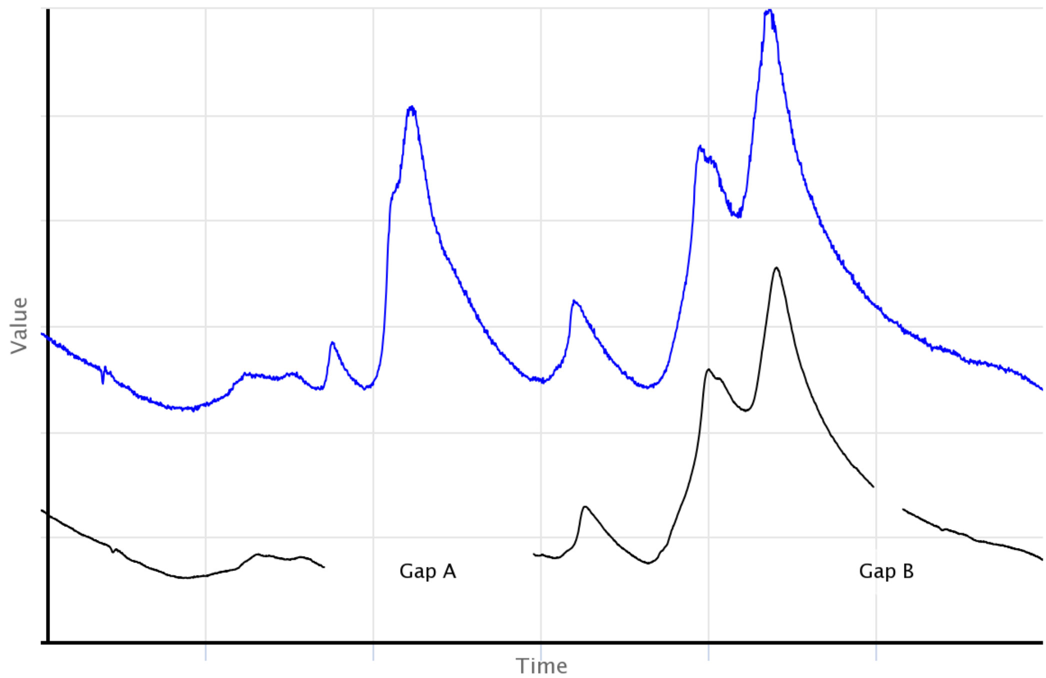


Figure 37 – Example of period with missing data (black trace) and comparative site (blue trace) overplotted. Gap A should only be filled using methods described in Section 4.20, whereas Gap B could be filled by a curve as described in Section 4.19.

4.20 Infilling a gap with synthetic data

A gap in a data series may be filled with synthetic data if a suitable predictive relationship can be derived with one or more variables from one or more adjacent or nearby sites.

4.20.1 The process

Follow these steps when creating a synthetic record:

- gather all available information that may assist with synthesising a record to fill the gap
- explore relationships useful to building models able to generate the necessary synthetic data
- decide the interval (timestep) of the synthetic data to be created
- decide the model to be applied
- create the model
- test the model and, if acceptable,
- apply the model to generate the required synthetic data
- review the synthetic data and, if acceptable,
- incorporate it into the record to be archived, with quality code of QC 300 applied
- describe the model and the accuracy of the synthetic data in a filed comment
- preserve and retain all working
- if desirable, retain the model for future use.

Method detail, including any provisos and exceptions relating to synthesising data for a specific variable is provided in the relevant annex for that variable.

4.20.2 Potential benefits

Because gaps can interfere with data analyses, filling a gap with synthetic data is preferred to leaving the period as missing. Depending on the variability of the data and the reliability of the relationship used to generate the synthetic data, periods of two to three weeks of synthetic data may be reasonably estimated.

4.20.3 Possible risks

The synthetic data generated by some methods may not be fully compatible with the data type and/or resolution of the time series into which they will be incorporated. For example, synthetic data intended for an instantaneous series may be generated from a relationship between hourly or daily averages. Most time-series management software do not permit the mixing of data types within the same time series, so the synthetic data derived will not be represented as averages once included in the record.

Results of regression may be overly affected by outliers or may under-represent actual extremes during the period of infill.

An event may occur at one site but not the other, leading to unreliable results unless other information is available to assist.

4.20.4 Effect on quality code

All synthetic data shall be quality coded QC 300.

4.20.5 Guidance for use

Use with caution, considering the above points. Each period infilled with synthetic data must be explained with a comment.

Synthetic data should not be included in model calibration or extreme event analysis without due consideration of its potential influence in the context of each specific project (McKerchar et al, 2010).

5 Applying Adjustments to Data

This section contains the rationale and general procedure for making any necessary modifications to the raw data.

5.1 Principles

- Data shall, whenever possible, be corrected or adjusted for value and/or time when it fails a relevant quality control test (see Section 3.6).
- Data that pass all relevant quality control tests need no modification.
- All modifications to data that are intended for archiving must be verified as necessary and appropriate.
- Data should not be routinely edited or adjusted to every verification value (e.g. by 'auto-calibration').
  - Other checks of the data, and diagnosis of the cause of anomalies and deviations, are required.
  - Random variation in the verification data (i.e. primary reference readings) may distort and/or add uncertainty into an otherwise consistent and reliable record from the sensor.
  - Maximum quality code of QC 400 will apply because duration of the adjustment is significant (see Section 6.2.3).
- Automated quality control and processing may be applied but periodic review by a skilled and experienced person is required (see Section 7).

  Note: Success of automated quality control and/or processing depends on redundancy in the data production system, e.g. more frequent verification data, backup sensors at site for the same variable, and/or similar nearby sites in a network.

5.1.1 Modifications to data

Any modification to data shall be:

- conservative
- traceable
- documented
- performed or approved by experienced personnel
- described in a time-bounded, time-stamped comment, and
- quality coded appropriately.

The goal for any environmental monitoring programme should be the collection of complete and reliable data. Unfortunately, equipment failure, vandalism and environmental conditions sometimes cause data loss or the collection of biased or erroneous data.

Any data intended for final archive must be representative of the variable measured. If the data collected are not representative it must be repaired, replaced, or removed prior to archiving. However, personnel dealing with environmental data have a duty to be conservative when altering or discarding any recorded data.

Any action on the data should be accompanied by efforts to minimise the future need for such intervention, given that the objective of best practice data collection is for each station to be configured and operated so that a continuous record is obtained from the measurements with minimal subsequent modification of the data necessary.

If verification indicates that the measurement system is operating as expected and recorded data are within tolerance of the primary reference, there should be no need to modify the data collected. Exceptions are:

- when isolated small spikes in a surrogate variable impact useful and reliable determination of the target variable
- when a small bias within tolerance persists until the source of the bias is found and the measurement system is adjusted accordingly. The data collected prior to the measurement system adjustment should then be adjusted similarly to remove its known bias.

Cause and extent of any issue detected in the data needs to be established to select an appropriate remedy, which may include addressing uncertainty or reliability issues with the reference(s). For this, and the above reasons, routine adjustment of data to reference, whether at site or during data collection or processing, is discouraged.

5.1.2 Traceability and data integrity

Data modification must always be done based on evidence and logic, not guesswork. All assumptions on which any modifications are made shall be defensible and recorded.

The process must be tracked via record keeping and associated documentation to ensure traceability of the work done so that alterations can be checked and reversed if necessary, including if the raw data are subsequently unavailable.

In some cases, reprocessing may be required in the future based on new evidence, such as a site survey, instrument calibration, or collection of further data.

5.1.3 Modifications explained

Any change to raw data must be:

- recorded with the original record
- explained in a comment (see Section 6), and
- assigned an appropriate quality code (see the Guidance Tables in each relevant Annex).

This is especially important when alterations are such that the resulting archived time series is recommended to be used with caution.

5.2 Processing steps

The processing should be planned and outlined in the organisation's procedures. Broadly, the processing steps shall include:

- assessing the data by running routine checks (see Section 3.6)
- comparing with field checks and references (see Section 3.6)
- assembling other evidence, such as calibration data, transformations made in the logger and/or telemetry system and any other transformations applied or required

  Note: Pre-repair calibration of an instrument can be useful to help reconstruct a reliable record.

- making an initial assessment against relevant NEMS
- reviewing relevant existing comments
- performing any editing required
- quality coding and adding any necessary comments (see Section 6)
- independent review of any editing and comments (see Section 7)
- a longer-term context data audit certified by an independent, authorised reviewer (see Section 7).

5.3 Order in which to apply adjustments

Adjustments to data should be made in this order, as and if required:

- time corrections
- linear transformations to the final measurement units (e.g. converting water level data measured in hPa to mH_2O)
- removal of sporadic and intermittent spikes
- linear transformations to correct for instrument configuration error (e.g. a wrong multiplier and offset)
- filtering, resampling, or replacing data to mitigate excessive noise (e.g. when rapid fluctuations in a water level record due to sensor fouling or wind will adversely affect the determination of flow)
- offset corrections
- other adjustments to minimise the effect of recording faults and/or to achieve conformance with field verifications (e.g. for drift or fouling)
- other linear or non-linear transformations as may be required (e.g. adjusting a 'clean' rainfall record to the primary reference totals)
- addressing any gaps.

5.4 Missing data

Avoiding loss of data should be a high priority for all organisations.

A gap in a series, created by missing data, must either be closed, infilled, or marked to prevent interpolation through the period of the gap if the data type is not discrete.

The decision to close or infill a gap, or leave the period as missing, must weigh up:

- duration of the gap
- desired reliability of the interpolated or synthesised data
- impact on usefulness of the overall record if not filled
- usual variability at the site
- availability of primary reference readings
- possibility of events having occurred in the missing period
- availability of the information needed to synthesise a record.

5.5 Infilling gaps

Infilling gaps should not be attempted until the actual record either side of the gap is available with duration at least 2–3 times the gap interval before and after.

Methods described in this Standard are not intended for record extension, nor for large-scale infill of multi-site datasets. As such, machine-learning methods are not included. If data are missing at the start (or end) of a time series, the start (or end) date and time of the dataset should be brought forward (or moved back) rather than attempting to fill the gap.

5.5.1 Choice of methods for infilling

Methods used to fill gaps shall be one of, in decreasing order of preference:

- inserting backup/secondary sensor data from the site
- inserting suitably frequent at-site observations, such as manual gauge readings
- interpolating a line or infilling a curve over a short period under stable conditions
- correlating from adjacent station data that have been checked for suitability
- using modelled data (preferably supported by observation or measurement, e.g. a flood level surveyed from debris marks), or
- estimated/synthesised by other means (which must be fully explained).

For recommended procedure and guidance in applying regression analysis see Appendix 2.

For method detail specific to a measured variable, see the Annex for that variable.

5.5.2 Infilling with synthetic data

Organisations shall provide synthetic data, where feasible, to fill gaps in datasets and to replace erroneous data except where explicitly stated otherwise, e.g. rainfall data (see Annex B).

The rationale is that:

- continuous datasets are of more use to most users
- all users will have access to the same records, and
- synthetic data generated by those closest to the data collection are likely to be better than that generated by the majority of end users.

However, it must be clear to data users where synthetic data exists.

Interpolated data is a special case where data are created only within the range of known data. Thus, in environmental applications where time and magnitude are relevant, we might synthesise but cannot interpolate a peak or a trough. We may interpolate between reference readings if confident the actual variation is represented and remained within the range of the bounding reference values.

Generally, it is unwise to fill gaps of more than two months duration, other than in a series of monthly observations or statistics (McKerchar et al, 2010). A lesser limit is prudent in some situations and for some variables. Refer to the relevant Annex for further details.

Quality code QC 300 must be assigned to identify which data are synthetic. Data Comments are also required to further define these periods and provide descriptions of how the data were synthesised and likely limitations on their usefulness (see Section 6.2.4.6).

Synthesised data must not alter extreme values for the record unless there is excellent corroborating evidence, such as incorporating a reliable and surveyed flood mark.

Generating the synthetic data and/or the description of their reliability may need to be redone if there is any change in future to the data used to generate the infill, for example, as a result of data audit or the collection of new data over an extreme event.

5.5.3 Describing accuracy of the infilled period

Accuracy of any relationship used to derive a synthetic record must be described in some way.

Useful statistics are:

- the correlation coefficient (r), which describes the strength of association between two sets of data, such as from a donor and a recipient site

- the regression coefficient (R^2), which is a relative measure of how well the recipient site data can be explained by, and therefore predicted from, the donor site(s)
- the standard error of the estimate (SEE), which is an absolute measure of the accuracy of prediction, being one standard deviation of the residuals from the equation of prediction. SEE is valid for non-linear regression. Most regression tools will provide this statistic.

A description of the process used to create the synthetic record is necessary and should include commentary on the suitability of the donor site or model, and other aspects relevant to give users an appreciation of how reliable the synthetic data are.

6 Metadata

Metadata describe the data, from where and how it has been measured to information about the data, including what has been done to it subsequent to its recording and key characteristics of the final dataset.

All required metadata must be created, collected, and/or collated, then verified and permanently archived.

Where backup data are incorporated in a time series intended for final archive the metadata requirements described in this section apply to the backup records as well.

6.1 Site metadata

Site metadata shall include:

- site and equipment details (including photographs, maps, plans, and relevant imagery)
- station and instrument calibration history (including pre-deployment checks and field validations)
- any assessment(s) to determine maximum quality code that the site is capable of achieving for the variable(s) measured
- legal and proprietary information, and
- all site visit records.

  Note: Site visit records include verification measurements collected during the visit, results of recorder inspections, and any other noted observations.

Detailed site metadata requirements for each variable measured at the site are set out in the relevant normative reference(s) and Annex(es) of this document.

Site metadata are normally stored in some form of site file or station history and may include use of document and/or asset management systems.

If imagery such as aerial photographs and surveys (e.g. LiDAR) has been obtained as part of operating the site it shall be documented, managed, stored, and preserved as for other forms of site metadata.

Note: Imagery may also exist historically, and/or as a result of other projects or the activities of other organisations also working in the area. Where such imagery is known to exist, including a descriptive summary of it in the site metadata is helpful.

Site metadata relevant to the time series being processed must be readily available as and when the data are processed to facilitate verification of the data, support data processing decisions, and to provide any site information needed for the metadata required to be attached to, and archived with, the time series.

6.2 Time-series metadata

Time-series metadata shall include:

- records of data acquisition, including data missing
- records of data processing decisions and actions
- quality codes
- comments
- results of quality assurance tests (see Section 7), and
- any data access agreements and/or waivers that constrain dissemination of the data.

6.2.1 Records of data acquisition

Data acquisition records include one or more of:

- an incoming data register
- a telemetry log
- a sample register
- laboratory test method(s) used, and
- 'office chits', i.e. recorder logbook or electronic field sheet entries made while in the office to document, for example, recording configuration changes initiated from the base rather than during a site visit.

Records relevant to the time series being processed must be readily available as and when the data are processed to facilitate verification of the data, support data processing decisions, and to provide information needed for the metadata required to be attached to, and archived with, the time series.

Records required to ensure traceability of data processing shall be permanently archived.

Periods of missing data must be verified as missing and, if the gap is not subsequently closed or filled during processing, assigned quality code QC 100 and accompanied by a Data Comment (see Section 6.2.4.6).

6.2.2 Records of data processing

Any alteration to, or discarding of, raw data shall be documented and/or recorded in a way that future generations can follow what has been done and why. It should not be necessary to refer to the person(s) who carried out the data editing for explanation.

Alterations to, or deletions of, raw data to be documented in this way include those actions applied:

- in the field to data already logged, and
- automatically by data acquisition systems, e.g. spike filtering, range censoring and any transformations of incoming telemetered data.

These records shall be permanently archived, such that all actions on the raw data contributing to the form of the final archived dataset are traceable and reversible at any time in the future.

6.2.3 Quality codes

Quality codes are coded metadata attached to the time-series data as tags or as a concurrent time series, to help convey provenance and reliability of the data. Quality codes facilitate valid data analysis and comparisons within and across multiple data series.

Quality coding shall be applied to the data according to:

- the NEMS *National Quality Code Schema*, and
- the specific requirements of this Standard, and
- the Annex of this document relating to each variable, and
- each relevant NEMS normative reference.

Quality codes shall be applied prior to any provision of data to users, including raw data delivered automatically.

Within the national schema, deciding between quality codes QC 500 and QC 400 often requires differentiating between 'minor' and 'significant' modifications to the data. Data producers must exercise some professional judgment. However, generally, modification can be regarded as 'minor' (QC 500) if it is:

- for a short period of no more than a few recording intervals, or
- a small change to values relative to tolerance, and/or
- a small change to timesteps relative to recording interval, and
- applied over no longer than the course of a single event or cycle.

Any modification beyond the above in terms of duration or degree of alteration of values or timesteps should be regarded as 'significant' (QC 400).

6.2.4 Comments

Comments are textual metadata associated by timestamp with the data that provide key information about the site, data, and dataset, and explain unusual features or events in the record that users of the data should be aware of but that are not readily conveyed by a quality code.

6.2.4.1 Comment formats

There are a number of advantages in having comments that follow standard formats and wording, primarily:

- standard wording and phrases minimise errors, help regulate style, and reduce ambiguity by reflecting consensus on the best way to describe a situation or action
- common terminology can provide easier searching within a comment database or listing.

As a minimum, a comment shall:

- specify, or be specific to, the site and measured variable(s) to which it applies
- be timestamped at the start of the period to which it applies; for example, a gap or synthetic data comment will be filed at the timestamp of the last actual value collected, and an event comment will be filed at the time of the start of the event
- specify the period over which it applies in the body of the comment (i.e. in addition to the timestamp)
- use dates that conform to common usage standards in New Zealand, i.e. not use American date format (see Section 1.2.1)
- specify times in NZST (UTC+12h) using a 24-hour clock and 1-second resolution (e.g. hh:mm:ss or hhmmss) (see Section 1.2.1 and 1.2.2)
- use New Zealand (UK) English
- comprise standardised wording whenever possible
- use plain, impersonal, unambiguous language
- minimise use of symbols, acronyms, codes, and abbreviations unless defined elsewhere in the comment set or in the NEMS *Glossary*
- be checked for correct spelling, punctuation, and grammar.

Note: Omitting correct and complete punctuation and grammar in the interests of brevity often causes ambiguity and incorrect interpretation.

Most time-series software packages provide several ways to build or connect to a database of comments.

Comments can be entered into one or more plain text files, spreadsheets or documents, or database. If the comments are entered into an Open Database Connectivity (ODBC) database, they can be accessed by any ODBC-compliant software. Therefore, this method is recommended.

Design of a system for storing, managing, and reporting comments should include capability to report them in an interoperable exchange format such as XML and more specifically OGC's WaterML2 (OGC, 2014).

The organisation may set standards for presentation (font, size, case, styles, numeric form etc.) and branding, but these should not compromise accurately conveying the information.

6.2.4.2 Comment categories and content

Comments shall include, but not be limited to:

- information about the site, installation, and characteristics of the data
- alerts and supporting information intended for end users of the data
- aspects not easily quality coded or otherwise quantified, and
- the NEMS documents and versions referred to.

Organisation of comments into categories helps with:

- prompting what comments are required and what they need to contain
- filtering and sorting comments from a large set to customise output for individual end users
- efficient data entry, particularly if standard content templates are also developed
- design of form-based applications to support data entry.

The following comment categories should be used:

- site/initial
- equipment
- operational
- data
- data processing (including corrections)
- transformations
- stationarity, and
- miscellaneous.

These comment categories are further explained in the following sections.

Optionally, the relevant measured variable(s) may be useful as a sub-category to aid in filtering comments.

Organisations without an integrated document store should consider including a Document Reference comment category to facilitate reference to related documents such as standard operating procedures, calibration certificates, scanned plans etc.

6.2.4.3 Site/Initial Comments

Historically, every time series stored, i.e. every site and measured variable combination, required an Initial Comment. Information common to all variables measured at a site was repeated in each Initial Comment. With modern storage systems it is possible to have a single Site Comment linked to the time series of all variables measured at a site.

Whichever configuration is implemented, these comments include:

- the site name and past and present aliases (if any)
- the site's geographic location, preferably to the nearest 1 m but at least to the nearest 100 m, in a coordinate system supported by Land Information NZ

  Note: For precision to the nearest metre, latitude/longitude coordinates, e.g. WGS84, must be expressed to five decimal places.
- names, and/or indices if applicable, of relevant environmental features, including whether the site is representative of a catchment, river, lake, coastal feature, and/or aquifer.
- names and/or indices of the relevant physical features, zones, and authorisations (e.g. airshed, bore number, consent number)
- the site's purpose (e.g. a brief description of the research programme)
- the variable(s) measured at the site (including any supplementary data)
- the variable(s) calculated from measurements at the site, i.e. variables for which data recorded at site are a surrogate
- brief details of other relevant site characteristics and influences (e.g. bore depth, altitude, nearby activity, and persistent issues affecting data quality)
- whether data are auto-checked and/or auto-processed, fully or partially
- the recording agency/agencies, past and present
- the start, and end date (if applicable), of the records
- list of other monitoring at the site, past and present, and
- any related sites and brief summary of their records (e.g. data used as supplementary, predictive, or in combination).

6.2.4.4 Equipment Comments

Equipment Comments include:

- details of the sensor(s) and data logger (e.g. type, power supply, deployment details, sampling regime, storage media, on-board processing algorithm(s))
- the range, resolution, and accuracy of the sensor(s)
- description of any structures, their purpose, and critical dimensions and levels (e.g. artificial level or flow controls, gauging structures, instrument mounting platforms, recorder towers, access ladders, well heads)
- primary data collection method (e.g. manual download and/or telemetry)

- type of reference(s)
- calibration and validation frequency.

Note: Include type as described in the NEMS documents in preference to use of brands, models, and/or serial numbers that a future data user may find difficult to interpret.

6.2.4.5 Operational Comments

Operational Comments describe:

- sensor relocation or operating environment changes, such as sensor elevation, aspect, exposure, relative position in a water body
- changes to references, including a change of datum
- compromised verifications (e.g. interference with references, poor on-site conditions, incomplete inspection)
- significant calibration issues affecting quality of the data (routine calibration data should be in a site metadata or instrument management system)
- significant site maintenance, and
- restrictions related to data access (e.g. authorisations, confidentiality, intellectual property).

6.2.4.6 Data Comments

Data Comments give details of:

- period of and reason for inclusion of backup data
- period and cause of missing record (gaps) not filled, with explanation of any failed attempts to infill where applicable
- period of and reason for synthetic record, how it was derived (e.g. other sites and data used, description of correlations and models), estimate of uncertainty/reliability/statistical confidence, and any limitations on usefulness
- method of data capture if not collected from a data logger (e.g. digitising, manual entry, CSV import)
- period and range of any data compression applied
- data stored as supplementary to the processed time series
- time-related events that affect the data
- observations that may assist with interpretation of the data
- any other reasons for downgraded quality codes not covered by other comments, and
- period of and reason for any other limitations on usefulness of the data that an end user should be made aware of.

6.2.4.7 Data Processing Comments

Data Processing Comments include:

- descriptions of:
    - pre-processing applied within the data logger or data collection system (e.g. telemetry or import software)
    - automated quality control methods, algorithms, and actions
    - automated processing applied to the data
- periods over which any of the above apply
- details of the editing carried out, including the reasons for it, errors found, assumptions made, and process applied
- the start and end dates and times of the period that has been modified
- a summary of the evidence confirming validity of the change
- name of the person carrying out the editing, and
- date the editing was done.

Where quality coding is implemented and suitably identifies affected data, comments about repetitive issues and editing of data may be aggregated to avoid overwhelming the comment set for the site.

6.2.4.8 Transformation Comments

Transformation Comments give details of any transformations applied to the data before archiving. Transformations may be applied to address issues of calibration, compensation, units of measurement, or conversion to another variable.

Adjusting rainfall data to the primary reference is a special case that is addressed in Annex B.

A calibration fail may compromise instrument stability as well as span and/or linearity. For this reason, instances of calibration fail must be identified, and the nature of the failure explained by an Operational Comment as well as any Transformation Comment that may be required.

In the case of variable conversion, the surrogate variable's Site/Initial Comment shall state the intended transformation as part of that site's purpose and list of associated variables (see Section 6.2.4.3), while the Transformation Comment must be filed with the archived target series. Where the target series is generated but not archived, e.g. conversion of stage to flow using a rating curve engine, requirements for comments about the transformation(s) are included in the NEMS that covers development of the model (e.g. NEMS *Rating Curves*) and are excluded from scope of this NEMS.

Transformation Comments should describe:

- the reason for the transformation
- the applicability and validity of the transformation, including assumptions made and evidence relied on
- the method and parameters of the transformation
- the start and end dates and times of the period modified
- name of the person(s) who derived and applied the transformation, and
- date the transformation was applied.

For further details, see the Annex covering the relevant variable.

6.2.4.9 Stationarity Comments

Stationarity Comments describe any event, or change in methods, measurement location or conditions that has occurred at a spatial and/or temporal scale that may cause loss of homogeneity in a long record. Examples are:

- significant changes of land cover and/or use (e.g. planting or milling a forest)
- historic data collection that is in some way significantly different (e.g. manual observations by a volunteer or nominated public observer)
- change in principle of a method (e.g. the definition of 'event' rainfall measurement, change of standard method or analytical standard)
- construction of a dam or diversion, or an irrigation or flood control scheme that impacts the site
- change of site purpose (e.g. from flood warning to full flow range)
- change in achievable data quality at a site (e.g. from a site assessment matrix)
- reference to the Standard(s) and version used.

This comment category may also be used to alert a user to the possibility of combining two or more at-site records under the assumption they are homogenous, for example, when a site is moved to another location but the intention is that the two records be regarded as a continuous dataset.

6.2.4.10 Miscellaneous Comments

Miscellaneous Comments are any other related comments that may assist a data user. Use of this comment category should be minimal.

7 Quality Assurance

Datasets shall be reviewed to confirm that they have undergone all necessary procedures to enable them to be used with confidence.

Less formal quality review occurs prior to archiving as each batch of processing is completed. A regular but much less frequent cycle of more formal audit of archived data is also recommended.

Processed data that have been quality controlled and/or edited and/or adjusted entirely by machine algorithms must be reviewed at least every two years by a suitably trained and experienced person. This review may be informal prior to archiving (see Section 7.2) or a formal audit (see Section 7.3).

Note: For clarity, data that are archived as verified and processed must be subjected to biennial audit if the processing is not performed and/or reviewed by a suitably trained and experienced person prior to archiving.

7.1 Requirements

All agencies shall implement standard methodologies for:

- verification, documentation, and quality control of new data
- review of all editing to ensure that all changes are necessary and appropriate, and no necessary changes have been missed
- review of metadata compiled for accuracy and completeness, including the quality codes assigned and comments to be filed, and
- periodic, more formal audit of archived data.

How these requirements are implemented will depend on each organisation's time-series management software.

7.2 Quality review

Quality review shall be undertaken by a suitably trained and experienced practitioner who is preferably not the person to have processed the data.

Completed reviews shall be signed and dated by the reviewer and tracked in the processing records (see Section 3.3).

Quality review sign-off should be part of an organisation's procedure to formally authorise update of the period of verified processed data and associated metadata to the final archive(s).

7.2.1 New data

For new data, confirm:

- there are no data missing that have not been marked as gaps or infilled
- no issues or anomalies have been overlooked
- differences between logged and reference values are acceptable
- all data are appropriately quality coded
- all other necessary metadata are present and accurate
- the data look sensible when plotted with:
  - previous data for the same variable at the same site, and
  - the same variable at a nearby site, and/or
  - a related variable at the same site
- data extremes are reasonable
- patterns in the data are believable, represent expected behaviour of the variable, and are not the result of interferences.

7.2.2 Editing applied

If editing has been applied, reconcile:

- gaps in the raw and processed data, before and after editing
- gaps and periods of synthetic infill with the comments and quality coding
- the adjustments applied with the differences between logged and reference values, before and after editing
- the adjustments applied with comparison between the raw and final verified time series
- the quality codes applied with the above tests, and with the results of quality control deviation tests, the processing log, and filed comments.

If editing has been applied, confirm:

- all assumptions, decisions, and explanations are reasonable
- all intended adjustments are done
- adjustments made are what was intended
- adjustments made are valid and justified
- editing did not create spikes, bias, steps, or distortions in the data, or make unintended time adjustments.

7.2.3 Metadata

Reconcile the quality coding and comments against:

- any editing applied
- a listing of all gaps

- each other
- the relevant field notes, and
- other records of actions such as instrument or configuration changes, annual inspections, etc.

Confirm:

- requirements of this Standard are met
- comments are present for changes in quality code that need to be further explained, e.g. periods of synthetic data
- quality codes align with comments, with respect to time and content
- reliability and accuracy of the data are adequately described
- comments intended for end users of the data are unambiguous and free of spelling errors, jargon, and poor language.

7.2.4 Tests for quality and accuracy

The following are some generic examples of data presentations and analyses useful for quality review:

- overplots of raw and processed data vs time, with
    - comments and gaps marked, and
    - quality code identified, e.g. by trace colour(s)
- auto-scaled overplots of processed data with corresponding reliable data at another site, or a related variable at the same site
- auto-scaled overplots of surrogate and target variable(s) vs time
- quality plots reproduced using the processed data (see Section 3.6.4)
- plots of difference between raw and processed data vs time
- cumulative departure of raw from processed data
- comparison of the distributions of raw and processed values for the same period
- tabulations and/or scatterplots of deviations from reference values, before and after processing
- mass or double-mass curves of:
    - raw and processed data
    - processed data with corresponding reliable data at another site
- Analysis of timesteps, e.g. by ranked maxima or plot vs time.

Specific examples for each variable can be found in the Annex for that variable.

7.3 Audit

An audit is a more formal quality check of data already archived. Review of the data presented for audit is recommended to be carried out by a suitably qualified and experienced practitioner who is independent of the recording agency.

Once audited it is very unlikely for data to be altered in future unless new information relevant to the period of data is obtained.

7.3.1 Benefits of audit

An audit reviews longer periods of data that are the result of several archive updates. As such, in addition to a final check on appropriateness, integrity, and completeness of the data processing and complied metadata, it considers:

- continuity between successive updates
- stationarity, and
- comparison with other data in a broader context, including opportunity to review data for related variables together, e.g. a combined audit of the stage record, gaugings and ratings for a site.

Following review, the data should be free of unexplained errors and uncertainty. Some deficiencies may remain in the data after audit, but the user of the data is made fully aware of them from the audit and can decide to proceed or not on that basis.

Further alteration of data that have passed an audit shall be formally controlled.

Information resulting from an audit about reliability, accuracy and utility of the data shall be collated into a formal report that is understandable by a knowledgeable third party and can be stored and retrieved in the future.

7.3.2 Audit cycle

A data audit shall:

- be undertaken at regular planned intervals appropriate to the needs of the agency and data users, or
- as defined by an organisation's quality management system, and
- generally, include no less than two consecutive years' data, and
- where the dataset includes transformations, include all periods of amended and new transformations since the last audit plus a period of 12 months preceding, or since station inception if less than 12 months prior.

7.3.3 Minimum audit requirements

As a minimum, for any variable, the analyses and information required for an audit are:

- site and deployment details:
  - location map with all relevant station locations identified
  - site details summary:
    - identify the water body and catchment or region,
    - identify the site purpose and any projects and stakeholders related to the record
    - state any limitations for data use
    - include associated variables, if available
    - identify stations used for comparison
    - for each station identify:
      - period of record included (using NZST)
      - station name and/or number
      - map reference
      - altitude, and
      - sensor type
  - instrument and installation details summary:
    - type(s) deployed
    - expected accuracy and resolution of each
    - summary of calibration history
  - photographs of the site and key features of the installation, with dates, location, and direction of view referenced
  - data verification method(s) summary
  - details of any supplementary measurements, and compensations or conversions applied to the data
- the comments and quality coding attached to the records, reconciled with the data plots and/or tabulations, and summarised for overall quality achieved

  Note: A year-by-year % stacked column chart of the quality coding applied provides a useful overview of quality achieved.

- data tabulations:
  - listing of gaps
  - listing of periods transformed and each transformation applied
  - listing of periods of synthetic data, and
  - extremes of data range for the full period
- data plots:
  - for the period of audit plus the year prior
  - for the decade, i.e. audit period plus previous nine (9) years

    - full scale of data recorded, and
    - partial range, to permit inspection of low to medium range if the data are highly skewed

      Note: Trimming the range at the upper quartile of the dataset usually suffices.

- deviation plots and/or tabulations:
    - before and after adjustments to reference(s)
    - demonstrating goodness of fit of any relationships applied
    - before and after transformations, including compensations and variable conversions (e.g. a bed plot for a rated flow station)
- timestep analysis

  Note: This is useful to identify unmarked gaps, and changes in method such as sampling interval or data compression that should reconcile with comments filed. The analysis may include plots of timestep vs time, a distribution of the timesteps, and/or tabulation of their ranked maxima.

- data comparisons with at least one other suitable site and/or variable, to demonstrate that there are no obvious remaining anomalies in the record

  Note: "Suitable" should be determined by mutual agreement between the recording agency and auditor. Statistical techniques such as double mass curves, direct comparisons of variables, or relationships between stations and/or variables (e.g. difference or correlation) may be employed.

- summary of annual station inspections that cover the period of audit, beginning with the most recent inspection prior to the period of audit
- summary of reference(s) used and their reliability
- assessment of stationarity, evaluating:
    - potential causes of loss of stationarity, such as:
        - change of instrumentation type, precision, or range
        - a different surrogate variable measured
        - change of laboratory provider
        - change of measurement location, perhaps due to changes in a riverbed or other conditions
        - change in conditions at the site, e.g. a new water take or discharge, or significant vegetation growth
        - changes in a natural system such as a catchment, perhaps related to planting/harvest and other land use change, and
        - effects of climate change
    - changes in statistics, such as annual or seasonal maxima or minima

- persistent non-conformance with expected verification tolerances
- for some variables, a discontinuity in double mass curves or their equivalent.

7.3.4 Other requirements

7.3.4.1 Audit content

Requirements specific to a variable, in addition to those listed in Section 7.3.3, can be found in the relevant Annex for that variable.

Audit of variables derived from surrogates, such as flow from stage or suspended sediment from turbidity, should include the target and surrogate series and the relationship calibration data.

It is prudent to audit at-point data within a region or water body together, for example, all rainfall records from a catchment or all water quality data from a lake.

Records other than those under review may be included in the audit. Where available, reliable records from other agencies may be used.

7.3.4.2 Audit outputs

Recommended audit outputs include:

- a mandatory electronic report, and
- an optional hard copy report.

7.3.4.3 Audit certification

The completed audit report shall contain:

- a list and/or summary of tests applied
- a list of any periods that have not passed audit, with reasons
- the name and signature of the auditor, and
- the date that the audit was signed off as completed.

8 Preservation of Record

8.1 Archiving policies, procedures and systems

The recording agency shall develop, maintain, and implement policies, procedures, and systems for the permanent archiving of records, including those needed for traceability of the data and the assessment of stationarity and fitness for purpose. These policies, procedures, and systems shall address:

- identification of records to be permanently retained
- provision of suitable secure and permanent storage for those records
- requirement for backing up electronic data
- future data format changes
- future obsolescence of hardware and/or software
- potential deterioration of media
- ability to access records as and when required
- the need for off-site duplication of records, and
- the organisation's disaster recovery plan.

8.2 Records required to be archived

The following records shall be stored, retained indefinitely and, if electronic, backed up regularly:

- original data as defined (see Sections 3.1.1, 8.2.1 and 8.2.2)
- final data as verified
- supplementary data (preferably registered and reviewed)
- all required metadata (see Section 6 and relevant Annexes)
- additional time series and/or metadata as specified in the 'Preservation of Record' section of the relevant Annex.

Note: Paper records may be scanned and stored electronically.

8.2.1 Original data

When pre-processing is carried out on the data logger or by a telemetry system, or the data are changed on import (e.g. compressed or transformed), the first write of the data to the time-series management system that will be used to process and permanently store the data is not the original data as captured.

In such cases, recording agencies may, as appropriate to their systems and the incoming data, retain original data by a suitable combination of the following methods:

- storing the original and the modified data on the data logger (or telemetry system) and retrieving (and retaining) both

- storing the files from the field stations as received, prior to writing the data to the time-series management system (possibly in a variety of formats, which may make subsequent retrieval difficult)
- writing incoming data simultaneously on receipt to an unmodified original data time series and to the telemetry/production system,
- accepting the first write to the time-series management system as the original data provided all pre-processing is fully documented, traceable, and reversible by, for example, also permanently storing all logger code and reporting all changes made during pre-processing.

The original (raw) data may be required at a later date, should archived data:

- be found to be in error
- become corrupted, or
- be lost.

Note: Original data stored in a multitude of small files of various formats that require reimport may make future retrieval of the original data very difficult.

8.2.2 Archiving unprocessed data

A recording agency may choose to permanently archive, as a final version of the data, a record that is not processed or verified. Usually, the record is a time series of original or supplementary data.

Requirements for permanently archiving supplementary data may be found in the relevant Annex.

Original data that are permanently archived as a final record must:

- be identified as such in a Data Comment (see Section 6.2.4.6)
- be described by Site, Equipment and Operational Comments as for a processed and verified record (see Section 6.2.4)
- retain a quality code of QC 200 (raw, not verified, quality unknown), and
- have its site metadata (see Section 6.1) and data acquisition records (see Section 6.2.1) permanently retained and accessible from an associated site or station history file, or similar.

8.3 Housekeeping

Data processing can create several copies and versions of information that must be managed, but many will be working versions and temporary files not required to be permanently retained.

If the time-series manager and existing document management system(s) do not provide or enforce housekeeping procedures to control proliferation of unwanted files and data, and prevent corruption, loss or muddling of data that are required to be permanently retained, the recording agency must develop, maintain, and implement the necessary policies, procedures, and systems separately. These should include:

- update/archiving register(s)
- physical authorisation procedures
- establishing filing protocols and systems
- establishing indexing systems
- file and/or time-series naming conventions
- establishing personal and shared work areas and protocols for their use
- protocols to regularly clear junk files.

Housekeeping procedures must also be developed and implemented to ensure referential integrity and security of any verification information and/or required metadata that are stored and maintained separately from the time-series management system, for example, instrument calibration records stored in an unlinked asset management system.

8.4 Storage of physical records

Physical records should be stored in suitably dry and secure storage indefinitely, with an adequately maintained indexing system to enable retrieval of specific items when required.

Some safeguards are required to prevent deterioration, for instance due to mould, insects, vermin, or birds. A digitised or scanned version of a paper record can be kept in preference or as an additional safeguard.

Some media may gradually become unreadable for other reasons. For example:

- dust accumulation on, or age deterioration of, magnetic media
- ink degrading due to light
- foil-backed punched-tape binding to itself if tightly wound
- required hardware and software becoming obsolete (e.g. tape and datapak readers, floppy disk drives).

9 References

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McKerchar A, Henderson R, Horrell G. 2010. *Standard procedures for creating and describing synthetic hydrological record.* NIWA Client Report No. CHC2010-002 prepared for Tasman District Council under an Envirolink project.

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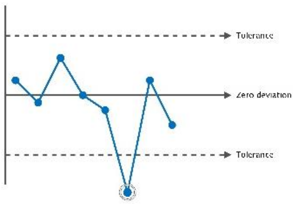
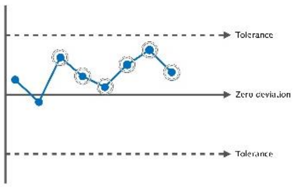
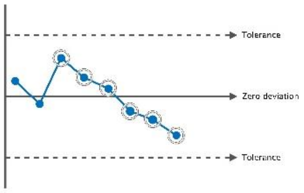
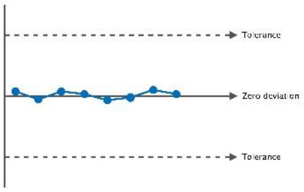
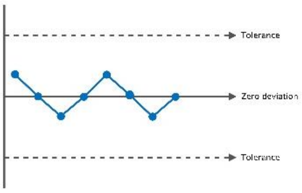
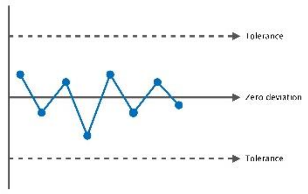
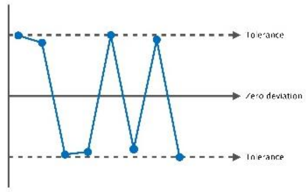
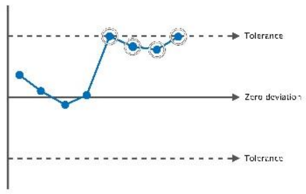
Appendix 1 - Interpreting Control Charts

The following table explains the features identified by control charts that should be followed up with diagnosis and remedy on site and editing of the data as needed to minimise the effect of the fault discovered or assumed to have occurred (after investigation).

Table 2 – Guide to interpreting control charts.

	A single value considerably beyond tolerance. The anomaly may be a spurious error, which are often human in origin.
	A run of deviations (although possibly within tolerance) but all biased in one direction. This is a systematic error, usually associated with method, i.e. something has 'shifted' in the measurement system.
	A trend in deviations (although possibly within tolerance). This is a systematic error indicating some drift in the measurement system.
	Deviations closely hugging zero compared to the tolerance. This may indicate the tolerance is too wide and the analysis is therefore not delivering the desired 'control' information.
	Deviations cycling (although possibly within tolerance). This anomaly may indicate interference of some kind that has a regular cycle, e.g. seasonal effects, weed growth, abstraction activity etc. It may not be feasible or appropriate to modify the installation and/or the data but any such behaviour identified should be explained in a Site Comment.

	Oscillating deviations (although possibly within tolerance). This is abnormal. Deviations should be random. This anomaly may be associated with unnecessary adjustment of the measurement system at each visit.
	Deviations hugging tolerance. This anomaly indicates the measurement system may not be delivering the desired resolution, or that deviations are from a mixture of 'samples', e.g. from use of two or more different reference instruments, such as multiple staff gauge boards with slightly different zeros or that are sited in different flow conditions.
	A 'step' in the deviations. This anomaly is similar in cause and effect to a run but is usually obvious sooner than for a run.

Appendix 2 - Using Regression Analysis to Synthesise Record

The recommended procedure for using regression analysis to synthesise a record is:

- compile the data for analysis
- scatterplot the data, with the donor site as the X-value and the recipient site (i.e. the site with the missing data) as the Y-value
- if no relation is evident do not proceed
- if the relation is apparently non-linear, fit a curve rather than a straight line, or transform the data, e.g. by taking square-root or logarithms, so a straight line may be fitted
- assess the goodness of fit (usually consideration of the regression coefficient R^2 is sufficient)
- inspect the residuals; they should be small and randomly spread without apparent trend or cycle
- apply the regression equation to predictor (donor) site values to synthesise predicted values for the recipient site
- plot the modelled data with the actual data to check its suitability
- apply quality code QC 300 to the period of synthetic data incorporated in the final record
- file a comment that explains the cause of the missing data and describes the regression including the donor site(s), period used for analysis, timestep and form of the data analysed, sample size, equation applied to generate the synthetic data, and the regression coefficient (R^2).

There are several aspects to consider when performing regression analysis.

- Because predictive power of a regression is a trade-off between bias and variance, analysis is usually best carried out using as long a concurrent record from suitable donor and recipient sites as possible.
- However, regression analysis models the average behaviour between two variables and is therefore an over-simplification that may not be a good representation for an individual period of missing record. Reliability may be improved by regressing shorter periods of concurrent record closer in time to the period of the gap (McKerchar et al, 2010).
- A suitable period and timestep for the input data must be decided, and whether the data will be transformed in some way, such as by taking daily means or logarithms. Interval of the data to be analysed should match the desired interval of the synthetic data to be generated. Regression analysis may need to be repeated several times to explore

what form is best, and to check for seasonal bias. If synthetic data are required to be filed at a different timestep, a new regression equation must be derived.

- Usually, because of its simplicity, least-squares regression is preferred, but the method may cause reduced variation in values at the recipient station (Johnston, 1999) leading to under-representation of extremes. Extremes must therefore be independently corroborated.
- X and Y are not interchangeable as they are for correlation. The equation obtained from regressing X on Y (i.e. using values of Y to predict X) cannot be used to predict Y from X by simply rearranging it mathematically if you happen to analyse the data back to front.
- Least squares regression is sensitive to outliers. An extreme value in the analysis creates a long 'lever' to the relationship and often falsely improves the regression coefficient (R^2).
- The regression equation could be linear or curvilinear, and/or developed from multiple donor sites.
- The regression coefficient R^2 is not valid for non-linear regression but fitting a curve to your data is not necessarily non-linear regression. Linear regression refers to linearity of the model parameters (i.e. the regression equation looks like $Y = a_0 + b_1X_1^n$ ($+ b_2X_2^n$ ...)) so you can fit a curve by raising the independent (X) variable to some power, or have multiple equations added together and still use R^2 as an indication of goodness of fit.
- Transforming back from logarithmic to natural space introduces a transformation bias that, if significant, should be compensated for prior to filing the synthetic data.
- Best modelling practice is to partition the input data, derive the relation using one half of the data, then test goodness of fit/describe the accuracy of prediction using the other half.

Further guidance may be found in Helsel and Hirsch (2002) but be aware that the United States does not use the metric system so quoted formulae may carry additional constants to convert the units.

Annex A Water Level Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous water level data captured and stored as data type instantaneous (continuous) (see Section 1.1.1).

1.1 Normative references

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

- NEMS *Water Level (Water Level Field Measurement Standard)*
- NEMS *Site Surveys (Code of Practice)*

Where reference is made in this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Water Level* v3.0.0'.

2 Quality Control

2.1 Additional metadata required

General requirements for site metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying water level data:

- surveyed information, including:
  - checks of datum continuity over time
  - cross-sections at key locations (e.g. recorder, control, standard gauging section, top and bottom of slope–area reach)
  - reduced levels of the sensor (e.g. orifice or intake pipe(s)) and key parts of the installation (e.g. recorder floor level, base of tower, top of bore casing, dip measurement initial point)
  - elevation and angle of section, if any, of any permanent structure used for gauging (e.g. a bridge)
  - bankfull level
  - cease-to-flow level, if possible
  - bathymetry, where available
- depth below surface of sensors suspended from buoys or platforms
- details of all structures, including:
  - design
  - as-built plan
  - photographs
  - records of any certification requirements

- photographs of controls and the environs of wellheads, buoys, and platforms etc., and any changes to these.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection and maintenance activities, and to identify steps in the data introduced by cleaning, or replacing or reconfiguring the sensor, data logger, and/or the installation.
- Check continuity of cycles in the data, e.g. tide or abstraction.

2.2.1 Comparisons

- Criteria for deciding a suitable comparison site are similar to those for selecting a suitable infill record donor site. See Appendix A.1 Section 3.
- Rainfall is often more informative if over-plotted as a cumulative trace.
- Use flow for comparisons if bed-shifts may confuse interpretation; however, the required ratings for both sites must be available and reliable.

  Note: A between-station flow comparison can help identify where a rating shift is needed.

  Note: Double mass plots are useful for assessing long-term stationarity of the flow data but not very helpful for day-to-day quality control of a water level record (a large but short-duration error may have very little overall effect on the mass curve).

In addition to cross-checking specific features in the data, look for disruption of:

- shape and pattern in the hydrographs
- lag times, and
- relative scaling of events.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

When using primary (and other) reference values to verify or to adjust recorded water levels the following should be assessed and considered:

- range-dependent variations in accuracy of staff gauge readings, arising, for example, from:
  - high stage boards that are some distance from the sensor
  - wave lap and surging

    - difficulty reading due to accumulation of debris, staining, reflection, or distance
    - penetration (of distance meters)
- the uncertainty of the reference reading(s)
- timing of the reading in relation to the rate of change of level
- stability of staff gauges and initial points.

The accuracy tolerances for water level data are small and can be overwhelmed by uncertainty in the reference reading, in which case:

- instrumentation and data should not be adjusted to reference values in these circumstances unless there is other corroborating evidence of faulty recording
- if adjusted, the adjustment(s) should be reviewed when reliable reference readings resume
- if reference reading uncertainty exceeds tolerance, or a reference reading is discarded as unreliable, the period of record that would be verified by that information shall be quality coded no higher than QC 500.

Investigate datum continuity if there is persistent bias, regardless of tolerance.

2.3.1 Datum continuity

Measurements of stage are defined as water levels above a known datum. Maintaining site datum and gauge zero is therefore a critical aspect of water level measurement.

A change of datum or gauge zero must be commented and may be compensated by an offset correction to the water level data, or if stage is being measured as a surrogate for flow, by a shift in the stage–discharge rating.

Identification of movement in any benchmark or reference level is easier if the datum continuity analysis over time is carried out using the differences in elevation rather than the actual elevations. Differences in elevation between at least three survey marks are required to be analysed to identify which mark is moving.

Refer to NEMS *Water Level (Water Level Field Measurement Standard)* for the site reference requirements for various site types, and to NEMS *Site Surveys (Code of Practice)* for how to survey and track the site datum, reference levels and gauge zero, and maintain those records in a Station Survey History.

2.4 Deviation tests

NEMS *Water Level (Water Level Field Measurement Standard)* tolerance is expressed as absolute or percent deviation depending on stage. The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure A 1) or stacking the charts (Figure A 2).

Use a deviation with range test to monitor range-dependant issues such as reference reading uncertainty, reference reading bias if using multiple gauge boards, and sensor calibration drift.

At stilling well sites where the primary reference is the plumb-bob, incorporate the external readings as a second set of reference values.

For water levels that range over an order of magnitude or more, such as at river sites and some groundwater sites, scatter-plotting logged values versus corresponding reference readings is of limited use. It is best to work with the differences.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Radar and other 'down-looking' sensors operate upside down and have better accuracy closer to the sensor. The tolerances must still be applied in the conventional sense of a greater expected accuracy at low stage and low flows.

Tests may be configured to update automatically with new data from the field.

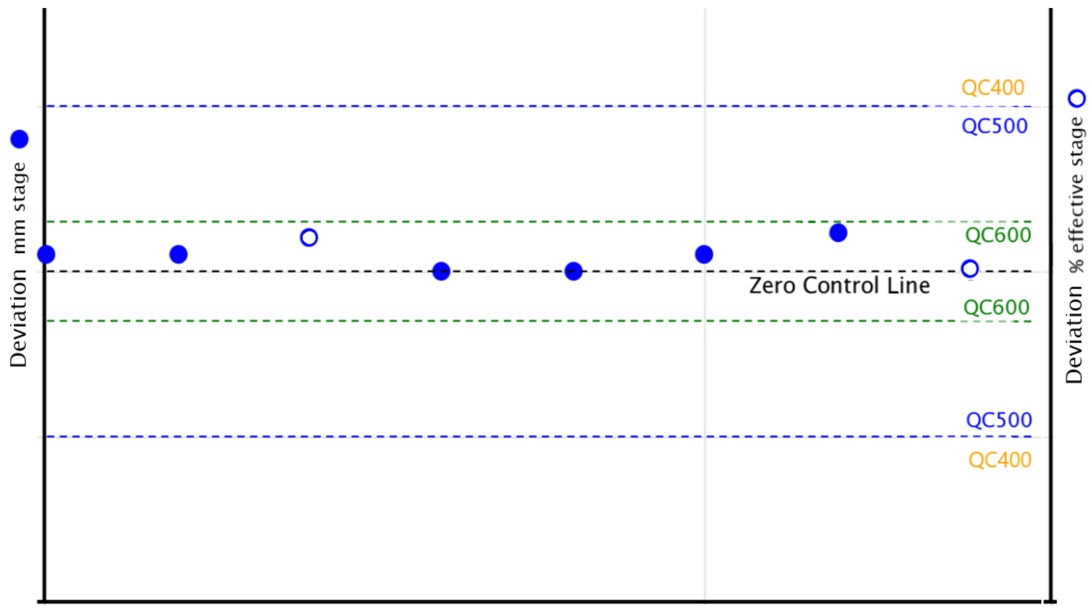


Figure A 1 – An example of a control chart with secondary axis where data are plotted in sequence using the axis applicable for the tolerance test, scaled to align the limits.

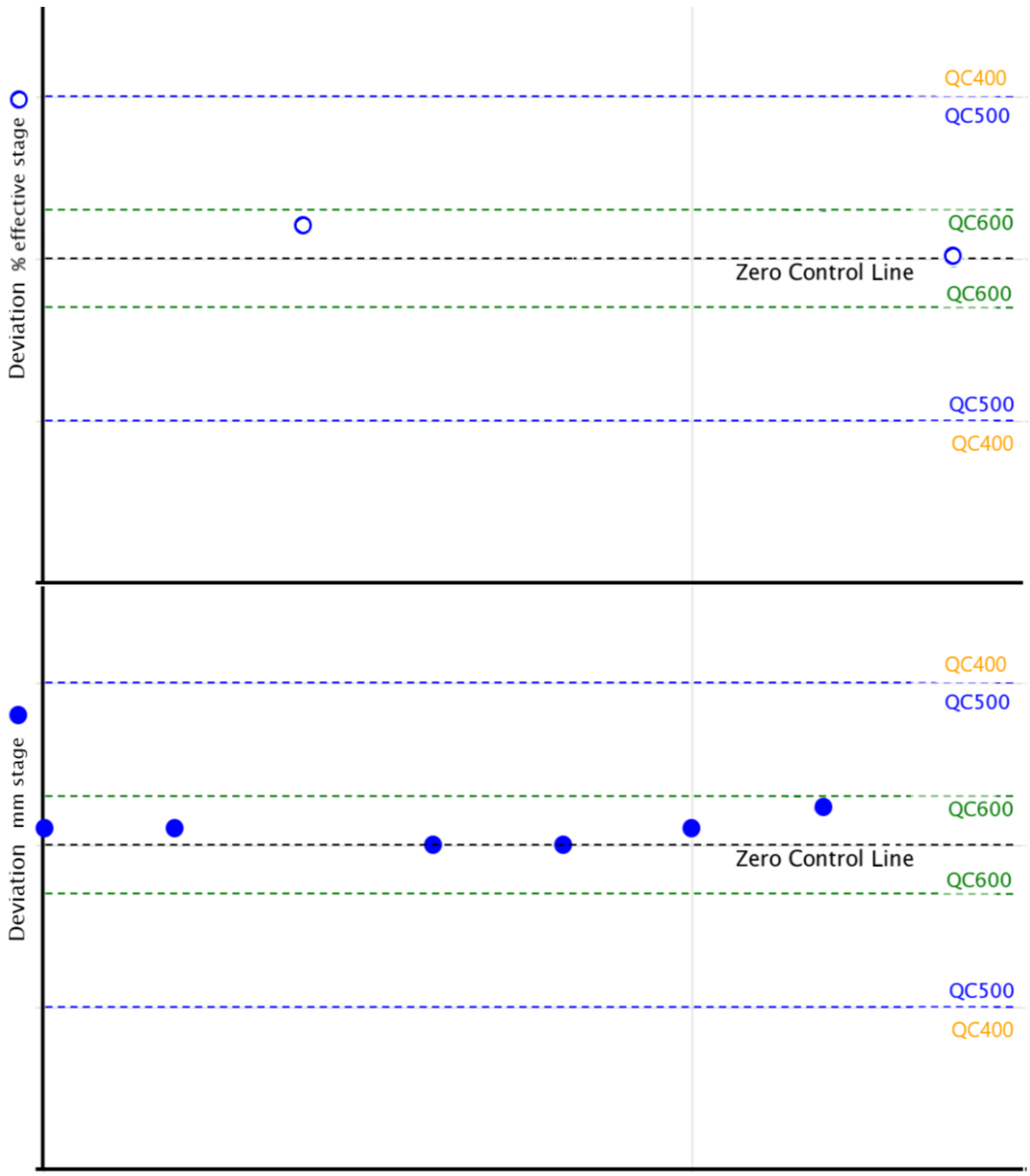


Figure A 2 – An example of a stacked control chart where data are plotted in sequence, but on the top or bottom chart depending on the applicable tolerance test.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water level data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The water environment (see Section 1.4.4 of NEMS *Water Level* v3.0.0)
- Site factors (see NEMS *Water Level* v3.0.0: Section 1.5 ‘River Stations’, 1.6 ‘Lake Level/Reservoir Stations’, 1.7 ‘Groundwater Stations’, or 1.8 ‘Sea Level Stations’)
- Interference, deterioration, and damage (e.g. human, biofouling, hydraulic conditions etc.) (see NEMS *Water Level* v3.0.0: Sections 2.2, 2.5, 3.2, and 3.8)
- Maintenance of recording datum (see Sections 3.4 to 3.7 inclusive of NEMS *Water Level* v3.0.0)
- Dependence on supplementary measurements (e.g. barometric compensation of unvented pressure transducer record)
- Instrument and installation function and operation, and conditions that adversely affect them (see Section 4 of NEMS *Water Level* v3.0.0).

3.2 Unintended offset or incorrect change of offset

The recording of water level requires a known and fixed datum be maintained.

Installation or instrument instability, or a device reset after power interruption, may cause a shift in recording zero that creates an unintended offset, biasing subsequent data by a constant or near-constant amount.

Some sensors must be installed at a different level to the recording zero, which then requires an offset be applied to obtain stage in terms of the gauge datum. This offset is usually programmed into the logger. If a mistake is made calculating or entering the offset, the data collected is biased by the amount of error in the programmed offset.

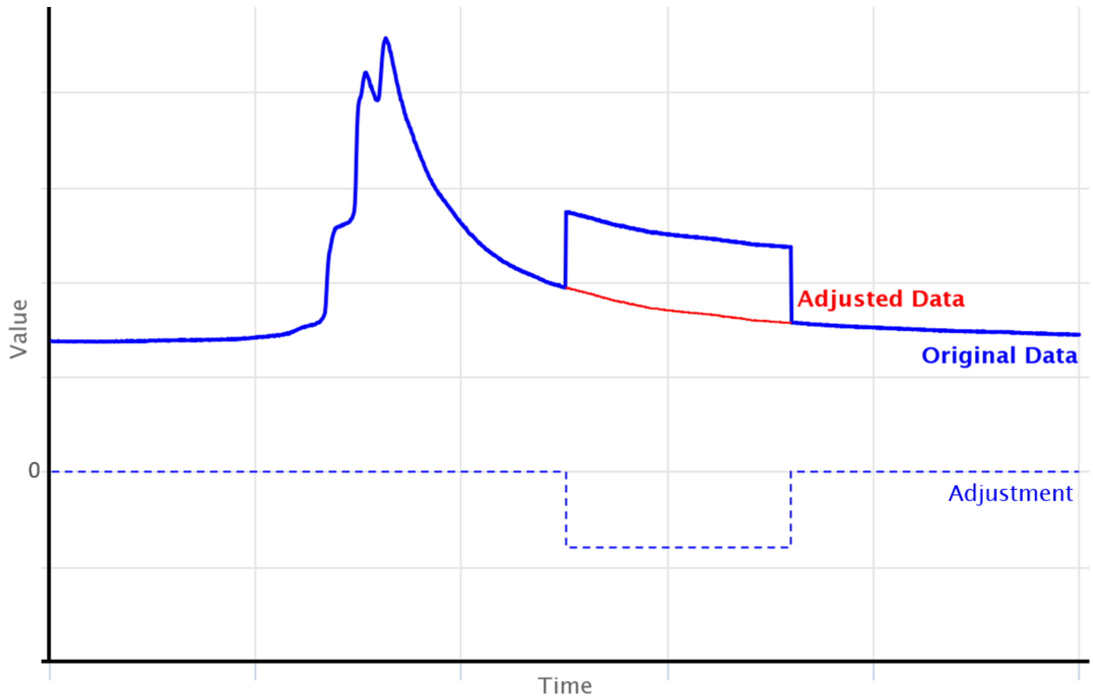


Figure A 3 – An example of part of a hydrograph offset by a constant or near-constant amount (blue line) with the adjusted data (red line) and showing the adjustment applied (blue dotted line).

Table A 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	A 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable, observable, and traceable at site by levelling and/or checking the logger program.	Fig. A 3 A 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.6 6.2.4.8 6.2.3 A 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from instrument resets, or from interference or fouling affecting the sensing system or the flow control(s). Cause of the step dictates how the preceding data should be repaired.

3.3.1 Instrument resets

If the step is due to an instrument reset:

- ensure it is not one half of a needed offset correction (see Section A 3.2)
- some form of drift leading up to the reset must be assumed to have occurred if the step is not a result of a change of datum and/or offset.

If the instrument is reset to implement a permanent datum shift:

- all prior stage data can be adjusted by the difference in datum, or
- the step can remain in the data, but with:
  - a filed comment alerting and explaining its presence, and
  - a new rating applied from the time of the shift, in which all stage values are adjusted by the difference in datum, if the water level record is intended as a surrogate for flow.

3.3.2 Interference

Steps in the data due to interference may be transient and self-correct, or persist until rectified during a site visit, or may result from an event that initiated a step-change in all subsequent data. Its source may be:

- mechanical, such as a float or counterweight catching on a valve, ladder, or other equipment in the well

  Note: Levels of potentially interfering items in a well should be known and recorded in the site file.

- environmental conditions such as temperature (freezing or heating), high sediment loads, or hydraulic effects such as backwater
- a combination of mechanical and environmental such as barometric pressure effects in a record from a pressure transducer with a blocked vent
- activities such as engineering works in the vicinity of the recorder.

Steps in the data due to interference may be compensated, as applicable, using:

- relationships with secondary measurements (e.g. temperature and/or barometric pressure compensation) (see Section 4.9)
- stage–discharge ratings if stage is being recorded as a surrogate for flow (refer to NEMS *Rating Curves*) and the interference directly affects the flow control(s)

- stage adjustment methods for fouling (see Section A 3.3.3), sticking or jamming (see Section A 3.3.4), silting (see Section A 3.4) or drift (see Section A 3.5).

Compensation should be applied consistently through a record by way of stage–discharge rating changes or stage adjustment. It is not good practice to arbitrarily swap methods within a record. Applying both methods to the same period should also be avoided.

3.3.3 Fouling

Fouling may be due to the accumulation of weed, debris, or sediment at, in or over the sensor, or to the ingress of animals or moisture into the workings of the sensing system.

Accumulation may be gradual or episodic and may self-clear naturally, or via some form of automated purging system, or persist until cleared during a site visit. Duration of any adjustment applied to the data must reflect the assumptions made about the nature, timing and extent of the fouling and its subsequent clearance. In most cases the appropriate adjustment is a simple special case of drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a non-zero value specified at the end of the period of adjustment (see Figure A 4).

Some forms of fouling may also cause noisy data, which should be smoothed or resampled before any adjustment is applied to eliminate a step (see Section A 3.7).

Fouling of the flow control(s) by debris or sediment is usually addressed by rating shifts (refer to NEMS *Rating Curves*). Fouling of a flow control due to weed growth may be addressed by stage adjustment or by rating shift but not both. Stage adjustment is generally preferable if the weed can be cleared at each site visit, the rating is otherwise stable, and the necessary adjustment is relatively small. Rating shifts are preferable if the weed is more prolific and persistent and becomes the dominant control feature for lengthy periods.

Stage adjustment may not be able to be guided by reference readings if the reference is also affected by whatever is fouling the sensor. Reference readings set aside due to fouling must be identified and explained in an Operational Comment.

Minor silting of stilling well intakes may be adequately compensated by a simple linear drift adjustment as for other forms of fouling but for blocked intakes and silting of the stilling well (see Section A 3.4).

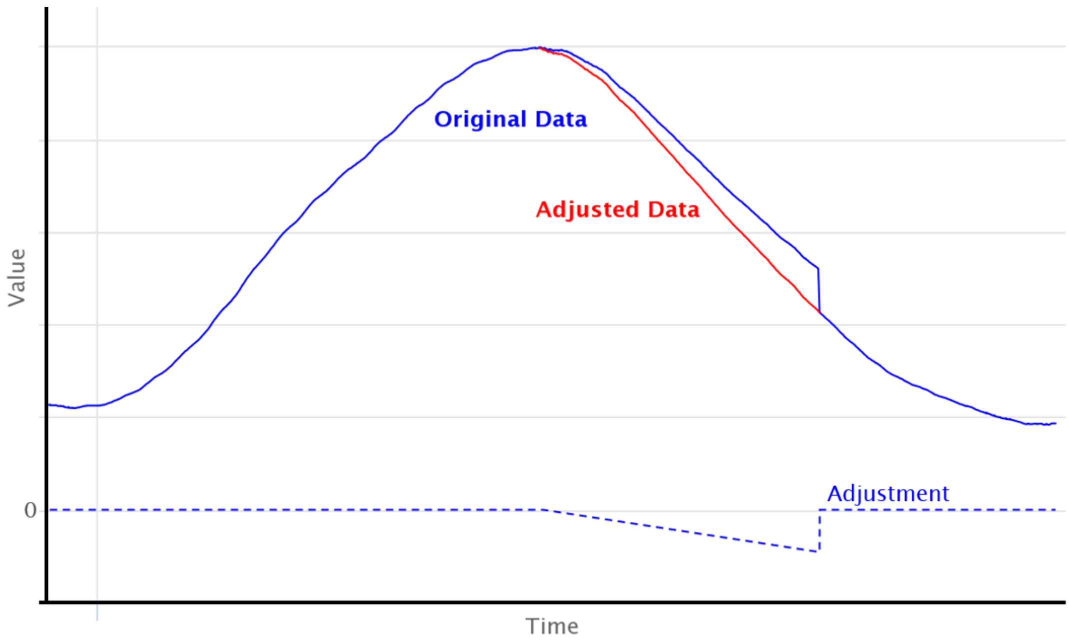


Figure A 4 – An example of an uncharacteristic step in the hydrograph (blue line) with the adjusted data (red line) and showing the gradual linear drift adjustment applied (blue dotted line) that is often referred to as a one-tailed ramp correction.

3.3.4 Instrument sticking or jamming

Instruments that incorporate pulleys or balance beams can record in steps if the pulleys are not free of friction or the balance beam electrical contacts are dirty. Response to changing water level is delayed, followed by a sudden 'catch up' that creates a sequence of steps in the data. 'True' water levels are the top of each step on the rising side of a hydrograph but bottom of each step when stage is falling.

A sticking encoder on a rising stage also has a high risk of the float-tape or beaded-wire slipping. The tape or wire may re-engage in another position and create an unintended offset (see Section A 3.2), or it may not re-engage and 'ride' the pulley.

A pulley with axis of rotation that is not horizontal may also cause the float-tape or beaded-wire to 'ride' the pulley. In situations of riding the pulley, the data are unreliable because the recording zero is no longer fixed. Verification of this situation is a combination of observation of pulley condition and comparison plots, and the affected data may need to be replaced with backup or synthetic data.

Surface followers use pulleys and electrical contact with the water surface. A poor electrical contact from a dirty probe would result in greater immersion of the probe and therefore levels consistently biased low, as well as the possibility of stepping.

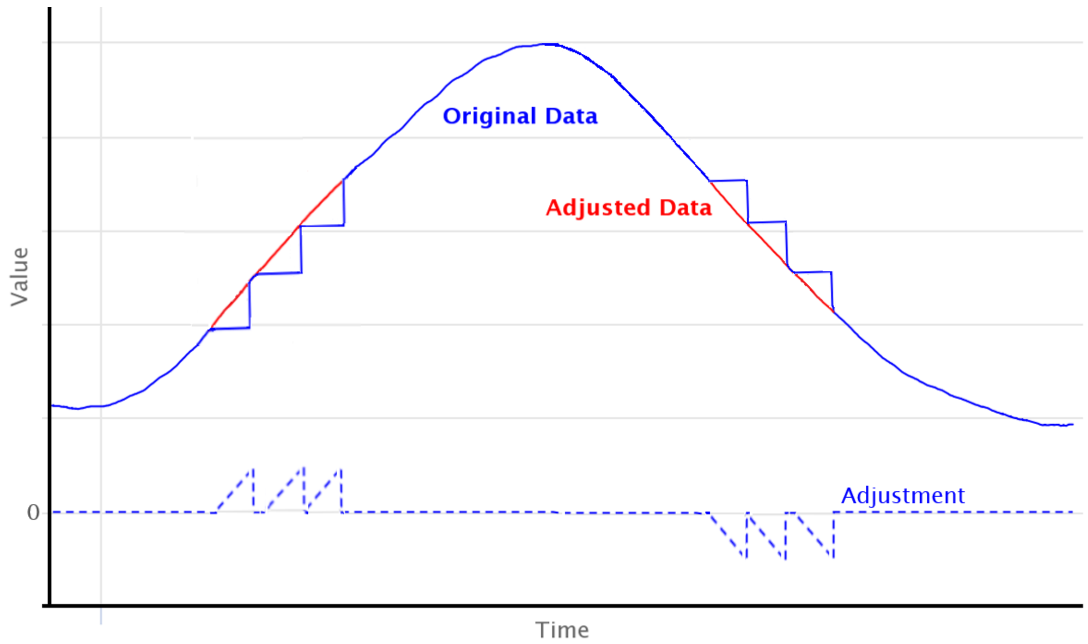


Figure A 5 – An example of uncharacteristic steps in the hydrograph (blue trace) with the adjusted data (red trace) and showing the successive linear drift adjustments applied to eliminate each step (blue dotted line).

Table A 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Instrument is not following the change in water level for a time then suddenly 'catches up'. May be repetitive. The surrogate stage record contains a step that translates to a sudden change in flow that cannot have occurred.	A 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down) and may flatline or appear 'held' down (or up) before the step.	Fig. A 4 Fig. A 5 A 2 3.6
Solution(s)	Linear drift adjustment with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace, OR stage–discharge rating(s) formulated and applied that eliminate any discontinuity in the derived flow record. Avoid applying drift adjustments over significant events.	4.4 OR NEMS *Rating Curves*
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change and Data Processing Comment required explaining identified cause and details of each stage adjustment applied (amount and period of adjustment), OR no change to stage quality code and rating(s) quality coded and commented. Flow series acquires lesser of the applicable stage or rating quality codes.	6.2.3 A 4.2.5 6.2.4.7 OR NEMS *Rating Curves*

3.4 Silting

Stilling wells and their intakes are prone to filling with silt and fines, usually occurring during a flood because floods transport most of the suspended sediment load. Accumulation of sediment in the intake(s) delays filling and emptying of the well causing lag (hysteresis). At site, the lag will be evident as a difference between internal and external water levels read from the plumb bob (EPB) and staff gauge, respectively.

Data affected by minor accumulations cleared promptly by flushing the intake(s) can be treated as fouling using a one-tailed linear drift adjustment applied from the peak of the causative event (zero adjustment) and ending with an adjustment equivalent to the step in the data, usually evident at conclusion of the flush when the intakes are again clear (see Section A 3.3.3). Any atypical 'lumpiness' in the hydrograph indicates a more severe problem requiring additional editing or replacement of the data to achieve a more representative hydrograph.

Intake blockages can become so severe that dampening occurs, minor events may be 'lost', and the shape of the recorded hydrographs is affected (see Figures A 6 and A 7). In such cases the faulty data must be removed and, if possible, replaced with an unaffected backup or a synthetic record.

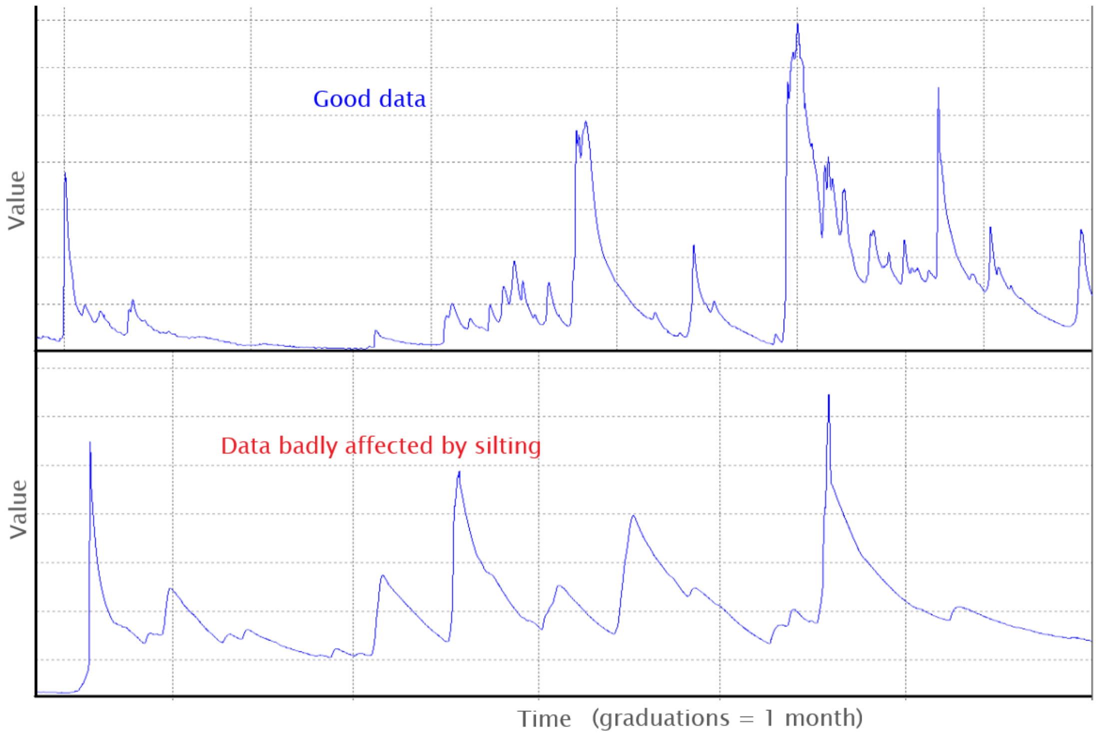


Figure A 6 – Comparison between good data (top) and data badly affected by silting of the stilling well intake(s) (bottom). Data are from the same site and instrument, for the same months, but in different years.

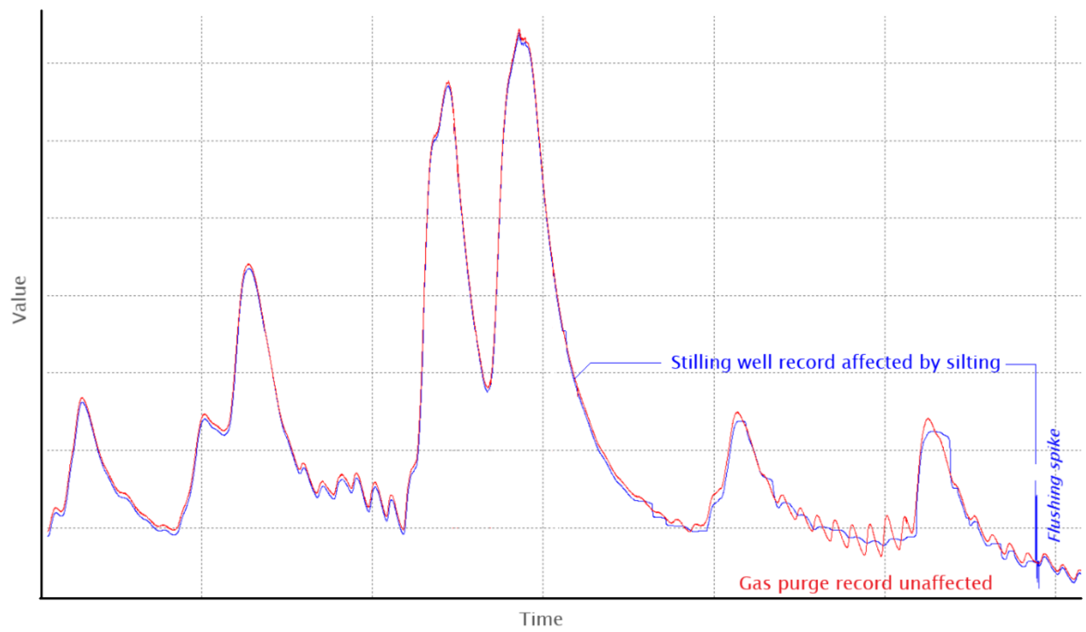


Figure A 7 – Comparison between good data (red trace) and data badly affected by silting of the stilling well intake(s) (blue trace). Data are from the same site and period but from different instruments. The gas purge record is unaffected by silting because its orifice is directly in the river and clear of sediment.

If the well itself fills with silt the full operating range of the float and counterweight may become compromised, or either may become stuck in the mud or an intake may cease to operate if its invert at the well connection is below the silt level. These situations may lead to some truncation of the hydrographs (see Section A 3.8) in addition to the usual silting problems.

Note: Reduced levels of the base of the well and the intake inverts at their connection to the well should be known and available from the station file for reference.

Table A 3 – Guidance for resolving silting effects in the data

Guidance for resolving silting effects in the data		see Section(s)
Issue(s)	Accumulation of sediment in a stilling well and/or its intake(s) results in hysteresis that affects hydrograph shape and may dampen or eliminate the recording of minor events.	A 3.4
Evidence	Differences between internal (well) and external (river) water levels. Results of additional observations and actions such as sounding of silt level, the 'float test', and intake/tower flushing. Trace of data when plotted lags comparison data, exhibits 'lumpiness' and atypical shape, and lacks minor events.	Fig. A 6 Fig. A 7 A 2 3.6

Solution(s)	If minor effect, a linear drift correction with zero adjustment at the peak of the preceding flood and maximum adjustment at the flushing step will suffice. More severe effects may need to be edited (if brief period), or replaced with unaffected backup or synthesised record, or deleted and marked as a gap.	4.4 5 or 4.16 4.20 A 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change and Data Processing Comment required explaining identified cause and details of each stage adjustment applied (amount and period of adjustment), OR Quality code applicable to the replacement backup record or QC 300 if synthetic, or QC 100 if left missing, and Data Comment required explaining identified issues and details of record substitution.	6.2.3 A 4.2.5 6.2.4.7 or 6.2.3 A 4.2.4 6.2.4.6

3.5 Drift

Other than fouling (see Section A 3.3.3), drift correction is usually needed to compensate for calibration drift. Submersible transducers are most prone. Ultrasonic sensors may also appear to drift but this may have more to do with temperature variations in the air or water column. Immersed ultrasonics normally also sense water temperature and self-compensate, which may be a source of faulty record if that compensation fails.

Calibration drift may be linear or non-linear. Which is applicable must be determined, if possible, by analysis of deviations from reference with time, and/or successive instrument validations. Non-linear drift adjustment may be approximated by a sequence of small linear drift adjustments, but these must be applied carefully to avoid distortion of the record, especially the shape of recessions.

Drift may occur for some time before detection and confirmation. Verification data normally used to control an adjustment may therefore include reference readings that encompass a wide range of water levels, some with large uncertainties. Avoid invalid adjustments by being selective about the reference values used to assess and control adjustment for drift.

3.5.1 Example invalid drift adjustment

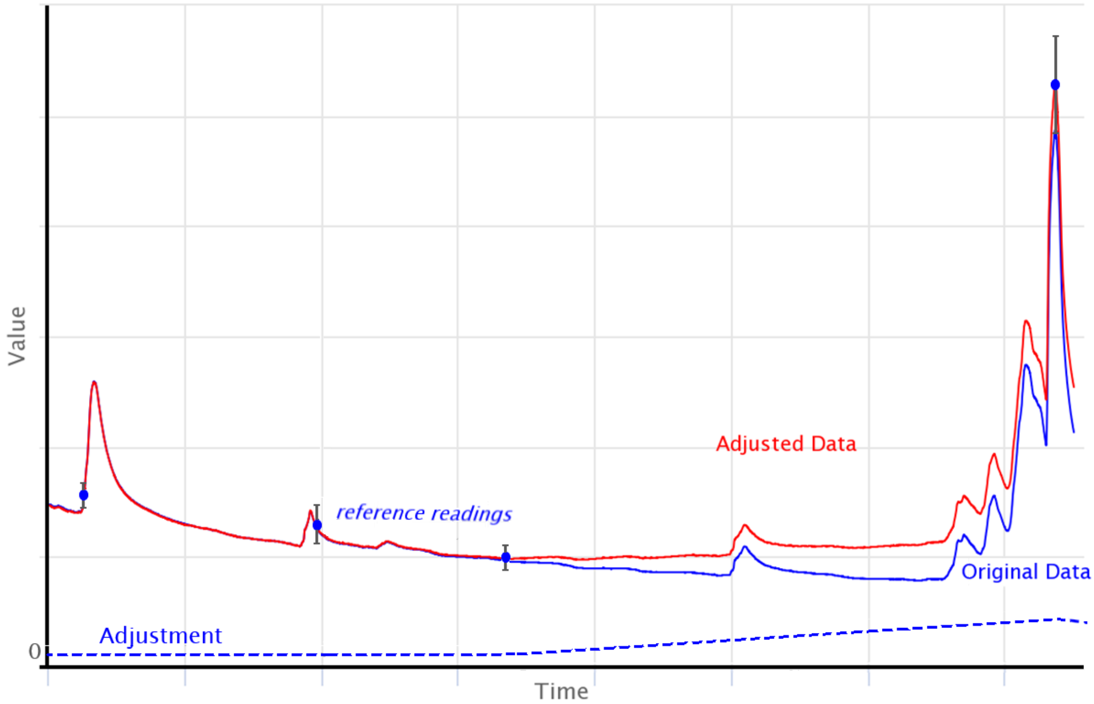


Figure A 8 – An example of a wrongly applied linear drift adjustment where the recession is unrealistically pulled upward by adjustment to a high stage reference value with large uncertainty (as indicated by the vertical error bars).

Table A 4 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	A 3.5
Evidence	Absolute differences between recorded and reference water levels increase with time. Physical cause may be identifiable such as biofouling, silting, or sensor validation results. When plotted, recessions appear uncharacteristically steep or flat.	Fig. 12 Fig. A 8 A 2 3.6
Solution(s)	Apply a linear or non-linear (percent) drift adjustment as applicable depending on whether the drift is determined to be linear or non-linear with time. A non-linear drift adjustment can be approximated by a series of small, short-duration linear drift adjustments, with care.	4.4 or 4.5
Metadata	QC 500 or QC 400 depending on ‘minor’ or ‘significant’ change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment).	6.2.3 A 4.2.5 6.2.4.7

3.6 Spikes

Power supply faults and electromagnetic interference are a common cause of isolated or intermittent spikes.

Isolated spikes in continuous water level data may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed, gap processes are required (see Section A 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section A 3.7).

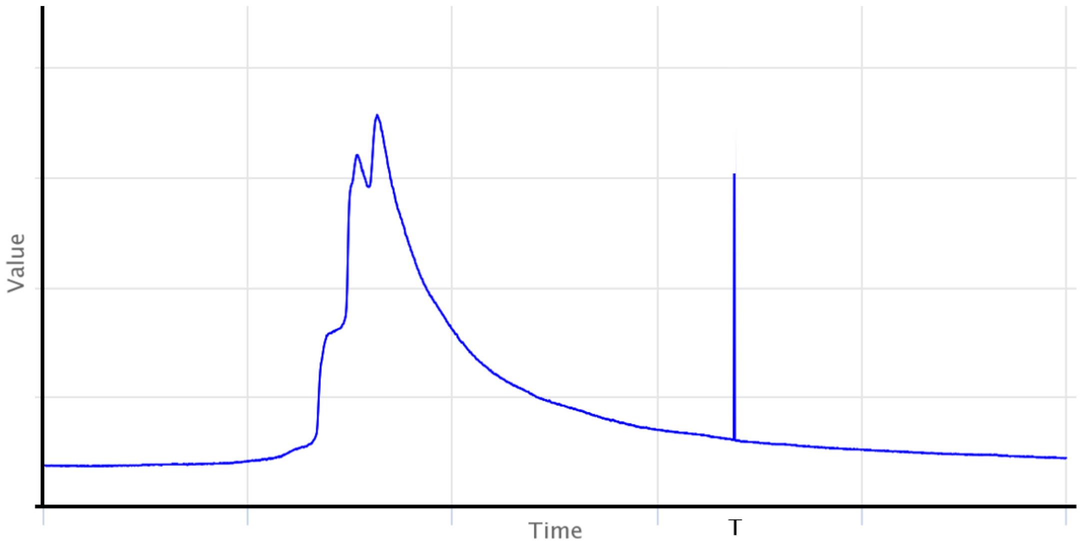


Figure A 9 – An example of a spike at time T that may be deleted or replaced.

Table A 5 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	A 3.6
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	Fig. A 9 A 2 3.6
Solution(s)	Delete or replace spurious values.	4.11

	If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	or A 3.11 or A 3.7
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 A 4.2.5 6.2.4.7 or A 3.11 or A 3.7

3.7 Noisy data

To select the appropriate filter, cause of the noise must be understood. The type of instrument and how it is installed are key factors.

A moving mean or median filter is appropriate when the noise is random about the representative value. Examples are record from a surface sensor (e.g. radar, laser or down-looking ultrasonic) affected by wave lap or vibration of the mounting structure. The filter output must be centred on the averaging interval but even so, induced hysteresis is possible such that if too large an averaging interval is used the resulting hydrographs show significant lag and may appear to 'tip' forward.

Tracking minima is more appropriate for noise resulting from over-reading, e.g. orifice burial or pressure fluctuations on an upstream facing pressure sensor (diaphragm or orifice).

Tracking maxima is more appropriate for noise resulting from under-reading, e.g. venturi effects on a downstream facing orifice, a current (i.e. mA) output sensor with dwindling power supply, or a surface follower or laser penetrating the water surface.

Pressure transducers often produce noisy data when they have been stressed and are close to failing. The noise may be random or biased depending on the individual instrument. Use of comparison plots is helpful in this case and some experimentation with various filters may be required to achieve the optimum result.

Table A 6 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations is outside tolerance. Range of fluctuations compromises accurate determination of flow.	A 3.7

Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. 7 Fig. 31 A 2 3.6
Solution(s)	'Smooth' with a statistical filter (e.g. moving mean) or resample (e.g. track maxima or minima). Method choice is determined by instrument type and identified cause. Some cautions apply.	4.12 Fig. 31
Metadata	QC 400 and Data Processing Comment explaining identified cause and method applied.	6.2.3 A 4.2.5 6.2.4.7

3.8 Truncation of hydrograph

Truncation occurs when the measurement system cannot record the full range of the variable of interest. For continuously recorded water levels any limit on the range of recording is almost always unintentional and undesirable, i.e. it is not the intention to collect censored data.

Truncation may be due to limits imposed by:

- the sensor or logger specification and/or programmed configuration, e.g. the electronic output range of a sensor or input range of a logger
- physical aspects of the installation, e.g. the possible range of float travel as governed by the level of the underside of the recorder housing floor, or the level of a sensor in relation to the range of levels that may occur in the water body
- a change in location, behaviour, or use of the water body, e.g. drawdown due to pumping or migration of a river channel away from the sensor.

Regardless of cause, the affected period must be replaced with backup data or treated as missing, i.e. either replaced with synthetic data or deleted, gapped, and documented as verified missing data.

In the case of data with a regular cycle (e.g. sea level or groundwater drawdown and recovery) it may not be appropriate to synthesise a replacement record (see Section A 3.11), but frequent gaps may compromise presentation and analysis of the data. Treating the record as censored in these cases may be a better option, but if so, must be quality coded QC 400 (i.e. 'compromised') and explicitly identified and explained by Data Comments.

Flatlining of a recession, as shown in Figure A 11, may be correct if consistent with the cease-to-flow level at the site. In this case the water level data need no adjustment, and the rating should associate zero flow with that cease-to-flow level.

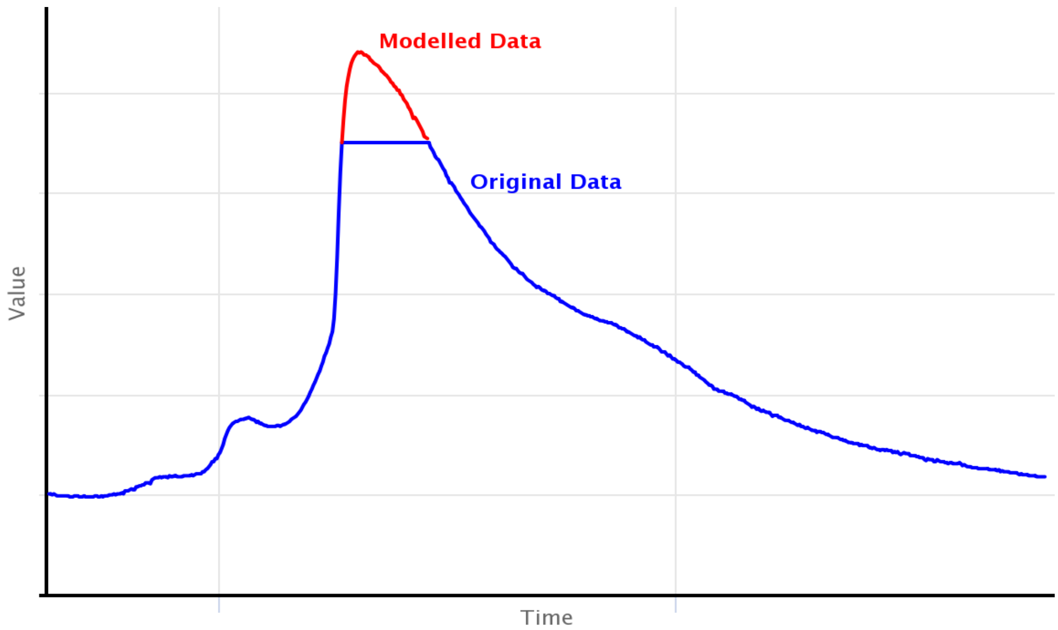


Figure A 10 – An example of a truncated flood peak (blue line) with the faulty data replaced by modelled data (red line). Peak level should be confirmed by survey.

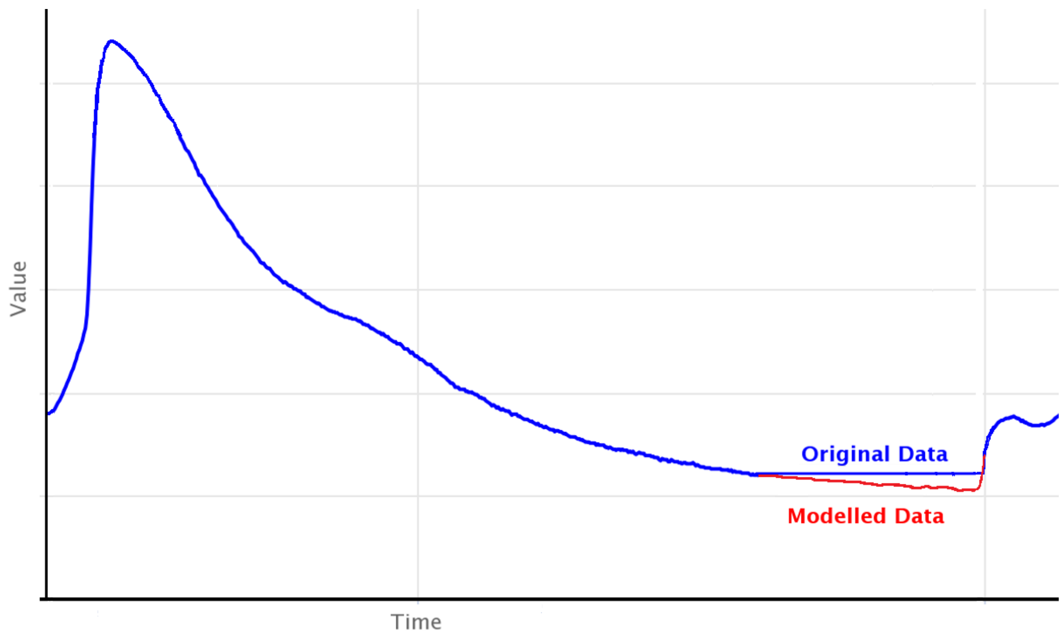


Figure A 11 – An example of a truncated recession (blue line) with the faulty data replaced by modelled data (red line). If the site is rated, minimum level should be checked against the rating to ensure derived flow is not less than zero.

Table A 7 – Guidance for resolving truncation of hydrograph

Guidance for resolving truncation of hydrograph		see Section(s)
Issue(s)	Full range of water levels is not recorded.	A 3.8

Evidence	Peak(s) or trough(s) flatline at a level consistent with cause identified by observation, field validations, and/or site surveys. Difference from actual peak level indicated by flood marks.	Fig. A 10 Fig. A 11 A 2 3.6
Solution(s)	Replace with backup data, or remove and treat as missing, or in limited circumstances accept as censored data. If removed, the gap created may be infilled with synthetic data if appropriate. Method choice is determined by site purpose, identified cause, and available supporting data. Some cautions apply.	4.16 to 4.20 incl. 1.1.5 A 3.11
Metadata	Quality code applicable to the replacement backup record, or QC 300 if replaced with synthetic infill, or QC 100 if left missing, or QC 400 if stored as censored. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 A 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means the range of the data is either wrongly reduced or expanded by some factor. The problem may arise from:

- wrong measurement units, e.g. imperial instead of metric, or
- incorrect sensor/logger configuration, e.g. wrong pulley size or wrong multiplier (and usually also then a wrong offset).

Because the recorder zero is usually set from the difference between reference and logged values at the time of configuration, a scaling error shows as differences in subsequent checks that vary in proportion with the difference between current water level and the water level at the time of configuration. If current water level is near the same as at the time of configuration, the verification difference between reference and logged value will be small and the scaling error may not be detected.

The error is most obvious when the extremes of recorded data are compared with independent observations such as flood levels, records from an adjacent site, previous data from the same site, or modelling results.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable there is no effect on quality code.

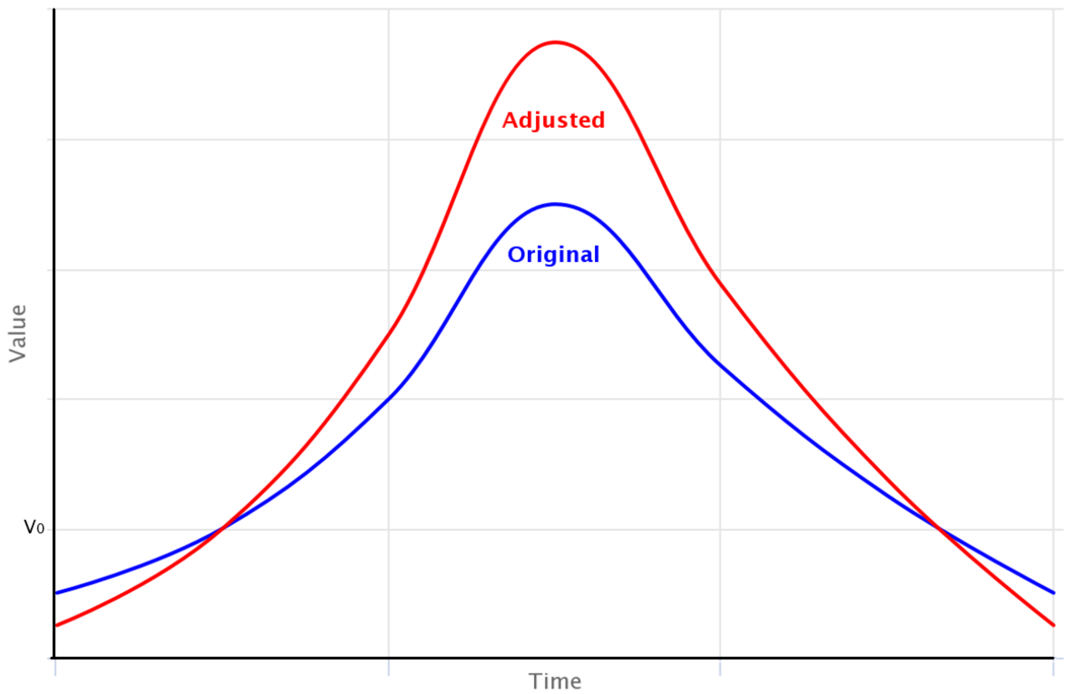


Figure A 12 – Example of the result of linear transformations to correct the scale of the data. V_0 is the value used to originally derive the instrument's configuration parameters.

Table A 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale of the data is wrong.	A 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	Fig. 28 Fig. A 12 A 2 3.6
Solution(s)	Apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	4.7
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.6 6.2.4.8 6.2.3 A 4.2.5 6.2.4.7

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section A 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Historically, mechanical recorder clocks frequently ran slow or fast, so most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table A 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	A 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with nearby sites.	Fig. 18 Fig. 26 A 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or A 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing or QC 300 if infilled, and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.5 6.2.4.7 6.2.3 A 4.2.4 6.2.4.6

3.11 Missing data

When considering the treatment and associated metadata requirements for missing water level data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is within a cycle or event up to a day
- a longer period may be up to 2 weeks
- an extended period is more than 2 weeks.

A maximum duration of one month for any period of infill is recommended for a river site, although this is dependent on:

- the typical and expected variation in levels at the site
- the possibility of a significant event having occurred, and
- reliability of the relationship(s) used to generate the synthetic record.

Data exhibiting a significant cycle such as tide or other frequent fluctuation (e.g. due to hydro-power generation) shall not be filled over a peak or a trough unless reliably modelled and/or the maximum and/or minimum levels of each cycle are known. Synthetic data other than interpolation are therefore not usually possible for a lake level site affected by seiche or wind tilt, or a sea level site.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in water level series, see Appendix A.1 to this Annex.

Table A 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	A 3.11
Evidence	Expected timestamps are not present in the raw data. A gap marker may or may not be present depending on data collection method. Comparison plot shows parts of hydrographs or entire events are missing. Investigation confirms data were not logged and/or not collected.	4.16 Fig. 9 Fig. 37 A 2 3.6
Solution(s)	Use backup data and manual observations where available, OR a) if brief with stable conditions, interpolate across gap b) if short with stable conditions, infill with a curve c) if longer period or unstable conditions, apply methods to infill with synthetic data, or mark the gap d) if an extended period, apply methods to infill with synthetic data if within recommended maximum duration, or mark the gap, or note a temporary site closure.	App. A.1 4.16 to 4.20 incl. 5.4 & 5.5 A 3.11

Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record and manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 A 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

The relevant quality coding flowchart may be found in NEMS *Water Level (Water Level Field Measurement Standard)* or in NEMS *National Quality Code Schema*.

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Guidance on how and when quality code must change as a consequence of data processing is provided in Section A 3 of this Annex.

4.2 Example water level comments

The following are templated examples of comments for water level stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water levels) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Water Level
Initial comment for *<river name>* River water level at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[1]
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type*[2]*>*
Drains *<catchment area to site>* km^2 and control is by *<flow control features>*

Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. weed growth, abstraction, high sediment*

[1] from *Catchments of New Zealand* (Soil Conservation and Rivers Control Council (SCRCC), 1956).

[2] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

load), adjacent site(s)> <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.

The following data is also measured at this site: *<list variables, including any backup recorder>;* <This site is rated to provide a record of Flow.>

The local recording authority is: *<name of recording/archiving agency>*

Lake station

Type: Site

Measurement: Water Level

Initial comment for <*name of water body*> water level at *<site name>*

Site number <*network number, ID or code*> on river *<river number>*[1]

The site is situated <*distance to outlet*> km from the outlet at grid reference *<map co-ordinates and type*[2]*>*

Drains *<catchment area>*km^2 of *<river name>* River catchment

Lake area is *<surface area>*km^2 and level is controlled by *<describe features e.g. natural outlet, dam, weir etc.>*

Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. weed growth, exposure to wind and waves, periodic drying up), adjacent site(s)>* <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.

The following data is also measured at this site: *<list variables, including any backup recorder>*

The local recording authority is: *<name of recording/archiving agency>*

Sea level station

Type: Site

Measurement: Water Level

Initial comment for <*name of water body*> Sea Level at *<site name>*

Site number <*network number, ID or code*> at grid reference *<map co-ordinates and type*[2]*>*

Situated *<brief location description>*

Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. biofouling, exposure (to wind and waves), means of calibration and reference, adjacent site(s)>* <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.

The following data is also measured at this site: *<list variables, including any backup recorder>*

The local recording authority is: *<name of recording/archiving agency>*

Groundwater level station

Type: Site Measurement: Water Level Initial comment for *<name, ID, or bore number>* Groundwater Station Located at *<map co-ordinates and type*[2]*>* drilled on *<date>* to depth of *<depth of well>*m Well construction: from *<depth>* to *<depth>*m diameter *<bore dia.>*mm and is *<cased, uncased, or screened>* Well type *<type>*[3] for *<purpose>*[4] Aquifer type *<type>*[5] depth *<depth>*m Aquifer lithology *<brief description>* Log available from *<name and contact details>* Consent *<number or* permitted use> Ground elevation *<level and datum>*m, Static water level *<level and datum>*m Additional information: *<site purpose, anything relevant to general interpretation of the record, additional bore location information if more than one bore in vicinity, aquifer properties, water quality grade, level of top of casing or tap used as reference, manual measurement frequency, adjacent bore(s)>* <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>. The following data is also measured at this site: *<list variables, including any backup recorder>* The local recording authority is: *<name of recording/archiving agency>*

4.2.2 Equipment Comment examples

Type: Equipment Measurement: Water Level Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The level sensor is a *<type and output e.g. 0-20mA submersible pressure transducer, gas bubbler and 0-5V dry pressure transducer, down-looking 4-20mA radar, SDI-12 shaft encoder with float and counterweight and 100mm pulley, etc.>* installed in (on) *<brief description e.g. 6m concrete tower, road bridge handrail, weighted cable down well, conduit attached to pier, steel box section secured on piles etc.>*. Sensor range is *<range and units>* with resolution of *<resolution>*mm and nominal accuracy of *<accuracy specification>*. Sensor output is converted to mm stage by *<details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset>*. Sensor calibration is valid for *<calibration period>* and field checked every *<validation frequency>.* Data is collected by *<method e.g. telemetry and occasional manual download>*.

[3] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring

[4] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused

[5] confined, unconfined, perched, or fissure

Similarly, for any backup sensor comment as above, as a separate comment if logged independently or added to the above from "The backup level sensor is a <*type and output* …" if using the same data logger.

Type: Equipment
Measurement: Water Level
Staff gauges installed on <*dd-mm-yyyy hhmmss*> surveyed from benchmark <*name of BM used as origin*>, level book <*reference and page*>. Adopted gauge zero is <*reduced level of gauge zero and datum*>. The <*number*> boards are <*describe range and location of each e.g. range 0.3m to 1.7m vertical board on left bank beside sensor, range 1.5m to 2.5m 30 degree sloping board on left bank opposite shed etc.*> The staff gauges are <*primary, or additional to the electric plumb bob primary*> reference at this site, read at every <*visit frequency*> site visit, and resurveyed <*site survey frequency*>. <*Add other relevant information such as prone to damage, silting or subsidence*>.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Water Level
Gas bubbler outlet moved on <*dd-mm-yyyy hhmmss*> from true left bank bridge pier to true right bank bridge pier. New orifice level is <*reduced level and datum, or equivalent stage*> and new offset applied from <*dd-mm-yyyy hhmmss*> is <*new offset*>. Trees on bank sides were trimmed back the same day to maintain access to the river channel.

The following are example comments about maintaining a known datum and reliable references for data verification, both essential to reliable measurement of stage. Information provided in such comments, for water level data, should include:

- details of placement and reduced levels of benchmarks
- changes to recorder zero
- vertical datum used
- type, number, placement, condition, and gauge zero of all reference gauges, including EPBs and external and internal staff gauges, and read points for dipping probes and pressure readings
- which reference gauge is primary
- instances of damage events, and
- reliability of reference readings.

Type: Operational
Measurement: Water Level
Gauge datum changed on <*dd-mm-yyyy hhmmss*> from <*old datum*> to <*new datum*>, refer level book <*reference and page*>. Gauge zero was <*reduced level of gauge zero and old datum*> and is now <*reduced level of gauge zero and new datum*>.

Type: Operational
Measurement: Water Level
Benchmark *<name>* installed on *<dd-mm-yyyy hhmmss>* lost on *<dd-mm-yyyy hhmmss>* as result of *<cause of loss e.g. being washed away or run over>*. Benchmark *<new name>* installed as replacement on *<dd-mm-yyyy hhmmss>*, located at *<co-ordinates and/or location description>* with reduced level *<reduced level and datum>*, refer level book *<reference and page>*.

Type: Operational
Measurement: Water Level
Staff gauge reading on *<dd-mm-yyyy hhmmss>* is unreliable because *<describe problem e.g. the board has been knocked over>* and is not used to verify the logged data. It was *<describe repair>* and resurveyed on *<dd-mm-yyyy hhmmss>*, refer level book *<reference and page>*.

4.2.4 Data Comment examples

Type: Data
Measurement: Water Level
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. *<Add any other relevant information such as why the gap has not been filled>.*

Type: Data
Measurement: Water Level
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Water Level
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Water Level
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least square regression or hydrological model, etc.>* with input data *<list sites, variables, and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. hourly or daily values only, or not recommended for model calibration etc.>*

Type: Data
Measurement: Water Level
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Cause is unknown but may be due to (or affected by) *<describe suspected cause>. <Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Level
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of C mm, linear drift adjustment of C_0mm to C_1mm etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in <u>specific</u> terms e.g. Range Test: values < x mm or > x' mm not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains <u>specific</u> detail of the tests applied to <u>this</u> data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational

Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

4.2.6 Transformation Comment examples

Transformations applied to a water level record prior to its archiving must be included in the water level metadata. Transformations to convert water level records intended as surrogate to the variable of interest are outside scope of the water level metadata (see Section 6.2.4.8).

Type: Transformation
Measurement: Water Level
Barometric compensation is applied to this record by *<describe method, including equations>* using *<frequency e.g. hourly or daily or simultaneous etc.>* atmospheric pressure readings from *<source of data e.g. a second pressure transducer at the top of the well, or name of nearby climate station, assumed constant value etc.>*.

Type: Transformation
Measurement: Water Level
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Water Level
Water levels are archived in metres head of water transformed from sensor readings in millibars using the relation 1 mbar = 0.010215 mH2O at 20C.

4.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Water Level
New *<type e.g. farm or public water supply, hydro-electricity storage, flood detention etc.>* dam commissioned on *<dd-mm-yyyy hhmmss>* at *<location description e.g. x-km upstream of recorder>* on *<name of stream, or unnamed tributary>* that will affect future runoff from *<dam catchment area>* of this recorder's catchment. Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is affected by dam construction.

Stationarity Comments can be used to capture and collate information about historical methods and data. A real example is provided below.

Type: Stationarity
Measurement: Water Level
The following is applicable from 01-06-1882. Flood levels prior to installation of the painted gauge(s) on the Rail bridge pier were obtained from reports of levels either surveyed or sounded below bridge decks. Relative level of the 1897 bridge deck has been deduced from descriptions provided in letters to the Board from NZ Railways and levels of the 1899 bridge surveyed in 1970, just prior to its demolition. The original bridge was washed away in the Easter 1897 flood. The 1899 road/rail bridge was on the same alignment, which was between the Rail bridge (built 1941) and the highway bridge (opened 1970). Painted gauges were installed and maintained on the Rail bridge from 1941. Readings from the Rail bridge painted gauge have had 6.7 feet (2.042m) added to adjust heights to current recorder datum. Readings from the original Kay Sand and Gravel (KSG) gauge are filed as read with discharge ratings compiled from gaugings filed to KSG stage. Best expected resolution from the old imperial gauges is 1-inch (25mm) with surges of 2 feet (0.61m) or more possible during high flows against the bridge pier. Between 1968 and 1971 gaugings' stage at low flows were pegged and surveyed because water levels fell below the Rail bridge gauge zero.

5 Quality Assurance

5.1 Datum continuity

Further to the requirements of Section 7 of this Standard, datum of water level records must be periodically reviewed for consistency.

- Review should precede any change to references at the site, including changes to benchmarks and gauge and recording zeros.
- Review must follow every update of the Station History with results from each Annual Station Inspection (see Annex D of NEMS *Water Level (Water Level Field Measurement Standard)*).
- Outcome(s) of the review must be added to the Station History. Any follow-up work required must be added to the tasks identified during the latest site visit.

A datum verification summary shall be included in any audit of water level data.

6 Preservation of Record

Refer to Section 8 of this Standard.

7 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix A.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, sea, or groundwater level)
- the duration requiring infilling
- the likelihood of stable conditions during the period missing
- the nature and availability of neighbouring donor sites
- prior existence of rainfall-runoff or other models
- availability of supporting observations and other evidence such as:
    - peak flood heights
    - manual gauge readings
    - rainfall record
    - surveyed levels
    - photographs.

2 Recommended Methods

The following methods are candidates for infilling gaps in water level records:

- inserting at-site observations of the primary reference gauge
- inserting other at-site manual observations such as surveyed levels, marks, and debris lines
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for short periods
- mathematical means such as calculating a curve, e.g. a river recession, groundwater drawdown/recovery, or tidal sine curve
- methods utilising a donor site or sites, such as:
    - copying a reference trace (from the same or another site)
    - linear or curvilinear regression equations
    - routing flows
    - using equivalent quantiles (percentiles) from flow duration curves
    - ratio of areas (i.e. transfer of specific discharge)
    - a combination of these methods, using multiple donor sites
- water budget
- rainfall-runoff model predictions, and

- outputs from other, possibly more complex hydrological, tidal, and/or hydraulic models.

Supplementary evidence, such as primary reference gauge observations of water level, suitably relevant rainfall records, photos, and flood debris levels, can be incorporated into all the methods detailed above to improve confidence in synthesised data.

Manual entry of intuitive estimates should be limited to gaps of no more than one day.

Infilling a recession by calculation, or by copying a reference trace, should be limited to the recession period in question.

If the synthetic data for a river site are derived from a fully calibrated routing, hydrological, or hydraulic model, gaps of up to two months duration might be reliably filled but the feasibility of infilling any gap longer than one month should be carefully assessed.

The other methods listed should not be used to infill a gap of more than one to two weeks duration, taking into account expected variability and the possibility of significant events having occurred within the period of the gap.

2.1 Infilling with observations

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected so they may be inserted into the record to avoid missing data. Most often the manual observations will be staff gauge readings and their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

Large floods can damage equipment, or water level can exceed the range of an instrument or drop below it. Thus, missing record often incorporates a period during which an extreme event has occurred. Every effort must be made to measure the extent of the event when subsequently visiting the site.

The following evidence can be incorporated as one or more points through which any synthetic infill must pass:

- a flood level represented by debris marks
- a low flow level indicated by lines of dried algae
- level indications from photos and/or video
- other evidence, such as an indication from the adjacent land occupier
- operating range of the installation, which should be known and noted in the station history file.

If evidence provides the timing of the extreme event, then this should be used to assign it a time; otherwise it can be derived from the method of creating the synthetic record.

2.2 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short (typically less than one day) gap in a water level record is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or recession curve. A straight line should only be used for brief periods, as there is no hydrological basis for that shape.

2.3 Infilling a recession

This method can be used if a longer gap (typically greater than one day) occurs over a period of known recession, i.e. no rain has fallen and neighbouring or upstream stations show a steady recession.

It may be sufficient to copy the recession of the neighbouring or upstream station, or a previous recession at the same site.

An unbroken flow recession can be estimated by connecting the adjacent periods of good flow record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the recession may be calculated from a master recession curve for the site, developed from the flow record. Derivation of a master recession curve is covered in many hydrological texts.

Note: Seasonal variation in recession behaviour may need to be taken into account.

If the infill has been derived as a flow recession it must then be transformed to stage using the inverted applicable stage–discharge rating(s). The stage–discharge ratings applied must cover the full range of the predicted data, which may require the ratings to be extended first.

2.4 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

For river sites, regression analysis is usually more successful if performed using flow rather than water level because the problem of bed shift in one or both sets of input data is eliminated. If the infill is derived from regression of flows, it must then be transformed to stage at the recipient site using the inverted applicable stage–discharge rating(s). The stage–discharge ratings applied must cover the full range of the predicted data, which may require the ratings to be extended first. It may also be necessary to adjust the infill stage to fit seamlessly into the existing record, in which case the end result must be plausible, for example, not introduce a rising recession.

Do not use equations forced to zero for regression of stage or flow. If negative flows are predicted, their significance, and the likelihood of periods of no flow at the recipient site, must be assessed. If periods of no flow are not plausible the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.5 Infilling flow by routing upstream flows

If a gap exists in a record of river flow, and an upstream site or sites exist, it may be possible to route these downstream to create a flow record at the downstream site. This flow record can then be converted to stage using an inverted stage–discharge rating. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1. Hydraulic routing is preferred, but if there is little attenuation of the hydrograph between the two locations a simple time shift and catchment area ratio adjustment may suffice.

There are several common routing techniques ranging from hydraulic, or distributed, routing that require data about river geometry and a lot of computing power, to hydrologic, or lumped, routing that solves a relatively simple continuity equation. Choice of technique will depend on length of the required period of infill, available input data and resources, and desired accuracy of the synthetic record.

2.6 Infilling flow using equivalent quantiles from flow duration curves

This method is described in McKerchar et al (2010) as the preferred means of creating a synthetic flow record. In concept, it is a form of regression. The relationship between donor and recipient sites is created by deriving a flow duration curve for each site from a period of concurrent record of five or more years, then associating flow values for equivalent percentiles into pairs of rating curve points. The 'rating' is then applied to the donor site flow record to transform it to a synthetic flow record at the recipient site, with a time lag if needed. The derived synthetic flow record at the recipient site is then converted to stage using applicable inverted stage–discharge rating(s). Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

The method provides a convenient means of comparing the sites' flow regimes, checking for seasonal bias, and assessing non-linearity while developing the relation.

Test goodness of fit by applying the relation over the concurrent period of record then plotting deviation of the synthetic from actual and calculating the standard error.

The method is not suitable for estimating flood flows because a storm producing a notable flood will almost certainly have variations in rainfall totals across two catchments. Simulation of flood flows requires detailed rainfall records and a suitable rainfall–runoff catchment model (McKerchar et al, 2010).

2.7 Infilling flow records by ratio of areas (specific discharge)

A simple but often effective method of creating flow data from a donor site is to transform flows at the donor site to specific discharge then multiply by the catchment area at the recipient site. If the gap is short and no large floods occurred, this is a useful technique. The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

Note: Flow divided by catchment area is known as specific discharge or specific yield, although specific yield is more usually associated with aquifers. A modification of this method is to use more than one donor site and/or weight the yield(s) e.g. recipient site yield is half the donor site yield.

2.8 Infilling flow record using a water budget

Records missing for a station that measures inflow to a reservoir can be estimated using the water budget method if accurate records are available of the reservoir outflow and the change in storage contained within the reservoir.

Mean daily inflow to the reservoir is equal to mean daily outflow plus or minus the change in reservoir volume over the day.

Where flow at the inflow station is not the total inflow to the reservoir, an adjustment may be required. The adjustment can be a drainage area ratio or some other assessed scaling factor. The scaling factor can be estimated by applying the water budget equation during periods when inflow, outflow and storage records are all available.

The water budget equation is: $Q\text{i} = K(Q\text{o} + \Delta C)$

where Qi = flow at inflow gauge; Qo = outflow from reservoir; K = inflow scaling factor and ΔC = change in reservoir storage, computed as midnight content at end of current day minus midnight content at end of previous day (start of current day).

The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

The same principle can be used to estimate missing outflow records for gauging stations located just downstream from a reservoir. The equation is rearranged to solve for outflow, Qo (WMO, 2010).

2.9 Infilling flow record using rainfall–runoff models

Rainfall–runoff models are time consuming to set up, and therefore should only be considered for infilling flow record if one already exists for the location. They also have the disadvantage that their output can be difficult to replicate. Rainfall–runoff models should only be considered when options to utilise a donor site have been rejected.

The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

3 Selecting a Suitable Donor Site

One or more adjacent, nearby, upstream and/or downstream hydrological stations may be suitable as donor site(s) to infill a gap in a recipient site record.

For flow stations, catchment characteristics such as area, topography, geology, rainfall distribution, and storage are critical factors to consider when assessing similarity.

- In some parts of New Zealand, such as volcanic areas, abandoned river channels, and areas with extensive modified drainage, hydrological regime can vary significantly between adjacent catchments, being strongly influenced by, respectively, the variability in volcanic and alluvial deposits, and by intervention to control the direction of drainage and discharge.

- The influence of activities such as abstractions or diversions must be carefully assessed, as must weather patterns prevailing at the time of the periods of data analysed and predicted. There may be large variation between rivers assessed to be hydrologically similar due to events occurring in one that did not occur in the other (McKerchar et al, 2010).

Compare an extended period of record from all candidate sites. However, depending on activities and weather patterns, it may be prudent to limit the analysis to two to three weeks of data either side of the gap. If stage is used rather than flow, a shorter period may avoid the derived relation being affected by bed shift.

Use overplots to compare timing and shape of hydrographs.

Use X-Y (scatter) plots to explore:

- the relationship between the sites, both visually and statistically (e.g. by correlation co-efficient, (r))
- potential non-linearity and seasonal bias, and
- the most suitable interval at which to generate the infill record. For example, a poor fit might only justify daily means, while an excellent fit might reasonably provide hourly values.

Note: Some software allows lag times to be assessed using scatter plots or other correlation tools; otherwise, these may be assessed using data overplots.

4 Other Considerations

4.1 Time resolution of infill data

The time resolution of infill data should be sufficient to convey realistic hydrograph shape and ensure that points of inflection, such as onset of rise and peaks, are sensibly represented; however, the time resolution should also reflect how the infill data were derived, for example, from hourly observations or synthesis of daily mean flows.

Use of longer interval means to synthesise infill poses a particular problem when incorporating the infill into the recipient record because most time-series managers do not allow the mixing of average in interval and instantaneous data in the same time series. Some judgment is required, and the filed comment(s) must make clear how the infill was derived and then incorporated into the record.

4.2 Seasonality of relationships

The effect of seasonality on the relationship used to derive a synthetic record should be explored. Seasonal variations may arise from climate differences between donor and recipient sites, irrigation activity, cycles of different land use or cover, or water allocation rules such as minimum flow periods. If significant, a relationship may be required for each season or part thereof.

4.3 Non-linear relationships

Any non-linear relationship derived between hydrological stations should be consistent with the differences in physical characteristics of their contributing catchments; for example, those arising from differences in storage, by way of geology, ice/snow cover, or the presence of reservoirs and lakes, that may lead to delayed or attenuated runoff or differing rates of baseflow depletion.

4.4 Using multiple donor sites

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contribution of each donor site.

Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

5 References

Joenssen D, Bankhofer U. 2012. *Hot Deck Methods for Imputing Missing Data*. In: International Workshop on Machine Learning and Data Mining in Pattern Recognition (pp. 63-75). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).

McKerchar A, Henderson R, Horrell G. 2010. *Standard procedures for creating and describing synthetic hydrological record.* NIWA Client Report No. CHC2010-002 prepared for Tasman District Council under an Envirolink project.

World Meteorological Organization (WMO). 2010. *Manual on stream gauging (vol. II) – Computation of discharge.* WMO Publication No. 1044. Retrieved from www.wmo.int/pages/prog/hwrp/publications/stream_gauging/1044_Vol_II_en.pdf (25 August 2020)

Annex B Rainfall Data Processing

1 General Overview

1.1 Normative references

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

> NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*

Where reference is made from this Annex to specific sections of the above document, its title is abbreviated and version stated, i.e. 'NEMS *Rainfall Recording* v2.1'.

1.2 Scope of this Annex

While the NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* does not specifically exclude other methods of automatic rainfall recording its content is limited to use of tipping bucket gauges.

This Annex is therefore also focused on the processing of rainfall data captured using tipping bucket gauges. The methods and tools are generally applicable to most other available and emerging means of digitally recording rainfall. However, this Annex and its normative reference will require revision to incorporate techniques specific to other instrumentation and methods that may be deployed in future or have been used in the past (e.g. digitised chart records or manually entered daily readings).

1.3 Effect of data type

Rainfall data may be captured and stored as totals in fixed intervals with regular timestep, or totals in intervals with irregular timestep, or tip-by-tip timestamped as they occur (now known as event data; see Appendix B.2 for more information about event rainfall data).

The data in all cases are incremental, i.e. values are totalled in any period, but they may be stored as a total in the preceding interval with interpolation or as discrete totals with no interpolation between adjacent values.

The difference in interpretation is essentially what is implied to have happened between timestamps and this affects how rainfall is totalled in any nominated period. This in turn has some bearing on how the data are verified and processed, especially if filed data elements are deleted.

For an interpolating data type, each value stored represents accumulation at a constant rate in the interval between adjacent timestamps that can be apportioned to any part-interval between the timestamps. Each timestamp also sets the start of the next value's accumulation. Rainfall is only considered to have ceased when a zero value is encountered; however, because the data are totals in the preceding interval the period of no rain is the duration of the timestep up to the timestamp of the zero value.

The Hilltop Software data types intended for tip data ('Six minute Rainfall' and 'Thirty minute Rainfall') are an interpolating hybrid whereby the data are stored timestamped as each tip occurred but when analysed, if there is no value stored in the six (or thirty) minutes prior, Hilltop inserts a zero value 'on the fly', i.e. it is not written to the data file. The interpretation is that each bucket took no more than six (or thirty) minutes to fill before tipping.

With a discrete data type, the value stored is instantaneous, i.e. all water tipped from a gauge bucket is assumed to have arrived in the bucket at the time of the tip. Totals are aggregated up to and including any value that coincides with the end of a requested totalling interval. Between timestamps no rain is deemed to have occurred, such that requesting a total for a period between adjacent timestamps will return a value of zero.

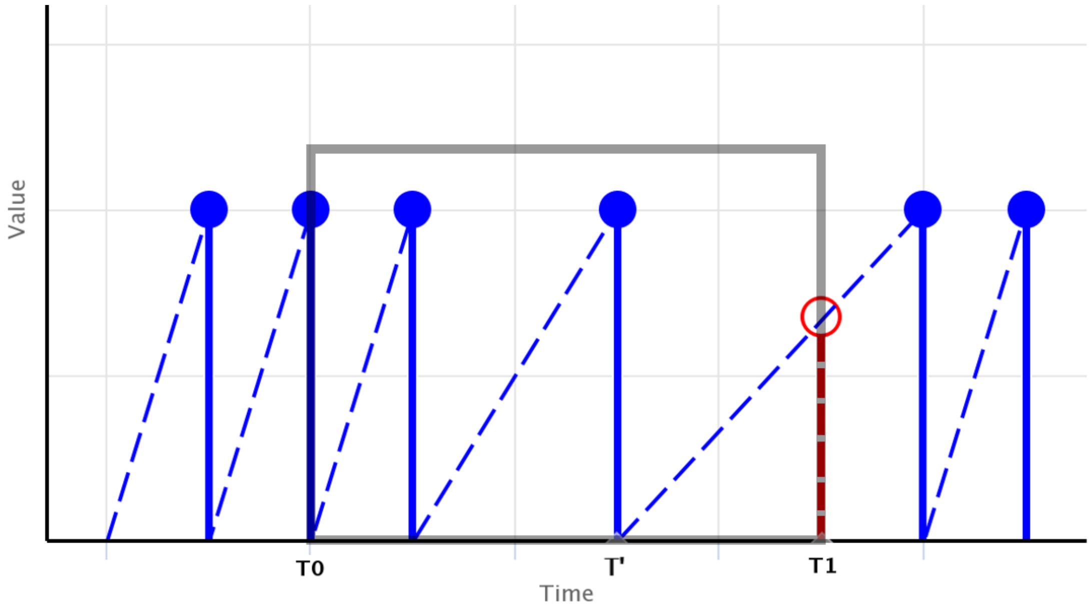


Figure B 1 – An example of the difference between interpolating and discrete incremental tip data. If the data type is discrete the dashed lines do not exist. If interpolating, the total from T0 to T1 (grey box) is the sum of the two blue dot values within the box plus the interpolated value at T1 (red circle). If discrete, only the two blue dot values within the box are summed. If totalling up to T0 there is no difference; each data type sums the two blue dot values up to and including T0. If totalling from T1 to the end, two blue dot values are summed if discrete, but if interpolating, only the part accumulation from T1 to the next blue dot is added to the last blue dot value. If totalling from T' to T1 a discrete data type returns zero while an interpolating data type returns the value interpolated at T1.

2 Quality Control

2.1 Rainfall Data Quality Matrix

The Rainfall Data Quality Matrix should be completed while on site at each visit. If not, it should be completed as the first quality control task of data processing (see also Section B 5.1.2).

2.2 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying rainfall data:

- details of all gauges present, including any reference or backup gauges beyond the immediate enclosure:
  - location
  - type, including whether fitted with an inlet siphon
  - dimensions, including storage capacity in terms of rainfall depth where relevant
  - orifice height, including whether installed with a splash grid if at ground level
  - method of measurement, including any other agencies involved
  - accuracy
  - resolution
  - recording interval
  - recording method, e.g. to data logger, electronic field sheet, paper logbook, direct transmission to base etc.
- details of any changes to the enclosure, instrumentation, or ancillary equipment during the record period
- relevant completed Rainfall Site Matrix assessments
- relevant completed Rainfall Data Quality matrix assessments
- observations of any change to exposure, aspect, or obstructions (see Section 2 of NEMS *Rainfall Recording* v2.1)
- results of gauge verification inspections (see Sections 3.3.1 and 3.4.1 of NEMS *Rainfall Recording* v2.1)
- details of relevant gauge validations (see Section 5.2 of NEMS *Rainfall Recording* v2.1) including:
  - date and time of the validation
  - method and equipment
  - required range of theoretical tip value(s)
  - reason for the validation, and

- outcome of the validation
- photographs of the enclosure and environs, and any changes to these.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.3 Plots and comparisons

2.3.1 Fixed interval totals

- Use five-minute totals, or totals at the recording interval if greater than five minutes, to check for anomalies such as:
  - spuriously high values indicative of interference (see Section B 3.2.2),
  - frequent occurrence of the same maximum value suggesting a range limit (see Section B 3.2.6 and Figure B 2)
  - prolonged periods of the same non-zero value that may be due to a partially blocked collector (see Section B 3.2.3 and Figure B 2).

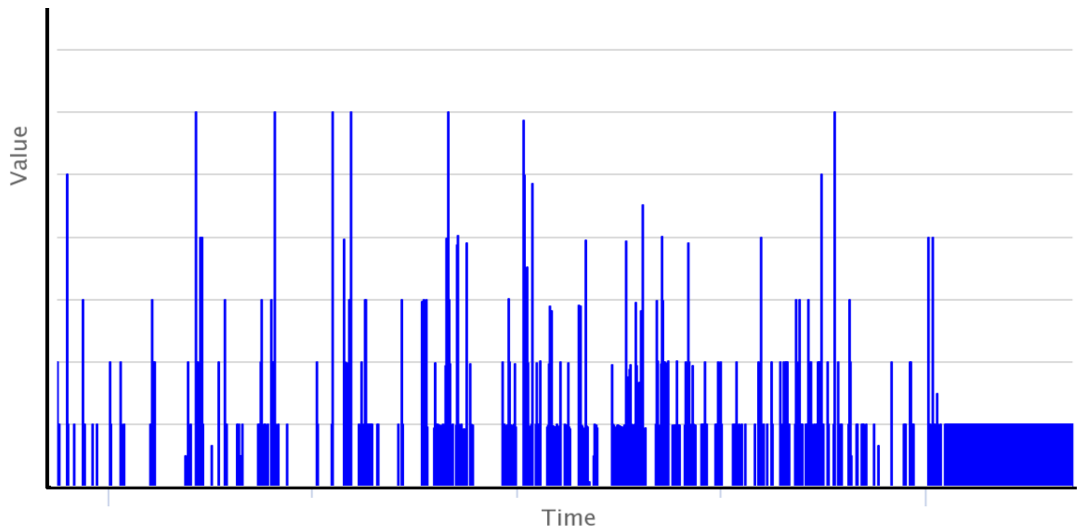


Figure B 2 – An example of a five-minute interval bar plot showing suspiciously repetitive maxima and a period of likely blockage at the end.

- Use hourly totals to confirm storm intensities. Twenty-five millimetres per hour is heavy rain and a useful threshold to apply at most gauges in New Zealand.
- Use daily totals to confirm magnitude and timing of events such as:
  - storms
  - dry spells
  - prolonged wet periods.

Note: Forecast heavy rain warnings are useful to sanity check storm event daily totals. 100 mm or more in 24 hours over a wide area is 'severe'.

2.3.2 Cumulative totals

For short periods of record, such as between successive site visits, cumulative totals are most useful when used in comparisons (see Sections B 2.3.3 and B 2.3.4).

Over longer periods, cumulative plots are useful to check for stationarity issues. In this context they are sometimes referred to as mass plots and are recommended to be included in any rainfall data audit.

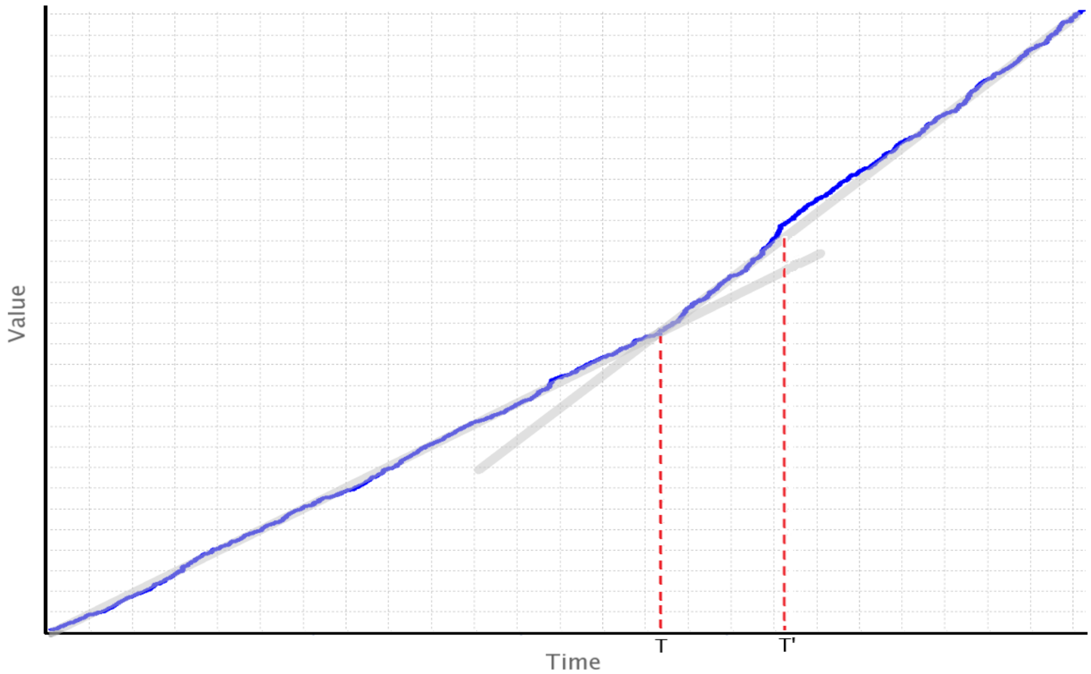


Figure B 3 – An example of a cumulative plot of a long period of record showing change in slope of the trace (indicated by grey lines) suggesting something changed from time T to compromise stationarity. The 'hump' around time T' should also be investigated.

2.3.3 Comparisons

- Use comparisons to:
  - cross-check the data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Use fixed interval and cumulative totals to check for anomalies. Compare the recorded intensity data with:
  - a reliable and representative record from another site (see Section B 2.3.4), or
  - a backup instrument at the same site, provided it is not affected by the same data quality issue(s), e.g. an overgrown enclosure, interference, or snow.
- Use a common totalling interval that is at least as long as the longest recording interval of the data to be compared.

For example, if comparing an event record with record from a standard daily gauge use a totalling interval of 24 hours from 9 a.m. or the daily data will be apportioned and thus misrepresented.

- If using a backup record for comparison, there should be no difference in scale or event timing other than due to resolution (bucket size and/or recording interval) differences.
- When comparing with another site, proportions, patterns, and timing of events should be similar and consistent, although allowance must be made for the passage of storms and fronts. Reference to weather situation maps may be needed.
- Use cumulative plots or period totals to confirm editing and adjustments. Compare intensity gauge records and primary reference gauge totals:
    - before and after any editing of data (Figure B 4), and
    - before and after adjusting the verified clean record to the corresponding primary reference gauge total(s) (Figure B 5).

2.3.4 Between-station comparisons

- Criteria for selecting a suitable rainfall comparison site are similar to those for selecting a suitable infill record donor site (see Appendix B.1 Section 2.5).
- Use between-station comparisons to:
    - check for transient problems that may occur and resolve between site visits, such as a temporary blockage or interference
    - identify when a problem detected during a site visit arose, e.g. loss of pulses to the data logger
    - investigate problems that develop gradually and may not be apparent from a single inspection, such as corrosion of moving parts.
- In the absence of a suitable comparison rainfall site, a record of water levels or flows resulting from the rainfall at or near the site can be used.
    - If plotting, use a log scale for flow if data range is a problem
    - Use cumulative totals, or a fixed totalling interval of near the time of concentration of the catchment, to investigate rainfall rates and event timings and proportions.

2.4 Gauge verification and validation

2.4.1 Tipping bucket (intensity) gauge

Verification and validation requirements are set out in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*.

Verification assesses condition of the gauge at each site visit and requires successful timely validation of the gauge. Failure to validate when required, or an unsatisfactory validation result, means the gauge does not pass its verification check and the data affected must be quality coded QC 400. The period of affected data is from the last successful validation or acceptable condition check, up to the next successful validation or acceptable condition check, whichever is longer.

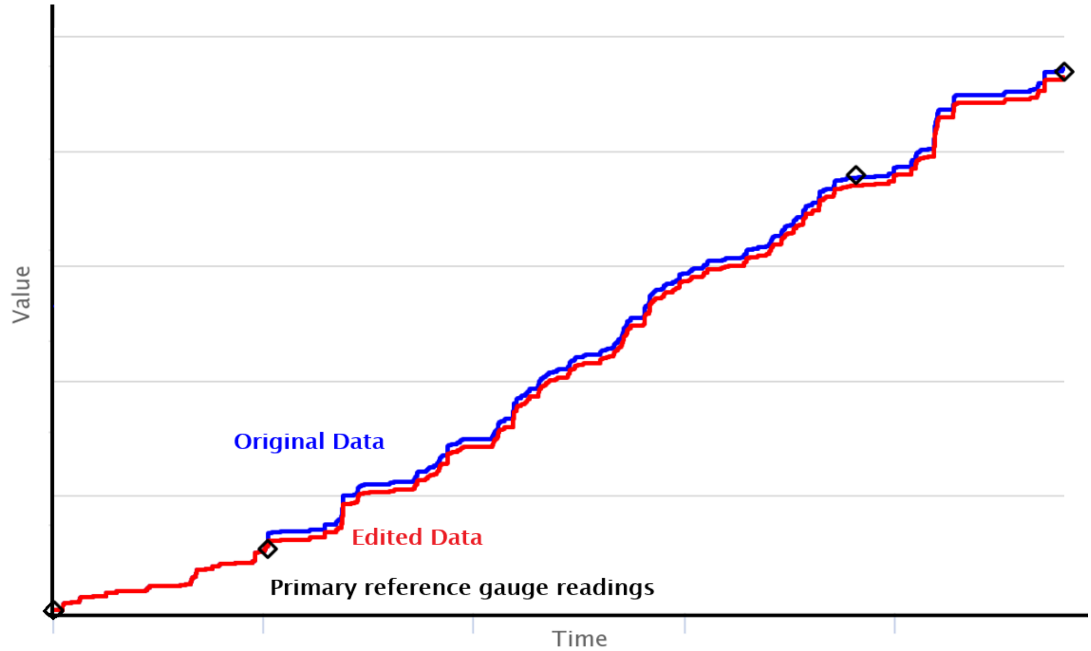


Figure B 4 – An example of a comparison plot of cumulative intensity and reference gauge totals before and after editing to remove validation test tips.

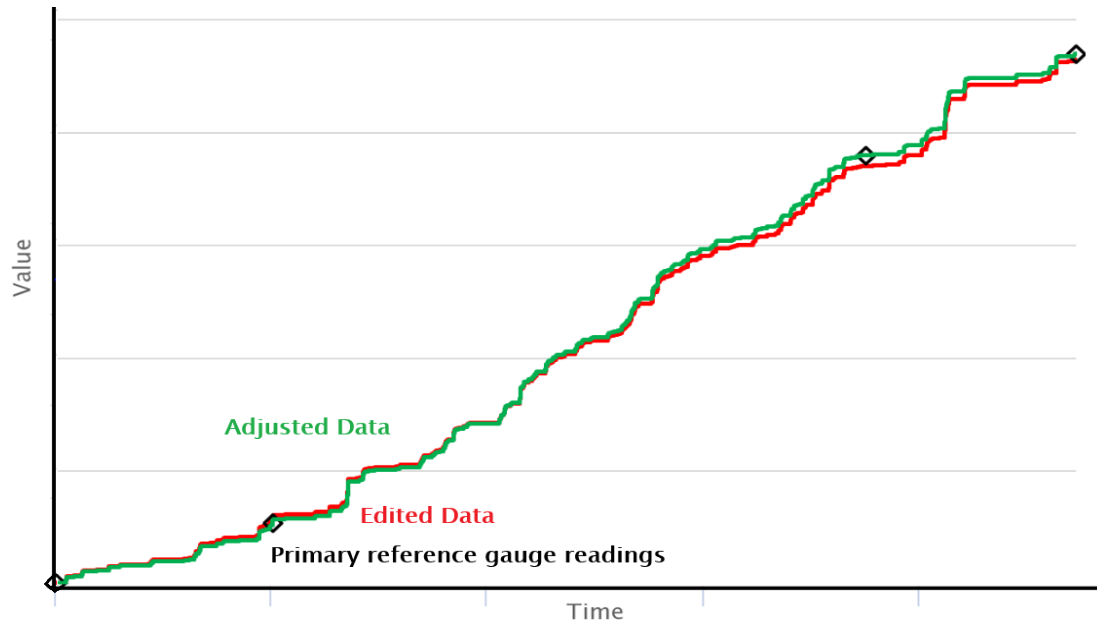


Figure B 5 – Comparison plot of the edited cumulative intensity and reference gauge totals from Figure B 4, before and after adjusting to the reference gauge totals.

Use the Rainfall Data Quality Matrix in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* to determine quality code for other outcome combinations of the verification and validation criteria.

Gauges fitted with siphons are calibrated to tip at a lower volume per bucket than gauges without. If a siphon is removed, unless the gauge is recalibrated it will over-read by a nominal 9%. The normal process of adjusting the record to primary reference gauge totals will compensate, but the clean unadjusted record will remain biased unless it too is adjusted for the difference in calibration by reducing the nominal tip value, e.g. from 0.5 mm to 0.455 mm.

2.4.2 Primary reference gauge

Verification requirements are set out in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*. There are no validation requirements for primary reference gauges.

Verification assesses condition of the gauge at each site visit. A primary reference gauge reading is deemed unreliable if any one of the verification criteria is not met when the gauge is inspected and its contents measured. Intensity data collected in the corresponding period between the preceding acceptable inspection and the 'failed' inspection cannot be quality coded higher than QC 400.

Primary reference gauge readings regarded as unreliable, for whatever reason, must be identified in any relevant quality control checks, e.g. control charts and deviation tests (see Section B 2.5). An unreliable or missing primary reference gauge reading may be replaced by an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

2.4.3 Test tips

Bucket function is tested by tipping them manually. Validation with a field calibration device puts water through the gauge that is not rainfall. If these additional tips are logged, they must be removed from the record. How this is best done depends on the data type used to store the data.

If the data are stored as discrete totals the entire data element for each test tip (i.e. the value and its timestamp) may be deleted because there is no interpolation, so no effect on apparent rate of accumulation of the next actual tip logged.

If the data are stored as an interpolating data type, edit each test tip value to zero to retain the timestamps and therefore capture in the time series that the buckets were known to have been left empty at that time.

Allowance should be made for any part-full bucket or siphon disturbed by gauge testing or cleaning.

Total the recorded data before and after removing the test tips and reconcile the totals with the number of test tips intended to be removed. Quality code is unchanged by the editing of test tips, and a comment is not required, but the reconciliation must be stored permanently with the processing records.

2.4.4 Status checks

Because there may be a long time between rain events, systems that record tip by tip (event data) are often set up to log and/or send a zero value and timestamp at regular intervals independent of the gauge, to indicate the site is still operating.

If the rainfall data are stored as discrete totals, these extra data elements in the record that do not originate from the rain gauge do not matter and can remain in the series.

If the rainfall data are stored as an interpolating data type, these extra data elements alter the apparent start and rate of accumulation of the next actual tip, influencing how the rainfall record is interpreted, and may alter reported rainfall intensities. Ideally, the extra data elements should be filtered from the record, but this may not be practical.

A Data Comment must be filed that describes the frequency of status data generated, its effect with respect to data type, and whether the status data elements remain in the processed record or have been filtered out. If filtered, reconcile the data before and after. The total amount of rainfall recorded in the period should be unchanged. Filtering to remove status data elements has no effect on quality code.

2.5 Deviation tests

NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* expresses tolerance as absolute or percent deviation depending on catch. Use the primary reference gauge reading to determine catch unless that is unreliable (see Section B 2.4.2). Test tips must be deducted from the intensity gauge total before calculating the deviation from reference (see Section B 2.4.3).

The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure B 6) or stacking the charts (Figure B 7).

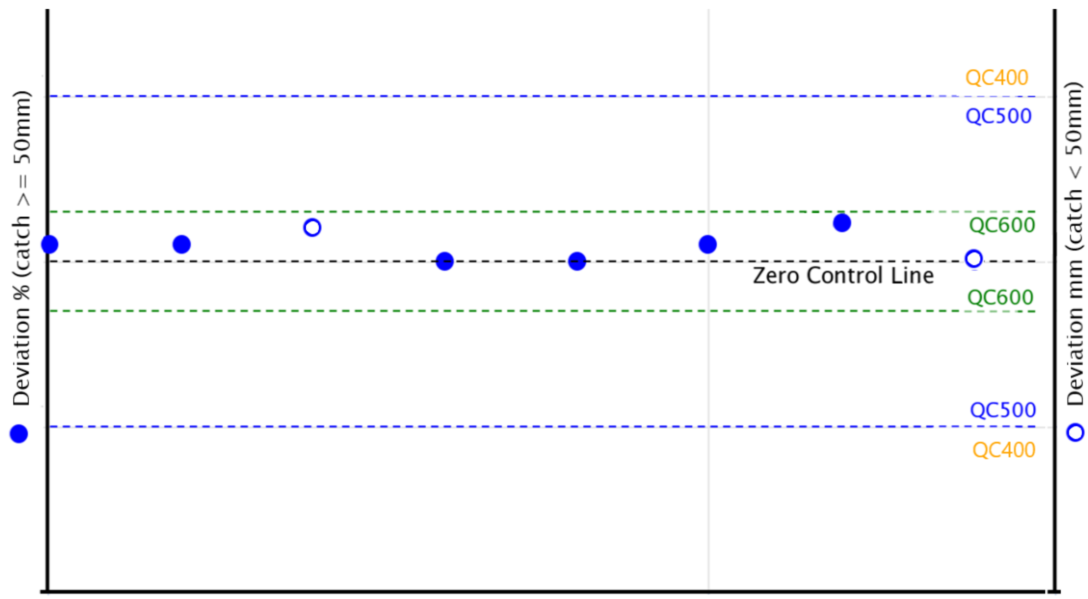


Figure B 6 – An example of a control chart with secondary axis where data are plotted in sequence using the axis applicable for the tolerance test, scaled to align the limits.

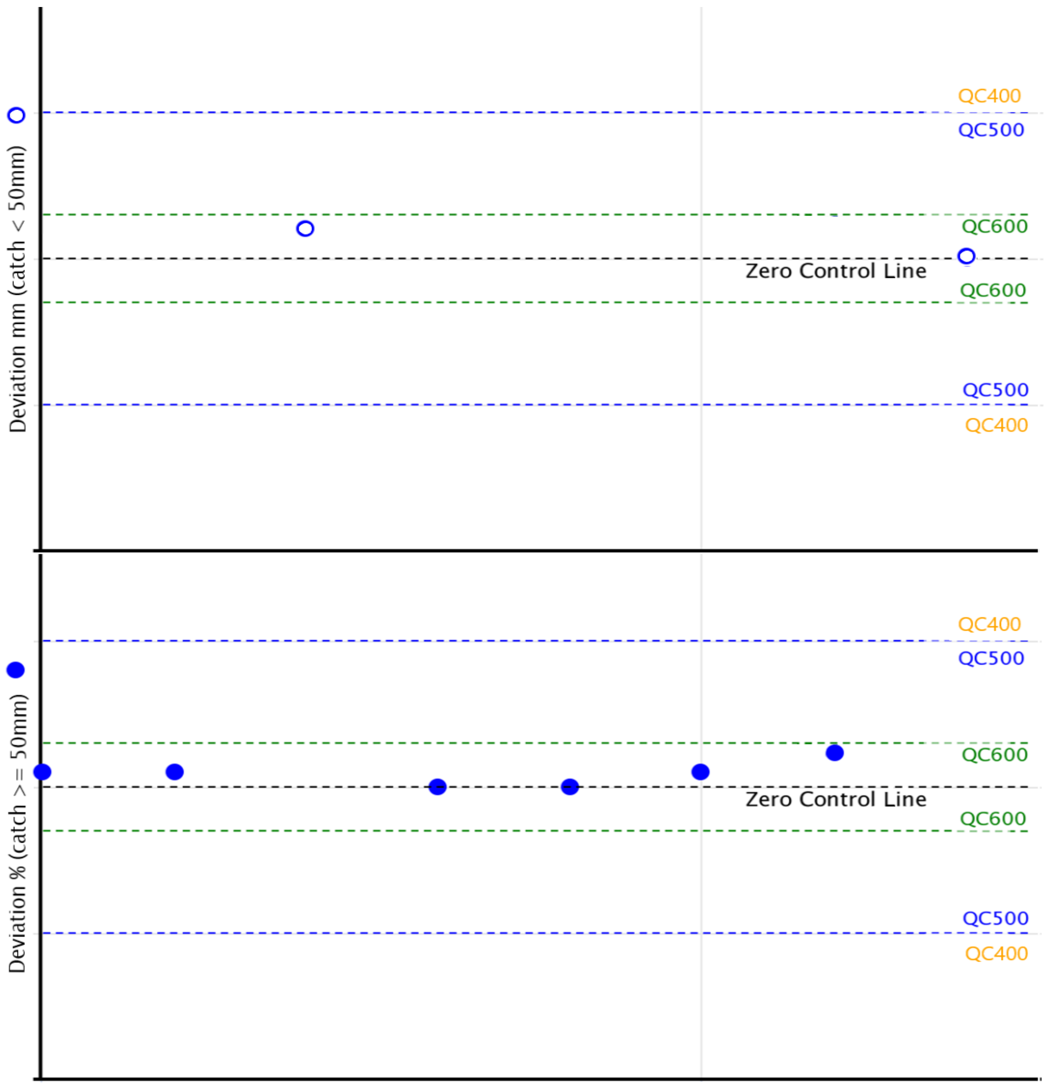


Figure B 7 – An example of a stacked control chart where data are plotted in sequence, but on the top or bottom chart depending on the applicable tolerance test.

Use a deviation with time test to investigate time-dependent issues such as leakage and/or evaporation from the primary reference gauge, or seasonal differences such as when snowfall affects the intensity gauge but not a standpipe reference gauge.

Account for uncertainty in primary reference gauge readings (e.g. use error bars if plotting). Identify any readings that are deemed unreliable but do not exclude them from the tests; the definition of unreliable encompasses a wide range of factors (see Section B 2.4.2).

A scatterplot of reference readings versus corresponding logger totals (net of test tips) can be useful to investigate calibration issues and intermittent problems with intensity gauge function, such as a faulty reed switch or partially blocked drain, that may not be identified during an inspection.

Tests may be configured to update automatically with new data from the field.

3 Potential Errors and Recommended Editing

This section describes common problems specific to rainfall intensity data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Site factors (see Section 2 of NEMS *Rainfall Recording* v2.1)
- Instrument installation, physical condition, and function (e.g. relative orifice heights; failure to generate and/or log a pulse; damage or deterioration resulting in leaks, restriction of bucket movement, and poor surface condition leading to additional evaporation or wetting losses) (see Section 3 of NEMS *Rainfall Recording* v2.1)
- Environmental conditions that adversely affect catch (e.g. evaporation of gauge contents, exposure to high winds, debris or solid precipitation accumulating in the collector) (see NEMS *Rainfall Recording* v2.1: Sections 2.2, 3.3.4 and 4.1.4)
- Primary reference gauge overflows and spills (see Section 4.1 of NEMS *Rainfall Recording* v2.1)
- Issues of calibration (see Section 5 of NEMS *Rainfall Recording* v2.1).

Issues with captured data are not always identifiable from the site visit verification alone. Some problems such as blockages, restriction of buckets, or failure to generate a pulse may be transient and occur and resolve between visits. Issues such as a leaking primary reference gauge may not be apparent from a single visit. Interpretation of plots and comparisons (see Section B 2.3) and deviation tests (see Section B 2.5) are necessary for these cases.

3.1.1 Systematic error

The components of systematic error in precipitation measurement are listed in Table B 1, adapted from Sevruk (1982). These sources of error are minimised in New Zealand by good site selection, design, and maintenance. Sevruk's correction techniques are not employed in the normal processing of rainfall data collected in New Zealand.

In NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*:

- the likely effect of wind on rainfall data quality is assessed by the Rainfall Site Matrix
- evaporation prevention is included in the verification requirements of a primary reference gauge (see Section 3.3.1 of NEMS *Rainfall Recording* v2.1)
- snowfall is treated very broadly, and only as an adverse environmental condition, via the Rainfall Data Quality Matrix
- wetting losses are not discussed or assessed.

Quality code does not compensate for bias in the data due to these effects and the quality code assigned is not specific to these sources of bias. It is therefore essential that data users are made aware of potential bias in the data from these sources via adequate comments.

Table B 1 – Main components of systematic error in precipitation measurement and their meteorological and instrumental factors, in order of general importance (Sevruk, 1982)

Error component	Magnitude	Meteorological factors	Instrumental factors
Loss due to wind-field deformation above gauge orifice	2–10% or 10–50% if snow	Wind speed at gauge rim during precipitation, and structure of precipitation	Shape, orifice area and depth of rim and collector
Wetting losses: internal walls of collector and in container when emptied	2–10%	Frequency, type, and amount of precipitation, drying time of gauge, and frequency of emptying container	As above plus material, colour, and age of collector and container
Evaporation loss from container	0–4%	Precipitation type, saturation deficit and wind speed at rim during time from precipitation end to measurement	Orifice area, isolation of container, colour and age of collector, or type of funnel
Splash (out and in)	1–2%	Rainfall intensity and wind speed	Shape and depth of collector and kind of installation
Blowing and drifting snow		Intensity and duration of snowstorm, wind speed, and state of snow cover	Shape, orifice area and depth of rim and collector

3.2 False intensities

3.2.1 Rainfall rate

When intensity is determined by dividing each tip value by its preceding timestep, false intensities can result. Causes are:

- siphon gauges tipping multiple times in a short interval if the bucket was near full prior to the siphon emptying and/or bucket capacity is less than that of the siphon

- additional zero value data elements written to an interpolating record by sources unrelated to the gauge, e.g. status checks (see Section B 2.4.4) and some CSV imports
- fixed interval data logging too frequent with respect to bucket capacity, e.g. 0.5 mm in a 1-minute timestep is an effective rate of 30 mm/hour,
- siphons and/or buckets storing more than one light rainfall event before emptying
- no mechanism or algorithm to identify periods of no rainfall.

The issue is more one of how the data are collected, stored, and interpreted than errors in the data per se. Solutions are one or more of the following, as applicable:

- aggregate tips into a reasonable fixed interval before dividing by that interval to determine rainfall rate
  For example, to avoid over-representing the rate of light rain (< 2.5 mm/hour) when using a 0.5 mm bucket, data should be aggregated into fixed intervals no shorter than 12 minutes.
- remove from the record any additional zero value data elements arising from status checks or importing of data (see Section B 2.4.4)
- implement documented assumptions about when a rain event begins, e.g. Hilltop Software's Six (or Thirty) minute Rainfall data type (see Section B 1.3)
- install equipment more suited to determining onset of rain and rainfall rate, e.g. drop counters and/or smaller capacity buckets.

3.2.2 Interference

Interference may result in over or under catch, may affect the intensity, backup, and/or primary reference gauge and may be transient or persist until rectified during a site visit. Causes may be:

- the deliberate acts of people, such as adding contents to or emptying a gauge; striking or shaking a tipping bucket to cause additional tips; or removing, damaging, or blocking the rim and/or collector
- animals striking, shaking, or rubbing a tipping bucket causing additional tips; chewing or pecking the cable between gauge and data logger causing additional pulses or loss of signal; or pulling over, or drowning in, standpipes
- site aspects in combination with environmental conditions that allow additional water to enter a gauge, e.g. installation of an overhead cable and/or nearby pole, aerial spraying or irrigation etc.
- electrical interference if cable is not sufficiently shielded, causing induced pulses to be logged, e.g. from communications equipment or a nearby electric fence, or insufficient debounce to resolve fluttering reed-switch closures into one pulse per bucket tip.

If significant, but transient and not obvious when the site is visited, and depending on which gauges are affected, interference can be detected as:

- unexpected or unusually high intensities apparent in bar plots
- larger than expected deviation of recorded rainfall from corresponding reference reading
- anomalies of timing and magnitude when compared with the backup gauge, or other intensity gauges at a nearby sites.

Brief or regular instances of identified interference can be edited from the record. Longer affected periods may need to be deleted and treated as missing record.

Interference may result in no data, which must also be treated as missing record (see Section B 3.5).

If the primary reference gauge is affected, its reading is unreliable and may need to be replaced with an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

3.2.3 Fouling

The collector, funnel or siphon may become blocked by windblown debris, bird droppings, spiderwebs, or solid precipitation. Fouling may result in under catch and/or unusually prolonged apparent rain events often with a relatively constant rainfall rate. Effects may be transient and resolve between site visits or persist until rectified during a site visit.

Fouling, if transient and not obvious when the site is visited, can be detected as:

- a gradual or 'rounded' rather than 'stepped' cumulative plot trace (see Figure B 8)
- unusually constant and prolonged intensities apparent in bar plots (see Figure B 9)
- larger than expected deviation of recorded rainfall from corresponding reference reading, especially if catch has spilled, splashed, evaporated, or been blown from the blocked collector
- anomalies in rain event timing and magnitude when compared with the backup gauge or other intensity gauges at one or more nearby sites.

Periods of identified fouling must be deleted and treated as missing record (see Section B 3.5).

If the primary reference gauge is affected, its reading is unreliable and may need to be replaced with an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

Another form of fouling is when the orifice or buckets become encrusted with airborne particles such as fine dust or pollen. If the orifice rim is affected, the result is similar to rim damage (see Section B 3.2.2). If the collector surface is affected, evaporation may be enhanced (see Section B 3.1). If the buckets are affected, it upsets their calibration (see Section B 3.2.5.).

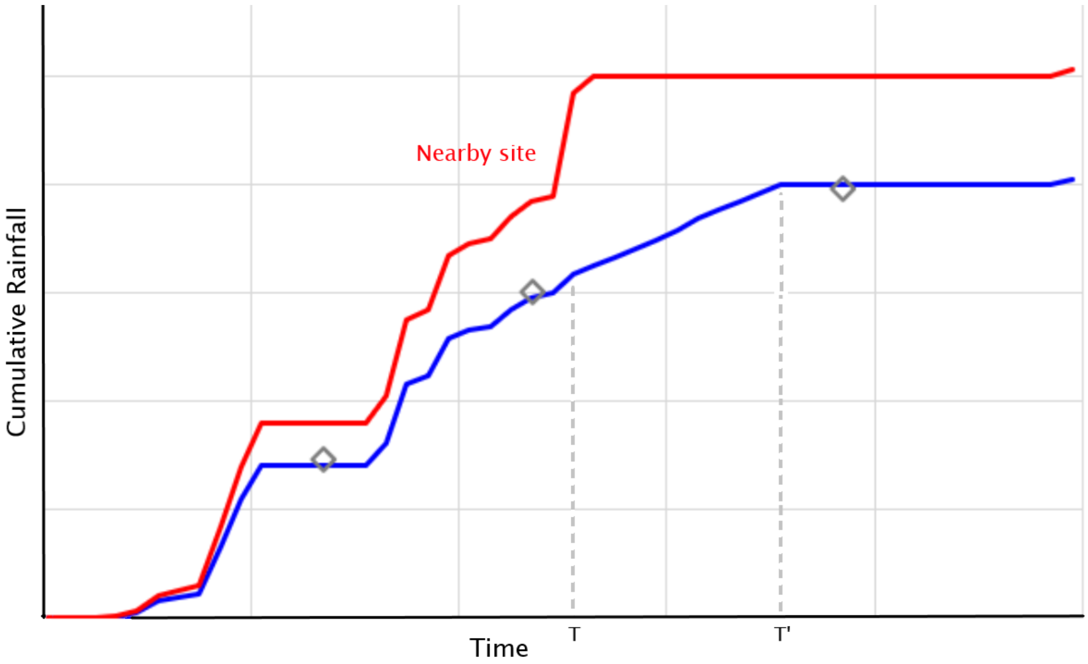


Figure B 8 – An example of a cumulative between-site comparative plot, with primary reference gauge readings, showing a period of fouling (blockage) between time T and T'.

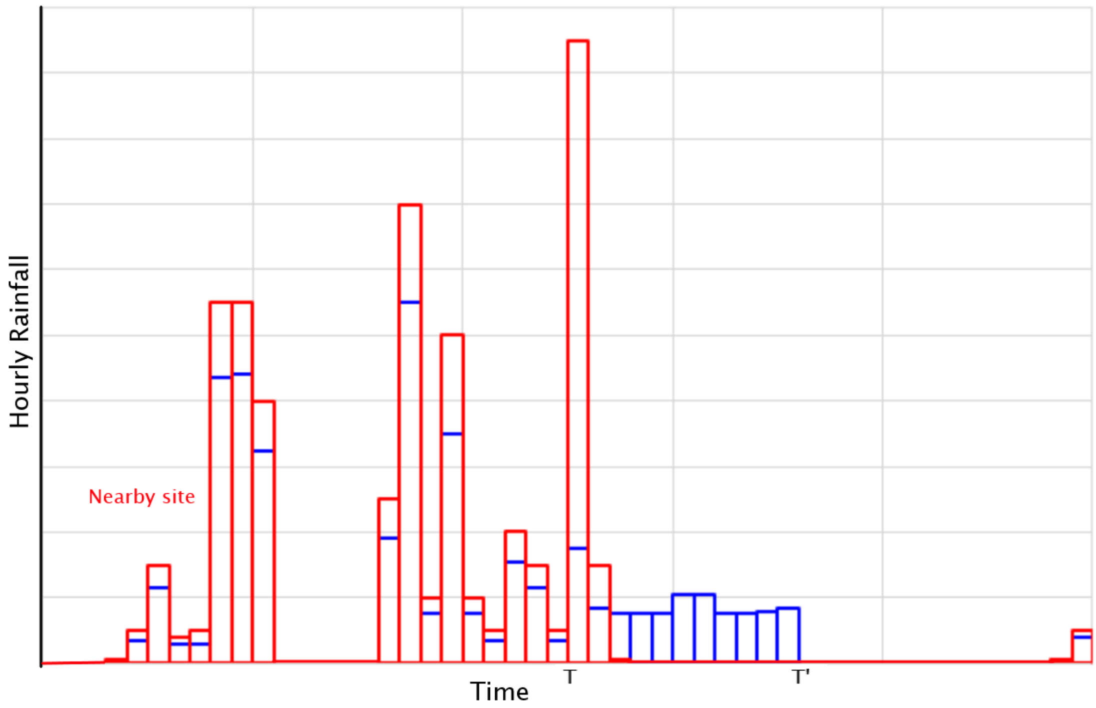


Figure B 9 – An example of a between-site comparative bar plot showing the same period of fouling (blockage) between time T and T' as in Figure B 8.

3.2.4 Restricted bucket movement

The tipping mechanism may partially or fully seize or jam due to:

- ingress of dust, dirt, pollen, or vegetation
- general deterioration due to age and/or corrosion (marine and geothermal environments are especially harsh)
- parts, such as the magnet, dislodging
- the base, if plastic, warping if too hot.

The above will usually cause the buckets to tip later and/or more slowly, and possibly spill/splash more or overflow, effectively upsetting gauge calibration. Recorded rainfall is biased low. Adjusting affected record to corresponding primary reference gauge total(s) is an acceptable solution for the bias; however, this only rescales each recorded tip value and does not alter timesteps or apply compensation gradually.

If the intensity gauge drain blocks, buckets can come to rest on water trapped in the base rather than on their calibration screws, and tip increasingly frequently as water level in the base rises until they are unable to tip at all. Recorded data are increasingly biased high until tipping ceases.

Adjusting the prior recorded data to the relevant assessed primary reference gauge total(s) is an acceptable solution to the bias; however, this only rescales each recorded tip value and does not alter timesteps or apply compensation gradually.

If the buckets can no longer tip:

- decide when that occurred, and
- assess the relevant reference gauge total(s), i.e. decide what proportion of the reference total(s) relate to each of the periods before and after tipping ceased, and
- substitute reliable backup data if available, or
- treat the period after as missing data (see Section B 3.5).

Note: The light plastic 'spoon' in cheaper tipping gauges that are often used as a backup intensity gauge can become bound by spiders' webs sufficient to stop them tipping. It is important to monitor and maintain gauge condition so the backup record can be used with confidence when required.

3.2.5 Loss of calibration

The intensity gauge must be level for the buckets to tip evenly and perform to calibration. A gauge that is not level is effectively out of calibration.

Quality code is determined from the Rainfall Data Quality Matrix. Any resulting bias in the data contributes to the deviation of intensity gauge (recorded rainfall) from reference catch and is compensated by adjusting the record to primary reference gauge totals. The clean intensity record remains biased if not adjusted. An Operational Comment is required to identify the period affected (see Section B 5.2.3).

Intensity gauges fitted with siphons are calibrated with a lesser bucket capacity. If a siphon is subsequently removed or installed, the gauge must be recalibrated as appropriate, or the data collected adjusted for bias (see Section B 2.4.1).

3.2.6 Range limits

Rainfall recording range limits may be encountered if the data logger is unable to keep up with the intensity gauge tip frequency or the input memory is too small to store each possible value in the desired form.

Switch closure input (tip frequency)

The data logger employed must be able to scan its inputs quickly enough to keep up with the maximum possible tip frequency of the intensity gauge or it will not count all the pulses sent to it. This frequency will depend on the maximum expected rainfall intensity and the size of the buckets. Inability to keep up means the most intense rainfalls will be under recorded while lesser events are unaffected.

This problem is easily detected if validation checks are carried out using an equivalent or higher rate of water delivery than the maximum expected rainfall intensity and consequent tips are logged to the same logger port or an alternate port with identical specification and configuration.

Detecting this problem in the data is otherwise difficult unless a backup gauge of bigger bucket capacity and/or an independent pulse counter that can keep up is available on site to compare with. To repair affected data, the most reliable available option from the following may be used:

- replace with reliable backup data
- use validation results to identify the intensity at which recording becomes compromised and pro-rata rescaling the data accordingly
- adjust all data to primary reference gauge readings, recognising that this rescales all the values and therefore the result should be checked by between-site comparison(s), or
- delete the affected period and treat as missing record.

Input memory (number of bits)

Loggers may have insufficient bits available for the data input depending on how the pulses are being logged. Logger port selection and configuration, frequency of logging, and size of the number to be stored influence likelihood of the problem.

For example, 10 bits can store a maximum unsigned value of 1023, which means if the data are logged every minute in 500 micrometre increments, the maximum intensity able to be stored is 1 mm/min or 60 mm/hr.

Figure B 2 illustrates the problem. Recorded values are clipped at a common maximum. Affected record is best replaced with reliable unaffected backup data, if available, or treated as missing (see Section B 3.5).

Storing the date and time of each tip uses much more storage and requires the logger to have adequate time resolution to ensure tips are not under-registered because they 'blur' together. The effect of insufficient time resolution is similar to the tip frequency problem (see Switch Closure Input (Tip Frequency)).

Table B 2 – Guidance for resolving false intensities

Guidance for resolving false intensities		see Section(s)
Issue(s)	Apparent rainfall intensities are inaccurate and/or incorrect.	B 3.2
Evidence	Implausible rainfall rates. Unexpectedly high or unusually constant or prolonged intensities. Larger than expected deviation between recording and reference gauges. Timing and magnitude anomalies when compared with other sites.	Figs. B 2 & B 8 & B 9 B 2 3.6
Solution(s)	If due to calculation method, modify method, OR Remove test tips, and zero values inserted as system checks or by import routines, OR If rain event timing is unaffected, rescale the data, e.g. adjust to primary reference or to the usual ratio of recorded to reference, or replace with backup data if available, OR If rain event timing is affected, e.g. by blockage of the collector, or maxima are clipped, replace with reliable backup data if available or delete the affected data then treat as missing.	B 3.2.1 or B 2.4.3 or B 4 & 4.8 or B 3.5 & 5.4 & 5.5
Metadata	Quality code is unaffected by removing test and status check values or adjusting to primary reference. Otherwise, quality code is as applicable to the backup data, or QC 300 if data are replaced by synthetic infill, or QC 100 if deleted and left missing, Data Comments are required explaining identified issue and cause and providing details of decisions made and methods applied.	B 5 6.2.3 6.2.4.6

3.3 Catch discrepancies

Calculation of the deviation of total recorded rainfall from the corresponding primary reference gauge reading will reveal unacceptable catch discrepancies as defined in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*. Deviations are monitored over time using quality charts (see Section B 2.5).

3.3.1 Site and environment factors

There will always be some difference in catch between gauges in the same enclosure due to their different size and/or position and possibly condition. Differences may also have a seasonal component.

Causative factors are:

- relative under or over exposure
- wind effects
- gauge size
- orifice height and diameter
- aspect
- obstructions to airflow, if any, past each gauge
- evaporation (which poor gauge condition or lack of prevention may exacerbate)
- blockage of the collector by airborne debris or solid precipitation.

Factors are often interrelated; for example, a taller or physically larger gauge is more prone to wind effects while a gauge at ground level may be buried by snow, if snowfall occurs in the area.

Discrepancies due to these factors are minimised by good site design, operation, and maintenance. The impact on data quality of the various factors is assessed via the combination of the Rainfall Site Matrix and Rainfall Data Quality Matrix. Clean recorded data is routinely adjusted to the primary reference, being the gauge least likely to change type and position over time, and thus this processing step compensates for variability in the impact of these factors through the record.

At some sites, a persistent bias may be evident over a relatively long time despite best practice installation and operation. If identified, describe the magnitude and direction of the bias in the Site/Initial Comment Additional Information.

3.3.2 Intensity gauge and recording faults

Catch discrepancies due to instrument and recording faults, other than those also associated with false intensities (see Section B 3.2), usually arise from failure to log pulses because of:

- a data logging fault, e.g. loss of logger power or a storage overrun
- loss of signal between the gauge and logger due to a break or disconnect in the cabling, or communication fail if logged remotely, or
- failure of the gauge to generate a pulse, e.g. a faulty reed switch, missing magnet, bound or floating buckets, or seized tipping mechanism.

If due to a data logging fault there may or may not also be a time fault (see Section B 3.4) depending on cause and how data capture has been configured.

In the other cases, data logging continues but no tips are recorded. The fault is usually identified by failure to record test tips during on-site verification of the gauge but may be transient and not apparent at the time of the site visit.

Comparison with reliable record from backup or nearby gauges is needed in any case to identify when the fault arose and the consequent period of missing record.

Sometimes buckets will only generate a pulse on one side. Rainfall recorded in the affected period will be about half what is expected. Either:

- replace the affected period with reliable backup data, assign quality code according to Section 3.5 of NEMS *Rainfall Recording v2.1*, and supply a Data Comment (see Sections 6.2.4.6 and B 5.2.4), or
- rescale the data to twice its nominal bucket size, e.g. 0.5 mm tips become 1 mm tips, or
- delete the affected period and treat as missing (see Section B 3.5).

Rescaling to twice the bucket size effectively halves the recording resolution. The result should be compared with a nearby site to assess the effect on timing of rainfall events. If there is little effect the quality code can be reassessed against the Rainfall Site Matrix and Rainfall Data Quality Matrix with the revised apparent resolution. If the data are still reasonably representative but event timing is affected, the quality code can be no more than QC 400. In either case, a Transformation Comment is required (see Sections 6.2.4.8 and B 5.2.6).

Otherwise, the affected period must be replaced with reliable backup data or treated as missing (see Section B 3.5).

3.3.3 Primary reference gauge catch loss and measurement errors

Catch discrepancies may arise from primary reference gauge readings affected by catch loss or measurement errors.

Catch loss

Catch loss may be caused by evaporation, leaks, or overflow.

A primary reference gauge without evaporation prevention, or that is leaking, is deemed unreliable and the intensity data collected in the corresponding period cannot be assigned a quality code of more than QC 400 (see Section 3.3.1 of NEMS *Rainfall Recording* v2.1).

A primary reference gauge that has overflowed is regarded as compromised and therefore the associated intensity record cannot be assigned a quality code of more than QC 400 (see Section 4.1.1 of NEMS *Rainfall Recording* v2.1 and the quality coding flowchart).

However, it is also possible and desirable to reduce resulting bias in the final adjusted series by doing one of the following, in order of preference:

- measure catch leaked from an inner can (usually recoverable from the outer can unless that is leaking too) and include in the reference reading
- replace the unreliable reference reading with an estimated reading (see Appendix B.1 Section 2.3), or
- incorporate the corresponding period of clean as-recorded data into the adjusted series without adjustment to reference.

A Data Comment must be filed for any period not adjusted to the primary reference totals, explaining why, and stating the reference gauge and corresponding final filed recorded totals (see Section B 5.2.4). Quality code for the unadjusted period can be no more than QC 500 and is otherwise determined by the Rainfall Data Quality Matrix.

Measurement errors

The most common primary reference gauge measurement errors are:

- spills while tipping gauge contents into a flask to measure
- miscounting the number of fills of the flask, and
- using the wrong dipstick.

A gauge intended to be measured by flask should always be dipped first. If contents are spilled, the dipstick reading can be substituted. If not dipped first, an estimate of the proportion spilled must be noted and incorporated into the reading uncertainty that is then used to assess quality code via the Rainfall Data Quality Matrix.

Possibility of miscounting is minimised if each fill of the flask is written down immediately after reading, then all summed to obtain the total reading. The dipstick reading, done first, provides confidence that every fill has been accounted for.

If the orifice and storage can diameters are known, dipped readings using the wrong dipstick, or measurements made using a conventional steel rule or tape if the graduated dipstick has been left behind, are recoverable by calculation.

For example, if the depth of catch in a can by conventional steel tape is X mm, equivalent rainfall depth $R = X (A/a)$, where A is the can cross-section area and a is the orifice cross-section area.

Note: if the gauge is of uniform diameter, i.e. $A = a$, rainfall depth is directly measurable with a conventional ruler or tape.

A reading may not be possible if gauge contents are frozen. This should be prevented whenever possible, or the contents carefully melted then measured as normal, or measurement and emptying postponed to a subsequent visit when contents are again liquid. If the gauge is a standpipe it is possible to measure down from the orifice to the ice surface, then subtract the measurement from the gauge capacity, but the reading obtained will be biased high because water expands when frozen.

If obtaining a primary reference reading is postponed it may be necessary to assess the part-total applicable to each visit, for example, if the intensity gauge was replaced during the visit on which the primary reference was not read (see Appendix B.1 Section 2.2).

Applicable quality code is determined by the Rainfall Data Quality Matrix measurement accuracy criteria. An Operational Comment is also required to document relevant calculations and explain a compromised reference (see Sections 6.2.4.5 and B 5.2.3).

Table B 3 – Guidance for resolving catch discrepancies

Guidance for resolving catch discrepancies		see Section(s)
Issue(s)	Unacceptable differences between primary reference gauge catch and total recorded rainfall in the same period.	B 3.3
Evidence	Deviations greater than tolerance. Possible long-term persistent bias. Failure to log test tips. Rain events missing or noticeably short when compared with other sites. Visible evidence of primary reference gauge leaks or overflows. Known and documented primary reference gauge measurement errors.	B 2 3.6
Solution(s)	Adjust recorded data to reliable primary reference readings. If error source is the primary reference, use dipped readings to confirm or as substitute, and/or assess or estimate catch as applicable to the nature of and period affected by the error. If error source is the intensity gauge and tips are being logged, rescale the data. Either adjust to primary reference or to the usual ratio of recorded to reference if adjusting the as-recorded series. If logging of tips has stopped, e.g. pulses are not being generated or registered, use comparison plots to identify from when, then substitute reliable backup data if available or treat the affected period as missing data.	B 4 4.8 App. B.1 B 4 4.8 B 2 3.6 B 3.5 5.4 & 5.5
Metadata	Document any long-term persistent bias in otherwise good data in the Site/Initial Comment. Applicable quality code is the least of that determined by the Rainfall Site Matrix and Rainfall Data Quality Matrix and the quality coding flowchart, or QC 300 if replaced with synthetic infill, or QC 100 if left missing. Various combinations of Data, Transformation, Equipment, Operational and Stationarity Comments are required depending on error source(s) and method(s) used to resolve.	B 3.3.1 B 5.2.1 6.2.4.3 B 5.1 B 5.2 6.2.4

3.4 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start (if shifted forward) or period end (if shifted back) is also a consequence that must be addressed (see Section B 3.5).

If the data are stored as an interpolating data type, a time drift adjustment alters the apparent rate of accumulation of each increment of rainfall and may affect reporting of intensities, especially those of short duration, more than if a discrete data type is used. Determining whether a clock drifted or stopped is therefore important for incremental data (see Figures B 10 to B 13 incl.).

Data logging may also have stopped when the clock stopped, or all subsequent tips may be tallied into a single stored value at clock restart, depending on how data collection is configured. A period of missing intensity record is a consequence of either, but a tip tally captures all rainfall volume since the clock stopped, that can then be apportioned to fill the gap using the same method as for a primary reference gauge total (see Appendix B.1 Section 2.1).

Historically, mechanical recorder clocks frequently ran slow or fast, so most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps but can only be detected in event (tip-by-tip) rainfall intensity data by comparing the processed data with the original, as in Figures B 4 and B 5.

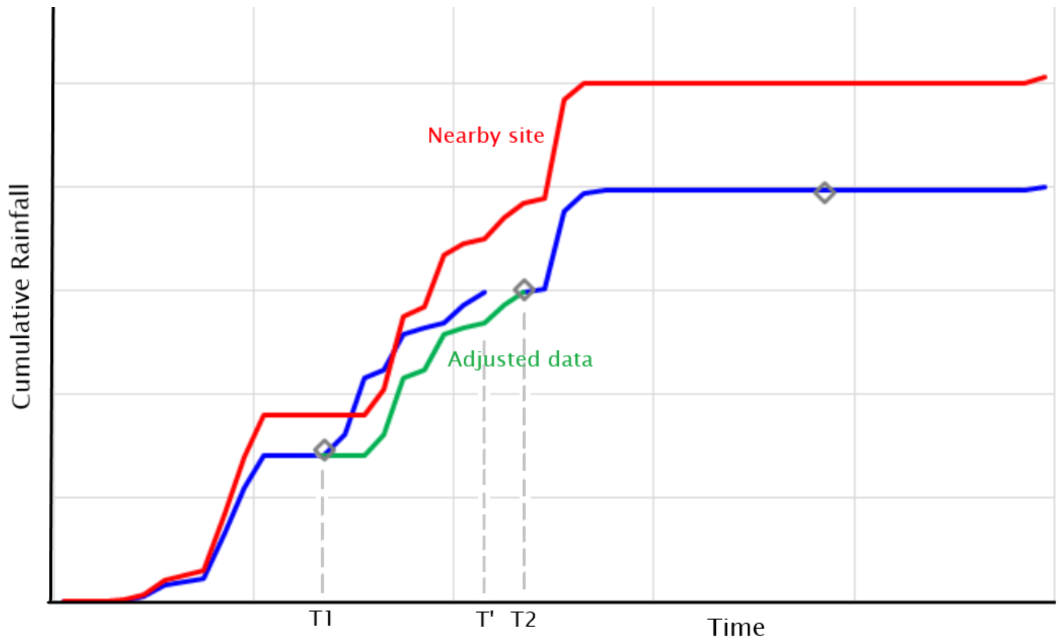


Figure B 10 – An example of a cumulative between-site comparative plot showing a time shift applied to incremental data. Data logged from T1 to T' are moved forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). The gap created after T1 has been closed as suggested by the nearby site. All other timesteps are preserved. Rainfall intensity is the same as before but event timing is later.

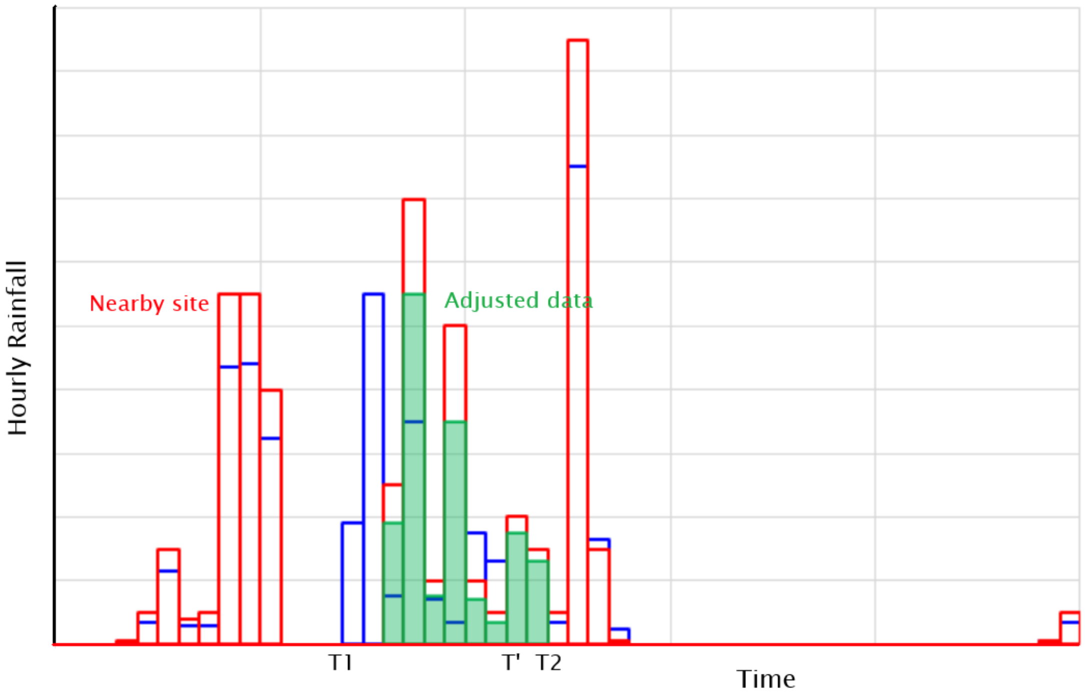


Figure B 11 – An example of a between-site comparative bar plot showing the same time shift as in Figure B 10. Data logged from T1 to T' are moved forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Rainfall intensity is the same as before but event timing is later.

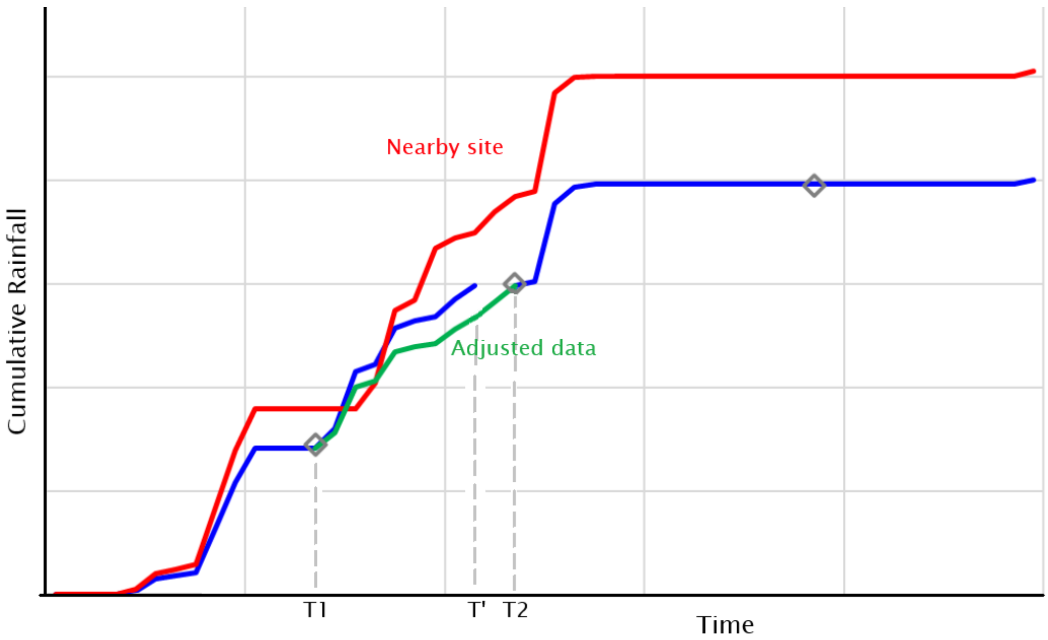


Figure B 12 – An example of a cumulative between-site comparative plot showing a time drift adjustment applied to incremental data. Data logged from T1 to T' are stretched forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Each timestep is stretched by the same proportion as the overall adjustment. Event timing is spread out and apparent rainfall intensity is less.

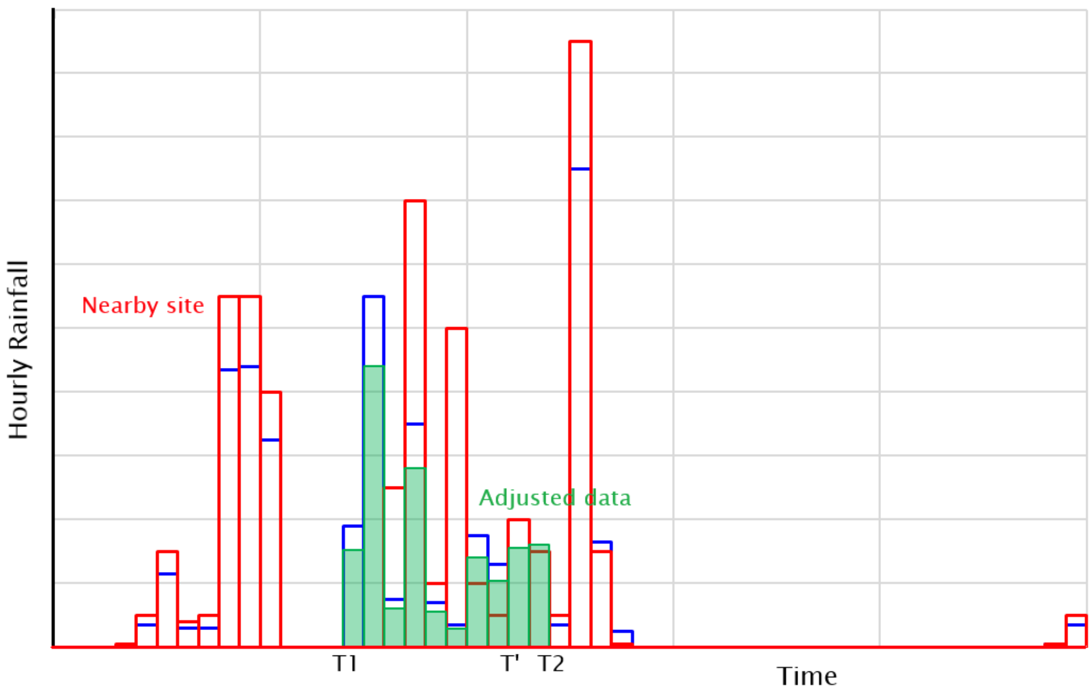


Figure B 13 – An example of a between-site comparative bar plot showing the same time drift adjustment as in Figure B 12. Data logged from T1 to T' are stretched forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Event timing is spread out and apparent rainfall intensity is less.

Table B 4 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	B 3.4
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with nearby sites.	Figs. B 10 to B 13 incl. B 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record, using apportioning to infill if total rainfall in period is available.	4.3 or 4.6 and/or B 3.5
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing or QC 300 if infilled and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	B 5.2.5 6.2.4.7 B 5.2.4 6.2.4.6 6.2.3

3.5 Missing data

If the data are stored as incremental totals of interpolating data type, a gap created by missing data must either be closed, infilled, or marked to prevent interpolation through the period of the gap.

If the data are stored as incremental discrete totals the concept of interpolation is not present; however, infill is still relevant although the data handling is different.

Gaps in the primary reference gauge adjusted series must be filled wherever possible. This series is more useful for analysis of rainfall volumes over long time periods, for which gaps in the record are problematic.

The clean but unadjusted series must be archived with gaps closed or with backup data substituted as applicable and available, but otherwise gaps may be marked but not infilled. This series may be more acceptable for storm intensity analysis, where the results of infilling gaps with synthetic data may be misleading, or a user of the data may choose to censor the adjusted series by reference to the corresponding unadjusted series.

When considering the treatment and associated metadata requirements for missing rainfall data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is no more than 48 hours
- a longer period may be two or more days up to one week, and
- an extended period may be a week or more.

Rainfall is a point measure, i.e. the data are specific to the location at which they were measured. New Zealand's geography and topography cause the spatial and temporal distribution of rainfall to be highly variable over relatively short distances. When selecting and applying an appropriate method for resolving missing data, variation in the distribution of rainfall in the vicinity at the time must be taken into account with consideration of the duration of the period missing (see Appendix B.1 Sections 2.5 and 3).

For example, it may not be appropriate to apportion a primary reference gauge total to the temporal distribution of rainfall at an adjacent site if one has experienced a thunderstorm and the other has not, even if the missing period is short and daily primary reference gauge readings are available.

Note: Synthesising a rainfall record is less certain than synthesising stream flow.

A continuous period of a month or more missing shall only be filled with backup data, primary reference gauge totals and/or assessed parts thereof, or synthesised monthly totals.

3.5.1 Closing gaps in incremental data

Closing a gap by removing the gap marker or flag in an incremental interpolating data series results in the next stored total (or the previous, if the data type is 'succeeding interval') being spread at a constant rate through what was the interval of the gap (see Section B 1.3).

Conversely, if the data type is discrete and the next stored total is accumulated, e.g. a tally of multiple tips or a primary reference gauge total, rainfall intensities derived from any interval including the total other than exactly aligned with the original gap will be misrepresented.

Generally, when using a time-series management system to store time-series data, repacking of data is not needed and is effectively redundant (see Section 4.13), but depending on the data type, some manual apportioning and/or repacking of the incremental data may be needed to improve representation of rainfall intensities when actual data are missing and only an accumulated total (including zero) is available to fill the missing period.

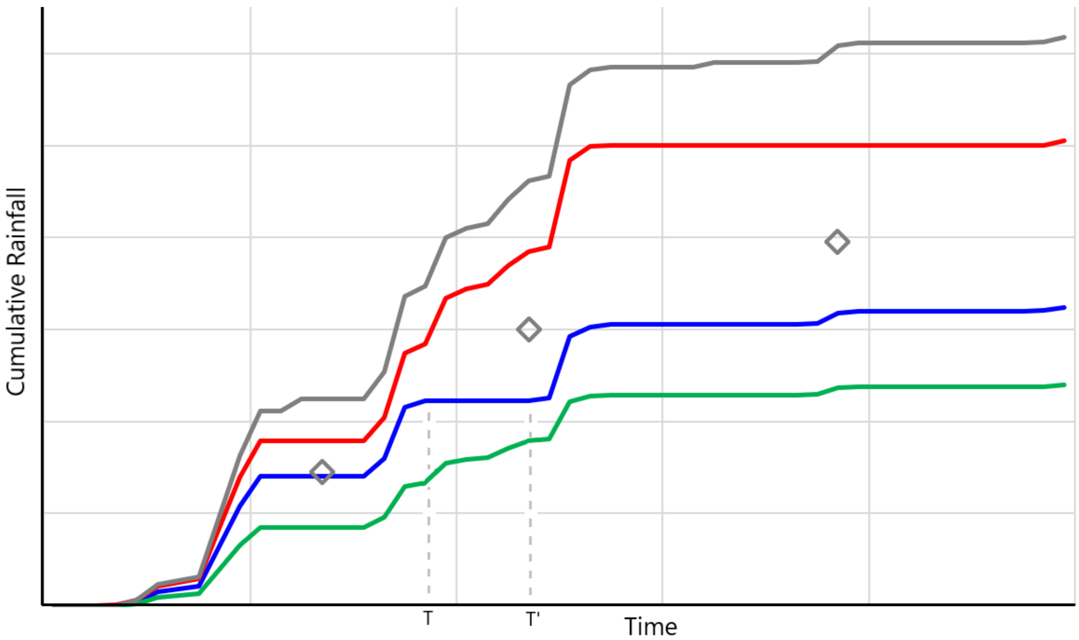


Figure B 14 – An example of a cumulative between-site comparative plot showing a period of rainfall missing in the blue trace between T and T', corroborated by the recorded total at T' being short of the primary reference total (diamond marker).

3.5.2 Methods for infilling gaps

For details on specific methods for infilling gaps in rainfall series, see Appendix B.1 of this Annex.

Table B 5 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	B 3.5
Evidence	Expected timestamps are not present in raw fixed interval data. A gap marker may or may not be present depending on data collection method. Intensity gauge catch is short compared with reliable primary reference and/or backup gauge. Cumulative plot shows unexpected flat period in the trace. Between-site comparison shows expected event(s) and/or catch are missing. Investigation confirms data were not logged and/or not collected.	4.16 Fig. B 14 B 2 3.6
Solution(s)	Use backup data and/or independent at-site observations if available and reliable, OR if a brief period with no rain event likely to have occurred, close the gap, OR apply one or more methods from Appendix B.1 to infill with synthetic data as appropriate to the available supporting data, OR mark the gap. If a month or more is missing, infill only with monthly values.	B 3.5 App. B.1 4.16 to 4.20 incl. 5.4 & 5.5

Metadata	No effect on quality code if brief and gap closed. Otherwise, quality code as applicable to the backup record and/or manual observations, or QC 300 if infilled with synthetic data or an accumulated total (estimated, assessed, or actual), or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including the expected reliability and resolution of any synthesised infill.	B 5.1 6.2.3 B 5.2.4 6.2.4.6

4 Adjusting Data to Primary Reference

Apart from infilling missing record and creating metadata, adjusting recorded data to the primary reference readings is the final required step when processing a rainfall time series and is intended to help preserve stationarity of the record by adjusting all intensity record to catch recorded by the gauge that is least likely to change type and location (position and height) over the lifetime of a site.

The adjustment is implemented by changing the recorded data increment, which changes apparent resolution of the intensity data, i.e. the size of each gauge bucket tip (see Section 4.8).

4.1 Snow

Snow may block the intensity gauge but be captured by the primary reference gauge. If periods when this has occurred are not identified, and the affected intensity data consequently removed and treated as missing (see Section B 3.5), the additional catch in the primary reference gauge will be spread over the corresponding period of rainfall as recorded, introducing a positive bias error to the adjusted data while retaining false intensities in the period of blockage.

In areas subject to occasional snowfall, possible snowfall events must be carefully investigated for evidence of gauge blockage, and if uncertain and not treated as missing data, a rational and considered decision must be made as to whether adjusting to primary reference gauge readings is appropriate for the corresponding recorded data that might include one or more snowfalls that have compromised rainfall recording.

A Data Comment must be filed for any period not adjusted to the primary reference totals, explaining why, and stating the reference gauge and corresponding final filed recorded totals (see Section B 5.2.4). Quality code for the unadjusted period can be no more than QC 500 and is otherwise determined by the Rainfall Data Quality Matrix.

In areas subject to frequent snowfall, alternate instrumentation, and methods more suited to conditions should be implemented.

5 Metadata

5.1 Quality coding

Quality code for rainfall data is set by three successive assessments:

- the Rainfall Site Matrix
- the Rainfall Data Quality Matrix, and
- data processing actions and final data status assessed against the quality coding flowchart

The quality coding flowchart and quality code assessment matrices can be found in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*. The flowchart is also available in NEMS *National Quality Code Schema*.

5.1.1 The Rainfall Site Matrix

The Rainfall Site Matrix effectively sets a maximum achievable quality code for any rainfall data collected from a recording site. This assessment should be completed before rainfall data are collected.

The result is unlikely to change frequently so the assessment may be stored in the Station History, but it must be current and known when inspecting the site and during processing of any data collected.

5.1.2 The Rainfall Data Quality Matrix

The Rainfall Data Quality Matrix uses information from each site visit to determine whether quality code for the data collected between visits should be reduced from the maximum achievable for the site. The Data Quality Matrix score is added to the Site Matrix score to decide quality code of data collected. This assessment should, for quality assurance preventive action purposes, be completed before departing the site, but if not, becomes the first step of quality control during data processing.

Nothing in the Data Quality Matrix is triggered by a data processing action. The effect of data processing actions on quality code are addressed in the third assessment against the quality coding flowchart criteria (see Section B 5.1.3).

By applying the Data Quality Matrix at the time of data collection it is possible to assign quality codes other than QC 200 to unprocessed data, but this may be misleading because processing actions may result in periods of data acquiring a different code.

Note: If the maximum possible quality for the data is QC 400 from the Site Matrix score the Data Quality score is immaterial and the Data Quality Matrix need not be used. However, maintenance and interpretation of quality control deviation tests requires the same information so it useful to complete the Data Quality Matrix in any case as part of the processing documentation.

5.1.3 Data processing actions and adjustments

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Adjustment of clean intensity record to reliable relevant primary reference gauge totals is required and has no additional effect on the quality code, i.e. this action is effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section B 3 of this Annex.

5.2 Example rainfall comments

The following are templated examples of comments for rainfall stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of rainfall) via some form of 'Site' and 'Measurement' key combination. These 'database keys' are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

Rainfall station

Type: Site
Measurement: Rainfall
Initial comment for the rainfall station at <*site name*>
In the catchment of the <*river name*> River, river number <*river number*>[6]
Situated at grid reference <*map co-ordinates and type*[7]> at an altitude of <*elevation*>m
Data is recorded as <*x*>mm tips counted as they occur *(or* totals in <*x*> minute intervals*)*
Additional information: <*alternate network number (e.g. Met. number), site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. exposure, obstructions, aspect, snow), adjacent site(s)*> <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.
The following data is also measured at this site: <*list variables, including any backup recorder*>
The local recording authority is: <*name of recording/archiving agency*>

[6] from *Catchments of New Zealand* (SCRCC, 1956).

[7] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

5.2.2 Equipment Comment examples

Type: Equipment Measurement: Rainfall Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. each tip as it occurs, or, mm totals at fixed intervals of x-minutes>*. The intensity gauge is a *<type, orifice dimensions and bucket size e.g. 0.5mm tipping bucket with 200mm diameter orifice and inlet siphon>* installed at a height of *<orifice height> (or* at ground level with splash grid*)* in a *<describe enclosure e.g. dimensions, type of security/fencing etc.>.* Gauge calibration is valid for *<calibration period>* and field checked every *<validation frequency>.* The backup intensity gauge is a *<type, orifice dimensions and bucket size e.g. 100x50mm rectangular orifice gauge with 1mm tipping spoon>* installed at a height of *<orifice height> (or* at ground level with splash grid*), <distance>* from the intensity gauge. Gauge calibration is *<give details of validity and checks, if any, e.g. as supplied and not field checked>.* Data is collected by *<method and frequency e.g. twice daily telemetry polling and occasional manual download>*.

If the backup intensity gauge is logged independently to a different logger and/or with a different sampling regime, a separate dedicated comment is preferable.

Type: Equipment Measurement: Rainfall Primary reference gauge installed on *<dd-mm-yyyy hhmmss>* is a *<type, orifice dimensions and capacity e.g. non-recording 3m standpipe with 150mm diameter orifice, or, large Octapent storage gauge with 1250mm capacity and 127mm diameter orifice>,* located *<distance>* from the intensity gauge at a height of *<orifice height> (or* at ground level with splash grid*).* The gauge is checked, and contents measured by *<describe method e.g. dipstick, and/or x-mm flask)* every *<verification (visit) frequency>*, at *<state resolution of readings>* resolution and expected accuracy of *<state achievable accuracy>.* Readings are captured to *<method and frequency e.g. paper (or electronic) field sheets each visit>* and transferred to computer by *<describe method e.g. manual entry to check data, or, import/upload to field station inspections etc.>*.

5.2.3 Operational Comment examples

Type: Operational Measurement: Rainfall Intensity gauge repositioned on *<dd-mm-yyyy hhmmss>* to *<describe relative location to previous>* to/because of *<provide reason>.* Gauge is now *<distance>* from the primary reference gauge at a height of *<orifice height> (or* at ground level with splash grid*).*

Type: Operational
Measurement: Rainfall
Gauge exposure changed due to *<provide reason e.g. removal of a tree, changes to enclosure fencing, new obstructions such as a building etc.>* noted on *<dd-mm-yyyy hhmmss>* (and effective from *<dd-mm-yyyy hhmmss>*).

Type: Operational
Measurement: Rainfall
Primary reference gauge dip reading of *<Y>* mm on *<dd-mm-yyyy hhmmss>* is calculated from a measurement of *<X>* mm using *<provide equation(s) and identify the variables e.g. Y = X(A/a) where A is can diameter and a is orifice diameter, or Y = C-X where C is gauge capacity>* because *<provide reason, e.g. wrong dipstick or conventional ruler used, or contents were frozen)*.

Type: Operational
Measurement: Rainfall
Primary reference gauge failed verification on *<dd-mm-yyyy hhmmss>* because of *<provide reason>.* Readings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are considered unreliable. Gauge was replaced (*or* repaired) on *<dd-mm-yyyy hhmmss>* with same *(or <describe type, location, and height> if different*).

Type: Operational
Measurement: Rainfall
Intensity gauge failed verification on *<dd-mm-yyyy hhmmss>* because of *<provide reason>.* Calibration is affected from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Gauge was replaced (*or* repaired) on *<dd-mm-yyyy hhmmss>* with same *(or <describe type, location, and height> if different*).

When a gauge is replaced, a corresponding Equipment Comment is required if the type, location, or orifice height of the gauge has changed (see Section B 5.2.2). If it is the primary reference gauge that has changed location and/or orifice height, a Stationarity Comment alerting and explaining the change is also required (see Section B 5.2.7).

Routine comment about verification failures of either gauge is recommended in a rainfall record because quality coding on its own is not sufficient to distinguish between problem-free data collected from an otherwise maximum achievable QC 400 site (according to the Rainfall Site Matrix) and data compromised by gauge condition or performance issues (QC 400 according to the Rainfall Data Quality Matrix) collected from an otherwise QC 600 capable site.

5.2.4 Data Comment examples

Type: Data
Measurement: Rainfall
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Sites considered for infilling the gap were *<list of sites and their grid references> (or* No suitable sites are available for infilling the gap*.)*
<Add any other relevant information such as why the gap has not been filled>.

Type: Data
Measurement: Rainfall
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Rainfall
Gap from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* closed with no rainfall assumed. Corresponding primary reference gauge catch is (assessed as) zero and no rainfall was recorded at the following nearby sites: *<list sites with grid references>.*

Type: Data
Measurement: Rainfall
Data capture method changed on *<dd-mm-yyyy hhmmss>* to *<describe new method e.g. event data, where each tip is timestamped as it occurs>*. (A zero-value status check is also generated on the logger every *<describe frequency e.g. hour, or day at a certain time>.*) Data was previously logged as *<describe previous method e.g. mm totals in fixed intervals of x-minutes>*.

Type: Data
Measurement: Rainfall
Data may be compromised by snowfall blocking the intensity gauge from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Primary reference gauge total from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is *<x>* mm. Corresponding recorded total is *<y>* mm. Recorded rainfall is not adjusted to primary reference gauge for this period.

Type: Data
Measurement: Rainfall
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Primary reference readings are not available. Record was generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression or rainfall-runoff model algorithm, etc.>* with input data of *<list sites and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. hourly or daily values only, or not recommended for hydrological model calibration, drought analysis etc.>*

Type: Data
Measurement: Rainfall
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Primary reference total for the infilled period is assessed as *<x>* mm from a gauge reading of *<y>* mm for the period *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Record was generated by apportioning the *<x>* mm with respect to *<provide interval e.g. hourly or daily>* values recorded at *<site name and grid reference>. <Add indication of reliability or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. not recommended for hydrological model calibration, drought analysis etc.>*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Rainfall
Values deleted (*or* edited to zero) from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove false (*or* test) tips due to *<identified cause e.g. interference, verification check, or validation>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Rainfall
Data filtered from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove zero values generated as *<frequency e.g. hourly, or daily (at hhmmss)>* site status checks. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Rainfall
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by (*or* for) *<method and parameters e.g. time drift (or shift) of x (hours, minutes etc.)>* to compensate for *<identified cause e.g. clock running slow (or fast), or wrong logger time at setup etc.>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Rainfall
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: 1-minute totals > x mm not accepted (or, removed (and gapped)); Gap Test: gap flagged if timestep > 48 hrs; Neighbour Test: error flagged when hourly totals differ from backup by > 2%; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

A Transformation Comment is not required for each change in the factor applied to adjust a rainfall record to its primary reference. It is sufficient to file a single Transformation Comment after the Site/Initial Comment, such as:

Type: Transformation
Measurement: Rainfall
All data, except where commented otherwise, is adjusted to primary reference gauge catch, which is independently measured at each recorder inspection. Logged rainfall is multiplied by the ratio of reference gauge total to logged total in each corresponding period. Resolution of filed rainfall therefore varies over time from the nominal rainfall depth represented by each gauge bucket tip.

Type: Transformation
Measurement: Rainfall
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is not adjusted to primary reference because the reference reading is unreliable (*or* not available).

An Operational Comment must be filed in association with the above that explains why a reference reading is unreliable or not available.

5.2.7 Stationarity Comment examples

Summarise results of Rainfall Site Matrix assessments into Stationarity Comments as they are completed. Include the determined maximum quality code achievable and the factors causing any downgrade to QC 500 or QC 400.

Stationarity Comments can also be used to capture and collate information about historical methods and data. A common change to be identified in a Stationarity Comment is date and time of each change in 'event' rainfall method (see Appendix B.2 to this Annex).

> Type: Stationarity
> Measurement: Rainfall
> Primary reference gauge replaced by *<new type>* (*and/or* relocated to *<new location> and/or* reinstalled at *<new height>*) on *<dd-mm-yyyy hhmmss>. <Add relevant before and after details and reason for change>. <Add period of overlap if any, and describe the correlation between readings from old and new configurations during period of overlap>.*

In the above example, replacement date and time is when readings from the new setup are adopted as primary reference and applied to the intensity data collected going forward.

Note: NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes) *requires at least a two-year overlap if a primary reference gauge is to be relocated.*

6 Preservation of Record

For rainfall sites, in addition to the requirements of Sections 6 and 8 of this Standard, the recording agency must store and retain indefinitely, and if electronic, back up regularly:

- all primary reference gauge data, including the original field observations
- the raw intensity gauge data
- the verified edited and quality coded intensity gauge time series, i.e. the clean data
- the fully processed time series, i.e. the clean data adjusted to primary reference gauge totals, with any missing record filled wherever possible and quality codes revised as applicable, and
- all required associated metadata for each of the above.

7 References

Sevruk B. 1982. *Methods of correction for systematic error in point precipitation measurement for operational use* (Operational Hydrology Report 21). Geneva, Switzerland: World Meteorological Organization.

Appendix B.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the duration requiring infilling
- the likelihood of no rainfall during the period missing
- the likelihood of heavy rainfall during the period missing
- the nature and availability of neighbouring donor sites
- prior knowledge of spatial and temporal rainfall distribution in the area (e.g. radar coverage, isohyet maps, altitude relationships, correlations between sites)
- prior existence of rainfall forecasts and other predictive rainfall models (as may be used as input to hydrological or hydraulic models)
- availability of supporting observations and other evidence such as:
    - primary reference gauge readings
    - a water level or flow record
    - ad hoc observations by, for example, the land occupier.

2 Recommended Methods

The following methods are candidates for infilling gaps in rainfall records:

- inserting all, or an assessed part, of the primary reference gauge total
- inserting other at-site observations, such as periods of no rain noted while on site or by the land occupier
- obtaining an estimated rainfall record from MetService, extracted from their radar imagery
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- methods utilising a donor site or sites, such as:
    - apportioning all or part of a primary reference gauge total to the temporal distribution of a suitable reference site
    - linear regression equations
    - estimates generated by algorithms in a rainfall–runoff model
      Note: Rainfall–runoff models used for near real-time flow prediction often include a step to estimate the model rainfall input for sites that have failed to supply actual data.
- interpolating from one or more isohyet maps of an event
- interpolating or extrapolating from an altitude relationship.

A combination of the above methods, for example, modifying a regression analysis to account for known periods of no rainfall at the recipient site, may improve results.

Infilling of missing data is only required to be attempted for the fully processed rainfall series, i.e. the record that is adjusted to the primary reference gauge totals. If reliable primary reference gauge totals exist, the corresponding record period(s) that include synthetic data generated by any method must sum to the relevant primary reference gauge total(s).

2.1 Infilling using primary reference gauge totals

When the intensity gauge(s) or data logging has failed, a rainfall total may still be available from the primary reference gauge. This total may pertain only to the missing period or to a longer interval, in which case the portion relevant to the missing period must be assessed (see Appendix B.1 Section 2.2).

The rainfall total covering the missing period can be filed as a single value at the end of the period. If the data type is discrete, this will cause errors of representation because the rain is assumed to have all occurred instantaneously at that time. If the data type is interpolating, the interpolation engine spreads the total evenly through the period at a constant rate, except for Hilltop Software's Six (and Thirty) minute Rainfall where the total is spread only through the previous six (or thirty) minutes.

The rainfall total covering the missing period may be apportioned, in order of preference, according to the temporal distribution of:

- rainfall for the same period at a suitable donor site (see Appendix B.1 Section 2.5), or
- values extracted from MetService rain radar for the location, or
- modelled rainfall predictions for the site.

Apportioning is achieved by scaling each value in the donor series by the ratio of the recipient to corresponding donor period totals, such that the infill sums to the recipient total rainfall for the period while acquiring the timestamps of the donor series. Apportioning therefore assumes the same temporal distribution of rainfall at both sites. This assumption should be tested whenever possible by comparing rainfall from several surrounding gauges.

Quality code for the infill using either method is QC 300; the total stored as a single value is 'limited measured data', while the temporal distribution of apportioned infill is synthetic. Comment(s) as for synthetic data are also required (see Sections 5.5.2 and B 5.2.4).

2.2 Assessing the primary reference gauge total

If a primary reference gauge reading relates to a period longer than the period of interest, the portion applicable to the period of interest must be assessed.

If the clean recorded intensity or backup gauge data are reliable up to the period of interest:

- determine the recorded total corresponding to the part period of the reference gauge reading up to the period of interest
- determine the average of all previous reliable deviations for the particular combination of intensity or backup gauge (i.e. same serial number, installation, and calibration period) and reference gauge
- rescale the part-period recorded total by that average, then
- deduct the rescaled part-period recorded total from the reference reading
- the remainder is the assessed portion of the reference reading.

For example:

- *Primary reference gauge reading for period 1-Mar-2020 10:30:00 to 3-May-2020 11:15:00 is 210 mm*
- *Period of interest is 20-Apr-2020 9:30:00 to 3-May-2020 11:15:00*
- *Recorded total for period 1-Mar-2020 10:30:00 to 20-Apr-2020 9:30:00 is 150 mm*
- *Average of previous relevant reliable deviations is -3%*
- *Rescaled recorded total for period 1-Mar-2020 10:30:00 to 20-Apr-2020 9:30:00 is (100-3)/100 x 150 = 145.5 mm*
- *Assessed portion of reference gauge total for period 20-Apr-2020 9:30:00 to 3-May-2020 11:15:00 is 210 – 145.5 = 64.5 mm*

If the primary reference gauge was not read and emptied during a site visit it may be desirable to assess the relevant portions of the subsequent reading and treat the two periods separately. The method of assessment is the same except the periods are bounded by the site visits and the period of interest is the first of the two.

Data adjusted to an assessed primary reference gauge total cannot acquire a quality code higher than QC 400. Most often, an assessed reference reading is required in relation to infill of missing record so the quality code will be QC 300.

If the intensity and backup gauge data at site are unreliable a suitable donor site (see Appendix B.1 Section 2.5) may be used. Quality code is restricted to QC 300 for any application of an assessed reference reading obtained by reference to a donor site.

Comment is required explaining the derivation of an assessed reference, regardless of method.

2.3 Estimating the primary reference gauge total

If a primary reference gauge reading is missing or compromised it may be estimated from the recorded intensity or backup gauge data by scaling the recorded total for the relevant period as for the assessment method described in Appendix B.1 Section 2.2.

If recorded intensity or backup gauge data is also missing or unreliable, a reference total can be estimated using one or more of the following methods:

- interpolation of, or prediction from, some form of relationship with one or more suitable donor sites (see Appendix B.1 Section 2.5):
    - regression analysis (see Appendix B.1 Section 2.6)
    - altitude/orographic relationships
    - mass (cumulative) curve comparisons
- interpolation of an isohyetal or raster (e.g. radar) map of the area for the relevant period.

Regression analysis is preferred because the goodness of fit and consequent uncertainty can be explicitly determined. Regression can be weighted by one or more of the other relationships and/or results sanity checked against maps of the spatial rainfall distribution of the period of interest, or of events within the period, or of rainfall distribution more generally. GIS tools are useful to explore spatial relationships and weightings.

A quality code of QC 300 applies to any application of an estimated primary reference gauge total and comment is required explaining derivation of the estimated rainfall regardless of method.

2.4 Infilling periods of no rain

A gap in a rainfall record may not have missed any rain. The absence of rain may be:

- known from documented observation at site
- inferred from nil reference gauge catch (actual or assessed) and no corresponding rainfall recorded at a nearby gauge, or
- predicted from a relationship with one or more nearby gauges.

Deleting the gap marker is not sufficient on its own to substitute a period of no rainfall. For the discrete data type, gap markers are irrelevant because there is, by definition, no interpolation to prevent. For an interpolating data type, deleting a gap marker allows the system to interpolate between the adjacent values which may be non-zero.

A record of nil rainfall can be created in the time series by deleting the gap marker (if any) and entering zero values at the start and end of the nil rainfall period. However, this is still only partially useful. For a discrete data type the additional zero values are of no consequence and a suitable Data Comment is more useful. For an interpolating data type the effective period of no rainfall begins from the last non-zero value stored prior to the zero value filed at the start of the infill period.

If the period of nil rainfall is known or inferred, quality code may be carried forward from the adjacent series, but a comment is required to explain that there was a gap in the record, no rain occurred, and how this is known or was inferred.

If the period of nil rainfall is predicted from a nearby site it is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section B 5.2.4).

2.5 Selecting a suitable donor site

One or more nearby stations can be used as a donor site to infill a missing record. When selecting suitable donor sites, consider:

- the relative locations of the recipient and donor sites, including altitude and aspect
- topographical influences and orographic effects and therefore likely rainfall gradient in the vicinity
- seasonal differences between the sites
- the weather pattern and type of rainfall at the time of the missing record, e.g. convective or frontal rain (warm or cold), and consequent effect on intensity and temporal and spatial variation.

Compare an extended period of record from recipient and donor site(s) using between-station comparisons and scatterplots. Between-station comparisons allow investigation of the timing and shape of hyetographs. Scatterplots allow exploration of:

- the fit between the two sites visually and by correlation co-efficient (r^2)
- the potential for lag, non-linearity, or seasonal bias, and
- the most suitable timestep for the infill. A poor relationship might only support generating daily values with acceptable uncertainty, while an excellent fit might permit hourly infill values.

In New Zealand rainfall distribution is potentially highly variable over relatively small areas. Similarity cannot be assumed without evidence even over short distances. Multi-site consideration is recommended.

2.6 Infilling by regression analysis

Regression analysis is an alternative to apportioning a primary reference gauge total (see Appendix B.1 Section 2.1) or can be used when no reliable data are available from any of the gauges at site.

- General procedure is described in Appendix 2 to the main document.
- Select one or more suitable donor sites (see Appendix B.1 Section 2.5).
- Analyse the period of the available primary reference gauge total, or if no reference total, a period of the same weather (or seasonal) pattern:
  - generally, about two to three weeks either side of gap, or
  - no more than two to three times the extent of the gap if an extended period (see Section B 3.5).

- Decide a suitable data interval for analysis and acceptable timestep of the infill, determined with reference to the extent of the gap and the quality of the relationship(s) (see Sections B 3.5 and 6.2.5).

Regression analysis is preferred to apportioning because the goodness of fit and consequent uncertainty can be explicitly determined. However, the derived relation may introduce a constant that predicts additional rain days or negative rainfall unless one of the following options is utilised:

- edit predicted infill values to zero when there is zero rainfall at the donor site(s) then redistribute the rainfall removed over the remaining non-zero infill values. This is an extra processing step that may not be warranted over the other options
- calculate the regression equation only when the donor site(s) have rain and apply it only to those times to generate the infill rainfall
- force the regression through the origin (0,0). This tends to inflate the R^2 and may discount topographic and orographic induced differences in the occurrence of light rain between sites.

2.7 Infilling from rainfall–runoff models

Rainfall–runoff models sometimes incorporate algorithms for estimating rainfall at a site from which data collection has temporarily failed. If such a model already exists that includes the recipient site, this is a viable source of infill data, but these models are time consuming to set up and have the disadvantage that their output can be difficult to replicate, so they are difficult to justify for the sole purpose of generating infill record.

Infill from this source is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section B 5.3.2).

3 Other Considerations

3.1 Seasonality of relationships

Seasonal differences tend to exacerbate topographic- and orographic-induced variability in rainfall distribution and may affect the reliability of some donor sites and not others. The effect of seasonality on the relationship(s) used to derive a synthetic rainfall record must be considered, and then accounted for if significant.

Examples are the occurrence of snow at one site and not the other during winter, seasonal differences in the relative strength and direction of the wind, seasonal differences in the influence of obstructions such as deciduous trees, and the relative frequency of summer thunderstorms.

3.2 Using multiple donor sites

Although multi-site consideration is recommended (see Appendix B.1 Section 2.5), multiple regression may not necessarily improve the accuracy of synthetic rainfall data because of the same potential variability that makes multi-site consideration necessary.

The relative usefulness and possible bias can be tested by developing relationships with several combinations of donor sites and comparing what they predict with the actual record. However, in most cases the occurrence and extent of missing record will not justify this level of analytical investment.

4 References

McKerchar A, Henderson R, Horrell G. 2010. *Standard procedures for creating and describing synthetic hydrological record.* NIWA Client Report No. CHC2010-002 prepared for Tasman District Council under an Envirolink project.

Appendix B.2 Changes to Event Rainfall

The definition of event rainfall data and its method of capture via tipping bucket rain gauges has changed in New Zealand since it became possible to record every bucket tip as it occurs and transmit and store data without data compression.

This appendix describes the historic method, what has changed, the consequent effect on selection of an appropriate time-series data type for storing the data, and the effect of data compression as applied to the data before it was permanently stored.

The combination of the method of event rainfall capture, the data type in which it is stored, and any compression applied, may affect how and what data are retrieved for analysis. Any change to any one of these factors without corresponding attention to the others may compromise stationarity of the time series. It is also a significant issue to resolve when migrating legacy data into new time-series management systems or adding data collected a different way to an existing time series.

1 Fixed Interval Recording

1.1 Punch-tape recorders

From the early 1970s until the introduction of Aquitel telemetry in the mid-1980s, rainfall intensity data were digitally recorded in New Zealand on punched paper tape using a recording interval of six minutes (one-tenth of an hour) centred on the hour.

To maximise the length of time a paper tape could be left on a recorder a method was devised of punching only when rainfall occurred, i.e. capturing only the rain events, and thus was known as 'event rainfall' data. The recorder punched a coded time when a pulse was received from the bucket gauge. The coded time incremented every six minutes.

When the tape was read the coded times were collated and converted by the processing software to the amount of rainfall in each six-minute interval. To then make most efficient use of the limited computer storage only the intervals containing non-zero values were written.

1.2 Aquitel telemetry

Aquitel remote telemetry units were set to log every 7.5 or 15 minutes and logged a value every interval whether tips had occurred or not. The base telemetry software compressed redundant values out of the time series as it wrote the data to file.

1.3 Data type

The data type used to store these data is incremental and interpolating with timestamp at the end of the interval, i.e. each value filed is the total rainfall in the preceding time interval, and the timestamp of the previous value sets the start of the current time interval. This means that when there is no rain, it is sufficient to store a zero value one recording interval immediately prior to the first non-zero value of the next rain event. The time-series manager (TSM) interprets all time from the last stored value of the previous rain event up to the time of the zero value as a period of no rain.

1.4 Data compression

All TSMs that are or were in use in New Zealand are capable of applying various forms of data compression. The universally common form that concerns data processing and data retrieval is the lossy process of removing redundant values from an interpolating time series. 'Redundant' is defined differently in the various software and in most systems the user has considerable control over the degree of compression applied.

Where compression has been applied, the period and range should be recorded in the metadata; however, automatic data compression using a range of zero was often a system default and rarely commented.

Fixed interval rainfall data were not usually compressed using a range other than zero, but legacy software TIDEDA implemented this differently to other TSMs and removed not only duplicate values but also those where the rate of rainfall was the same, and therefore removed proportionally more data elements, as shown in Table B 6.

Table B 6 – Fixed interval and event rainfall time series and TIDEDA data compression

Rainfall with recording interval of six minutes				As filed in TIDEDA compressed to range = 0	
Fixed interval data		'Traditional' event data			
Date/time	Rain (mm)	Date/time	Rain (mm)	Date/time	Rain (mm)
24/07/2020 12:00	2.5	24/07/2020 12:00	2.5	24/07/2020 12:00	2.5
24/07/2020 12:06	3.0	24/07/2020 12:06	3.0	24/07/2020 12:06	3.0
24/07/2020 12:12	2.0	24/07/2020 12:12	2.0	24/07/2020 12:12	2.0
24/07/2020 12:18	0	24/07/2020 12:42	0	24/07/2020 12:42	0
24/07/2020 12:24	0	24/07/2020 12:48	0.5	24/07/2020 13:00	1.5
24/07/2020 12:30	0	24/07/2020 12:54	0.5		
24/07/2020 12:36	0	24/07/2020 13:00	0.5		
24/07/2020 12:42	0				
24/07/2020 12:48	0.5				
24/07/2020 12:54	0.5				
24/07/2020 13:00	0.5				

The original fixed interval data are recoverable from the compressed time series by resampling (repacking) the compressed data to the recording interval, provided the compression range applied was zero.

2 Tip Recording

This method logs bucket tips as they occur, to a time resolution of one second, and has become known as event recording or event rainfall.

On receipt of each pulse from the tipping bucket gauge a logger may store a value with timestamp (either a rainfall depth or a tip count), or just the timestamp. Processing software converts counts to rainfall depth for filing in the time series.

Time interval between each stored value varies and is not predictable.

Note: One-second time resolution records quite precisely when the bucket tipped but not when the rain collected in the bucket actually fell. Resolution of tipping bucket rainfall data depends more on bucket size.

2.1 Zero values

When there is no rain, no data will be logged from the gauge. Long dry spells become problematic in that it cannot be certain the site is still working unless inspected, so some agencies program their loggers to store a zero value at a regular interval such as once or twice every day at the same time, or on the hour every hour.

For the interpolating data type this practice presents a false interpretation of the data because the rate of rainfall accumulation is determined by the time interval between preceding and current timestamps regardless of the preceding value. The gauge bucket may indeed be filling due to rainfall as the status check value of zero is being logged.

2.2 Data type

These data are incremental because they are intended to be totalled but may be stored in a discrete or interpolating data type.

2.2.1 Discrete totals

If stored in a discrete data type, there is no valid interpolation between data elements and therefore no apportioning of rainfall between timestamps by way of assuming an average rate of accumulation.

Rainfall is taken as having occurred in the instant a bucket tipped and total rainfall in any period is simply tallied on that basis. Zero values inserted in the data have no effect.

2.2.2 Total in preceding interval

If the data are stored in an interpolating data type, interpolation is valid, and apportioning can occur.

Rainfall is taken as having occurred at a constant rate over the interval between successive timestamps. In this way two interpretations are possible depending on whether zeros are added by the logger:

- the rainfall is deemed to have accumulated in the period between the time of the immediately preceding stored zero value and the current tip time, or
- if there are no zero values stored in the data, rainfall is deemed to have accumulated in the period between the time of the immediately preceding tip and the current one, which leads to an interpretation that there is never a period of no rain.

Total rainfall in any period is the sum of values for all intervals wholly within the period, plus amounts apportioned to any part intervals at the start and/or end of the specified period.

A value of zero stored in the data changes the apparent rate of accumulation of the subsequent bucket tip because the timestamp of the zero value sets the start of the next accumulation interval. Zero values inserted into tip data therefore have some effect on statistics calculated from the data, although the effect may not be significant depending on the analysis undertaken.

Hilltop Software does not support discrete totals but offers two data types for tip recording that insert a zero value into the time series 'on the fly' when statistics are calculated from the data, at either 6 minutes or 30 minutes prior to a tip, if no tips are filed in that interval. In this way Hilltop Software establishes that any recorded bucket tip accumulated over no more than the previous 6 (or 30) minutes without altering the stored data.

2.3 Data compression

Lossy compression of tip data stored as discrete totals should not be attempted because technically there is no redundant data to remove.

If tip data are stored as total in preceding interval and zero values have been regularly inserted there is some incentive to compress redundant zero values out of the time series before permanent storage. However, the effect of data compression on the non-zero data is likely to be software dependent and somewhat unpredictable due to the irregular intervals between data elements. Any data compression applied should be a range of zero and restricted to periods of only zero values.

3 Combining Records of Different Type

Rainfall recording at many sites has changed from fixed interval (including 'old-style' event recording) to tip recording ('new-age' event recording). This is a significant change to the method of capturing rainfall data from tipping bucket gauges that affects how the rainfall is subsequently represented and interpreted, to the extent that most TSMs offer different data types for their storage.

Data should be stored in the data type most appropriate to the method of capture. Records of different data type should not be combined in the same time series unless the TSM software supports combining data of different type.

Facilities for combining data of different type vary. Some TSMs support the storing of data of different interpolation method in the same time series. Other TSMs allow two or more time series of different data type to be stored separately but concatenated for analysis.

Annex C Processing of Gauging Results

1 General Overview

This Annex contains further specific guidance for the post-processing, quality review, documentation, and archiving of measurements of open channel flow (i.e. discharge gaugings, hereafter referred to as gaugings) after a discharge result has been obtained.

The data processing required to obtain a discharge result from the field measurements is included in NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data)*.

1.1 Normative references

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

- NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data).*

Where reference is made from this Annex to specific sections of the above document, its title is abbreviated and version stated, i.e. 'NEMS *Open Channel Flow* v1.1'.

1.2 Documenting the data processing system for gaugings

Discharge measurements that have been registered (see Section C 1.2.1) and reviewed (see Section C 2) shall be archived in a database (also see Section C 6).

Methodologies applied by each agency to process and preserve gauging data shall be documented by the agency. Procedures vary widely depending on the combination of:

- gauging method(s) and instrumentation used
- choice of software to process gaugings, and
- the time-series manager in which results will be permanently stored.

Some time-series managers store gauging results as a multi-item time series with associated electronic forms and 2-D cross-section data to store the measurement detail. In these systems all fields in the multi-item data must contain values, so a default or flag value is stored if an item is missing (see Appendix C.3 Section 5). Any changes or adjustments to, or deletions of, data must be rolled through to all parts of the gauging, which may need to be managed manually depending on the system and process. Housekeeping procedures are needed for data stored in these systems.

Some systems store gaugings in relational database tables and use queries to make selected gauging data available to other system tools and applications, such as a Ratings workbench. These systems are better at maintaining integrity of the data but require additional processes to view and manipulate the data as a time series.

Complexity of the gauging information stored varies between systems and gauging methods. Facilities vary and not all gauging methods and formats are handled to the same extent. The archiving system may store one or more of the following:

- raw measurement data, which may be manually input, and may be recalculated each time the measurement is accessed so results can potentially change if the system software changes
- editable summary results as determined and generated by the system software and/or from manual data entry
- proprietary summaries, imported as editable data or as a webform or non-editable image
- data imported from smart devices, which may include the measurement data that may then be recalculated on import, or be the proprietary calculation and/or summary results in an exchange format offered by the device software
- measurement metadata imported from the gauging instrument and/or smart device and/or retrospectively manually entered.

Adequate mechanisms shall be put in place to store all relevant metadata with, or accessible from, or indexed from, the actual discharge measurement.

Procedures must ensure all requirements for control of editing (see Section 3.8), metadata (see Sections C 2.1 and C 4), and preservation of record (see Section C 6) are satisfied for all gaugings stored. Additional housekeeping and/or manual procedures may be needed.

For example, additional procedures may be required for permanent storage of, and access to, the original measurement data outside of the time-series management system, or for controlling and tracing the editing of data to ensure integrity across all related parts if not managed entirely by the system.

1.2.1 Gauging register

Each gauging returned to the office must be entered chronologically into a register with a minimum of the following noted:

- river name
- site name
- gauging method, and
- date and time of the measurement.

A unique identifier for each gauging is obtained from this register to be used for all data and records associated with the gauging.

Note: Identifiers are more helpful for Ratings work, and registration errors are easier to find, if the identifier is sequential. Some time-series management systems only support numeric identifiers.

A discharge measurement subsequently deleted from its site record must not be removed from the register. Deletion of the measurement must be recorded in the register, with the date on which the deletion was actioned and by whom.

The register should also record the following:

- the computed discharge result
- stage assigned to the gauging (if any)
- the gauging party
- the purpose of the gauging

  Note: Purpose dictates what takes priority when gauging. Requirements for some purposes may conflict with others. Examples are: i) gaugings intended to calibrate a rating need a stage measurement whilst gaugings to assess compliance with minimum flow rules may not, and ii) gaugings for habitat assessment may be done at locations unsuited to discharge measurement because measurement of velocities in that habitat type is the objective, and those gaugings would not be used to calibrate a rating.

- date the gauging is input into the time-series management system
- cross-referencing as is helpful to traceability, e.g. to a data import log, accompanying suspended sediment measurement, original data file, electronic field sheet etc.

1.2.2 Original records

The discharge measurement and supplementary data (whether electronic, or paper records) on arrival at the office shall be:

- entered into a register (see Section C 1.2.1), and
- permanently identified with site identifiers, unique measurement number, and relevant date(s) and time(s), and
- moved from field computers, handheld devices, phones, or backup media to permanent storage locations, or
- if paper records, indexed and stored in a fireproof secure location.

All original records shall be retained indefinitely by the recording agency.

Note: The original record may be required at a later date, should the archived processed data be found to be in error, corrupt, or lost.

2 Quality Control

2.1 Additional metadata required

Expanding on the generic metadata requirements described in Section 6, the following metadata (as applicable) shall be collated, verified, and permanently archived, and be accessible as needed when verifying and archiving discharge measurements:

- site and equipment details:
  - location of the measurement cross-section(s) and/or reach
  - proximity to any associated water level reference and identification of any possible undesirable influences (see NEMS *Open Channel Flow* v1.1 Section 2.3.4)
  - stage heights from each water level gauge at site, at start and end of the discharge measurement, and while gauging if stage is changing rapidly (also see Section C 2.3)
  - deployment details, including type of instrument or meter, method of deployment, and sampling regime (may be coded)
  - measurements related to instrument deployment (e.g. transducer depth, azimuth, meter distance above weight, size of weight, airline length, vertical and horizontal angles, length of reach etc.)
  - observations that support or impact the method, e.g. wind speed and direction at water surface, water temperature, salinity, turbidity and/or water clarity
  - factors affecting suitability of the reach for gauging

  Note: statistical uncertainty analysis does not account for the impact of poor measurement conditions or poor practice on the result., such as may be caused by the presence of weed, turbulence, low SNR, soft substrate, or difficulty sounding depths and/or setting the meter.

- station and/or instrument calibration details:
  - serial number(s) of instrument(s) used
  - calibration data, including date of most recent calibration, and calibration parameters and limits (see Section C 2.2)
  - ground-truthing as needed for image velocimetry methods
  - magnetic declination for moving boat ADCP methods
  - results of pre- and post-deployment tests (see Section C 2.2)
- measurement details:
  - gauging number
  - gauging party
  - recording agency
  - discharge result calculation method
  - discharge result uncertainty, calculation method, and coverage factor
  - sampling detail (which may be coded), e.g. number of verticals and sampling points, proportions of measured to unmeasured area, extrapolation methods etc.
  - estimate(s) of alpha, as applied to surface velocities to obtain mean velocity
  - quality code assessment.

2.2 Deployment tests and checks

To achieve a quality code of QC 600, instruments used for discharge measurement must have a current and valid calibration, be used within their calibrated range, and be serviceable when deployed. Calibration history and results of pre- and post-deployment tests must be available to the processor. Quality code can be no more than QC 500 in any of the following circumstances and an Operational Comment must be filed giving the reason(s) for the reduced quality code:

- instrument is overdue for calibration, is damaged, or was used outside its calibrated range (e.g. above or below velocity thresholds), or in a manner that invalidates the calibration (e.g. a meter calibrated without its guard but used with the guard in place, or a Doppler instrument deployed before it had reached equilibrium with water temperature)
- instrument is used without recommended clearances (e.g. from stream bed and/or banks, or transducer blanking and screening distances)
- instrument fails a pre- or post-deployment check, e.g. a beam check, spin test, or compass calibration.

It is possible to request a damaged current meter be recalibrated in its damaged condition before repair, enabling the discharge to be recalculated using the 'as is' calibration to recover the measurement. If this has been done, an Operational Comment must be filed providing details of the 'as is' calibration and reason for it (see Section C 4.2.3).

2.3 Stage height for the gauging

A stage height for the gauging is required if the gauging is to be used to develop a stage–discharge rating for the site (see NEMS *Open Channel Flow* v1.1 Section 2.4).

The stage height assigned is the mean gauge height representative of the discharge measured (see Appendix C.1). It should be obtained in a consistent manner for the site, and the usual source and method(s) be recorded in an Equipment Comment (see Section C 4.2.2).

If there is some distance between the gauging location and the location of the water level reference, lag due to time of travel may need to be accounted for when determining mean stage height for the gauging. Time of travel can be estimated by dividing the distance between the two locations by the mean velocity for the gauging.

Uncertainty of stage can outweigh uncertainty of discharge measurement in situations where stage is changing rapidly, or lacks resolution, or is difficult to determine due to on-site conditions. An Operational Comment is required in any of these situations stating the uncertainty in the stage height assigned to the gauging (either calculated, observed, or estimated) and the reason(s) for it.

Stage height assigned to the gauging must be reconciled with the filed stage record. If significantly different, the difference must be resolved. If the filed stage record is independently edited or adjusted, agreement with stage height(s) assigned to any gauging(s) in the period altered must be re-evaluated.

Note: The stage–discharge rating fitted to gaugings will be applied to the filed recorded stage to derive a record of flow. If the stage assigned to a gauging is different from the filed recorded stage at the file time of the gauging, no matter how well the rating curve is fitted to the gauging the measured and corresponding derived rated flows will not match.

2.4 Calculation of uncertainty

A quantitative uncertainty for the discharge measurement result must be calculated whenever possible and stored and presented with the result in expanded form, to coverage factor 2 (95% level of confidence). The uncertainty is also used to determine quality code for the measurement (see Section C 4.1).

Discharge measurements are composite quantities that depend on several component quantities, so the total error of the measurement is a combination of the errors in all component measurements. Uncertainty for the discharge result is determined using statistical rules for combining the component standard deviations.

Uncertainty analysis is applied after all measurement bias has been corrected (JCGM, 2008, their Section 3.2.4) and measurement protocols have been implemented with rigour (JCGM, 2008, their Section 3.4.8), (Muste and Lee, 2013).

Note: For more information see JCGM (2008) and ISO 5168:2005.

2.4.1 Rotating-element current-meter measurements

Calculate uncertainty using the standard algorithms described in ISO 5168:2005 and ISO 748:2007 section 9.3. ISO methods are in terms of one standard deviation so the uncertainty obtained must be multiplied by 2 for 95% level of confidence.

2.4.2 ADV instruments

Calculate uncertainty using the standard algorithms described in ISO 5168:2005 and ISO 748:2007 section 9.3 with modifications to account for specific uncertainty components associated with these instruments and/or to set aside those not applicable.

Use the 'ISO' option if offered a choice of method by the instrument manufacturer but note the coverage factor and multiply by 2 if needed to obtain uncertainty to 95% level of confidence.

If the time-series manager recalculates the measurement and uncertainty after import the uncertainty calculation shall be by the same ISO methods and reported to coverage factor 2. If the uncertainties obtained then differ, preference shall be given to the time-series manager result unless a software fault is suspected.

2.4.3 ADCP profilers with velocity-area stationary method

Use the manufacturer's software to calculate uncertainty, selecting the 'ISO' option if offered a choice. Note the coverage factor and multiply by 2 if needed to obtain uncertainty to 95% level of confidence.

The 'ISO' calculation is based on ISO 5168:2005 and ISO 748:2007 section 9.3 with modifications by the instrument manufacturers.

For example, the Teledyne implementation is based on a relative standard uncertainty model developed by Huang (2012), subsequently reviewed by Muste and Lee (2013).

2.4.4 ADCP profilers with velocity-area moving boat method

Use QRev to calculate the uncertainty (see Section C 2.6). This software was developed by the United States Geological Survey (USGS) to provide a consistent set of calculation methods for all ADCP brands. It uses similar principles to ISO 748:2007 and ISO 5168:2005 in that it assigns uncertainty to components of the gauging then combines the component uncertainties to obtain overall uncertainty at the 95% level of confidence. The uncertainty value obtained is not strictly quantitative (USGS, 2020).

2.4.5 POEM instruments

There is no specific method for calculating uncertainty of discharge measured using POEM instruments, but the principles of ISO 5168:2005 and ISO 748:2007 section 9.3 can be applied.

Note: Hilltop Software applies the same calculation as for rotating element current meters, which may overstate the uncertainty for POEM gaugings because uncertainty associated with moving parts does not apply to the POEM.

2.4.6 Float-based surface velocity measurements

Use ISO 748:2007 Annex F.

2.4.7 Image velocimetry methods

A standardised method specific to surface velocity discharge measurements is still needed, but the uncertainty analysis framework for velocity-area discharge methods as used in ISO 748:2007 applies (Le Coz, pers. comm., 7 January 2021). Specific error sources to consider are:

- alpha errors (Hauet et al, 2018)
- image orthorectification errors (Le Coz et al, submitted)
- velocity errors, specific to signal processing (LSPIV/STIV/SVR), projection (SVR angles), time averaging, space averaging, extrapolation into unmeasured areas, etc.
- operator-related effects, and
- depth errors due to bed evolution, and positioning/projection errors.

Comparisons to reference discharges and intercomparison experiments are useful to document the likely uncertainty of surface velocity discharge measurements.

A typical uncertainty of at least ±15% at the 95% level of confidence is generally assumed for surface velocity measurements by a trained user in good conditions, for which the estimation of alpha is generally regarded as the dominant source of error if the riverbed is stable. Uncertainty in estimated wetted area due to bed movement adds more uncertainty to the discharge result.

2.4.8 Salt dilution methods

GUM- (*Guide to the expression of uncertainty in measurement*, 1995) aligned methods and software are under development (Hauet at al., 2020) taking into account uncertainties in:

- the mass of salt injected
- the measurement of time
- the conductivity to concentration relation
- possible exceedance of applicable range of the conductivity to concentration relation
- computation of the area under the conductivity curve
- imperfect tracer (salt) mixing
- loss or gain of tracer (salt) along the reach, and
- unsteadiness of the flow.

2.4.9 Volumetric methods

Use ISO 5168:2005 to combine the component uncertainties associated with measurement of volume and time.

2.4.10 Weirs and flumes for discharge measurement

Use ISO 5168:2005 to combine the component uncertainties associated with:

- measured head

  Note: Hook or point gauges with a vernier may be needed to improve resolution of head measurement at low stages with small structures.

- the dimensional measurements and correctness of the structure, for example, the angle, verticality, and straightness of a V-notch

  Note: Dimensional measurement and correctness of the structure is critical for the theoretical discharge formulae to hold true.

- the various constants and corrective factors, for which estimates and tolerances are given in the relevant ISO standards.

  Note: In New Zealand, site factors such as sediment transport, relatively steep slopes, and lack of sufficiently large weir ponds, usually render *theoretical ratings inaccurate and field rating by current meter is required. Thus, accuracy of flow determination at most sites with structures is generally governed by quality of the current meter gaugings, their scatter on the rating curve, and stability of the structures and their reaches.*

2.4.11 Indirect methods

Apply the principles in ISO 5168:2005, although it may be difficult to get enough repeat measurements to calculate component standard deviations.

2.5 Review of results

The minimum measurement results required to be filed, as listed in NEMS *Open Channel Flow* v1.1, are:

- stage (mean gauge height) for the computed discharge (see Section C 2.3)
- the computed discharge
- gauged cross-section area (where applicable) (see Section C 2.7.1)
- mean velocity of discharge (where applicable) (see Section C 2.7.2)
- gauging method code (see Annex C of NEMS Open Channel Flow v1.1)
- calculated total uncertainty of the measurement (see Section C 2.4)
- quality code (see Section C 4.1)
- filed in NZST (or CHAST as applicable) (see Section 1.2.2) at the date and time of mean gauge height.

  Note: If a measurement is completed over a peak or trough then the time of mean gauge height may occur at more than one time. The time assigned to the measurement should be whichever is closer to when the larger portion of the flow was measured.

This Standard adds the following to the above list of required items:

- the unique gauging identifier (see Section C 1.2.1)
- alpha value(s) used for surface methods.

Additional items also commonly filed are listed in Appendix C.3.

Each measurement shall be reviewed by:

- the data collector, preferably in the field before departure so errors can be rectified or a repeat measurement done, and
- a second person, during or after processing of the measurement and before archiving.

In general, all results must be reviewed for errors of:

- configuration, deployment, and calibration, including:

- metadata entry errors (site, party, location etc.)
    - poor choice of instrumentation and/or measurement location
    - inappropriate instrument settings
    - instrument out of calibration, not calibrated, or used outside calibrated range
    - failed pre- or post-deployment tests and checks (see Section C 2.2)
    - poor measurement technique
    - effect of inclement conditions e.g. strong wind or extreme temperature
- arithmetic in the computation, such as in calculating:
    - point velocities
    - means of depth, velocity, head, or time
    - subsection areas and discharges
    - total width, area, volume, and discharge
- logic and consistency, such as:
    - gauging number not sequential with date/time order of measurements
    - number of verticals or transects disagrees with codes assigned
    - stage assigned inconsistent with stage at start and end of the measurement, and rate of change
    - file date/time not between start and end date and time of the measurement
    - stage assigned deviates from corresponding filed stage by more than measurement tolerance
    - mean velocity of discharge (discharge divided by wetted area) not plausible
    - stage below CTF, but discharge is not zero
    - muddled units
    - adjustments for vertical and/or horizontal angles, or extrapolations into unmeasured areas, are not applied when needed, or results are not as expected.

Checks of arithmetic, logic and consistency can be automated.

2.5.1 ADCP moving boat method measurement review

ADCP discharge measurements have aspects that are specific to this method. The following items shall be confirmed in the data:

- transducer offsets, screening distances, edge distances and shape, temperature and salinity match the field notes
- a moving bed test using a proper technique has been conducted and assessed

- if a moving bed was detected, an appropriate alternative to bottom tracking was used (see Appendix C.2)
- total exposure time is greater than 720 seconds
- transects collected are reciprocal pairs
- the average boat speed was less than the water speed
- pitch and roll are within calibrated range and not excessive
- course changes are minimal and gradual
- sufficient edge cells have been properly measured

  Note: If the physical edge is a vertical wall the edge cells should be no closer than the equivalent of the depth of water at the wall.

- the number of missing or invalid ensembles (data) is not excessive. If 10 percent or more of the ensembles are missing in one location where there is a significant part of the flow and neighbouring data are of poor quality, then the measurement quality shall be downgraded

  Note: The number of missing or invalid ensembles that will result in a poor measurement is difficult to establish because the location and clustering of the missing data is important. If 50 percent is missing but every other ensemble was valid then this would be a good measurement.

- the number of missing depth cells is not excessive. If 25 percent or more are missing, then the measurement quality shall be downgraded unless they are spread randomly through the measurement
- extrapolation methods are appropriate for the wind and velocity conditions observed at the time of measurement.

  Note: Wind and horizontally stratified density currents are the most common reasons for velocity profile not conforming to the 1/6th power law (WMO, 2010).

  Note: Manufacturers and the USGS provide software for the purpose of assessing potential non-standard velocity situations. Details of QRev and others can be found on the USGS OSW Hydroacoustics website.

Further details on reviewing ADCP measurements are summarised in Appendix F of Mueller and Wagner (2009).

2.5.2 ADCP stationary method measurement review

The following items shall be confirmed in the data:

- diagnostic test results are passed and logged
- the ADCP clock is set
- temperature readings are valid
- no errors in ADCP draft, water depths, widths etc. apparent from the contour plot

- number of panels and % of discharge per panel is acceptable; within 5% of total is preferred but otherwise within 10%
- flow vectors and flow direction are consistent, with no obvious errors
- SNR/intensity; look for spikes caused by obstructions
- minimum number of valid ensembles and sampling duration has been achieved
- top and bottom extrapolations are reasonable extensions of the measured portions; alternates to the 1/6th power law should reflect conditions observed at the time of measurement.

  Note: For SxS Pro, check there are enough bins measured to allow reasonable extrapolations at the top and bottom. In clear water, there may be several missing bins.

  Note: Moving boat measurements at the site can also be used to guide appropriate extrapolation choices.

2.6 QRev

QRev is software developed by the USGS to improve processing of moving boat ADCP gaugings. It offers:

- consistent processing algorithms and discharge calculation methods irrespective of instrument brand
- automated data quality checks and filtering, and improved handling of invalid data
- automated application of loop corrections, stationary moving bed analysis, and unmeasured area extrapolations, and
- an estimated uncertainty for the measurement (see Section C 2.4.4).

QRev is recommended for field processing of moving boat ADCP gaugings and is required for office review of results (see Section C 2.5).

The international variant QRevInt (current version 1.09) is recommended for New Zealand (QRev 4 is the USGS current release). Its design leads the user through the processing steps in the most effective order and uses a traffic light system and messages to inform the user of the status of each step.

The following is summarised from the User's Manual (USGS, 2020):

- work from left to right across the tabs in the interface to obtain the best navigation data, then the best depth data, and finally the best water data. The discharge result is then based on the best available data
- green indicates data under the respective tab have passed all internal quality checks
- yellow (or orange) with warning symbol indicates data have failed some of the internal quality checks and users should (re)evaluate that data

- red with attention symbol indicates data have failed some of the internal quality checks, with possible significant effect on discharge, and users must address the issue(s)
- blue text indicates a setting changed from the original by the user(s). Add a comment within QRev noting the reason for the change, to facilitate any further review and assist with compiling the Data Processing Comment (see Section C 4.2.5) needed when archiving the gauging.

QRev is fast, powerful, and easy to use. There is potential, therefore, to manipulate options until a desired result is achieved. It is important to know when to depart from automated selections and settings and why, and when to stop processing and accept the result. It is strongly recommended that organisations develop a Standard Operating Procedure for use of QRev to guide these aspects.

2.7 Derived and related data

Cross-sections and hydraulic variables derived from gaugings are useful:

- when developing stage–discharge rating curves
- when indirect methods are needed to estimate discharge, and
- for 'bulk' quality review such as during an audit (see Section 7.3).

2.7.1 Cross-sections

Gauged cross-sections should be plotted and reviewed for depth and width anomalies. If the sampling point locations and/or point velocities are also available, they should be reviewed for anomalies not consistent with any field notes.

Gauging cross-sections are most useful if they can be compared by overplotting or differencing. To do this effectively they should be on the same alignment at the same location with the same initial point, orientation, and datum.

For hydraulic analysis or determination of discharge using surface or indirect methods, cross-sections must be a true cross-section, oriented true left to true right, with offsets increasing. Values may be stored as depth below or elevation above some datum. Datum may be water surface or some other physical reference, such as a bridge deck, or an assumed or nominated survey datum, e.g. mean sea level (MSL) or New Zealand Vertical Datum (NZVD).

If archived cross-sections are intended for hydraulic analysis, data review must ensure that either the above conditions are satisfied for any cross-section stored or there are sufficient metadata stored with the gauged cross-section to enable the required manipulations (e.g. datum conversion) to be performed at time of analysis in the future.

Note: Oblique sections and transects adjusted by the horizontal angle of section may approximate a true cross-section if the reach is reasonably uniform but otherwise cross-sections from 'distance made good' oblique sections and transects may be misleading.

2.7.2 Hydraulic variables

Check that $Q/A = V$ and $A/P = R$ for each gauging where these are obtainable,

where Q is discharge, A is cross-section area, V is mean velocity of the discharge, P is wetted perimeter, and R is hydraulic radius.

These checks can be automated.

Sanity check any measured, derived, applied and/or stored values of (water surface) slope and resistance factors, e.g. Mannings 'n'.

Check that vertical and horizontal angle corrections intended to be applied have been applied and have altered component measurements as expected:

- vertical angle corrections reduce depths
- angle of section corrections reduce widths
- angle of current corrections reduce point velocities.

Confirm that, if the corrections are not stored with the measured data, the measurement metadata records what corrections have been applied.

3 Potential Errors and Recommended Editing

Errors can be difficult to identify. They may not be found unless the gauging plots off the rating curve. At unstable sites errors may still not be detected. Checks cannot compensate for careful and accurate observation and field documentation.

However, a gauging should not be assumed to be in error and disregarded simply because it plots off the rating.

Gaugings left to deviate by more than 8% from their relevant rating curve must have a Data Comment filed to verify that they have been checked and to provide an informed explanation for the deviation (see Section C 4.2.4).

3.1 Sources of errors

Errors in gauging data may be random, systematic, or spurious in nature.

3.1.1 Random error

Errors are random (stochastic) when measurements vary according to chance. Random errors follow a normal distribution. Scatter of individual measurements around their mean is unbiased.

Random error is influenced by sample size and sensitivity of measurement.

3.1.2 Systematic error

Systematic errors (biases) are a consequence of errors of method or use of instrumentation in compromised condition. If the cause of the bias can be determined an unbiased measurement may be recoverable. Some examples are:

- incorrect calibration of any measurement instrument, including the possibly less obvious such as distance markings on bridges and taglines that may have stretched
- sampling error, such as measuring single-point velocities at 40% of depth instead of 60% of depth
- scaling and configuration errors such as wrong magnetic declination, failing to apply an angle of section correction, or not multiplying meter counts by multiples where required, e.g. Large Ott x5 or x10 options.

Unlike random errors that show as scatter of gaugings about a rating curve, systematic errors may not be detectable at an unstable site, being assumed instead to be due to a shift in rating. Particular care must be exercised to ensure that systematic error is minimal in any discharge measurement.

With respect to gaugings, most systematic errors behave like random errors and in many cases, one category may be embedded in the other. ISO 5168:2005 conforms to GUM methodology (GUM, 1995) in that it treats random and systematic error identically, this being a significant change from earlier versions of ISO 5168 (see Annex I of ISO 5168:2005).

3.1.3 Spurious error

Spurious errors are usually human in origin or the result of malfunction. Often, they are gross errors, identifiable, and possibly recoverable. Outlier tests may be applied (see ISO 5168-2005 Annex D).

It must be emphasised that in all cases outlier tests or discarding of data shall be done only if there is independent technical reason for believing that spurious errors may exist; data should not be thrown away lightly.

3.2 Editing gauging data

Depending on the error identified, measurement data, configuration settings, processing options, measurement metadata, or one or more summary results may need to be altered.

Editing methods are determined by the various software used to process, manage, and store the measurement and result data, and its associated metadata, but in general are largely manual processes.

Changes to measurement data, configuration settings or processing options will usually require the gauging to then be reprocessed and/or recalculated. In some cases, reimport of the measurement may be necessary.

Most software is sensitive to where in the gauging data structure editing is initiated from. Failure to start the editor at the correct level in the structure may result in inconsistent and/or orphaned related parts when changes are saved.

When editing gauging data, ensure that:

- the data to be edited are accessed from the 'parent' data source or primary record and are edited in the correct manner to ensure all changes roll through to all other related parts of the measurement and results
- derived data are also recalculated and amended as necessary (see Section C 2.7)
- any change to the site identifier(s) and/or unique gauging identifier is also noted on any other data, documents and files carrying those identifiers (see Section C 1.2.1)

  Note: In some systems it is extremely difficult to change an identifier once it has been assigned.

- stage height corrections are cross-checked against the filed stage (see Section C 2.3)

  Note: The filed stage rather than the gauging stage may be at fault.

- angle corrections are applied to the correct component variable(s) (see Section C 2.7.2)

  Note: Historically, angles of section and current were often lumped together and corrections applied only to the total area. Sometimes only the discharge was adjusted, or the corrections were not applied at all. This of course affects the reliability of stage–area and stage–velocity relations derived from this historic data.

- if the file time of the gauging is changed, or it is refiled under another site, the now defunct duplicate is removed from the dataset (see Section C 3.3)
- the Gauging Register is updated (see Section C 1.2.1)
- a Data Processing Comment is filed for any change to the original data collected (including configuration settings and field metadata) (see Section C 4.2.5)
- original data are annotated that it has subsequently been altered, when, why and by whom
- other measurements do not require the same or similar amendment

  For example: correcting a mistake in a meter calibration entered into a gauging logger used for a number of measurements across many sites.

- other related metadata are changed or added as needed to maintain consistency and integrity of all data filed, e.g. revised and/or new quality codes and other comments.

3.3 Deleting gauging data

A discharge measurement should only be deleted from a dataset in limited circumstances, such as:

- if it is a defunct duplicate (see Section C 3.2)
- if it is affected by non-recoverable known technical or operational issues that render it spurious (see Section C 3.1.3).

When deleting gauging data, ensure:

- all related parts of the deleted measurement are removed
- original data are annotated that it has subsequently been deleted from the record, when, why and by whom
- the deletion is noted in the Gauging Register (see Section C 1.2.1).

4 Metadata

4.1 Quality coding

The quality of a discharge measurement can be assessed:

- quantitatively by calculating uncertainty, and
- qualitatively based on performance objectives.

Both methods are necessary in combination because calculated uncertainty on its own does not account for all influences on measurement quality and/or quality of result (see Section C 2.4).

The relevant quality coding flowchart may be found in NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data)* or in NEMS *National Quality Code Schema*.

If the measurement location and conditions or practice at the time are not conducive to good measurement, the quality code assigned to the measurement must be reduced regardless of the calculated uncertainty:

- to QC 500 if best practices were not met, or
- to QC 400 if the measurement is known or suspected to be compromised.

The most significant practices affecting measurement quality relate to the choice of measurement section and sampling technique. The more uniform the measurement reach and flow conditions the less influence these factors have, except for dilution methods that require the opposite, i.e. maximum possible turbulence and mixing.

For ADCP gaugings, measurement quality is a combination of the above factors, the instrument knowing where it is (position and orientation), and its ability to reliably determine velocity using sound as a surrogate. These factors are reflected in the quality code assessment matrix for moving boat ADCP measurements that determines quality code for those measurements (see Annex D of NEMS *Open Channel Flow* v1.1).

Quality code must also be reduced to QC 400 if the measurement has undergone significant modification from the original, and/or post-processing selections depart significantly from expected options, unless the changes are fully traceable (e.g. a revised calibration) and have not required interpretation and assumption.

For example: Quality code QC 400 would apply to an ADCP measurement with best-fit velocity profile extrapolations departing significantly from the 1/6th power law, and to a gauging subject to large angle corrections on the basis that the measured data have undergone significant modification.

Any discharge measurement assigned a quality code less than QC 500 shall be commented to explain the reason for the reduced code. If no other comment category is applicable a Data Comment must be filed to satisfy this requirement (see Section C 4.2.4).

4.2 Example gauging results comments

The following are templated examples of comments for gauging data.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of results and/or the measurement record) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

The standard SI unit should be used from options shown in the example below unless data are required to be stored as integers or values are consistently very small, e.g. flows in ml/s.

Type: Site
Measurement: Gauging
Initial comment for the gauging station: *<station name>*
On the *<river name>* River, river number *<river number>*[8]
The station is situated at grid reference *<map co-ordinates and type*[9]*>*
Gaugings above stage height *<limit of safe wading>*mm are carried out by *<method(s) used for gaugings not waded>*

[8] from *Catchments of New Zealand* (Soil Conservation and Rivers Control Council (SCRCC), 1956).

[9] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Units, unless otherwise stated, are
1) Mean stage height in metres *(or* millimetres*)*
2) Discharge in m^3/s *(or* l/s *or* ml/s*)*
3) Area in m^2 *(or* cm^2*)*
4) Mean velocity in m/s *(or* mm/s*)*
5) Maximum depth in metres *(or* millimetres*)*
6) Water surface slope in mm/1000m
7) Water surface width in metres *(or* millimetres*)*
8) Hydraulic radius in metres *(or* millimetres*)*
9) Wetted perimeter in metres *(or* millimetres*)*
10) Sediment concentration in g/m^3 (mg/l)
11) Water temperature in degrees C *(or* degrees C x1000*)*
12) Stage change in mm/hr
13) Gauging method code (ccnn) where cc = method and nn = number of verticals
14) Number of verticals and sample points (nnpnnpnnp) where nn = number of verticals and p = number of sample points
15) Calculated uncertainty of measurement to 95% level of confidence as % *(or* % x10*)*
16) A flag to indicate if a comment is also filed (1 = comment present, 0=no comment)
17) A numeric code for the agency that carried out the gauging
18) Gauging number as registered by the recording authority
The gauging result is filed at the time of mean stage height for the measurement.
Additional information: -1 indicates missing data. The format changed from 15 to 18 items in 2005. Earlier results may not have measurement uncertainty (item 15) or a comment flag (item 16) available. *<Add purpose of station, the flow controls if results are used for rating development, and persistent issues that affect gauging quality e.g. weed, turbulence, high sediment and/or debris load, geothermal, clarity (low SNR), periodic backwater, tidal etc.>*
The following is also measured at this site: *<list variables>*
The local recording authority is: *<name of recording/archiving agency>*

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Gauging
Instruments used to measure discharge at this site include: *<list types>*. Calibration of *<state type>* occurs *<state frequency> (repeat for each type)*. Calibration records are stored in *<provide database or file reference(s) as applicable to each type>* and accessible via *<provide means of access e.g. file request, computer application, intranet etc.>*.

Type: Equipment
Measurement: Gauging
Gaugings are assigned mean stage height calculated from primary reference gauge readings (*or* the logged stage, *or <state source e.g. the staff gauge, or internal plumb bob>*) unless otherwise stated.

Type: Equipment
Measurement: Gauging
Manned cableway decommissioned on *<dd-mm-yyyy hhmmss>*. High flow measurements from this date onward are done using an ADCP mounted in a remote-controlled moving boat.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* is recalculated using the 'as is' calibration of *<date/time of calibration>* due to damage to the meter during the measurement.

Type: Operational
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* was carried out by *<other agency>* who hold the original records.

4.2.4 Data Comment examples

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has been checked with no obvious reason for the *<+ (or –) x%>* deviation from the rating but rating shift is unlikely.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has point velocities observed over 20s instead of the normal 40s to minimise uncertainty in assigned stage height because of rapid change during the measurement.

Type: Data
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> includes an estimate of overflow that bypassed the gauging cableway. Discharge measured was <*x* m^3/*s*>, estimated overflow was <*x* m^3/*s*> *(*added into the final result as a side flow*)*.

Type: Data
Measurement: Gauging
Stage for gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> is affected by backwater.

The following examples are reproduced from NEMS *Rating Curves* v 2.0.0 where they are headed 'Gauging Deviation Comment'. NEMS *Rating Curves* will be updated in future to refer to the examples below, which are modified to be consistent with the comment framework and format established by this Standard.

Type: Data
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> deviates <*+ (or –) x%*> from the rating curve. When compared with other gaugings on the same cross-section, the mean velocity is lower than expected. Significant problems with floating weed were experienced while gauging and it is suspected the meter remained weed-bound despite attempts to keep clear.

Type: Data
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> deviates <*+ (or –) x%*> from the rating curve. When plotted on the stage–area curve, area is greater than expected. Accurate sounding was difficult and vertical angles severe. A rating change occurred on the event that prevented useful resurvey of the section after the event.

Type: Data
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> deviates <*+ (or –) x%*> from the rating curve. Analysis of the ADCP gauging data indicates problems with a moving bed, causing velocities to be under-recorded.

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> has been filed at a stage height of <*x mm*> consistent with the adjusted filed stage record. The weighted value of the original observations is <*y mm*> but these were affected by <*reason for the adjustment*>.

Type: Data Processing
Measurement: Gauging
Gauging <*unique identifier*> on <*dd-mm-yyyy hhmmss*> has been reprocessed with the following adjustment(s): <*list the changes to original settings*>. Original settings were <*explain need for change e.g. incorrectly entered or defaults not applicable etc.*>

4.2.6 Stationarity Comment examples

Type: Stationarity
Measurement: Gauging
Gaugings from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> are filed at the end *(or* start*)* time of the measurement. Gaugings from <*dd-mm-yyyy hhmmss*> onwards are filed at the time of mean stage height for the measurement.

5 Audit

Further to the requirements of Section 7.3 of this Standard, combining audit of gauging data with audit of stage–discharge ratings for the site is recommended.

Gauging coverage and frequency should be reconciled periodically with rating requirements using methods described in Annex I of NEMS *Rating Curves* v 2.0.0. Audit is a convenient time to do this.

6 Preservation of Record

The following data shall be archived, retained indefinitely and, if electronic, backed up regularly by the recording agency:

- all original records
- unedited raw instrument data (the original data as recorded)

  Note: The original raw data may be required at a later date, should the archived data be found to be in error, become corrupted, or be lost.

- completed field sheets and gauging cards (paper or electronic). Paper records must be clear, legible, and protected from deterioration
- instrument validation data (results of pre- and post-deployment tests and checks, compass calibrations, GPS reliability, and loop and moving bed tests)
- supplementary measurements and observations (e.g. temperature, wind, salinity, SNR)
- configuration and deployment information (e.g. current meter rating, transducer depth, screening distances, magnetic declination, horizontal angle of section)
- reviewed final measurement data

- calibration records
- site and time-series metadata.

Electronic files created in the field should be backed up while in the field whenever possible. Reusable storage such as datapaks, storage cards, and instrument memory must be downloaded, and data checked and backed up, before the storage is cleared.

Whenever possible archived measurements shall be locked to prevent further unintended alteration.

7 References

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Appendix C.1 Computation of Mean Gauge Height for a Gauging

This appendix is reproduced from Annex C of NEMS *Rating Curves*.

The mean gauge height for the period of the gauging shall be calculated according to the formulae below:

(a) For larger rivers, if the fluctuations are less than 50 mm, an arithmetic mean shall be used.

For smaller rivers, the time-weighted method (c) is most often preferred.

(b) If the fluctuation is 50 mm or more, ISO 748:2007 recommends using a discharge weighted calculation:

$$h = (q_1 h_1 + q_2 h_2 + q_3 h_3 + \ldots + q_n h_n) / Q$$

where: h is mean gauge height

Q is the total measured discharge $= (q_1 + q_2 + q_3 + \ldots + q_n)$

$q_1, q_2, q_3 \ldots q_n$ = discharge measured during time interval 1, 2, 3, ... n, and

$h_1, h_2, h_3 \ldots h_n$ = average gauge height during time interval 1, 2, 3, ... n.

(c) However, Rantz et al (1982) demonstrates that method (b) tends to overestimate stage height, and suggests that where the change in discharge with stage height is linear in the range of stage that occurred during the measurement, a time-weighted mean is better.

This is calculated from:

$$h = (t_1 h_1 + t_2 h_2 + t_3 h_3 + \ldots + t_n h_n) / T$$

where: h is mean gauge height

T is the total time for measurement

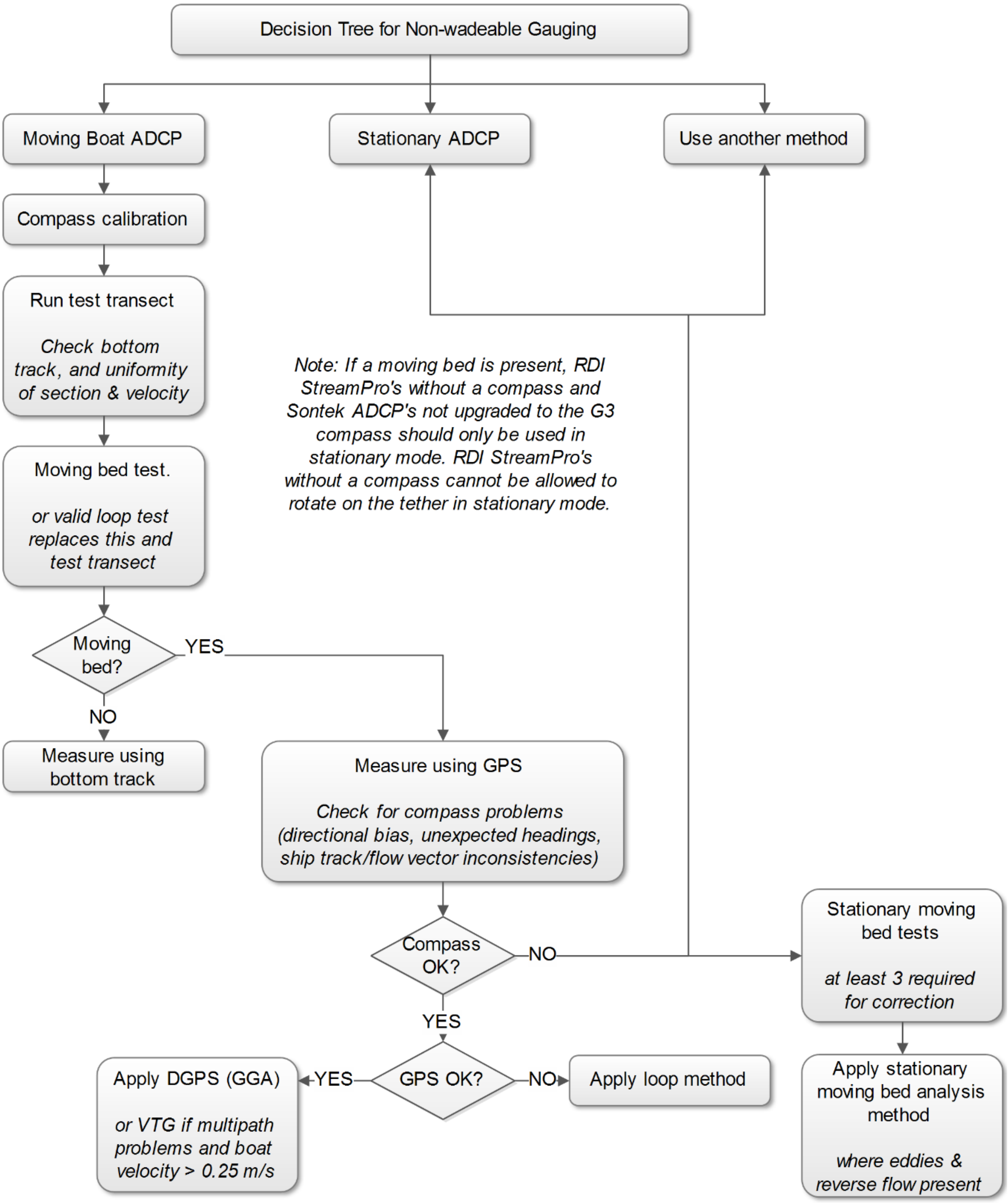
$t_1, t_2, t_3 \ldots t_n$ = duration of time intervals between breaks in the slope of the gauge height versus time graph, and

$h_1, h_2, h_3 \ldots h_n$ = average gauge height during time interval 1, 2, 3, .. n.

(d) Where the change in discharge with stage height is curvilinear, neither method (b) nor (c) is reliable, and Rantz et al (1982a, p. 173) recommend that the mean of the two estimates be used.

Note: Rantz et al (1982a) also provide examples of the calculations.

Appendix C.2 Decision Tree for Non-wadeable Gauging



Adapted from Water Survey of Canada SOP (Campbell, 2015)

Appendix C.3 Gauging Results – Items and Codes

The items and codes listed apply to any gauging, whether or not the station also has a water level recorder.

All gauging results are stored with an associated timestamp being the date and time of the mean water-level height (stage) for the measurement (see NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data*).

1 Minimum Requirements

From 'The Standard – Open Channel Flow' in NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data)*:

- stage for computed discharge
- computed discharge
- cross-section area (where applicable)
- mean velocity of discharge (where applicable)
- method code
- uncertainty
- quality code
- time of mean gauge height, and

From this Standard (Processing of Environmental Time-series Data):

- the assigned unique gauging identifier.

2 10-item Gauging Results (historic)

Item 1 Mean stage height (for the gauging)

Item 2 Discharge (as measured)

Item 2 Area (of gauging cross-section)

Item 4 Mean velocity (usually determined from Discharge/Area)

Item 5 Maximum depth (of gauging cross-section)

Item 6 Wetted perimeter (of gauging cross-section)

Item 7 Hydraulic radius (usually determined from Area/Wetted perimeter)

Item 8 Water surface slope (if measured, otherwise -1)

Item 9 Sediment Transport (if measured, otherwise -1)

Item 10 Temperature (of water) (if measured, otherwise -1)

3 15-item Gauging Results (legacy & Hilltop)

The 10-item format was reordered and expanded to 15 items as follows:

Item 1 Mean stage height (for the gauging)

Item 2 Discharge (as measured)

Item 2 Area (of gauging cross-section)

Item 4 Mean velocity (usually determined from Discharge/Area)

Item 5 Maximum depth (of gauging cross-section)

Item 6 Water surface slope (if measured, otherwise -1)

Item 7 Width (surface width of gauged cross-section)

Item 8 Hydraulic radius (usually determined from Area/Wetted perimeter)

Item 9 Wetted perimeter (of gauging cross-section)

Item 10 Sediment Concentration (note change to 'concentration' in mg/l from 'transport' under the 10-item form)

Item 11 Temperature (of water)

Item 12 Stage change (in mm/hr over duration of gauging, 999 = over peak)

Item 13 Method (a code of format *ccnn* where *cc* is a code for gauging method, and *nn* is total number of measured verticals, if applicable)

Item 14 Number of verticals and sample points (if applicable, format *nnpnnpnnp* where *nn* is the number of verticals sampled at *p* points in the vertical)

Item 15 Gauging Number (format *cnnnnn* where *c* is an agency code originally issued by NIWA)

4 18-item Gauging Results (legacy NIWA)

NIWA (and by default, other users of TIDEDA) changed from 15 to 18 items in 2005. Items 1 to 14 are the same as for 15-item gauging results.

Item 15 Gauging Uncertainty (percent +/-)

Item 16 Comment Flag. (0=no comment, 1=comment in comment file)

Item 17 Gauging Agency (a hard-coded list of New Zealand agencies used by NIWA; if unassigned use 99: Other Agency)

Item 18 Gauging number (the ID assigned to each gauging when registered)

5 Missing Items

Any item not measured or not available was manually assigned a value of -1 in the historic and legacy results formats. Later implementations where gauging results are written automatically from the discharge calculation (e.g. Hilltop Software) may default to a value of 0 if no data is available.

6 Gauging Method Codes

Gauging method codes can be found in Annex C 'Discharge Measurement Method Codes' of NEMS *Open Channel Flow Measurement (Measurement, Processing and Archiving of Open Channel Flow Data)*.

7 Gauging Agency Codes

Gauging agency codes are not standardised for New Zealand. Some agencies are using NIWA's current national coding system, others have developed their own set of codes for their measurements and those they acquire from other organisations then store in their own systems. In long data series there may be a combination of both as agencies and practices have changed over time.

Discharge measurements exchanged between organisations are usually issued a new gauging number by the receiving agency with agency code for the source organisation assigned from the recipient's system. However, gauging results exchanged between organisations may not be recoded on receipt and therefore when assimilated, agency codes may conflict or mislead. If origin of a result is important to a data user additional enquiry should be made.

Annex D Water Temperature Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous water temperature data measured using in-situ sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of water temperature compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held device.

1.1 Normative references

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

- NEMS *Water Temperature (Measurement, Processing and Archiving of Water Temperature Data)*
- NEMS *Water Quality Parts 1 to 4: Sampling. Measuring, Processing and Archiving of Discrete Groundwater (River Water, Lake Water, Coastal Water) Quality Data*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Water Temperature* v2.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

1.2 Water temperature as a supplementary variable

Many other water quality variables are affected by water temperature. Measurement methods for these variables usually require concurrent measurements of water temperature that are applied to the dependent sensor output in some way to obtain the measurement results for the dependent variable.

Organisations may choose to permanently archive the water temperature data collected as a supplementary rather than primary time series, and therefore not apply the procedures in this annex. However, the supplementary data should be:

- inspected and edited for gross errors
- quality coded QC 200
- identified in the Site/Initial Comment for the variable that is dependent on it (see Section 6.2.4.3), and

- described in a Data Comment for the variable that is dependent on it (see Section 6.2.4.6).

If the organisation chooses to permanently archive the water temperature data as a primary time series, it may be changed by editing described in this annex, which may impact derivation of any dependent measurements. Processing inter-dependent time series together is strongly recommended.

In any case, the impact on the dependent variable of editing the associated water temperature record must be assessed when the dependent variable is processed, which would necessitate the water temperature data being processed first.

Quality code of dependent data may be affected by quality of the water temperature data. This is addressed in the annex applicable to the dependent variable.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying water temperature data:

- site details:
  - type of environment (see NEMS *Water Temperature* v2.0: Sections 1.2.3, 1.2.4, 1.2.5, or 1.2.6, as applicable)
  - measurement objective(s) and target characteristic(s) to be measured (see NEMS *Water Temperature* v2.0: Sections 1.2.1 and 1.2.2)
  - the record documenting the site selection process and its evaluation (see Section 1.2.2.2 of NEMS *Water Temperature* v2.0)
- instrument details (in-situ sensor and reference instrument):
  - sensor type, model, manufacturer, and serial number
  - sensor accuracy, resolution, and response time, as specified by the manufacturer
  - the sensor range, as deployed
  - characteristics of any on-board anti-fouling mechanism
  - date, laboratory, and identifier for each calibration
  - the calibration relation(s), if and when supplied; these are essential if applied on the data logger by the user
  - date and results of any validations (i.e. checks on the calibration of the sensor other than by verification during field visits), and
  - date and time of each deployment

- sensor deployment details as applicable to the water body:
    - sampling method and data-logging interval
    - details of data logged as backup, secondary, and/or for which water temperature is intended as supplementary
    - method(s) used for verification of sensor readings
    - installation details that have potential to impact data quality, such as signal conversion, transmission path and distance between sensor and logger, and logger bandwidth (see Section 2.1 of NEMS *Water Temperature* v2.0)
    - photos of the deployment showing mounting/housing detail and location context
    - any known influences on water temperature at the site (see Section 1.2 of NEMS *Water Temperature* v2.0)
    - date, time, and reason(s) for any relocation of the sensor
    - the level of the temperature sensor with respect to:
        - the water level gauge, where co-located
        - the water surface
        - the riverbed or lakebed
        - screen depths and water level range in bores
        - likely temperature gradients
    - any changes over time in the measurement environment
- reference readings, including:
    - instrument used
    - uncertainty in the result if greater than ± 0.3°C, and/or
    - information about when, where, and how each reading was obtained (e.g. proximity to the in-situ sensor).

These metadata must be verified, and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by cleaning, replacing or reconfiguring the sensor, data logger, and/or the installation.
- Check continuity of the daily sine curve and that each daily maximum and minimum occurs at a plausible time.

2.2.1 Comparisons

- Use comparisons to:
    - cross-check data for anomalies, and
    - confirm editing and adjustments have been properly carried out.

- Compare the recorded data with:
    - other associated variables recorded at the site, e.g. water level, flow, and water quality variables dependent on temperature
    - a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)
    - an auxiliary instrument at the same site, e.g. a multi-parameter instrument that may be recording over a different range, accuracy and/or resolution, provided it is not also affected by the same data quality issue(s)
    - verification measurements, and validation results, if any.

2.2.2 Between-station comparisons

Unless there are local influences there will usually be good agreement between water temperatures recorded at quite distant sites within the same river system, and between nearby sites in adjacent rivers of similar physical character, sufficient to verify diel variation and weekly cycles.

Records of flow or water level at sites either upstream or downstream may also be useful to confirm occurrence and timing of rapid changes in water temperature.

For example, a fresh in a wide gravel-bed river during summer will tend to rapidly reduce water temperature while a fresh in winter will tend to raise water temperature, and tidal influx in estuaries will superimpose twice daily peaks on the daily sine curve.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons to identify:

- sensor exposure due to low water levels or dry channel, and
- change in and/or disruption of:
    - diel and seasonal patterns
    - shape and pattern of temperature response to high flows, tide cycles, snow melt, or other flow fluctuations, e.g. abstractions, discharges, gate closures, or hydropower generation
    - relative timing of daily maxima and minima
    - daily temperature range

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

Reference values used to verify a water temperature record are obtained directly, using an independent reference thermometer.

When using reference values to verify or to adjust recorded water temperature the following should be considered and assessed:

- results of calibration of reference thermometers (see Section D 2.3.1)

- results of validation of in-situ sensors (see Section D 2.3.2)

  Note: Pre-deployment and subsequent periodic validation of in-situ sensors was required under NEMS Water Temperature *v1.0 but is not under NEMS* Water Temperature *v2.0.*

- measurement stability and location relative to the sensor (see NEMS *Water Temperature* v2.0: Sections 3.3.2, 3.3.3 and 3.3.4)
- timing of the reference measurement with respect to sensor readings

  Note: Simultaneous readings are the most reliable for data verification, especially when temperature is changing rapidly. NEMS Water Temperature *v2.0 Section 3.3.4 requires a second reading with a different reference thermometer if there is unexplained disagreement on first inspection. This second reference reading should be paired with a simultaneous second sensor reading with their associated date and time distinct from the first inspection.*

- precision and accuracy of the reference reading.

A reference reading is unreliable, and must be identified as such, if:

- the reference reading is outside the calibrated range of the reference thermometer (in which case the reference thermometer may be retrospectively calibrated (see Section 2.3.2 of NEMS *Water Temperature* v2.0)), or
- repeat measurement with a second reference thermometer (see Section 3.3.4 of NEMS *Water Temperature* v2.0) agrees with its simultaneous logged value within tolerance (the initial reading is assumed then to be unreliable), or
- reference reading uncertainty exceeds verification tolerance.

An Operational Comment (see Section D 4.2.3) is required for any instance of verification reliant on repeat measurement with a second reference thermometer (see Section 3.3.4 of NEMS *Water Temperature* v2.0).

If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and
- the period of record that would be verified by the disregarded check shall be quality coded no higher than QC 500.

Water temperature record should not be adjusted to any reference value where the difference between the reference and corresponding recorded value is overwhelmed by uncertainty in the reference reading unless there is other corroborating evidence of faulty recording. If adjusted, the adjustment(s) should be reviewed when reliable reference readings resume.

2.3.1 Calibration of reference thermometers

Calibration of reference thermometers is described in Section 2.3 of NEMS *Water Temperature* v2.0. Calibration is conducted annually to accuracy ± 0.3°C at all required calibration points over the expected deployment range. A calibration history must be maintained and be accessible (see Section 2.3.4 of NEMS *Water Temperature* v2.0).

If a reference thermometer fails calibration:

- all reference readings with that instrument since its last successful calibration must be reviewed for reliability, and
- any adjustments to data using subsequently unreliable reference readings must be reassessed and revised where necessary.

2.3.2 Validation of in-situ sensors

Under NEMS *Water Temperature* v1.0, pre-deployment then biennial validation of in-situ sensors was required using the same method and criteria as for reference thermometers (see Section D 2.3.1).

Validation of in-situ sensors is not required under NEMS *Water Temperature* v2.0. In-situ sensor performance is only required to be checked by two-monthly single point verifications.

Note: Single point verifications, regardless of number or frequency, would not usually cover the full range of temperatures recorded by an in-situ sensor because site visits are unlikely to be in the very early morning. However, temperature sensor calibration drift is rare in instruments currently deployed in New Zealand; they usually maintain calibration or fail catastrophically. Failed sensors are replaced. A 'before repair' calibration to assist with data recovery is not possible from a sensor that has failed catastrophically.

2.4 Deviation tests

From NEMS *Water Temperature (Measurement, Processing and Archiving of Water Temperature Data)*, tolerance is expressed as absolute deviation. Performance can be monitored using a simple control chart (see Section 3.6.4.2) or deviation with time (see Section 3.6.4.4).

If pre-deployment and periodic validation of the in-situ sensor is not carried out analysis of deviation with range (see Section 3.6.4.5) is strongly recommended to monitor for loss of calibration, including evidence of loss of linearity, especially at the low end of temperature range for which there are usually few verification readings available (see Section D 2.3.2).

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water temperature data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The water environment, with respect to:
  - location of the sensor in relation to:
    - water levels and river- or lakebed, and
    - physical heat sinks and sources that are not part of the usual environment, e.g. where a sensor may be affected by radiant heating of its own or an adjacent sensor's mounting or housing
  - adequate mixing to avoid bias
  - the relative locations of the sensor and point of collection of reference measurements at various flows (see Section D 2.3)
- Instrument deployment and operation, and conditions that adversely affect them (see Sections 1 and 2 of NEMS *Water Temperature* v2.0)

  Note: The sensor and cable between it and the analogue to digital conversion needed for data logger input are a calibrated couplet. Unless electronically boosted, recording accuracy is affected if length of the cable exceeds about 5 m. If digital conversion (e.g. to 4–20 mA) is done at the sensor then this signal can be transmitted over much longer distances without loss of accuracy.

- Interference and damage (e.g. human, debris or biofouling, flood damage etc.) (see Section 1 of NEMS *Water Temperature* v2.0), and
- Instrument performance, including:
  - maintenance of calibration (see Section 2 of NEMS *Water Temperature* v2.0)
  - electronic transients, and
  - over-ranging.

Site factors and influences that are difficult to avoid are measured as part of the target characteristic(s) (see Section 1.2 of NEMS *Water Temperature* v2.0) and therefore are not sources of error. These factors and influences must be described in the Site/Initial Comment (see Section D 4.2.1).

3.2 Unintended offset or incorrect change of offset

Analogue sensors usually require an offset and multiplier to be programmed into the data logger to convert sensor signal to measurement units. If a mistake is made calculating or entering the offset, the data collected are biased by the amount of error in the programmed offset.

Note: An error in the multiplier also affects the value of the offset to be applied.

A sensor that has been shocked, for example, hit by debris or knocked during site maintenance, can sometimes develop an offset that biases all subsequent readings by a constant or near-constant amount.

With sufficient verification data, if an unintended or incorrect offset is present, deviation tests will show a persistent bias over the affected period. Investigate probable cause and confirm the period of data that is biased.

- If due to a logger program change, there will be a step in the data at the time the program was changed.
- If due to shock, carefully inspect a data plot and/or use a comparison with closely associated data to find the step.

The remedy depends on cause.

- If due to a logger configuration mistake that is known and fully traceable, the correct data can be re-established by calculation and transformation without doubt.
- If the offset is inferred from verification differences and/or steps in the data, the adjustment is a constant applied that minimises the steps and bias without creating a step in the data.

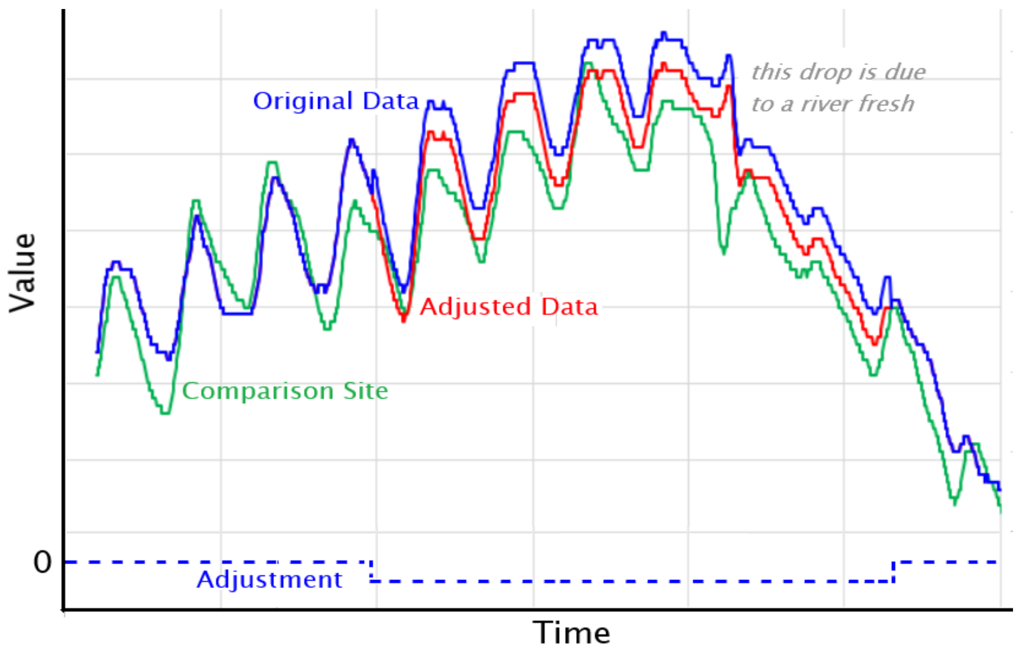


Figure D 1 - An example of a period of water temperature data offset by a constant amount (blue line) with the adjusted data (red line) and showing the comparison site used to identify the affected period (green line) and the adjustment applied (dotted line).

Table D 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset, or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	D 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and traceable at site by checking the logger program.	Fig. D 1 D 3.2 D 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	D 4.2.6 6.2.4.8 6.2.3 D 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- change of logger program offset (see Section D 3.2)
- replacement of the sensor
- moving the sensor to a different location (vertical or horizontal)
- interference or disturbance around the sensor
- clearing or cleaning the sensor.

Cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

In most cases the appropriate adjustment is a simple special case of linear drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a specified non-zero value at the end of the affected period (see Figure D 2).

3.3.1 Instrument replacement

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, describe the change in an Operational Comment (see

Section D 4.2.3) that references relevant Equipment Comment(s) (see Section D 4.2.2) as needed. If the data subsequently collected are offset from data previously collected as a result of the change, leave the step-change in the data but identify and explain it in a Stationarity Comment (see Section D 4.2.7).

If either instrument (existing or replacement) is an analogue sensor, confirm the relevant multiplier and offset applied. Rescale data affected by a configuration error (see Section D 3.9) and correct for any consequent offset error (see Section D 3.2), which should eliminate the step.

If neither of the above situations applies and calibration of the replacement instrument is confirmed by pre-deployment validation, assume some form of drift in the existing replaced instrument and address it (see Section D 3.4).

3.3.2 Interference or disturbance

Interference may be due to the actions of people or animals on or about the sensor. If the interference rapidly warms or cools the sensor and/or its immediate surrounds, the affected record will step up or down respectively over one or two recording intervals, then gradually recover when the interference moves or dissipates, or conditions equilibrate. Normal temperatures are expected to resume after one or two hours at most.

Disturbance may change position or location of the sensor, expose the sensor, or an event such as bank collapse, accumulation of debris, or bed movement may bury the sensor.

Site maintenance, self-cleaning mechanisms, and water sampling activities may themselves interfere with the recording of ambient water temperature by insulating the sensor or altering the movement of water around it.

Data recorded in these cases may be valid but not fit for purpose and therefore require, as a minimum, an appropriate lesser quality code and a Data Comment (see Section D 4.2.4).

Temperature changes due to tidal influence, salinity variations, geothermal or runoff inputs, and passage of floods are part of the target characteristics to be measured and not interference or disturbance that impacts data quality.

3.3.3 Sensor clearance or cleaning

Clearing or cleaning the sensor may result in a step in the recorded data. Temperature sensors that are buried or fouled may be insulated by the covering material, resulting in a delayed response to water temperature changes that resolves once the sensor is clean and clear.

Biofouling occurs when an algal film grows on the sensor that can be compounded by fine sediment settling in the algae. Chemical fouling occurs when a chemical film accumulates on the sensor, e.g. from tannins in the water. Both forms of fouling are gradual accumulations that may progressively affect readings. Sensor burial may be gradual, episodic, or associated with a single, relatively sudden, event.

Note: Partial clearing and/or cleaning may occur naturally during floods because of the drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment.

Fouling behaviour and the corresponding evidence in the data is dependent on sensor cleaning method (e.g. wiper or brush, ultrasound, or pumped air or water). Fouling may affect sensor readings non-linearly with time, especially if the cause is biological accumulation. However, if magnitude of the error is small, a linear drift adjustment to eliminate any step introduced by cleaning is an acceptable solution.

Fouling may also cause noisy data, which should be smoothed or resampled (see Section D 3.6) before any adjustment is applied to eliminate a step (see Figure D 2).

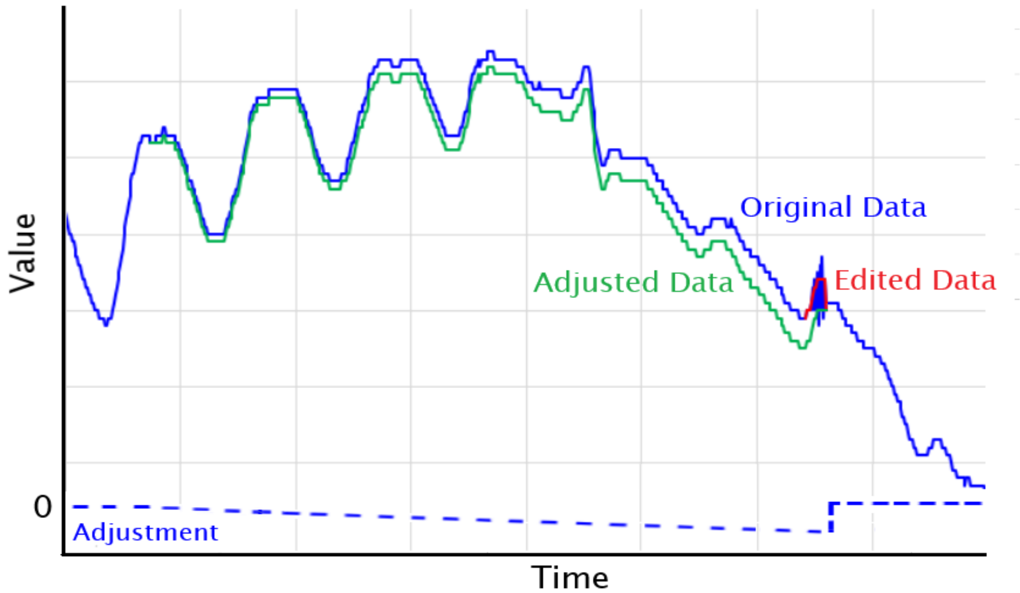


Figure D 2 - An example of a period of increasingly elevated data ending in a brief period of excessive noise before sensor cleaning returns readings to normal (blue line). Noise is edited first (red line), then a linear drift adjustment applied (dotted line) to progressively reduce the elevated values and eliminate the step at adjustment period end (green line).

Table D 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in temperature between successive readings that disrupts continuity of the sine curve. Prior data are often biased.	D 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data	Fig. D 2 D 2 3.6

	when plotted steps suddenly up (or down). May be evidence of increasing bias in prior data.	
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Change or remove values affected by interference or fouling. Treat gaps created as missing data. Linear drift adjustment with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace.	D 3.3.1 D 3.9 D 3.5 D 3.6 D 3.11 D 3.4 4.4 & 4.5
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. If rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the adjustment(s) applied (amount, type, and period of adjustment) is required, OR Refer to missing data guidance as applicable.	D 4.2 & 6.2.4 D 3.9 & D 4.2.6 6.2.3 D 4.2.5 6.2.4.7 D 3.11

3.4 Drift

It is relatively rare for temperature sensors to drift with time but an unstable analogue to digital converter (the device delivering volts or milliamps to the logger from the sensor output) might drift. Elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift. If drift is identified, and confirmed linear with time, apply a linear drift correction to the affected period.

3.4.1 Calibration drift

Linearity of temperature sensor response is usually achieved by applying a calibration relation to the sensor output. The calibration relation may be anything from linear to a high order polynomial. For some sensors, the polynomial may be supplied as part of the calibration information with the expectation that the user will apply the calibration equation on the logger.

Temperature sensor calibration drift is range dependent (rather than time dependent) and likely non-linear. It is usually associated with loss of linearity of response; however, it is rare for this to occur and the sensor to remain operable. A sensor exhibiting loss of linear response must be replaced.

Instances of fouling (see Section D 3.3.3), over-ranging (see Section D 3.7), or sensor exposure (see Section D 3.8) must be isolated from analysis of calibration drift and treated beforehand.

Affected data may be adjusted by applying a non-linear transformation to the values as determined from results of instrument validation, and/or from several verifications over as wide a range of values as possible within a relatively short period of time. The transformation may be applied as one or more equations, or by a look-up function, or as a rating curve.

Note: Sensor validation in the field is impractical so the in-situ sensor will usually have been removed and replaced. Verification checks may not be available for the lower end of the temperature range because temperature minima tend to occur before dawn.

Proper adjustment of the prior data should eliminate any step-change resulting from instrument replacement. If affected data cannot be reliably adjusted, it must be deleted from the record and the period treated as missing data (see Section D 3.11).

Table D 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	D 3.4
Evidence	Differences between recorded and reference temperature increase with time and/or vary with value. Physical cause may be identifiable, such as biofouling or sensor validation results. Drift with time may be evident when plotted with a comparison trace.	D 3.4 D 2 3.6
Solution(s)	Apply linear or non-linear drift adjustments as applicable depending on whether drift is determined to be linear or non-linear with time. A non-linear drift adjustment with time can be approximated by a series of small, short-duration linear drift adjustments, with care. Apply a transformation derived from instrument validation results if drift is value dependent. Remove affected record if transformation is not possible, then treat as missing data.	D 3.4 4.4 or 4.5 4.7 & 4.9 D 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment), OR Refer to missing data guidance as applicable.	6.2.3 D 4.2.5 6.2.4.7 D 3.11

3.5 Spikes

Unexpectedly low values are usually associated with data transmission interruptions or power supply problems. Solitary unexpectedly high values can occur due to electronic transients.

Isolated spikes may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or discarded using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20 and D 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section D 3.6).

Table D 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	D 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	D 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or D 3.11 or D 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 D 4.2.5 6.2.4.7 or D 3.11 or D 3.6

3.6 Noisy data

Noise in water temperature data is most often caused by interference (see Section D 3.3.2) or faulting electronics. Interference is usually of short duration and the effect generally random. Faulting electronics may be due to poor connections or imminent failure of the sensor, requiring replacement, and effect on the data may be erratic.

Noise with random effect due to interference may be edited or resampled by hand or filtered using a fixed or moving interval mean or median. Ensure the results of filtering do not disrupt the expected range and timing of diel cycles nor create a step at the boundary with adjacent unadjusted data.

Delete periods of noise due to faulting electronics and treat as missing data (see Section D 3.11).

Table D 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Fluctuations are high frequency and exceed expected sensor accuracy. Range of fluctuation compromises use as supplementary data for other variables.	D 3.6
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. D 2 D 2 3.6
Solution(s)	Method choice is determined by identified cause. Manually edit or resample, or 'smooth' with a statistical filter, if random noise due to interference. Otherwise delete affected period and treat as missing.	D 3.6 Fig. D 2 4.12 or D 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	6.2.3 D 4.2.5 6.2.4.7 or D 3.11

3.7 Over-ranging

Over-ranging occurs when water temperature to be measured is outside a sensor's calibrated range. In New Zealand this would normally only be encountered in geothermal areas (high temperatures) or during severe winters in the deep south (low temperatures). Data loggers and some sensors may prevent the recording of over-range values. Occurrences truncate (clip) water temperature at a constant maximum or minimum value or create a gap in the record. Other sensors may continue to output a non-linear response.

In any case an in-situ sensor must not be used outside its calibrated range (see Section 2.3.2 of NEMS *Water Temperature* v2.0). Over-range values recorded must therefore be clipped to the calibrated range (see Figure D 3) or deleted and treated as missing data (see Section D 3.11).

Datasets that include periods of truncated or clipped over-ranging may be filed as a censored time series with appropriate metadata (see Sections 1.1.5 and D 4); however, treating affected periods as missing data is preferred (see Section D 3.11), especially if the temperature record is required for accurate determination of another variable, e.g. dissolved oxygen. A change of over-range threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section D 4.2.7).

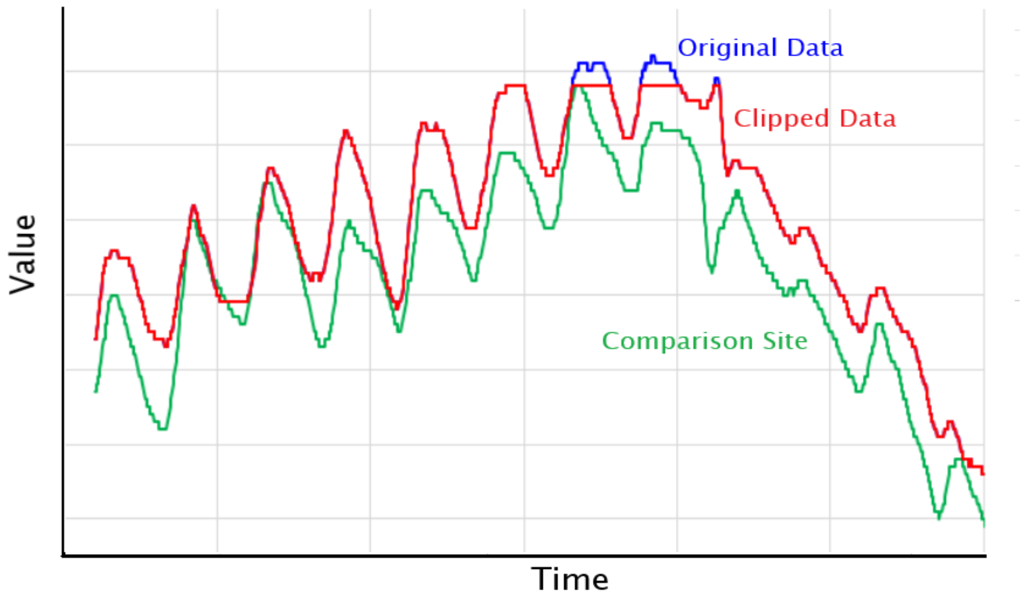


Figure D 3 - An example of a period of over-range data (blue line) clipped at the maximum of calibrated range (red line) to be stored as censored data.

Table D 6 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	Measured values are outside calibration range of the sensor, or full range of water temperature is not recorded.	D 3.7
Evidence	Values exceed known calibrated range of the sensor or over-ranged record flatlines or has gaps when temperatures are at or near extremes of calibrated range. May be verified by independent measurements.	Fig. D 3 D 2 3.6
Solution(s)	Remove over-range values and treat as missing data or clip data at extremes of calibration range and store as censored data.	4.16 to 4.20 incl. D 3.11 1.1.5

Metadata	QC 100 if left missing, or QC 400 if stored as censored data. Data Comments are required explaining identified cause and providing details of decisions made and methods applied. A Stationarity Comment is required if threshold and/or treatment is changed.	6.2.3 D 4.2.4 6.2.4.6 D 4.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently, and possibly intermittently, by a drop in water level caused by bed scour, channel migration, channel works, drawdown, storage depletion, tide, or deliberate interference, or when removed for cleaning. Measurements while exposed will be of air temperature with radiant heating also possible.

If the level of the temperature sensor is known relative to water level datum a water level threshold can be determined below which the corresponding temperature data collected must be regarded as not representative of water temperature.

A change in water temperature characteristics will also likely be observed that persists until the sensor is re-immersed and has reached equilibrium.

Remove data affected by sensor exposure from the record and treat the period as missing data (see Section D 3.11).

Note: Section 1.2.5 of NEMS Water Temperature *v2.0 requires the influence of dryness to be measured in groundwater systems but verified affected data should not be included in the archived processed record of water temperature or used to compensate other variables for water temperature.*

Table D 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	Air rather than water temperature is recorded.	D 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels of sensor and water, or consequence of an event known to have occurred).	D 3.8 D 2 3.6
Solution(s)	Remove false data and treat as missing.	4.16 to 4.20 incl. D 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 D 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor/logger configuration.

Water temperature data collected in the wrong measurement units is usually recoverable. Explicit conversion by mathematical relation between different units of temperature measurement, e.g. Fahrenheit to Celsius, is possible.

- Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different.
- Verification data must be in the same measurement units as the continuous data collected to be directly comparable.

Sensor output as current (Amps) or potential (Volts) requires conversion to temperature units on the data logger using a multiplier and possibly an offset. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent verification checks that vary in proportion to the logged value.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable and do not compromise precision, there is no effect on quality code.

Table D 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	D 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	D 3.9 D 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	D 3.9 4.7

Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	D 3.9 D 4.2.6 6.2.3 D 4.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section D 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table D 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong. and/or data are missing.	D 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal distribution anomalies are apparent when compared with data from a similar nearby site.	Fig. 18 Fig. 26 D 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or D 3.11

Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 D 4.2.5 6.2.3 D 4.2.4 6.2.3 D 4.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous water temperature data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel cycle, i.e. within the rising or falling side of the sine curve, but not over the peak or trough
- a longer period may be one or more days up to one week, and
- an extended period may be a week or more.

A maximum duration of one month for any period of synthetic infill is recommended, dependent on:

- the typical and expected variation in temperature at the sensor location
- the possibility of one or more significant events having occurred that may have altered the sensor environment, and
- reliability of the relationship(s) used to generate the synthetic record.

Water temperature can be strongly influenced by local factors such as location of the sensor in the cross-section and depth profile, nature of the surrounds above and below water, and the degree of mixing brought about by velocity distribution. If the water is not well mixed the data can be quite specific to the location at which the temperature is measured. When selecting and applying an appropriate method for resolving missing data, the likely variation at the sensor location must be taken into account with consideration of the duration of the period missing (see Appendix D.1).

For water temperature, backup data include data obtained from another sensor at site of a different type and/or standard, and manual observations using a reference thermometer that are intended to fill a brief or short period of missing data, provided the backup data are collected near the primary sensor or in a well-mixed environment.

Periods of synthetic infill of more than short duration must not be used as supplementary data for other measurements, e.g. dissolved oxygen.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in water temperature series, see Appendix D.1 to this Annex.

Table D 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	D 3.11
Evidence	Expected timestamps are not present in the raw data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire cycles or parts of cycles are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 D 2 3.6
Solution(s)	Use at-site backup data and manual observations including verification readings where available, OR a) if brief, interpolate across gap, except if a peak or a trough b) if short period, interpolate across gap or infill with a curve, but not over a peak or trough c) for longer and extended periods, apply methods to infill with synthetic data, or mark the gap d) if a month or more is missing, mark the gap or note a temporary site closure.	App. D.1 D 3.11 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record or manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 D 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

The relevant quality coding flowchart may be found in NEMS *Water Temperature (Measurement, Processing and Archiving of Water Temperature Data)* or in NEMS *National Quality Code Schema*.

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Guidance on how and when quality code must change as a consequence of data processing is provided in Section D 3 of this Annex.

4.2 Example water temperature comments

The following are templated examples of comments for water temperature stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water temperatures) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Water Temperature
Initial comment for <*river name*> River temperature at <*site name*>
Site number <*network number, ID or code*> on river <*river number*>[10]
The site is situated <*distance to coast*> km from the mouth at grid reference <*map co-ordinates and type*[11]> Drains <*catchment area to site*> km^2 and is monitored for <*site purpose and target characteristics*>.
Additional information: Site is affected by <*persistent adverse conditions at site (e.g. weed growth, abstractions or discharges, bed movement)*>. Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>.
<Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>.
The following data is also measured at this site: <*list variables, including any backup temperature recorder*>*;* <This record is used to derive <*list variables e.g. DO% saturation*>>.
The local recording authority is: <*name of recording/archiving agency*>

Lake station

Type: Site
Measurement: Water Temperature
Initial comment for <*name of water body*> temperature at <*site name*>
Site number <*network number, ID or code*> on river <*river number*>[10]
The site is situated <*distance to outlet*> km from the outlet at grid reference <*map co-ordinates and type*[11]> Drains <*catchment area*>km^2 of <*river name*> River catchment and is monitored for <*site purpose and target characteristics*>. Lake area is <*surface area*>km^2 and level is controlled by <*describe features e.g. natural outlet, dam, weir etc.*>
Additional information: Site is affected by <*persistent adverse conditions at site (e.g. weed growth, exposure to wind and waves, periodic drying up)*>. Sensor is located <*brief*

[10] from *Catchments of New Zealand* (SCRCC, 1956).

[11] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

description of sensor placement and environment>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>

The following data is also measured at this site: <*list variables, including any backup temperature recorder*>*;* <This record is used to derive <*list variables e.g. DO% saturation*>>.

The local recording authority is: <*name of recording/archiving agency*>

Sea station

Type: Site

Measurement: Water Temperature

Initial comment for <*name of water body*> Sea temperature at <*site name*>

Site number <*network number, ID or code*> at grid reference <*map co-ordinates and type*[11]> Situated <*brief location description*> and is monitored for <*site purpose and target characteristics*>.

Additional information: Site is affected by <*persistent adverse conditions at site (e.g. biofouling, exposure (wind and waves))*>. Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>

The following data is also measured at this site: <*list variables, including any backup temperature recorder*>*;* <This record is used to derive <*list variables e.g. DO% saturation*>>.

The local recording authority is: <*name of recording/archiving agency*>

Groundwater level station

Type: Site

Measurement: Water Temperature

Initial comment for <*name, ID, or bore number*> Groundwater temperature.

Located at <*map co-ordinates and type*[11]> and monitored for <*site purpose and target characteristics*>.

Drilled on <*dd-mm-yyyy hhmmss*> to depth of <*depth of well*>m >. Well construction: from <*depth*> to <*depth*>m diameter <*bore dia.*>mm and is <*cased, uncased, or screened*>

Well type <*type*>[12] for <*purpose*>[13] Aquifer type <*type*>[14] depth <*depth*>m

Aquifer lithology <*brief description*>. Log available from <*name and contact details*>

Consent <*number or* permitted use>

Ground elevation <*level and datum*>m, Static water level <*level and datum*>m

[12] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring

[13] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused

[14] confined, unconfined, perched, or fissure

Additional information: Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <*Additional bore location information if more than one bore in vicinity, and aquifer properties, water quality grade if available*>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured at this site: <*list variables, including any backup temperature recorder*>*;* <This record is used to derive <*list variables e.g. pH*>>.
The local recording authority is: <*name of recording/archiving agency*>

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Water Temperature
Recorder installed on <*dd-mm-yyyy hhmmss*> is a <*describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.*> data logger, recording <*describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes*>. The temperature sensor is a <*type and output e.g. 4-20mA or 0-5V etc. thermistor or resistance temperature detector etc.*> installed in (*or* on) <*brief description e.g. weighted cable x-m down well, or below moored buoy, plastic conduit attached to timber pier, steel box section secured on piles etc.*> positioned at <*reduced level and datum, or equivalent stage, or briefly describe*>. Sensor range is <*range and units*> with resolution of <*resolution*> and nominal accuracy of <*accuracy specification*> calibrated on <*calibration date*>. Sensor output is converted to degrees Celsius by <*details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset*>. Sensor calibration is valid for <*calibration period*>. Site is visited <*verification frequency*>*.* Data is collected by <*method e.g. telemetry and occasional manual download*>.

Create a similar but separate comment for any backup sensor or secondary source of water temperature data at the site, to avoid the comments becoming too long and complex.

Create a similar but separate comment for any replacement sensor if any of the previously described details change as a consequence. Include confirmation that all other details have not changed. For example:

Type: Equipment
Measurement: Water Temperature
Replacement temperature sensor is a <*type and output e.g. 4-20mA or 0-5V etc., thermistor or resistance temperature detector etc.*> installed on <*dd-mm-yyyy hhmmss*> in the existing installation. New sensor range is <*range and units*> with resolution of <*resolution*> and nominal accuracy of <*accuracy specification*> calibrated on <*calibration date*>. Sensor output, calibration frequency, site visit frequency, and data collection method are unchanged.

Type: Equipment
Measurement: Water Temperature
Verification data is obtained *<state frequency>* by *<describe method and instrument(s) used e.g. manual readings from a calibrated reference thermometer, or handheld instrument ABC, positioned as close to the sensor as possible, etc.> <Add other relevant information such as range, units, serial number, and calibration frequency of the reference thermometer or handheld>.*

4.2.3 Operational Comment examples

Type: Operational
Measurement: Water Temperature
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.>*. New location is *<describe new environment>*. New sensor position is *<reduced level and datum, or equivalent stage, or briefly describe>*.

Type: Operational
Measurement: Water Temperature
Sensor cleaned on *<dd-mm-yyyy hhmmss>*. <Recorded temperature was briefly elevated (*or* lowered) while sensor was temporarily exposed>.

Type: Operational
Measurement: Water Temperature
Verification reference reading on *<dd-mm-yyyy hhmmss>* was collected *<distance vertical and/or horizontal>* from the sensor due to *<provide reason e.g. high flood preventing access>*. Some deviation from recorded value is expected.

Type: Operational
Measurement: Water Temperature
Sensor replaced on *<dd-mm-yyyy hhmmss>* because *<provide reason>*. <Replacement sensor is a different type (*or* model) (*or* range). Refer to the associated Equipment Comment for its specifications.>

Type: Operational
Measurement: Water Temperature
Verification reference reading adopted for *<dd-mm-yyyy hhmmss>* was collected using a second reference thermometer. The initial reference reading is assumed unreliable.

4.2.4 Data Comment examples

Type: Data
Measurement: Water Temperature
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. *<Add any other relevant information such as why the gap has not been filled>.*

Type: Data
Measurement: Water Temperature
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Water Temperature
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Water Temperature
From *<dd-mm-yyyy hhmmss> (*to *<dd-mm-yyyy hhmmss>)* data above the calibrated sensor range of *<x degrees C>* is clipped (*or* deleted) and the data series is filed as censored (*or* with gaps, *and/or* with missing record infilled).

Type: Data
Measurement: Water Temperature
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression, etc.>* with input data *<list sites, variables, and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. not recommended as supplementary data or for model calibration etc.>*

Type: Data
Measurement: Water Temperature
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. poor mixing, suspected interference, intermittent flow, fouling, low power, pumping, etc.>. <Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Temperature
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x degrees C, linear drift adjustment of* x_0 *degrees C to* x_1 *degrees C etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x °C or > x' °C not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

4.2.6 Transformation Comment examples

Transformations applied to a water temperature record prior to its archiving must be included in the water temperature metadata.

Type: Transformation
Measurement: Water Temperature
A calibration adjustment is applied from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<describe method e.g. equation, look-up function, or rating etc.>* Maximum adjustment is *<x>* degrees within the range *<temperature range affected>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Water Temperature
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>.* Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Water Temperature
Water temperatures are archived in degrees Celsius (C) transformed from sensor readings in Fahrenheit (F) using the relation C = (F -32)/1.8 rounded to nearest 0.1°C.

4.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Water Temperature
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.>*. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment.

Type: Stationarity
Measurement: Water Temperature
New effluent discharge consent *<provide consent number and consenting agency>* operative from *<dd-mm-yyyy hhmmss>* at *<location relative to sensor e.g. x m (or km) upstream>* on *<name of stream, or unnamed tributary>* may affect water temperature data recorded at this site after this date.

Type: Stationarity
Measurement: Water Temperature
Data is a censored series. Maximum calibrated range and therefore censoring threshold was changed on <*dd-mm-yyyy hhmmss*> from <*x degrees C*> to <*x' degrees C*>. <Refer to the <*reference e.g. site file, asset management system etc.*> for calibration details.>

Stationarity Comments can also be used to capture and collate information about historical methods and data.

5 Preservation of Record

Refer to Section 8.

Appendix D.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, estuarine, sea, or groundwater)
- location of the sensor in the cross-section and depth profile
- the nature of the surrounds above and below water, e.g. presence of any heat sources or sinks
- the duration requiring infilling
- the degree of mixing at-site during the period missing
- availability of other relevant time series, such as:
    - at-site backup water temperature data (see Section D 3.11)
    - at-site flow or water level data
    - water temperature, flow, or water level data from elsewhere in the same water body
- likelihood during the period missing, of:
    - an event causing disturbance or alteration of the sensing environment, or
    - inflows that may affect temperature, e.g. a nearby discharge
- availability of supporting observations and other evidence, such as:
    - verification readings
    - manual observations using the reference thermometer intended as infill, and
    - other readings, e.g. during sampling or gauging, that may have been measured using an instrument other than the reference thermometer.

2 Recommended Methods

The following methods are candidates for infilling gaps in water temperature records:

- inserting one or more of:
    - at-site backup water temperature data
    - at-site verification readings
    - other at-site manual readings obtained using the reference thermometer
    - readings obtained at-site or nearby in the same water body from other instruments, e.g. a Doppler current meter.
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for brief and short periods (see Section D 3.11)
- mathematical calculation of the sine curve or copying from a reference trace (from the same or another site) for short periods (see Section D 3.11)
- generating a record from results of a linear or curvilinear regression with one or more donor sites.

Manual readings can be incorporated into all the above methods to improve confidence in the synthesised data.

Periods of a month or more should not be filled with synthetic data.

2.1 Infilling with backup water temperature data

Backup water temperature data must be verified as for the primary record for the period it is required, including assessment for over-ranging and sensor exposure that would preclude its use.

Local effects and differences in instrument design and calibration make it unlikely the two records will directly overlap. Small adjustments may be needed to eliminate steps at the junction of the primary and infill backup series.

2.2 Infilling with observations

Verification readings may be used to assist with infilling a gap.

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected so they may be inserted into the record to avoid missing data. These will usually be additional reference thermometer readings and their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

2.3 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section D 3.11) is to intuitively ‘draw it by hand’, i.e. manually insert values to complete a straightforward rise or fall within a diel cycle. If a straight line is a good approximation, deleting the gap marker may be all that is required to close the gap.

2.4 Infilling the curve between adjacent peaks and troughs

It may be sufficient to copy values from a similar period of record at the same site, or from another site in the same water body that is sufficiently representative.

Note: Seasonal variation in diel cycles may need to be taken into account.

An unbroken curve can be estimated by connecting the adjacent periods of good water temperature record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the curve may be calculated from the sine curve formula $y = a\sin(bx + c)$ where a is the amplitude, b is the period, and c is the phase shift of the sine curve.

2.5 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Do not use equations forced to zero for regression of water temperature. If negative temperatures are predicted, their significance, and the likelihood of periods of below zero water temperature at the recipient site, must be assessed. If periods of below zero temperature are not plausible the analysis should be discarded.

Apply the regression equation intended to generate the synthetic record to another period of record of similar duration and season where recipient site data exists and compare actual and predicted maximum and minimum temperature. If the difference between actual and predicted for either extreme exceeds ± 0.5°C the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.5.1 Selecting suitable donor sites

One or more donor sites should be selected from other water temperature recording sites in the same water body; however, acceptable results may be obtained from regression with water temperature recording sites in adjacent water bodies with similar physical characteristics.

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contributions of each donor site. Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

Compare an extended period of record from all candidate sites. Assess whether lag is needed on any input.

Note: Lag times, if needed at all, will usually be small compared to flow travel times.

2.5.2 Time resolution of the synthetic record

Time resolution of the synthetic record should match the primary recording interval.

Note: Although a longer interval average may improve the correlation, incorporating average in preceding or succeeding interval data into an instantaneous series with diel cycles distorts the timing of those cycles unless the time-series manager permits mixing of average in interval and instantaneous data in the same series.

The filed comment(s) must make clear how the synthetic infill was derived and then incorporated into the record.

2.5.3 Seasonality of relationships

Seasonal variation in water temperature is typical for most water bodies except deep groundwater. The effect of seasonality on the relationship used to derive a synthetic record should be explored, especially if potentially influenced by factors such as snow melt or stratification. If significant, relationships may be required for each season.

3 References

Joenssen D, Bankhofer U. 2012. *Hot Deck Methods for Imputing Missing Data*. In: International Workshop on Machine Learning and Data Mining in Pattern Recognition (pp. 63-75). Springer Berlin Heidelberg. Available from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).

Annex E Turbidity Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous turbidity data measured using in-situ sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of turbidity compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held device or sampled and analysed in a laboratory.

1.1 Normative References

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

- NEMS *Turbidity (Measurement, Processing and Archiving of Turbidity Data)*
- NEMS *Measurement of Fluvial Suspended Sediment Load and its Composition*
- NEMS *Water Quality Parts 1 to 4: Sampling. Measuring, Processing and Archiving of Discrete Groundwater (River Water, Lake Water, Coastal Water) Quality Data*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Turbidity* v1.2'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

Note: At date of publication of this Annex, NEMS Turbidity *and NEMS* Suspended Sediment *are undergoing review and significant changes are expected, including the introduction of additional time series and data processing procedures to improve standardisation of turbidity measurement between sites and instruments. This Annex will be revised to align with the updated NEMS soon after their release.*

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying turbidity data:

- instrument details:
  - sensor model, manufacturer, and serial number

- the instrumentation standard; for example, ISO 7027
  - the sensor range, as deployed
  - characteristics of the on-board anti-fouling mechanism
  - date, laboratory, and identifier for each calibration, and
  - date and time of each deployment
- sensor deployment details (see also Sections 1.2 and 1.4 of NEMS *Turbidity* v1.2):
  - sampling method and data-logging interval
  - details of any backup, secondary and/or supplementary data logged
  - method(s) used for verification of sensor readings
  - photos of the deployment showing detail and bankside context
  - date, time, and reason(s) for any relocation of the sensor
  - the level of the turbidity sensor with respect to the water level gauge, where co-located
  - bed clearance under the sensor, and
  - any changes over time in composition of the bed material
- results of samples analysed in a laboratory, including:
  - uncertainty in the result, reported to 95% level of confidence
  - analysis method, and
  - information about when, where, and how each sample was taken (see Section 3.3 of NEMS *Turbidity* v1.2).

These metadata must be verified, and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection and sampling activities, and to identify steps in the data introduced by cleaning, recalibrating, or replacing the sensor.
- Check each high turbidity event for anomalies or gaps due to over-ranging or sensor saturation.

2.2.1 Comparisons

- Use comparisons to:
  - cross-check data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
  - other associated variables recorded at the site, e.g. water level, flow, and suspended sediment concentration
  - a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)

    - an auxiliary instrument at the same site, e.g. one that may be recording over a different range, provided it is not also affected by the same data quality issue(s)
    - verification measurements and validation results.

In addition to cross-checking specific features in the data, look for change in and/or disruption of:

- shape and pattern of turbidity response to high flow events
- baseline turbidity (usually coincident with low flows)
- relative timing of peak turbidity to peak flow (or water level)
- relative scale of events.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.2.2 Between-station comparisons

Compare recorded data with reliable catchment rainfall and/or upstream and/or downstream records of turbidity, flow and/or suspended sediment concentration to confirm occurrence and timing of events, but otherwise, due to the local variability and relative nature of turbidity measurement, comparison with neighbouring stations is of limited use.

2.3 Reliability of reference values

Reference values used to verify a turbidity record can be obtained while on site, using an independent hand-held meter, or by way of samples collected then analysed later in a laboratory.

When using reference values to verify or to adjust recorded turbidity the following should be considered and assessed:

- results of validation of field instruments (see Section E 2.3.1)

  Note: Laboratory instruments are subject to the calibration and validation requirements of the laboratory method of analysis.

- measurement or sample location relative to the sensor (see NEMS *Turbidity* v1.2: Sections 3.3.2.1 and 3.3.2.2)
- timing of the reference measurement or collection of the sample

  Note: NEMS Turbidity *v1.2 Sections 3.3.2.1 and 3.3.2.2 require these to be coincident with the data-logger reading but after any disturbance caused by sampling and/or sensor cleaning has settled. NEMS* Turbidity *v1.2 Section 3.3.5 recommends an additional measurement or sample before any servicing of the sensor.*

- integrity of the sample(s) (see Section 3.3.2.2 of NEMS *Turbidity* v1.2)

- laboratory analysis method(s) (see NEMS *Turbidity* v1.2: Sections 3.3.2 and 3.3.4)
- precision and accuracy of the reference readings or sample results, which may vary with range, or if samples are intended for multiple uses.

  Note: Samples exceeding 750 FNU may require dilution procedures in the laboratory that increase uncertainty in the result.

  Note: Precision and accuracy requirements differ between NEMS Turbidity (Measurement, Processing and Archiving of Turbidity Data) *and NEMS* Water Quality (Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data*.*

Turbidity record should not be adjusted to any reference value where the difference between the reference and corresponding recorded value is overwhelmed by uncertainty in the reference reading unless there is other corroborating evidence of faulty recording. If adjusted, the adjustment(s) should be reviewed when reliable reference readings resume.

If the field instrument used to obtain reference readings fails validation, all reference readings obtained using that instrument, since its last successful validation or calibration, are unreliable and must be identified as such on any quality plots.

If reference reading uncertainty exceeds verification tolerance, or a reference reading is disregarded as unreliable, the period of record that would be verified by that information shall be quality coded no higher than QC 500.

2.3.1 Validation of field instruments

Calibration of any instrument used in the field is validated:

- pre-deployment (see Section 2.3 of NEMS *Turbidity* v1.2), and
- at the zero-point, annually, after cleaning (see Section 3.3.7 of NEMS *Turbidity* v1.2), and
- when quality charts indicate a possible loss of calibration (see Appendix 1 and Section E 2.4).

2.3.2 Laboratory results

Laboratory results must be supplied as the raw unrounded measurement value with its associated uncertainty of measurement (UoM) to be useful for:

- verifying the continuous data collected, and
- calibrating relationships when the data are intended as a surrogate.

Note: For laboratories this is a departure from their standard practice and will require prior arrangement (see 'The Standard – Discrete Water Quality (Rivers)' and Section 5.5.1 of NEMS Water Quality Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data*).*

Laboratory results are subject to extensive quality processes but errors, usually of human origin, may still arise. Agencies making use of laboratory results must ensure procedures exist and are implemented to ensure any error found is identified, and corrected wherever possible, at every instance of the result being stored, including at the source laboratory, to prevent future transfers of results reintroducing the error.

2.4 Deviation tests

From NEMS *Turbidity (Measurement, Processing and Archiving of Turbidity Data)*, tolerance is expressed as absolute or percent deviation depending on turbidity value. The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure E 1) or stacking the charts (Figure E 2).

Use deviation with range analysis to monitor issues such as reference reading uncertainty, sensor baseline drift, and loss of calibration, including loss of linearity.

For turbidity that ranges over several orders of magnitude, scatter-plotting logged values versus corresponding reference readings is of limited use. It is best to work with the differences.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

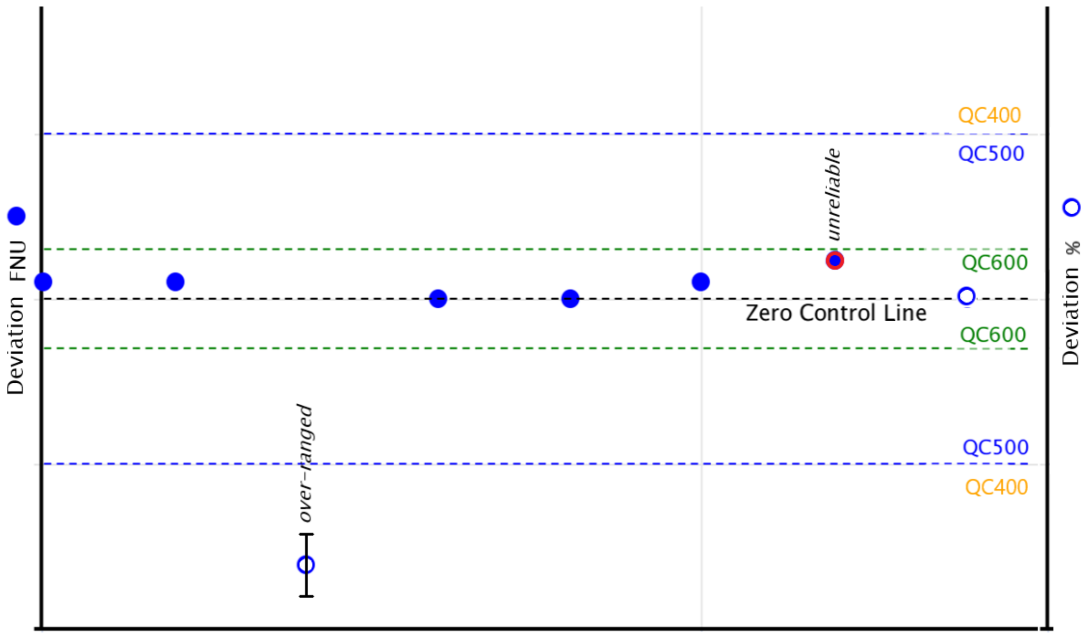


Figure E 1 - An example of a control chart with secondary axis scaled to align the limits, where data are plotted in sequence using the axis applicable for the tolerance test, and with error bars when the uncertainty is significant, and annotated to aid interpretation.

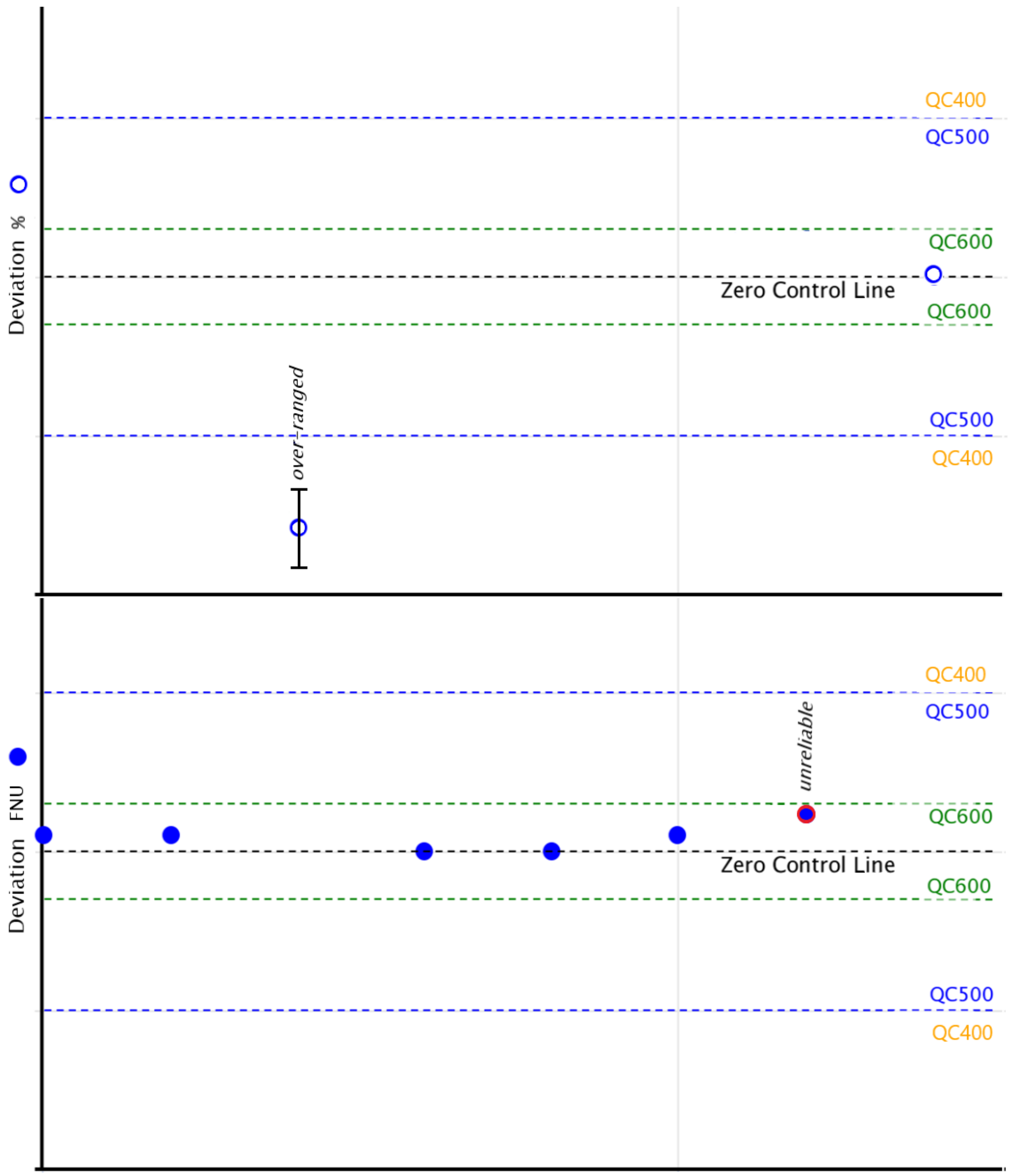


Figure E 2 - An example of a stacked control chart where data are plotted in sequence on the top or bottom chart depending on the applicable tolerance test, with error bars when the uncertainty is significant, and annotated to aid interpretation,

3 Potential Errors and Recommended Editing

This section describes common problems specific to turbidity data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The water environment, with respect to:
  - location of the sensor in relation to water level
  - the relative locations of the sensor and point of collection of reference measurements at various flows (see NEMS *Turbidity* v1.2: Sections 1.2.2, 1.4, 3.3.2 and Annex B), and
  - the nature and distribution of the suspended material (NEMS *Turbidity* v1.2 'Introduction').
- Site factors (see Section 1.2.4 of NEMS *Turbidity* v1.2).
- Instrument deployment and operation, and conditions that adversely affect them (see NEMS *Turbidity* v1.2: Sections 1.2, 1.4 and 2.2).
- Interference, deterioration, and damage (e.g. human, fouling, hydraulic conditions etc.) (see NEMS *Turbidity* v1.2: Sections 1.4.2 and 3.2).
- Instrument performance, including:
  - maintenance of calibration (see NEMS *Turbidity* v1.2: Sections 2.2, 2.3 and 3.3.7)
  - electronic transients, and
  - over-ranging and/or saturation.

3.2 Unintended offset or incorrect change of offset

Analogue sensors usually require an offset and multiplier to be programmed into the data logger to convert sensor signal to measurement units. If a mistake is made calculating or entering the offset the data collected are biased by the amount of error in the programmed offset.

Note: An error in the multiplier also affects the value of the offset to be applied.

Annual clear water zero-point validation (see Section 3.3.7 of NEMS *Turbidity* v1.2) may reveal the sensor has developed an offset. Investigate probable cause of the offset and identify the period of prior data that is biased. Quality control deviation tests may show a trend or persistent bias that helps reveal the affected period. The adjustment required depends on cause. If due to gradual lens deterioration, the adjustment should be gradual, i.e. compensation for a 'baseline' drift (see Section E 3.4.1) rather than an offset correction.

Note: Gradual deterioration due to abrasion is unlikely with modern turbidity sensors unless the suspended sediments are highly abrasive, such as volcanic glass.

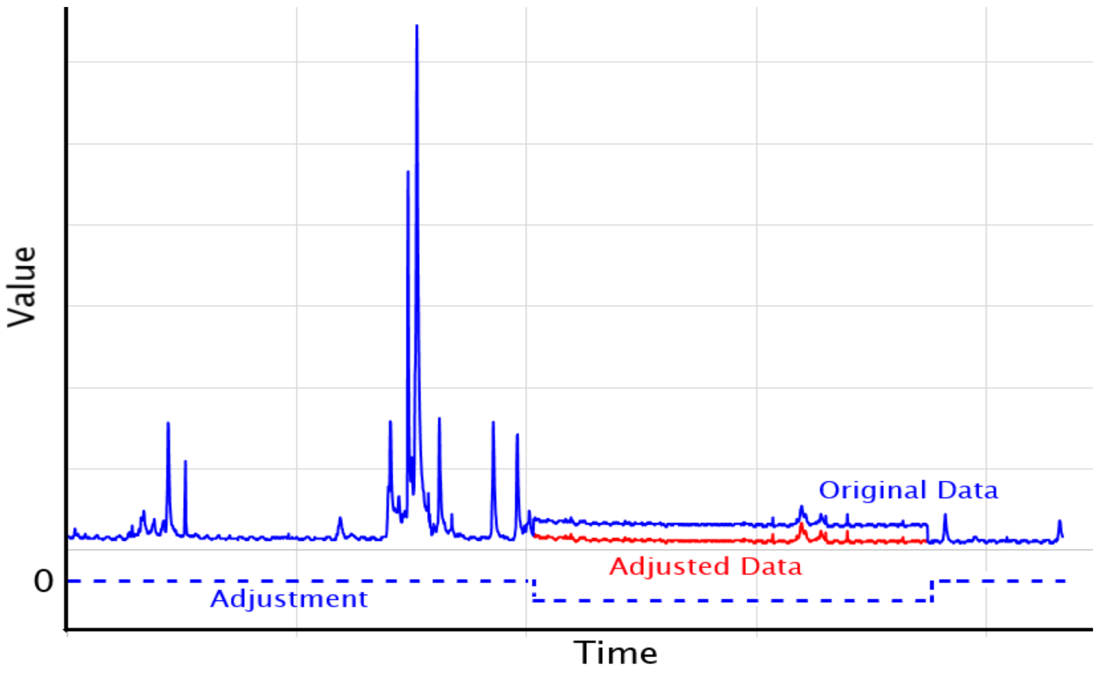


Figure E 3 - An example of a period of turbidity data offset by a constant amount (blue line) with the adjusted data (red line) and showing the adjustment applied (dotted line).

Table E 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset, or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	E 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount, observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and traceable at site by clear water zero-point validation and/or checking the logger program.	Fig. E 3 E 3.2 E 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	E 5.2.6 6.2.4.8 6.2.3 E 5.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- replacement of the sensor
- sudden occurrences of interference, or macro-fouling (values step up)
- clearing or cleaning the sensor (values step down).

Cause of the step dictates which data should be repaired and how.

3.3.1 Instrument replacement

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, and data subsequently collected are offset from data previously collected, the step-change created must remain in the data and be identified and explained by a Stationarity Comment (see Section E 5.2.7).

If either instrument (existing or replacement) is an analogue sensor, confirm the relevant multiplier and offset applied. Data affected by a configuration error must be rescaled (see Section E 3.9) and corrected for any consequent offset error (see Section E 3.2), which should eliminate the step.

If neither of the above situations applies and calibration of the replacement instrument is confirmed by its pre-deployment validation, some form of drift in the existing replaced instrument must be assumed and addressed (see Section E 3.4.2).

3.3.2 Interference and macro-fouling

Interference may be due to the actions of people or animals, on or about the sensor, malfunction of the cleaning wiper leaving it 'parked' over the optics, light contamination during daylight hours caused by insufficient deployment depth, or an event such as a flood or bank collapse burying the sensor or raising the streambed into the sensor's field of view.

Macro-fouling occurs when solid objects are caught within, or otherwise invade, the sensor's detection volume. Examples include vegetation snagged on the sensor or its housing, loitering fish, and encroaching in-stream vegetation (macrophytes).

Affected record typically steps up significantly over one or two recording intervals, then maintains exceptionally high or over-range values until the cause moves, or is removed, either naturally, or by way of maintenance during a site visit.

Site maintenance, self-cleaning air or water purges, and water sampling activities may themselves interfere with the recording of normal turbidity by stirring up sediment around the sensor.

If the object moves frequently in and out of the sensor's view the affected data may be treated as for spikes (see Section E 3.5) or noise (see Section E 3.6). Otherwise affected data must be removed, and the consequent gap treated as missing record (see Section E 3.11).

3.3.3 Sensor clearance or cleaning

Clearing or cleaning a sensor removes fouling that has caused elevated turbidity readings. Baseline turbidity is re-established, often with a step down apparent in the data at the time, or shortly after if turbidity is also temporarily elevated by the disturbance of sediments during cleaning operations.

Macro-fouling and sensor burial are addressed in Section E 3.3.2.

Biofouling occurs when an algal film grows on the sensor lens that can be compounded by fine sediment settling in the algae. Chemical fouling occurs when a chemical film accumulates on the sensor lens, e.g. from tannins in the water. Both forms of fouling are gradual accumulations that progressively elevate back-scatter readings until the lens is cleaned of the accumulated material.

Note: Partial lens cleaning may occur naturally during floods because of the drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment.

Adjustments applied to the elevated data must reflect assumptions made about the nature, timing, duration, and extent of the fouling and its subsequent clearance. In many cases the appropriate adjustment is a simple special case of drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a non-zero (and in this case, negative) value specified at the end of the period of adjustment (see Figure E 4). However, fouling may increase sensor readings non-linearly, especially if the cause is biological, in which case a non-linear drift adjustment is required (see Section E 3.4).

Fouling may also cause noisy data, which should be smoothed or resampled (see Section E 3.6) before any adjustment is applied to eliminate a step (see Figure E 4).

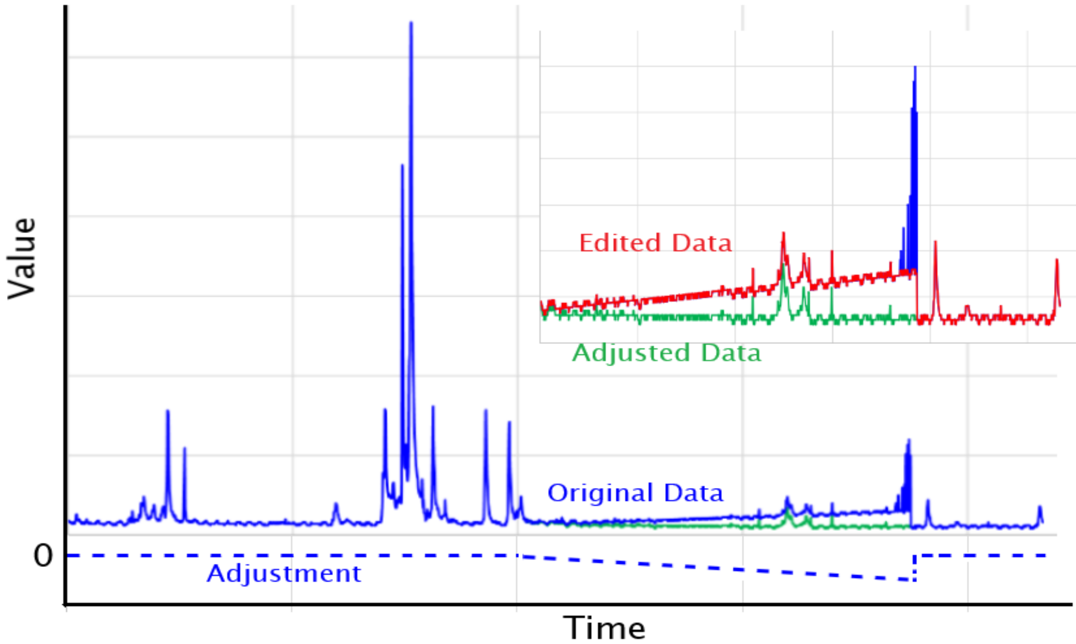


Figure E 4 - An example of a period of increasingly elevated data ending in a brief period of excessive noise before sensor cleaning returns readings to normal (blue line). Noise is edited first (red line), then a linear drift adjustment applied (dotted line) to progressively reduce the elevated values and eliminate the step at adjustment period end (green line).

Table E 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Large change in turbidity between successive readings that is not due to change in turbidity of the water body. If used as a surrogate for suspended sediment concentration (SSC) the step translates to an unlikely sudden change in sediment load.	E 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down) and may flatline or appear 'held' down (or up) before the step.	Fig. E 4 E 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Change or remove values affected by interference or fouling. Treat gaps created as missing data. Drift adjustment (linear or non-linear as applicable) with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace. Avoid applying drift adjustments over significant events.	E 3.3.1 E 3.9 E 3.5 E 3.6 E 3.11 E 3.4 4.4 & 4.5

Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. QC 200 applies to all data from non-NEMS compliant instruments. If rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the adjustment(s) applied (amount, type, and period of adjustment) is required, OR Refer to missing data guidance as applicable.	E 5.2.3 E 5.2.2 E 5.2.7 E 5.1 E 3.9 E 5.2.6 6.2.3 E 5.2.5 6.2.4 E 3.11

3.4 Drift

Drift may occur for some time before detection and confirmation. Verification data normally used to control a drift adjustment may therefore include reference readings that encompass a wide range of turbidity values, some with large uncertainties. Avoid invalid adjustments by being selective about the reference values used to assess and control adjustment for drift.

3.4.1 Baseline drift

Baseline drift may be caused by gradual deterioration of the sensor lens or its internal electronics. Both situations are relatively uncommon with modern good quality sensors but highly abrasive sediment such as volcanic ash, or moisture ingress, may still cause problems. Baseline drift may also be due to biofouling or chemical fouling (see Section E 3.3.3).

Baseline drift many be linear or non-linear with time but is not value dependent, i.e. all readings are elevated by an offset that increases with time until cause is resolved, e.g. by polishing the lens. Linearity over time should be investigated by inspection of a plot of the data and evidence of trend in a deviation with time plot. Value independence should be confirmed using a deviation with range plot.

If the baseline drift is linear with time a linear drift adjustment is appropriate to re-establish the unbiased baseline (see Figure E 5).

Non-linear baseline drift with time may be adjusted using suitable non-linear drift adjustment tools or may be approximated by a sequence of small, short-duration linear drift adjustments with time (see Figure E 6), but these must be applied carefully to avoid distortion of the record, especially during periods of low turbidity and/or flow recession.

Possible over-ranging or sensor saturation as a consequence of elevated baseline must also be considered (see Section E 3.7).

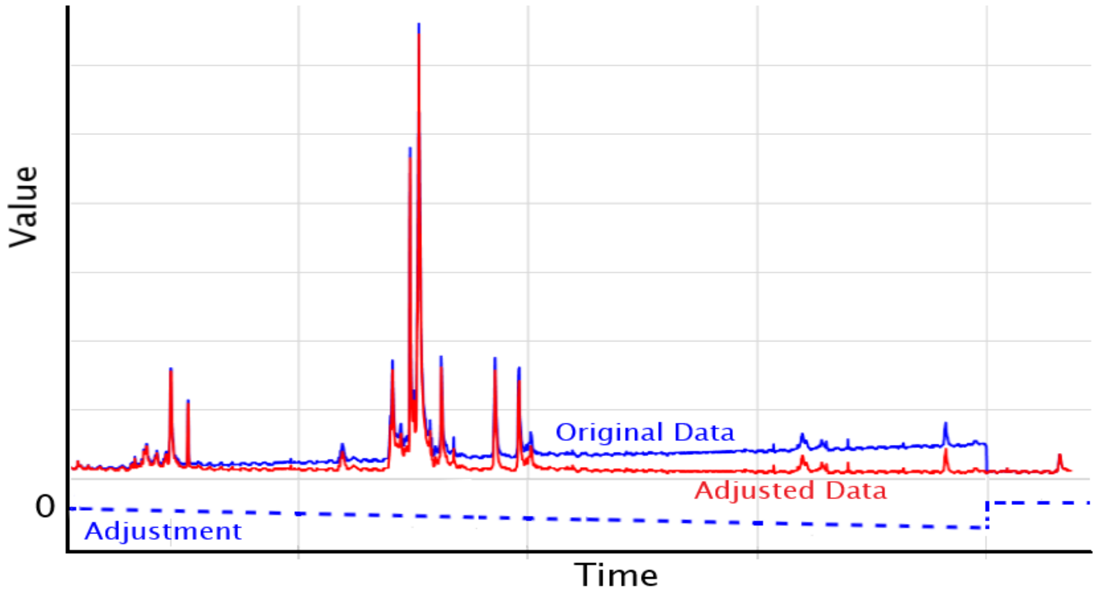


Figure E 5 - An example of baseline drift (blue line), with the adjusted data (red line) and showing the linear drift adjustment applied to remove the increasing bias (dotted line).

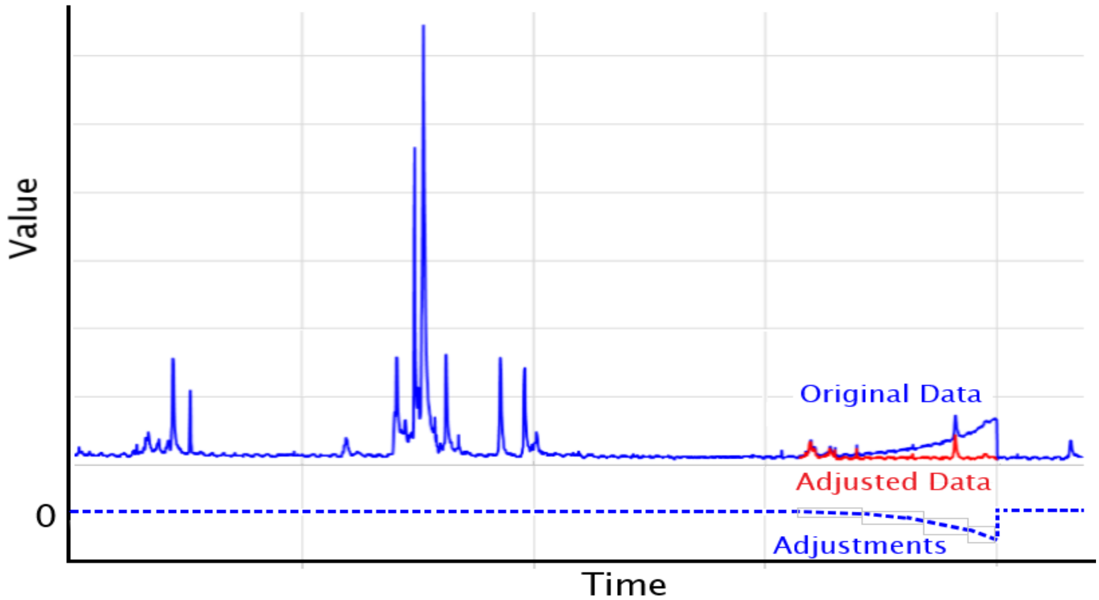


Figure E 6 - An example of non-linear calibration drift offsetting the baseline (blue line), with the adjusted data (red line) and showing the succession of small, short-duration linear drift adjustments (grey boxes) applied to remove the increasing bias (dotted line).

3.4.2 Calibration drift

Calibration drift may be linear or non-linear in value and/or time dimensions and may introduce a variable offset and/or alter the scale of the data. The nature of the drift must be determined wherever possible, by analysis of deviations from reference with time and with range, and/or from successive instrument validations. Instances of sensor over-ranging and/or saturation (see Section E 3.7) or sensor exposure (see Section E 3.8) must be isolated from analysis of calibration drift.

Calibration drift over the range of the sensor is usually associated with loss of linearity of response over the calibrated range. Affected data may be adjusted by applying a non-linear transformation to the values as determined from results of the instrument validations. The transformation may be applied as one or more equations, or by a look-up function, or as a rating curve. A sensor exhibiting loss of linear response must be replaced. Proper adjustment of the prior data should eliminate any step-change resulting from instrument replacement. If affected data cannot be reliably adjusted, it must be deleted from the record and the period treated as missing data (see Section E 3.11).

Non-linear drift adjustment that progressively alters the scale of the data with time, e.g. a linear %value drift adjustment (see Figure E 7), is not appropriate if the calibration drift causes a worsening offset but does not affect the relative range of measured values, i.e. the drift affects only the baseline (see Section 3.4.1).

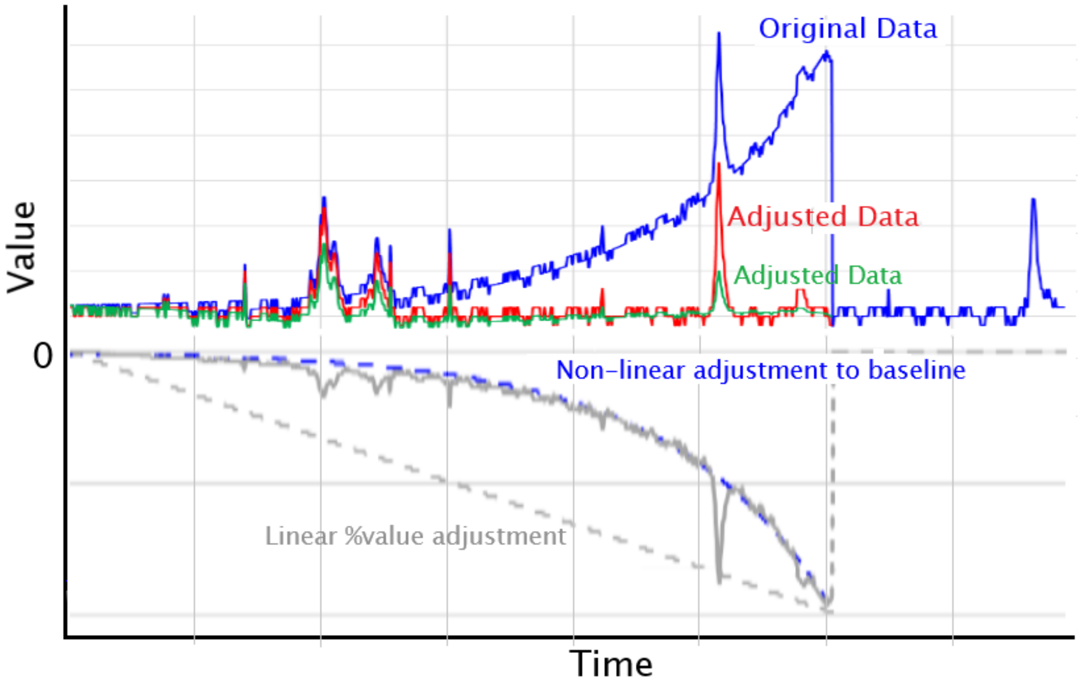


Figure E 7 – Comparison between a non-linear adjustment (blue dashed line) applied to a baseline affected by non-linear drift (blue line) and the resulting adjusted data (red line), and a linear %value drift adjustment (grey dashed line) that subtracts an increasing proportion of the logged values with time (grey line) to eliminate the drift but also progressively reduces the scale of the data (green line).

Table E 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	E 3.4
Evidence	Differences between recorded and reference turbidity increase with time and/or vary with value. Physical cause may be identifiable, such as biofouling or sensor validation results. Drift with time causes 'uphill' recessions, evident when plotted.	Fig. E 5 Fig. E 6 Fig. E 7 E 2 3.6
Solution(s)	Apply linear or non-linear drift adjustments as applicable depending on whether drift is determined to be linear or non-linear with time. A non-linear drift adjustment with time can be approximated by a series of small, short-duration linear drift adjustments, with care. Apply a transformation derived from instrument validation results if drift is value dependent. Remove affected record if transformation is not possible, then treat as missing data.	E 3.4 Fig. E 5 Fig. E 6 Fig. E 7 4.4 or 4.5 4.7 E 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment), OR Refer to missing data guidance as applicable.	6.2.3 E 5.2.5 6.2.4.7 E 3.11

3.5 Spikes

Unexpectedly low values are relatively rare in turbidity data and usually associated with power supply failure. Solitary unexpectedly high values can occur due to electronic transients or floating debris passing within range of the sensor's optics. Data affected by intermittent macro-fouling may exhibit continual and possibly erratic spiking to high values if the cause is moving back and forth in the current.

Isolated spikes in continuous turbidity data may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required.

Intermittent spikes may be deleted manually or discarded using a numerical filter. A track minimum filter may be more successful than a threshold filter if there is frequent spiking to values within the range of the reliable data. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20 and E 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section E 3.6).

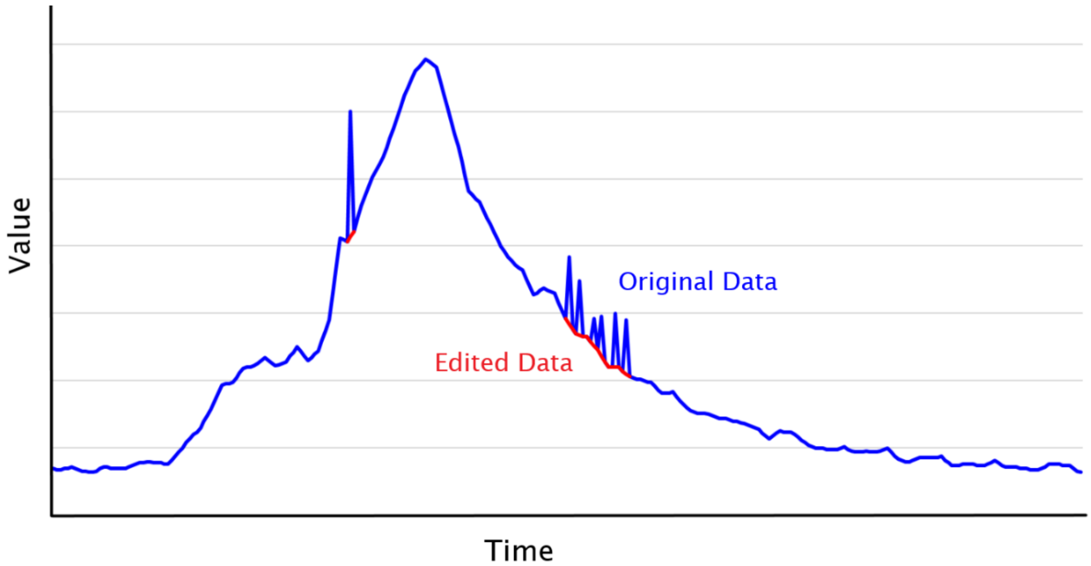


Figure E 8 - An example of a solitary spike (rising side) and frequent spiking (falling side, blue line) and the result of deleting or replacing the implausibly high values (red line).

Table E 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	E 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation and elimination of cause if possible.	Fig. E 8 E 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or E 3.11 or E 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 E 5.2.5 6.2.4.7 or E 3.11 or E 3.6

3.6 Noisy data

Noise in turbidity data is usually caused by interference or transient fouling that results in elevated values (see Section E 3.3.2). Affected values may be filtered out by tracking the minima by hand or machine algorithm (see Figure E 5). Because the noise is not randomly distributed about the expected true value an averaging, moving mean, or median of values filter is not appropriate. The edited data must be carefully assessed to confirm that the minima selected are not also elevated.

If insufficient values are retained to reliably represent the turbidity measured, treat the period as missing data (see Section E 3.11).

Table E 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations is outside tolerance. Range of fluctuations compromises use as a surrogate to determine suspended sediment concentrations.	E 3.6
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. E 8 E 2 3.6
Solution(s)	Resample, or 'smooth' with a statistical filter. Method choice is determined by instrument type and identified cause. Tracking minima is usually the most appropriate. Some cautions apply.	E 3.6 Fig. E 8 4.12
Metadata	QC 400 and Data Processing Comment explaining identified cause and method applied.	6.2.3 E 5.2.5 6.2.4.7

3.7 Over-ranging and sensor saturation

Over-ranging occurs when turbidity exceeds a sensor's calibrated range. The value returned when the range is exceeded varies according to the type and brand of sensor and may be an error code.

Data loggers and some sensors may prevent the recording of values exceeding the sensor's stated calibrated range. Occurrences truncate turbidity events at a constant high value or create a gap in the record. Other sensors may continue to output a non-linear response until reaching saturation (plateauing) at a maximum value.

Over-ranging may be difficult to detect in the record from some instruments because turbidity beyond the instrument's range results in reduced turbidity values due to absorption of the light emitted from the sensor dominating over back-scattering. In some cases, the peak of a turbidity event may appear to collapse or invert due to this effect (see Figure E 9).

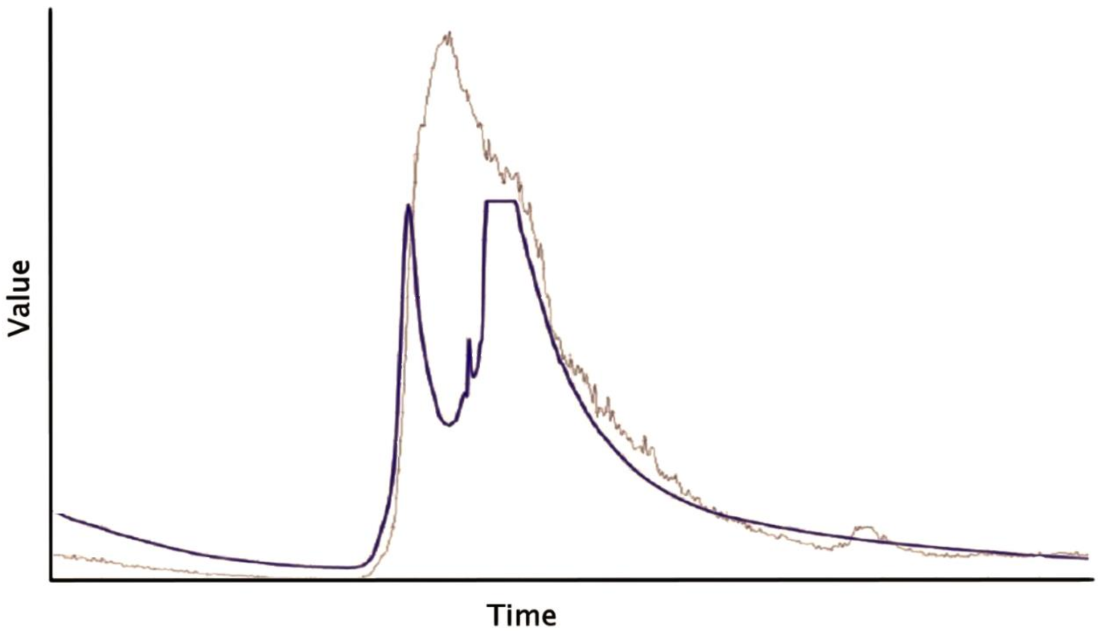


Figure E 9 - An inverted turbidity peak caused by the absorption of light emitted from the sensor dominating over backscattering (dark line) compared with the same event as recorded by another sensor at the site with a larger calibrated range (ghosted line).

When processing turbidity data, it is important to understand how the sensor responds as turbidity increases beyond its stated calibrated range and be alert to the possibility of false readings or data loss near the top of that range.

False readings must be removed from the record, then treat as for missing data.

Datasets that include periods of truncated over-ranging may be filed as a censored time series with appropriate metadata (see Sections 1.1.5 and E 5); however, treating affected periods as missing data is preferred (see Section E 3.11). A change of over-range threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section E 5.2.7).

See also Section 8 of NEMS *Fluvial Suspended Sediment Load* v0.1.1.

Table E 6 – Guidance for resolving over-ranging and sensor saturation

Guidance for resolving over-ranging and sensor saturation		see Section(s)
Issue(s)	Full range of turbidity is not recorded. False readings may be recorded that cause suspended sediment concentrations derived from turbidity as a surrogate to be grossly under-estimated.	E 3.7

Evidence	Over-ranging record flatlines or has gaps when turbidity is at or near top of calibrated range. Peak collapses or inverts at high turbidity if saturation occurs. May be verified by independent measurements.	Fig. E 9 E 2 3.6
Solution(s)	Replace with backup or secondary data, or remove and treat as missing, or in limited circumstances accept as censored data. If removed, the gap created may be infilled with synthetic data if appropriate. Method choice is determined by site purpose, identified cause, and available supporting data. Some cautions apply.	4.16 to 4.20 incl. E 3.7 E 3.11 1.1.5 App. E.1
Metadata	Quality code applicable to the replacement backup or secondary record (QC 200 applies to data from non-NEMS compliant instruments). QC 300 if replaced with synthetic infill, or QC 100 if left missing, or QC 400 if stored as censored. Data Comments are required explaining identified cause and providing details of decisions made and methods applied. A Stationarity Comment is required if threshold and/or treatment is changed.	6.2.3 E 5.1 E 5.2.4 6.2.4.6 E 5.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently because of bed scour or deliberately to avoid biofouling at low flows. The value returned varies according to the type and brand of sensor and may not necessarily be zero.

The level of the sensor lens in relation to the water surface, and the minimum required deployment depth of the sensor, must be known when verifying and processing turbidity data. Combine this information to obtain a threshold water level below which the turbidity data must be regarded as compromised.

Remove data affected by sensor exposure or light contamination from the record and treat the period as missing data (see Section E 3.11).

See also Section 8 of NEMS *Fluvial Suspended Sediment Load* v0.1.1.

Table E 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	False values are recorded.	E 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels, or consequence of an event known to have occurred).	E 3.8 E 2 3.6

Solution(s)	Remove false data and treat as missing.	4.16 to 4.20 incl. E 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 E 5.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor/logger configuration.

For turbidity, data collected in the wrong measurement units are not recoverable. Explicit conversion by mathematical relation between different units of turbidity measurement is not possible.

- Units assigned to measured values must be consistent with the measurement protocol used.
- Data must be stored in the units in which it was measured.
- The metadata must state the units of measurement.
- Verification data must be in the same units of measurement as the continuous data collected to be directly comparable.
- Any change in turbidity units of measurement at a site must be identified by a Stationarity Comment (see Section E 5.2.7).
- Data in different units for the same site must be differentiated and preferably be stored as separate time series.

Note: Design of the sensor and its calibration standard determine the units of turbidity measurement. Because turbidity is a relative measure of an optical property of water, there is no mathematical relationship between any two units of measurement. This is true for all field deployments despite calibrating sensors of different type to the same standard, i.e. NTU and FNU are not the same unless the substance being measured is the formazin colloid. In the field, variations in colour, and particle size and shape, also affect the scattering of light of different wavelengths such that turbidity measured in NTU will not be the same as turbidity measured in FNU.

Turbidity series measured in different units at a site over time cannot be combined into a homogenous series of turbidity but may be used as a surrogate for a homogeneous series of suspended sediment concentration if separate relationships are developed with each turbidity series.

Sensor output as current (Amps) or potential (Volts) requires conversion to measurement units on the data logger using a multiplier and possibly an offset. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent checks that vary in proportion to the logged value.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier). If the necessary transformations are fully traceable there is no effect on quality code.

Table E 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	E 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	E 3.9 E 2 3.6
Solution(s)	Turbidity data in the wrong units are not recoverable. File turbidity data in the units in which they were measured. For instrument configuration errors, apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	E 3.9 4.7
Metadata	QC 200 applies to data from non-NEMS compliant instruments. Equipment and Stationarity Comments may also be needed. If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	E 5.1 E 5.2.2 E 5.2.7 E 5.2.6 6.2.3 E 5.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section E 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table E 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	E 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with discharge data from the same site.	Fig. 18 Fig. 26 E 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or E 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 E 5.2.5 6.2.3 E 5.2.4 6.2.3 E 5.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing turbidity data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is up to a day within an event or cycle, or period of stable conditions

- a longer period may be one or more days up to one week, and
- an extended period may be a week or more.

Turbidity is highly variable, and the data can be quite specific to the location at which the turbidity is measured. Catchment and local factors combine to influence the at-site turbidity. When selecting and applying an appropriate method for resolving missing data, the likely variation at site must be taken into account with consideration of the duration of the period missing (see Appendix E.1).

Note: Catchment factors include the combination of rainfall, soil type, landcover, land use, drainage network complexity and sediment composition each with its own spatial and temporal distribution and variability. Dissolved colour and microscopic algae influence low turbidity readings but are not directly related to suspended sediment composition and transport. Other influences may change rapidly or arise from very small, localised areas, e.g. runoff from a localised thunderstorm cell, or input or disturbance due to some upstream activity.

A continuous period of a week or more missing shall only be filled with backup or secondary data, or synthetic data corroborated by at least weekly supplementary measurements within the period synthesised.

For turbidity, backup data are data obtained from another sensor at site of the same type and conforming to the same standard and measurement units as the primary sensor. Secondary data may be obtained from another sensor at site of a different type, standard and/or units but for which a reliable relationship between it and the primary turbidity data can be derived. Supplementary measurements include verification data and results of water samples intended to fill gaps and/or calibrate surrogate relationships.

A maximum duration of one month for any period of infill is recommended, although this is dependent on:

- the typical and expected variation in turbidity at the site
- the possibility of a significant event having occurred, and
- reliability of the relationship(s) used to generate the synthetic record.

If the turbidity record is intended only as a surrogate for suspended sediment concentration, gaps must be marked (see Section 4.16) but infilling of gaps can and should be left until the series is converted to suspended sediment concentration (see Section 8.2 of NEMS *Fluvial Suspended Sediment Load* v0.1.1).

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in turbidity series, see Appendix E.1 to this Annex.

Table E 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	E 3.11
Evidence	Expected timestamps are not present in the raw data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire, or parts of events are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 E 2 3.6
Solution(s)	Use at-site backup, secondary and/or supplementary data, and manual observations where available, OR e) if brief with stable conditions, interpolate across gap f) if short with stable conditions, infill with baseline or a curve g) if longer period or unstable conditions, apply methods to infill with synthetic data, or mark the gap h) if an extended period, apply methods to infill with synthetic data if within recommended maximum duration, or mark the gap, or note a temporary site closure.	App. E.1 E 3.11 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the alternate record and manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 E 5.2.4 6.2.4.6

4 Post-Processing Data Manipulation

4.1 Combining two concurrent at-site records

At sites that experience high sediment loads it may not be possible to cover the range of likely values during high turbidity events and obtain turbidity readings with sufficient resolution at low turbidity using the same instrument. In such cases two instruments of the same type, standard, and measurement units, but different range and resolution, may be installed (see Figure E 9).

Record from the two sensors should be processed simultaneously with one used to aid verification of the other. Once verified, the two records must be combined into a single time series for archiving. The value at which to accept one record over the other is dependent on issues of over-ranging and sensor saturation of the lower range instrument (see Section E 3.7) and may not be the same for every event. Small time corrections may also be required to eliminate any steps due to timing issues at the junction of the lower and full range series.

4.2 Transformations

It is not possible to mathematically convert between different turbidity measurement units. There are no physical formulae for this purpose (see Annex E Section 3.9).

Transformations that apply a graphically or statistically derived relationship may be used for infilling gaps (see Appendix E.1) and conversion of turbidity as a surrogate to the target variable, usually suspended sediment concentration (see Annexes E and F of NEMS *Fluvial Suspended Sediment Load* v0.1.1).

5 Metadata

5.1 Quality Coding

The relevant quality coding flowchart may be found in NEMS *Turbidity (Measurement, Processing and Archiving of Turbidity Data)* or in *NEMS National Quality Code Schema*.

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Guidance on how and when quality code must change as a consequence of data processing is provided in Section E 3 of this Annex.

Data from any sensor not conforming to ISO 7027 are not NEMS-compliant and must be quality coded QC 200.

5.2 Example turbidity comments

The following are templated examples of comments for turbidity stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time-series of turbidity) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Turbidity
Initial comment for *<river name>* River turbidity at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[15]

[15] from *Catchments of New Zealand* (SCRCC, 1956).

The site is situated <*distance to coast*> km from the mouth at grid reference <*map co-ordinates and type*[16]>
Drains <*catchment area to site*> km^2 and channel is <*describe main bed/bank features e.g. willow-lined alluvial, silt bed with erodible grassed banks, rock-lined gorge, etc.*>
Additional information: <*site purpose, including whether a surrogate for suspended sediment; anything relevant to general interpretation of the record; persistent adverse conditions at site (e.g. biofouling, bed mobility, very high sediment loads); upstream or downstream site(s) also measuring turbidity*> <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured continuously at this site: <*list variables e.g. water level, flow, backup and/or secondary turbidity*> Samples are collected and analysed for <*list variables measured by laboratory analysis*>
The local recording authority is: <*name of recording/archiving agency*>

Lake station

Type: Site
Measurement: Turbidity
Initial comment for <*name of water body*> turbidity at <*site name*>
Site number <*network number, ID or code*> on river <*river number*>[1]
The site is situated <*distance to outlet*> km from the outlet at grid reference <*map co-ordinates and type*[2]>
Drains <*catchment area*>km^2 of <*river name*> River catchment
Lake area is <*surface area*>km^2 and level is controlled by <*describe features e.g. natural outlet, dam, weir etc.*>. Inflow source is <*groundwater, rainfall, snowmelt, glacial etc.*>
Additional information: <*site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. biofouling, recreational boating, algal blooms, drying out, etc.), site(s) on inflows also measuring turbidity*> <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured continuously at this site: <*list variables e.g. water level, flow, backup and/or secondary turbidity*> Samples are collected and analysed for <*list variables measured by laboratory analysis*>
The local recording authority is: <*name of recording/archiving agency*>

5.2.2 Equipment Comment examples

Type: Equipment
Measurement: Turbidity
Recorder installed on <*dd-mm-yyyy hhmmss*> is a <*describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.*> data logger, recording <*describe logging and sampling regime e.g. instantaneous*

[16] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

readings at fixed intervals of x-minutes>. The turbidity sensor is a <*type and output e.g. 0-20mA ISO 7027 compliant optical back-scatterer reporting in FNU, etc.*> installed in (*or* on) <*brief description e.g. weighted cable x-m below moored buoy, conduit attached to pier, steel box section secured to bank etc.*>. Sensor range is <*range and units*> with resolution of <r*esolution and units*> and nominal accuracy of <*accuracy specification*>. Sensor output is converted to turbidity units by <*details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset*>. Sensor calibration is valid for <*calibration period*>. <Zero point is checked annually>. Site is visited <*state frequency e.g. weekly, monthly, or as required from inspection of the data*> to clean the sensor and obtain verification data. Data is collected by <*method e.g. telemetry and occasional manual download*>.

Create similar but separate comments for any backup sensor or secondary source of continuous turbidity data at the site, to avoid the comments becoming too long and complex.

Type: Equipment
Measurement: Turbidity
Verification data is obtained <*state frequency*> by <*describe method and instrument(s) used e.g. readings from handheld instrument positioned as close to the sensor as possible, or grab samples, or by auto-sampler, then laboratory analysed etc.*> <*Add other relevant information such as range, units and calibration frequency of the handheld; collection location and laboratory method for water samples; any other intended uses for the data e.g. developing surrogate relations*>.

5.2.3 Operational Comment examples

Type: Operational
Measurement: Turbidity
Sensor moved on <*dd-mm-yyyy hhmmss*> from true left bank bridge pier to true right bank bridge pier. New location provides more bed clearance at low flows. Sensor optics are now positioned at <*reduced level and datum, or equivalent stage*>.

Type: Operational
Measurement: Turbidity
Sensor cleared of silt and debris on <*dd-mm-yyyy hhmmss*>. Turbidity briefly elevated by activity then settled 10 FNU lower than before.

Type: Operational
Measurement: Turbidity
Verification sample on <*dd-mm-yyyy hhmmss*> was collected 20m from the sensor due to high flood preventing access. Significant deviation from recorded value is expected.

Type: Operational
Measurement: Turbidity
Sensor replaced on *<dd-mm-yyyy hhmmss>* with an ISO 7027 compliant instrument. Refer to the associated Equipment Comment for its specifications.

Type: Operational
Measurement: Turbidity
Zero-point validation completed on *<dd-mm-yyyy hhmmss>* with no offset apparent and no action required.

5.2.4 Data Comment examples

Type: Data
Measurement: Turbidity
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>. <Add any other relevant information such as why the gap has not been filled>.*

Type: Data
Measurement: Turbidity
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Turbidity
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>*. Record generated by *<describe non-statistical method e.g. graphical extension of turbidity-discharge event loop, manually inserting values to complete the rise or recession, etc.>* with reference to the following data *<list sites, variables, and periods used>. <Add information relevant to reliability of the synthetic record e.g. flow conditions, antecedent rainfall, suspected sensor saturation accounted for (or not) in period etc.>. <Add limitations on usefulness e.g. not recommended for use as a surrogate measure>.*

Type: Data
Measurement: Turbidity
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>*. Record generated from *<provide the relation e.g. state the equation(s) or function(s)>* obtained by *<method e.g. simple least squares or multiple regression, LOWESS etc.>* with input data *<list sites, variables, and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. not recommended for use as a surrogate measure>.*

Type: Data
Measurement: Turbidity
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Turbidity
Gap in record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to the sensor over-ranging beyond *<top of calibrated range and units>*. Period is not able to be infilled because the autosampler also failed.

Type: Data
Measurement: Turbidity
Maximum calibrated range of the sensor *is <value and units> <Add date/time range if relevant>*. Turbidity exceeding this range is assigned the stated maximum value when logged. The record interpolates and is therefore a continuous but censored series.

Type: Data
Measurement: Turbidity
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Cause is unknown but may be due to (or affected by) *<describe suspected cause>. <Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Turbidity
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Data resampled using a track minima filter from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to minimise noise due to frequent elevated readings caused by *<identified cause>*. <Some bias may still be present>. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of C mm, linear drift adjustment of* C_0*mm to* C_1*mm etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x FNU or > x' FNU not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

Transformations applied to a turbidity record prior to its archiving must be included in the turbidity metadata. Transformations to convert turbidity records intended as surrogate, to the variable of interest, are outside scope of the turbidity metadata (see Section 6.2.4.8).

Type: Transformation
Measurement: Turbidity
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling (and/or offset) error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

5.2.7 Stationarity Comment examples

Type: Stationarity Measurement: Turbidity Change of sensor location on *<dd-mm-yyyy hhmmss>* caused a -3 FNU step-change in recorded baseline turbidity, verified by subsequent adjacent independent readings. Data has not been adjusted to eliminate the difference.

Type: Stationarity Measurement: Turbidity Sensor replaced on *<dd-mm-yyyy hhmmss>* with an ISO 7027 compliant instrument conforming to NEMS Standard (see associated Operational Comment). Prior record, measured in (*or* by) *<state key difference(s) in sensor characteristics, measurement units etc.>* is available from *<state the site and/or data source and/or variable/measurement under which the previous data is stored>.* The two series are not homogenous for turbidity <but may be used with appropriate calibrations to derive a homogenous series of suspended sediment concentration>.

Type: Stationarity Measurement: Turbidity Data is a censored series. Maximum sensor range and therefore censoring threshold was changed on *<dd-mm-yyyy hhmmss>* from *<x FNU>* to *<x' FNU>*. Refer to the corresponding Equipment Comment for sensor details.

Stationarity Comments can also be used to capture and collate information about historical methods and data.

6 Preservation of Record

Refer to Section 8 of this Standard.

Appendix E.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, or estuarine)
- the duration requiring infilling
- the availability of other relevant time series, such as:
    - at-site backup turbidity data
    - at-site secondary turbidity data
    - at-site flow or water level data
    - upstream or downstream turbidity, flow, or water level data
- the likelihood of:
    - stable flow conditions during the period missing
    - heavy rainfall within the catchment during the period missing
    - other upstream or localised sediment input and/or disturbance events, e.g. engineering works, dam releases, recreation
- availability of supporting observations and other evidence such as:
    - verification readings
    - water sample results
    - ad hoc observations, and
    - photographs and/or video.

2 Recommended Methods

The following methods are candidates for infilling gaps in turbidity records:

- inserting one or more of:
    - at-site backup turbidity data
    - values derived from at-site secondary turbidity data
    - water sample results collected with the purpose of infilling missing periods such as anticipated over-ranging
    - other at-site ad-hoc and manual observations, including verification readings and water sample results collected for surrogate calibration purposes
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for short periods in stable conditions

- mathematical calculation or copying from a reference trace to infill a period known to be in recession
- generating a record from a relationship between turbidity and discharge.

2.1 Infilling with backup turbidity data

Backup turbidity data must be verified as for the primary record for the period it is required, including assessment for over-ranging and/or sensor saturation, or sensor exposure, that would preclude its use.

Local effects and any differences in instrument range and resolution make it unlikely the two records will directly overlap. Small time corrections may be required to eliminate any steps due to timing issues at the junction of the primary and infill backup series.

2.2 Infilling using secondary turbidity data

Secondary turbidity data may be collected at site from a different turbidity sensor or a suspended sediment sensor.

Note: Suspended sediment sensors usually also measure light transmission or scattering but their output is calibrated directly to suspended sediment concentration.

Using a recent period of overlapping primary and secondary data covering as much of the anticipated range of the missing primary turbidity data as possible:

- derive a relationship between the primary and secondary data
- fit one or more functions to the relationship

  Note: When fitting functions be mindful of issues of over-ranging, sensor saturation or exposure, and interference.

  Note: Locally weighted scatterplot smoothing techniques that fit a continuously varying function over the turbidity range are preferred. Simple regression techniques may be used with care to ensure regression equations are appropriate over the full range of data to which they will be applied, for example, so as to not produce negative turbidity values. This may require the relationship to be partitioned by time and/or range of values.

- apply the function(s) to transform secondary data for the period of missing primary data
- insert the transformed data into the primary record
- make minor adjustments if needed at the junction of the primary and infill series to eliminate any steps between them.

2.3 Infilling using water samples collected for this purpose

Samples may be collected manually or by auto-sampler.

If collected at adequate temporal resolution, results of laboratory analysis of the samples (using the same measurement protocol and reported in the same measurement units as the primary data) may be inserted directly into the primary record and the interpolation engine left to create the continuous record.

If there are insufficient samples to ensure adequate form of the data, i.e. resolution and definition of turbidity peaks and recessions is poor, the sample results should be treated as ad-hoc observations (see Section 2.4 of this Appendix E.1).

If the measurement protocol and units are different the samples must be treated as secondary data (see Section 2.2 of this Appendix E.1).

2.4 Infilling with ad-hoc and manual observations

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected that can be inserted directly into the record to avoid missing data. Most often these will be readings using a handheld meter, but they may be results from laboratory analysis of samples taken at the time. In either case their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

Verification readings, and water samples intended for calibration of the conversion relation when turbidity is measured as a surrogate, may also be used to assist with infilling a gap. These observations can and should be incorporated as one or more points through which any synthetic infill must pass.

If the turbidity record is intended only as a surrogate, infill any gaps directly in the target record once generated (see Section E 3.11).

2.5 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section E 3.11) in a turbidity record is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or recession curve. A straight line should only be used for brief periods.

2.6 Infilling a recession or baseline

These methods can be used if a longer gap (see Section E 3.11) occurs over a period of expected declining or baseline turbidity where flow is known to be in recession, upstream turbidity is also declining or at baseline respectively, no rainfall has occurred in the vicinity during the period, and local sediment disturbance is unlikely.

Baseline values may be extended forward to infill the gap.

For recessions:

- it may be sufficient to copy the recession of an upstream turbidity station, or a previous recession at the same site, or

- a recession can be estimated by connecting the adjacent periods of good turbidity record with a straight line or smooth curve on a semi-logarithmic plot, or
- the recession may be estimated from the discharge series using a suitable relationship (see Section 2.8 of this Appendix E.1).

2.7 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Because of the variability of turbidity over time and between sites, regression between turbidity records from different sites shall not be used.

Regression between discharge and turbidity at the same site is more acceptable but because of turbidity variability between individual events, other than for filling a recession (see Section 2.6 of this Appendix E.1), the method described in Section 2.8 of this Appendix E.1 is preferred.

Regression between at-site turbidity and suspended sediment concentration is an acceptable method of obtaining the relationship needed to infill using secondary data (see Section 2.2 of this Appendix E.1).

Do not force the regression through zero. If zero turbidity is predicted, its significance and likelihood must be assessed. Regression analysis that results in periods of predicted negative turbidity or implausible zero turbidity should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.8 Infilling using relationships with discharge

2.8.1 Characteristics of turbidity–discharge relationships

Relationships between turbidity and discharge typically show substantial variability over time and from site to site. This variability stems largely from the dependence of turbidity on the concentration and characteristics (mainly grain size) of suspended material, which can vary, for any given discharge:

- within high-flow events
- between events
- seasonally
- over multi-year periods, because of legacy effects of large catchment-disturbing events (e.g. rainstorms, landslips, earthquakes, change of land cover and/or land use), and
- from catchment to catchment.

Although suspended sediment is generally understood to be preferentially carried on the rising limb of a discharge hydrograph, the timing of peak turbidity typical for a site may be before, with, or after the peak discharge (see Figure E 10).

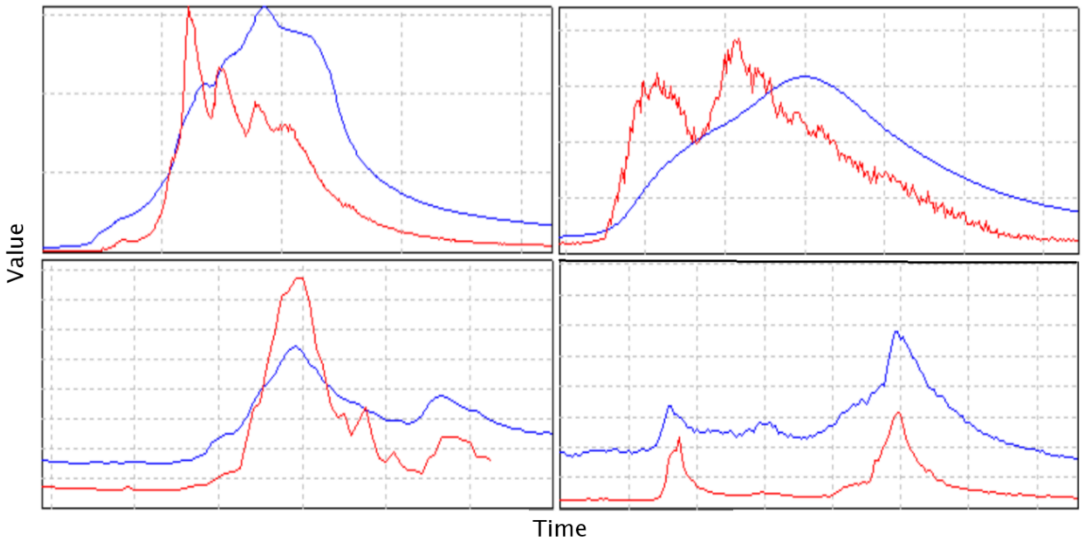


Figure E 10 - Examples of the relative timing of peak discharge (blue) and peak turbidity (red) in three North Island rivers: a large catchment with disparate tributaries (top left), a medium-sized catchment with high loads of fine sediment (top right), and a smaller mountain catchment with rapid runoff and homogenous sediment (bottom).

Within-event variability can be relatively simple, affected only by some hysteresis between rise and fall, or complex, where, for example, there is staggered arrival and varying durations of different contributing inputs from different tributaries.

The turbidity–discharge relation may therefore have one or more of the following characteristics:

- simple bivariate, i.e. turbidity able to be adequately and uniquely predicted from only the at-site discharge
- stationary in time
- varies with the rate of change of discharge
- varies with suspended sediment composition, which may be source dependent, e.g. one or more specific tributaries, or bank versus bed erosion
- event-dependent hysteresis, i.e. the relation forms a loop that varies with each event
- varies seasonally, and/or
- changes over time.

2.8.2 Developing and applying turbidity-discharge functions

Any turbidity–discharge relation shall be developed using periods of reliable turbidity and discharge record.

The form of function(s) selected, and the method(s) used to apply them, must be consistent with the typical patterns of variability in the turbidity–discharge relationship at site (see above Section 2.8.1 of this Appendix E.1). Options include:

- regression equations (simple, linear, polynomial, or multiple) applied using transformations or lookup functions
- locally weighted scatterplot smoothing techniques that fit a continuously varying function over the turbidity range using lookup functions, or
- one or more rating curves, that may be linear or non-linear, simple, or looped, change over time, and be applied and managed by the time-series manager's rating engine.

If a relation is applied to other periods of missing turbidity data where corresponding discharge range is greater than that used to derive the relation, the synthetic turbidity record generated must remain within the sensor's calibrated range or be censored.

2.8.3 Infilling truncated events

When turbidity data are missing or have been discarded because the sensor over-ranged or saturated, generate synthetic infill from a looped turbidity–discharge relation as follows:

1. Plot processed turbidity versus discharge, linking the data points in their time sequence (see Figure E 11).
2. Identify where the loop is incomplete or truncated beyond the maximum recorded turbidity, and/or is affected by saturation (i.e. the peak is inverted) (see Figure E 11).
3. Extend the two ends of the reliable data until the extensions intersect to complete and close the loop (see Figure E 11). There must be enough reliable adjacent data for the extensions to converge. If convergence within a plausible range of predicted turbidity values is not possible another infilling method must be used, or the period remain as a gap.
4. Read values from the plot to obtain two turbidity–discharge functions, one each for the missing portions of the rising and falling limbs of the turbidity event (see Figure E 11).
5. Apply the functions to discharge values as applicable to complete the record of the turbidity event (see Figure E 12).

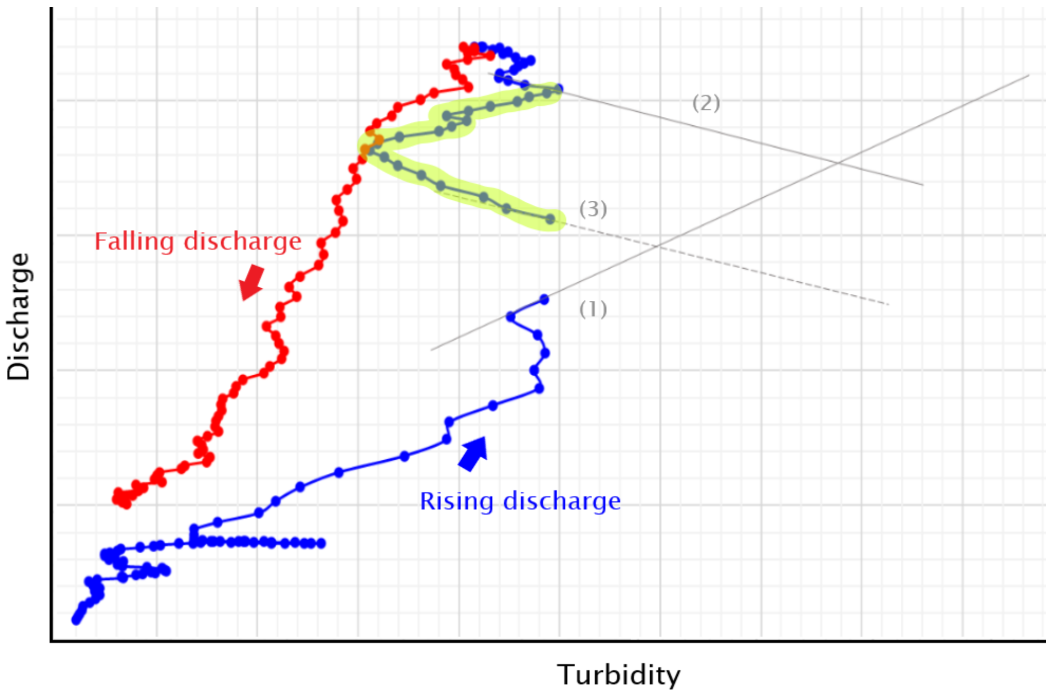


Figure E 11 – An example of a turbidity–discharge event loop with a gap due to over-ranging and a possible saturation inversion (highlighted). If saturation is assumed, extensions (1) and (2) extrapolate and close the loop. If the sensor is believed to have over-ranged but not saturated, extensions (1) and (3) apply (see also Figure E 12).

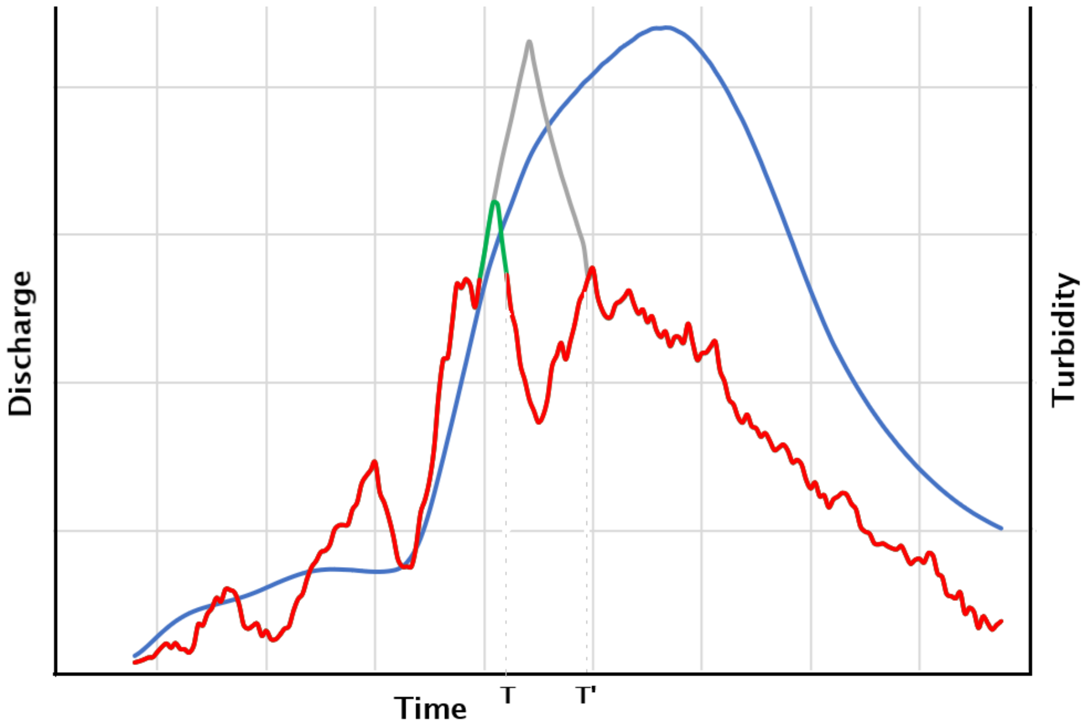


Figure E 12 - Example of two possibilities to infill a turbidity record using the extensions shown in Figure E 11. If sensor saturation is assumed between time T and T', equations for straight lines (1) and (2) in Figure E 11 produce the grey turbidity peak. If the dip in recorded turbidity (red line) is not due to saturation and is retained, equations for straight lines (1) and (3) in Figure E 11 produce the green turbidity peak.

Annex F Water Meter Data Processing

1 General Overview

1.1 Normative references

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

- NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)*
- *New Zealand Water Measurement Code of Practice* (Irrigation New Zealand, 2018)

Where reference is made from this Annex to specific sections of the above NEMS document, the title is abbreviated and version stated, i.e. "NEMS *Water Metering* v3.1.0". Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

Reference to specific sections of the *New Zealand Water Measurement Code of Practice* (Irrigation New Zealand, 2018) ('the COP'), an industry best practice guide to meeting requirements of the Resource Management (Measurement and Reporting of Water Takes) Regulations 2010, is via NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)*.

The COP precedes the Resource Management (Measurement and Reporting of Water Takes) Amendment Regulations 2020, implementation of which is staged from September 2022. The Amendment Regulations increase the required frequency of data recording and reporting but otherwise do not affect data processing procedure.

1.2 Scope of this Annex

While NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)* has a current focus on near real-time data, the processing guidance contained in this Annex is applicable to any continuous time series of water take measured using in-situ water meters in full pipes and managed in electronic form as value in interval data (see Section 1.1).

The data may be collected and logged pulse by pulse (i.e. 'on event' of a known volume, also known as 'heartbeat'), or as incremental total volume in fixed regular intervals of time, and transmitted:

- via telemetry, pulse by pulse in real time, or pushed or pulled in batches at some regular polling interval in near real-time
- by upload to servers using, for example, FTP or cloud services or webpages, at intervals ranging from near real-time to annually that satisfy information needs and consent and regulatory requirements

- by import from CSV, XML or WML2 files (or similar data exchange format as desired by the agency), submitted daily, weekly, seasonally, or annually according to consent and regulatory requirements, or
- by transfer or import from a field device when the data logger has been manually downloaded during a service visit.

1.3 Effect of data type

The data may be captured as a flow rate or by counting pulses generated when a known fixed volume has passed through the meter. The data are required to be stored as a volume in the interval, achieved by integrating flow rates or totalling pulses.

The intervals may be of fixed duration with regular timestep or variable with irregular timesteps, including pulse by pulse timestamped as they occur, referred to as 'heart' or 'on-event' data logging.

Values may be volume in preceding interval or cumulative volume with time. Some devices, e.g. Harvest units, log cumulative volume by counting the pulses themselves rather than replicating the meter totaliser display, i.e. differences between successive stored values should match the simultaneous change in meter totaliser readings but the numbers logged will not necessarily be the same as those displayed by the meter totaliser.

The data in all cases are incremental with interpolation. Each value stored represents accumulation at a constant rate in the interval between adjacent timestamps that can be apportioned to any part-interval between the timestamps.

Note: Discrete totals are not considered suitable for water meter data because requesting a total for a period between adjacent data elements will return a value of zero.

For volume in preceding interval data, each timestamp also sets the start of the next value's accumulation. Water take is considered to have ceased when a zero value is encountered in the record. The period of no take is the time between the immediately preceding timestamp and the timestamp of the zero value.

Some time-series managers can store water meter data as cumulative totals and resolve the data to volume in the interval without explicit manual transformation, e.g. Hilltop data type 'Meter Reading'. With this data type, a period of no take is indicated by successive data elements of the same value.

'Heart' and 'on-event' systems only log when a pulse or change of state has occurred. When an interpolating incremental data type is used for this data, zero values must be inserted into the record to define periods of no take. Thus, zero values generated by the logger and stored for the purpose of confirming the site is operative alter interpretation of the data. Logging a different variable, e.g. battery voltage, or generating status values into a separate data storage area avoids this problem.

Hilltop Software provides a hybrid data type, 'Thirty minute Rainfall', for water meter 'event' data whereby, instead of storing zero values in the record, the software inserts a zero when reading the stored data if there is a period of more than thirty minutes between timestamps. In other words, zero take is assumed between the timestamp of the previous stored value and thirty minutes prior to the current value, and the apparent rate of take derived from the current value increases.

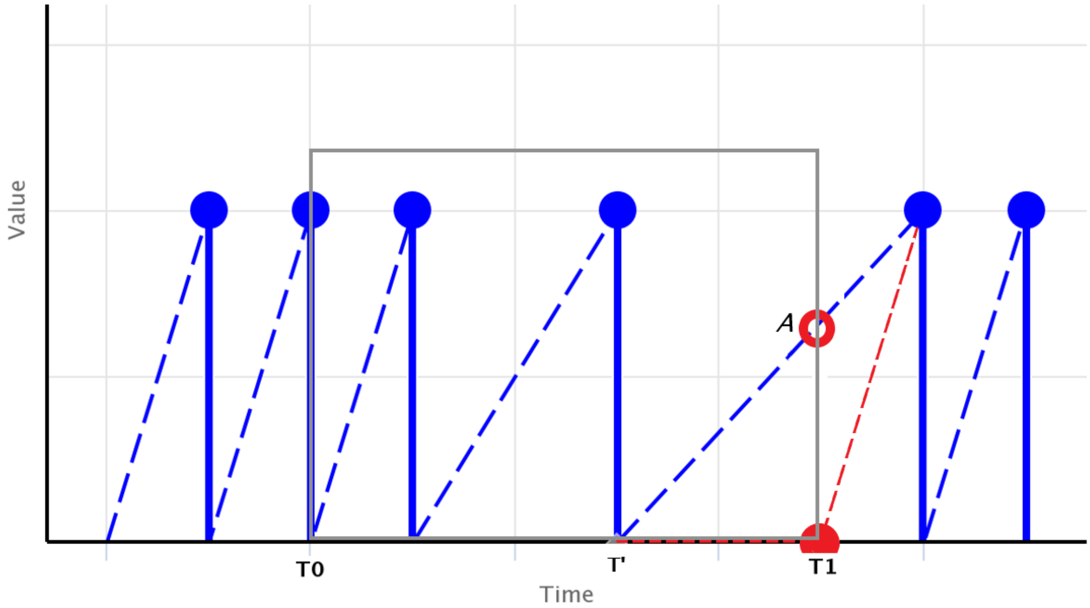


Figure F 1 – An example of how inserting zeros into a record of 'on-event' ('heart') pulses, stored as an interpolating incremental data type, alters interpretation of the data. If a zero value is inserted at T1 the total volume in interval T0 to T1 (grey box) is two pulses, whereas without the inserted zero value the total is two pulses plus the interpolated value A (the pro-rated portion of the next pulse assuming a constant rate from T' (blue dashed line)). If the volume between T' and T1 was queried, without a zero inserted at T1 the value returned is A, but if a zero value is inserted at T1 the value returned is zero.

It is critical to accuracy and interpretation of water use data that capture method and data type used to store the data are understood and correctly matched. Both must be comprehensively described in the time-series metadata.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying water meter data:

- meter details:
  - the unique meter identifier used by the consenting agency to associate the meter with its corresponding consent and location of abstraction, and with the site name or number under which the data and metadata are stored if different from this identifier

Note: Over the lifetime of a consent a meter identifier may have several meter serial numbers associated with it as all or parts of physical meters are replaced.

  - meter type, model, manufacturer, and serial number(s) (see Section 1.4 of NEMS *Water Metering* v3.1.0 (refers to Section B2.1.5 of the COP))
  - the instrumentation standard and accuracy class; for example, OIML R49-1 class 2 (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - units, resolution, and display range of meter totaliser (see Section 1.3 of NEMS *Water Metering* v3.1.0 (refers to Sections B2.1.2, B2.1.4 (both), and B2.1.6 of the COP))
  - form of output to data logger, e.g. flow rate or pulse, including details of any signal conversion applied (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - date, laboratory, and identifier for the wet lab certification (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - date of installation and name of installer (see Section 3.4.3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.4, B2.1.1 and B2.2.1 of the COP))
  - date and time, verifier, method, and result of each verification (see Section 4.1 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4 of the COP)), and
  - date, time, and reason for any change of, or to, the meter (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP) and Sections B2.1.8 and B2.1.9 of the COP)
- relevant regulatory and planning context:
  - type of take, e.g. surface or groundwater
  - use type, e.g. crop irrigation, public water supply, snow making
  - consent number, decision, and conditions
  - service agreements with third party providers

    Note: Third party providers are intermediaries between the consent holder and consenting authority that may design, install and/or verify abstraction and/or metering systems and/or collect and/or host water meter and/or flow measurement data.

  - regional rules, e.g. minimum flow restrictions
  - water allocation designation and/or water management zone and/or plan
  - whether seasonal monitoring is permitted, i.e. the data logger is switched off in the off-season

    - any provisions for temporary exemptions from abstraction controls and records of those exemptions.
- deployment details:
    - installation report, including as-built diagram and photographs, (see Section 3.4.9 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.11 of the COP))
    - applicable flow rates (i.e. Q1, Q2, Q3 and Q4 as described in the NEMS *Glossary*) and whether variable rate of take is possible
    - measurement type, e.g. flow, volume, pulse count, or meter reading
    - units, resolution, recording interval, and time zone of the logged data
    - inspection and maintenance records (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP))
    - meter location by GPS, and with respect to point of abstraction (see Section 2.1 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1 and B2.3.6 of the COP))
    - details of other takes and/or meters on the same distribution network (see Section 2.1 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1 and B2.3.6 of the COP))
    - description of any issues potentially affecting accuracy of recording, e.g. water quality, nearby electrical equipment (see Section 3.4.1, of NEMS *Water Metering* v3.1.0 and Sections B2.2, B2.3.5, B2.3.12, D1.3.1, and Appendices of the COP)
    - date, time, and reason for any change to the installation, including location of the meter or configuration of pipework (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP) and Sections B2.1.8 and B2.1.9 of the COP)
    - details of any backup, secondary and/or supplementary data logged, e.g. site status flags, tamper flag, site power supply, portable pump GPS location, rainfall, soil moisture, bore water level, pump run hours, and/or pump electricity records
- verification of data collection:
    - method(s) used for data verification readings, including who reads the totaliser at what frequency and how and where the readings are provided and stored
    - all records of inspections as detailed in Section 4.2.2 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4.7 of the COP)
    - all results of performance tests described in Section 4.2.3 of NEMS *Water Metering* v3.1.0.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

2.2.1 Fixed interval totals

- Use 15-minute volumes, or volumes at the recording interval if fixed and greater than 15 minutes, to check for anomalies such as:
    - spuriously high values indicative of flow instability or interference (see Section F 3.3)
    - inconsistent patterns of use indicative of possible unmarked gaps in the data (see Section F 3.8)
    - out of range values, including negative values (see Section F 3.3).

    Note: If the time-series manager censors bar plots to positive increments use a different method to check for negative values.

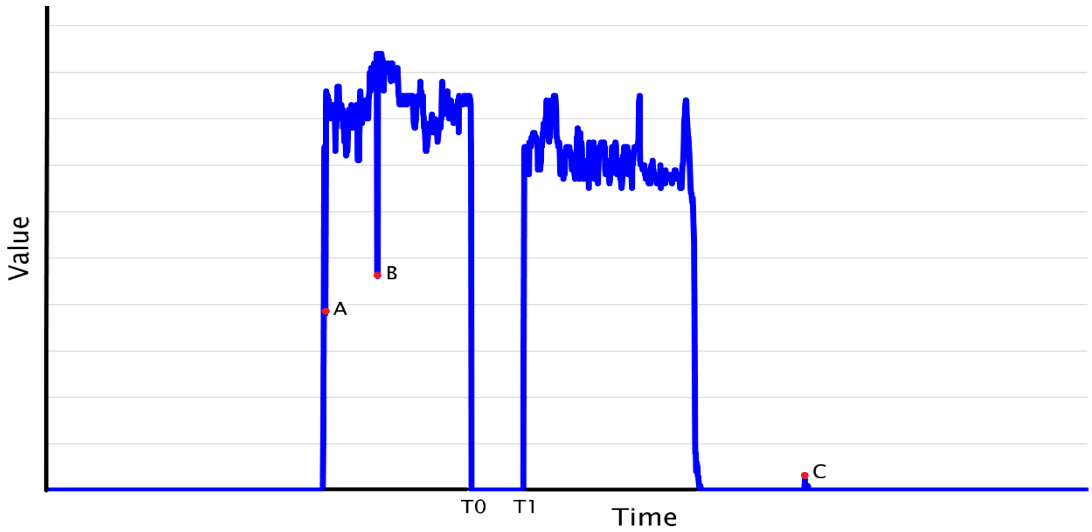


Figure F 2 – An example plot of hourly values in a 3-month period showing values at A and B that are half their adjacent values (data elements are missing and because of the incremental interpolating data type the next logged value is averaged over a two-hour interval), values of zero between T0 and T1 that may be missing pulses, and very small values at C that may be noise.

- Use interval(s) consistent with consented limits, e.g. hourly, daily and/or weekly maximum take, to review periods of apparent non-compliance for possible data recording anomalies.

2.2.2 Cumulative totals

Plots of cumulative totals allow rapid visual assessment of anomalous patterns and timing of apparent use and/or trends that require further investigation, especially if pump cycles are frequent and/or irregular (see Figure F 3).

A multi-year plot, for example over the duration of the consent, annotated with the date and time of each verification of the installation and/or any change in, or of, the meter or its installation, assists with identifying:

- any stationarity of record issues arising from meter and/or installation changes
- whether drift, if any, was gradual over the period between verifications
- when drift became significant if it was not gradual for the entire period.

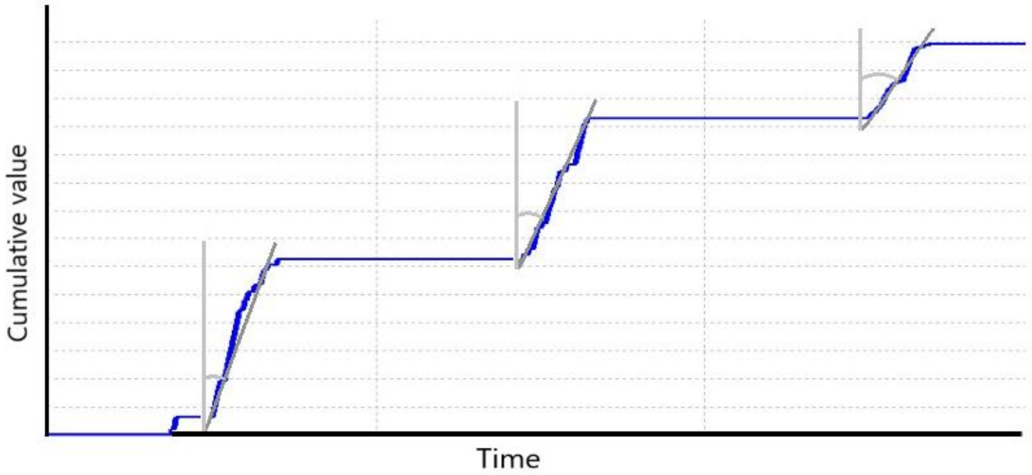


Figure F 3 – An example cumulative plot of three water years showing an apparent 'false start' to the first season and declining water use. Slope of the trace represents rate of use. Average rate per season (grey sloping lines) declines with volume each year and should be investigated and confirmed to not be due to deteriorating metering equipment.

2.2.3 Comparisons

- Use comparisons to:
  - cross-check the data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Use fixed interval and cumulative totals to check for anomalies. Compare the logged data with:
  - any backup, secondary or supplementary data from the same site (see Section F 2.1) that may confirm a common data quality issue, e.g. power supply or data logger failure, or identify issues of timing, scale, or tampering
  - a reliable and representative record from another site (see Section F 2.2.4).
- Use a common totalling interval that is at least as long as the longest recording interval of the data to be plotted.

  For example, if comparing an 'on-event' water use record with standard daily rainfall, use a totalling interval of 24 hours from 9 a.m. or the daily rainfall data will be apportioned and thus misrepresented.
- If using a backup record for comparison, there should be no difference in scale or event timing other than due to resolution and/or recording interval differences.

- When comparing with other sites, proportions, patterns, and timing of use should be consistent with how the various elements of the abstraction and metering configuration interact.
- Compare the entire water year (to date if not yet ended) with previous years and investigate any magnitude, timing, and patterns of use inconsistent with earlier record.
- Use cumulative plots and/or period totals to confirm editing and adjustments. Compare the data before and after:
    - editing applied, and/or
    - infill of missing record (Figures F 4 and F 5), and/or
    - rescaling of the data applied to correct for configuration (set-up) errors (Figure F 5).

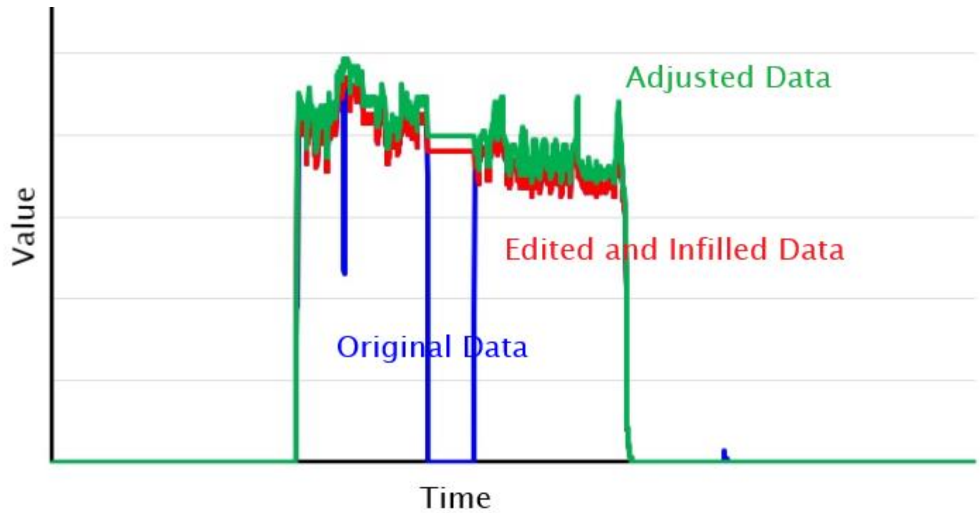


Figure F 4 – An example of a comparison plot of hourly volumes before and after removal of off-season noise and infilling of missing record, followed by a scaling adjustment that compensates for the meter under-reading as revealed by later verification.

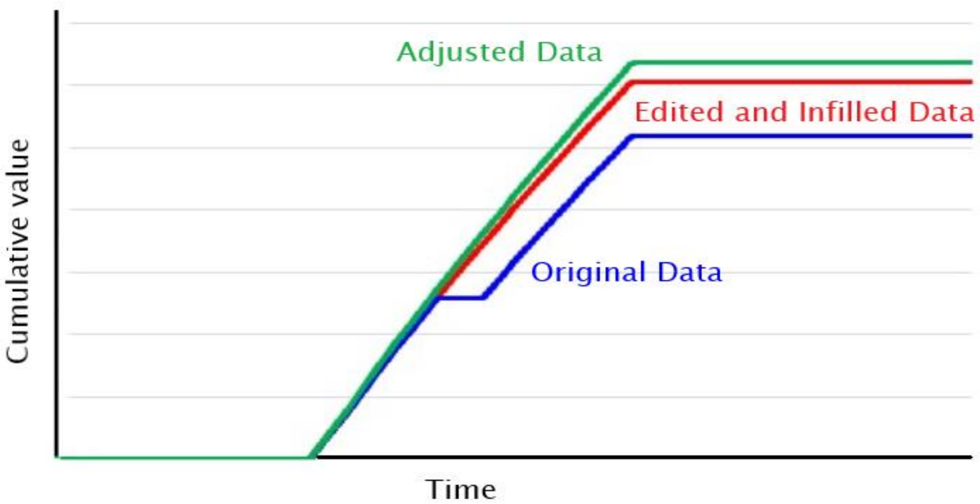


Figure F 5 – The cumulative version of Figure F 4, showing cumulative volume before and after removal of off-season noise and infilling of missing data, followed by a scaling adjustment that compensates for the meter under-reading revealed by later verification.

2.2.4 Between-station comparisons

- Criteria for selecting a suitable water use comparison site are similar to those for selecting a suitable infill record donor site (see Appendix F.1 Section 2.5). In any case, the comparison site(s) for any assessment of recorded volumes must be part of the same metered distribution network.
- Use between-station comparisons to:
  - check for transient problems that may occur and resolve between site visits, such as interference
  - identify when a problem detected during a site visit arose, e.g. loss of pulses to the data logger
  - investigate problems that develop gradually and may not be apparent from a single inspection, such as deterioration of the meter or leaks.
- Initial identification of timing issues, e.g. commencement of a seasonal take or periods of restricted take, may be assisted by comparing with other takes in the vicinity, or local rainfall, soil moisture, groundwater levels and/or source stream flows but these comparisons cannot be used to assess recorded volumes.

2.2.5 Portable pumps

- Use mapping services to check that GPS location data collected from portable pumps are feasible (e.g. aligns with consented abstraction locations, does not plot in the ocean if supplying fresh water).
- If a pump has been used in multiple locations, confirm:
  - water use data associated with each location has been filed to the correct site, and
  - no water use data have been lost, and
  - all water use recorded is associated with a recognised and authorised abstraction location.

2.3 Verification

2.3.1 Verification of installation

Requirements are set out in NEMS *Water Metering* v3.1.0 Section 4.1 (refers to Sections B1.1.2 and B2.4 of the COP).

Verification of the installation must be carried out by a suitably qualified accredited person to confirm the metering system meets the accuracy required by the Regulations:

- on commissioning, and
- after a change to or of the meter and/or installation, and
- at intervals or on events as required by the conditions of consent, or
- otherwise at no more than five-yearly intervals.

For quality coding purposes, verification of the installation is assessed in terms of currency, i.e. if the last verification has 'expired' because more than five years has elapsed (or less if consent requires), or the installation has been altered, all data recorded between expiry date and the next installation verification must be quality coded QC 200 (non-verified).

However, if an overdue installation verification is completed no later than twelve months after expiry and before the next irrigation season, and the meter is found compliant, quality code of the QC 200 data may then be upgraded as if verification had been completed within the required time.

When determining the result of an installation verification, uncertainty of the method is taken into account (see Section B2.4.10 of the COP).

For example: If uncertainty of the independent reference reading is ±2% (accounting for all error sources) and the installed service meter total differs from this reference by 3% then the meter complies with the ±5% accuracy requirement of the Regulations. If the service meter total differs by 4% compliance is uncertain; it must differ from the reference reading by more than ±7% (2% + 5%) to be assessed as non-compliant.

Results of each verification, including assessed difference and uncertainty regardless of compliance, must be summarised in an Operational Comment (see Sections 6.2.4.5, F 3.1.1, and F 5.2.3) filed at the time of each verification.

Data from a compliant meter can be quality coded QC 600 provided all other QC 600 criteria are met.

Independent reference readings obtained during installation verifications must be reported and considered with their uncertainty in any time-series data quality control checks, e.g. control charts, tabulations, and deviation tests (see Section F 2.4).

Logged data and totaliser readings from the service meter, including those obtained for verification of data collection (see Section F 2.3.2), may under limited circumstances be retrospectively rescaled following an installation verification.

- If the difference between service meter and independent reference readings is within the uncertainty of the reference reading, there is no justification to adjust values from the service meter.
- If the service meter is verified compliant with the accuracy requirement of the Regulations, data recorded from it are not to be adjusted.
- If the service meter is not verified compliant with the accuracy requirement of the Regulations (i.e. includes non-compliant and inconclusive results), the data from it may be retrospectively rescaled provided the discrepancy is traced to a configuration error at set-up, for example, an incorrect multiplier.
    - Quality code rescaled data as QC 400 (significant modification).
    - Quality code data not verified compliant, but not rescaled, as QC 200 (no quality).

2.3.2 Verification of data collection

Requirements are set out in NEMS *Water Metering* v3.1.0 Section 4.2 (refers to Section B2.4.7 of the COP).

Service meter totaliser readings are periodically compared with the cumulative total recorded in the corresponding period(s) between totaliser readings. Provided the installation verification is current, if there is no more than 1% difference between the totaliser and logger totals the corresponding record may be quality coded at least QC 500.

Note: Totaliser readings are the difference between current and previous values read from the meter's display. Pulse count data logging is usually independent of the meter's display such that if cumulative totals are logged, values stored will not be those displayed by the meter, but differences calculated over the same period of time should match.

To achieve QC 600 all other requirements of the site inspection (see Section 4.2.2 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4.7 of the COP)) must also be met, which would normally preclude record checked against totaliser readings supplied by the consent holder from achieving QC 600.

While abstraction is occurring the meter display may be changing rapidly. The time of the reading becomes a critical factor in determining agreement with the volume logged. Ideally the totaliser should be read when the abstraction is not operating, but if not, the logger time must also be checked and clocks synchronised before the totaliser is read or the reading may be deemed unreliable for data quality control purposes.

Off-season totaliser readings may be regarded as reliable with only the date supplied if there is separate confirmation that there has been no water use in that day. These readings may then be filed with a nominal time of 12:00:00 NZST but must be accompanied by an Operational Comment stating that the time of the reading is nominal.

In terms of timeliness, a water meter record cannot be fully verified without a totaliser reading at the start and end of the record period. For seasonal takes this would ideally be at the start and end of the abstraction season; however, a mid-season reading is also desirable to catch data quality issues that would otherwise impact an entire water year's data.

QC 600 data requires a totaliser reading in each water year and with no more than 12 months between readings. Until a reliable 'period end' totaliser reading is obtained, recorded data can only be assigned QC 200 (non-verified), or QC 100 if a gap. Once the necessary totaliser reading has been obtained the quality code can be reassessed as follows:

- QC 500 applies, if:
  - QC 600 cannot be achieved, and
  - the logged total is no more than 1% different from the corresponding volume recorded by the totaliser, or

- the logged total is more than 1% different from the corresponding volume recorded by the totaliser but the pulse output has been tested and confirmed to be operating correctly and one or more gaps are identified and marked that (are assumed to) account for any shortfall beyond the 1% tolerance.

- Otherwise, QC 400 applies, provided the record can still be regarded as representative of the actual water use, albeit somewhat compromised.

Recorded data that are not representative must be deleted and treated as a gap. Data are not representative if they:

- are demonstrably false (e.g. implies negative water use, or exceeds maximum possible pump rate), or
- have under-registered by more than 5% compared with corresponding reliable totaliser volume(s) and the difference cannot be attributed to known or assumed gaps in the data, or
- have over-registered by more than 5% compared with corresponding reliable totaliser volume(s) and the difference cannot be attributed to wrong recording scale and/or units.

2.3.3 Pulse output tests

Pulse output may be observed and assessed for signal strength and reliability using an oscilloscope with the abstraction system running at its usual flow rate. This may be referred to as a 'rate test' and is intended to ensure that the meter's electronic output corresponds with the recording device (see Sections 4.2.3 and 3.4.8 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.9 of the COP)).

Some meters offer a simulation mode that allows test pulses to be generated.

- These will appear on the data logger but not on the totaliser and must be accounted for when assessing verification differences (see Sections F 2.3.1 and F 2.3.2) and ultimately removed from the record.
- Total the recorded data before and after removing the test pulses and reconcile the totals with the number of test pulses intended to be removed. Quality code is unchanged by the editing of test pulses, but a Data Processing Comment is required, and the reconciliation must be stored permanently with the data processing records.

2.3.4 Status checks

If abstraction is periodic, systems that record pulse by pulse (i.e. 'on event' or 'heartbeat' data) are often set up to log and/or send a zero value and timestamp at regular intervals independent of the water meter, to indicate the site is still operating.

Because the data are stored as an interpolating data type, these extra data elements alter the apparent start time and rate of accumulation of the next increment of volume logged, influencing how the record is interpreted, and may alter reported rates of water use (see Section F 1.3). The extra data elements should be filtered from the record, but this may not be practical unless they are stored at the same time each day.

A Data Comment must be filed that describes the frequency of any status data generated, its effect with respect to data type, and whether the status data elements remain in the processed record or have been filtered out. If filtered, reconcile the data before and after to ensure nothing else has been removed. The total volume recorded in the period should be unchanged. Filtering to remove status data elements has no effect on quality code.

2.4 Deviation tests

Track data collection verification results using a control chart (Figure F 6) or other suitable multi-period collation, analysis, and record of deviations.

- Test pulses must be deducted from the logger total before calculating deviation from the totaliser reading (see Section F 2.3.3).
- Deviations calculated from totaliser readings deemed unreliable should be included but labelled or tagged as 'unreliable'.
- If using a chart, plot outliers along the top or bottom of the chart rather than rescaling the chart to incorporate them to avoid loss of plot resolution.

Intervals between installation verifications are too long to be useful on their own for data processing decisions, however:

- all installation verification reports (see Section B2.4.8 of the COP) must be permanently stored in the site file or station history
- an Operational Comment must be filed at the time of each installation verification that includes sufficient detail to quantify any bias in the data (see Section F 3.1.1)
- a summary of results should be collated and maintained for easy reference, tracking and scheduling (see Sections F 2.3.1, F 2.4.1, and Table F 1), and
- outcomes can be incorporated in sequence with the data collection verifications to aid data processing decisions (Figure F 6).

Use a deviation with time test to investigate time-dependent issues such as leakage or gradual deterioration of metering equipment.

A scatterplot of totaliser readings versus corresponding logger totals (net of test pulses) can be useful to identify data totalling errors, totaliser reading errors, and scaling issues arising from a mismatch of measurement units.

Tests may be configured to update automatically with new data from the field.

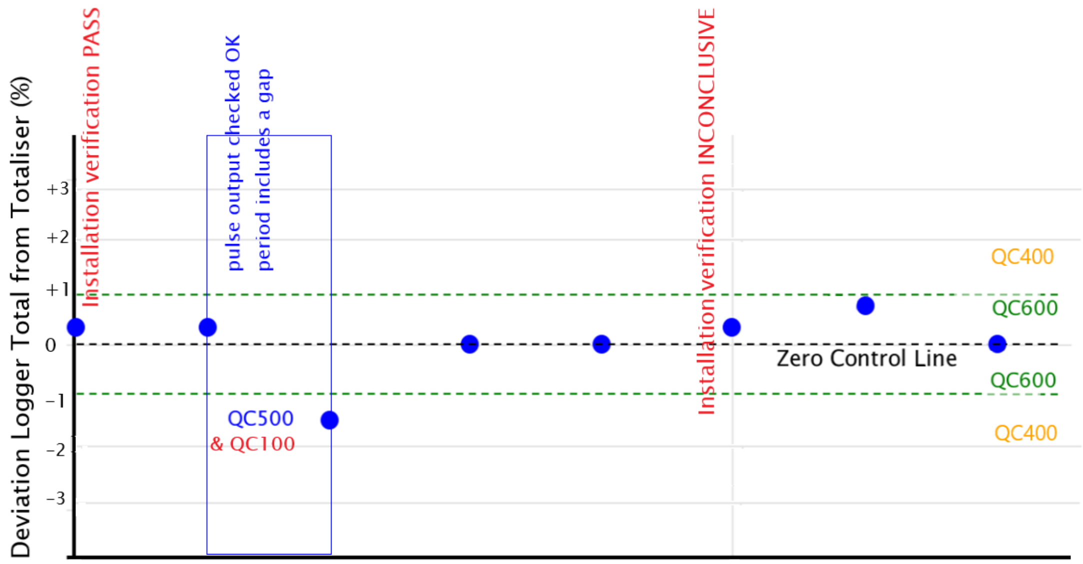


Figure F 6 – An example of a control chart used to track verification status and quality coding decisions for water meter data.

2.4.1 Interpretation of installation verification results

Percent deviation of the service meter volume from the independent reference volume (i.e. $((meter - reference)/reference) \times 100$), plus the determined uncertainty of the reference measurement:

- must not exceed ± 5% for the meter to be compliant with the accuracy requirement of the Regulations, or
- must lie wholly outside ± 5% for the meter to be non-compliant with the accuracy requirement of the Regulations, and
- is inconclusive in terms of compliance if neither of the above apply because the extent of uncertainty traverses the accuracy threshold.

Refer to Section F 2.3.1, and Section B2.4.11 of the COP, for more explanation.

Table F 1 – Example of a Summary of Installation Verification Results.

Date	Meter	Volumes (m^3)		Diff.	Tolerance	Result	Verifier
	Serial #	Reference	Meter	%	%		
10.01.05	123	20.0 ± 1.2%	19.3	-3.5	-4.7 to -2.3	PASS	ABC Ltd
20.12.09	123	31.3 ± 1.5%	30.0	-4.1	-5.6 to -2.6	INCONCL.	ABC Ltd
08.12.14	123	25.3 ± 2.2%	23.4	-7.5	-9.7 to -5.3	FAIL	XYZ Inc.
15.12.14	4442	32.0 ± 2.0%	32.6	1.8	-0.2 to 3.8	PASS	XYZ Inc.
30.11.19	4442	27.5 ± 2.1%	28.4	3.3	1.2 to 5.4	INCONCL.	XYZ Inc.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water meter data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Site factors (see Section 2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1, B2.3.6 and B2.3.7 of the COP)).
- Instrument installation, physical condition, and function (e.g. pipe configuration, failure to generate and/or log a pulse, damage to or deterioration of the meter, restriction of the meter's moving parts, vibration, and power supply issues leading to poor or loss of recording) (see Section 3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3 of the COP)).
- Environmental conditions that adversely affect meter performance and/or recording (e.g. water quality, interference, poor hydraulic conditions, temperature extremes, and inundation) (see Section 3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3 of the COP)).
- Issues of calibration and performance identified by verification (see Section 4 of NEMS Water Metering v3.1.0 (refers to Section B2.4 of the COP)).
- Data transfer from providers and between systems (see Sections 5.1 and 5.2 of NEMS *Water Metering* v3.1.0 (refers to Sections D2.2, D2.3 and D2.4 of the COP)).

Issues with data capture are not always identifiable from a site visit alone. Some problems such as cavitation, electrical interference, or failure to generate a pulse may be transient and occur and resolve between visits. Gradual deterioration of performance may not be apparent from a single visit. Interpretation of data plots and comparisons (see Section F 2.2) and deviation tests (see Section F 2.4) are necessary for these cases.

3.1.1 Systematic error

Because logged data are not routinely adjusted to the results of installation verifications (see Section F 2.3.1) and there can be a relatively long interval between those verifications, a small bias may persist in a water use record for a considerable period of time.

Quality code does not compensate for bias in the data and the quality code assigned is not exclusive to presence of bias. It is therefore essential that data users are made aware of potential bias in the data via adequate reference in Operational Comments to the results of all installation verifications and not only those that are compromised or identify significant calibration issues (see Sections 6.2.4.5, F 2.3.1, and F 5.2.3).

3.2 False calculated rate of take

When rate of take is calculated by dividing each stored volume increment by its preceding timestep false rates can result. Causes are:

- additional zero value data elements added to the record by sources unrelated to the meter, e.g. status checks (see Section F 2.3.4) and some time-series CSV imports
- additional pulses logged while meter testing under simulation mode (see Section F 2.3.3)
- fixed interval data logging too frequent with respect to the measurement resolution of metered volume
- no mechanism or algorithm to identify periods of no water use.

The issue is more one of how the data are collected, stored, and interpreted than errors in the data per se. Solutions are, as applicable:

- remove from the record any additional data elements (i.e. values and timestamps) arising from status or simulation mode meter checks or the importing of data (see Sections F 2.3.3 and F 2.3.4)
- select a fixed data logging interval that returns a rate close to the normal operating flow rate of the abstraction when divided into the volume increment
- aggregate pulse count data into a reasonable fixed interval before dividing by that interval to determine the apparent rate of take
- implement documented assumptions about the likely interval of accumulation of each pulse, e.g. Hilltop Software's 'Thirty minute Rainfall' data type (see Section F 1.3).

3.3 Spikes

Spikes in water meter data may be caused by:

- the sudden onset of flow ('first rush') and consequent acceleration of the meter, possibly with cavitation
- shockwaves ('water hammer') due to sudden flow variation, e.g. when a pump shuts off
- backflow causing dials to go backwards, logged as negative increments
- electronic transients and electrical interference from electric fences, overhead power lines, or other nearby electrical equipment
- a missing data element (next value is apportioned over two timesteps)
- pulse counters that have reset to zero on a fault, which may then trip a 'round the clock' algorithm in some software, e.g. Hilltop Software's Meter Reading data type, or result in a negative stored volume.

Treatment of spikes and outcome of that treatment depends on the combination of:

- cause of the spike
- whether increments of volume or accumulating volume are stored
- the software and data type used to store the values, and
- whether interpolation is allowed to apply.

If using a time-series manager and data type that does not count an incremental value if its interval is undefined, the simplest way to eliminate the influence of a spike is to insert a gap marker immediately prior to the spurious value, i.e. prevent interpolation from defining its interval.

Note: The spurious value is still present in the series, but it is not included in any plot or aggregated total because it is effectively nulled by not having an interval associated with it. The start of the next interval is defined by the timestamp of the spike, so the subsequent value is counted as normal.

Note: For Hilltop Software's Meter Reading data type, inserting this gap element (marker) also usefully stops the 'round the clock' algorithm from causing a spurious increment if a pulse count has reset to zero on a fault.

If the times-series manager and data type does count every value stored whether its interval is defined or not, the spurious data element (i.e. the value and its timestamp) must be deleted and the consequent gap marked.

Resulting gaps are then treated as missing data (see Section F 3.8).

Spike removal method and its consequent effect on the stored data must be understood. The wrong approach for the time series and data type may result in reliable values that follow the spurious being ignored or spread across more than one recording interval leading to under-reporting of volumes and/or rates of water use.

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section F 3.4)

Table F 2 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious implausible values recorded.	F 3.3
Evidence	Value significantly different from adjacent values. Observable in a bar plot of the data at its recording interval, or at 15-minute intervals if logging 'on-event'. Confirmation by close inspection of values logged, and by field investigation and elimination of cause, if possible.	Fig. F 2 F 2.2.1 F 3.1 F 2 3.6

Solution(s)	Insert a gap marker immediately prior OR delete the spurious data element(s) and replace with a gap marker, depending on the time-series software and data type employed. Apply missing data processes to the resulting gaps. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	F 3.3 4.11 4.16 F 3.8 F 3.4
Metadata	QC 100 for gaps and a Data Comment explaining reason for the gap. Revise these if the gap is subsequently infilled. Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 F 5.2.4 6.2.4.6 F 3.8 F 3.4

3.4 Noisy data

The most common causes of noisy water meter data are electrical interference, mechanical meter bounce, and deficient 'empty pipe' settings. All arise directly from issues at site, which should be investigated and addressed to eliminate the problem wherever possible.

Electrical interference and mechanical meter bounce (rapid multiple switch closures instead of a single clean pulse) cause over-registering. Occurrence can be detected in the data as:

- unexpected or unusually high rates of abstraction
- anomalies in the timing of abstraction.

Initial identification of the problem is therefore usually by way of consent non-compliance alerts, but cause should then be confirmed by:

- a pulse output test ('rate test'), and/or
- an installation verification with focus on possible causes of interference and over-registering.

Affected data must be assessed for representativeness. If not adequately representative of the actual volumes of water through the meter the affected period(s) must be deleted and treated as missing record (see Section F 3.8). Filtering or rescaling shall not be applied because the interference is unlikely to be either entirely random, or consistent and proportional in effect.

If not discarded the affected data must be quality coded QC 400 (representative but compromised). Data Comments must be filed to explain the reason(s) for the reduced quality code, why the affected data have not been discarded, and any limitations on use of the data.

Noise due to deficient 'empty pipe' settings adds apparent use to the record when the take is not operating. With portable pumps it may be due to wind acting on exposed pipes. The possibility of actual use must be investigated and discounted. Verified periods of no abstraction can be set to zero with quality code QC 500. Otherwise, assess and treat affected periods as for the other forms of interference described above.

Table F 3 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Pulse fluctuations compromise accurate determination of water use. Over-registering of volumes and rates.	F 3.4
Evidence	Timing and rate of abstraction anomalies. Apparent non-compliance with consent limits and/or off-season use. Field investigations, including pulse output tests and installation verification results. Problem resolves after cause is addressed.	F 3.4 F 2 3.6
Solution(s)	Assess representativeness of the data. Downgrade the quality code of compromised data. Discard periods not representative and mark as a gap. Set verified periods of no abstraction to zero. Apply missing data processes to the resulting gaps.	F 3.4 4.12 4.16 F 3.8
Metadata	QC 500 for verified no abstraction set to zero. QC 400 for compromised data. QC 100 for gaps. Data Comment(s) explaining reason(s) for downgraded quality codes or gap. Revise quality code and comments for gaps subsequently infilled. Refer to missing data guidance as applicable.	F 3.4 6.2.3 F 5.2.4 6.2.4.6 F 3.4 F 3.8

3.5 Loss of calibration

Loss of calibration may be due to:

- poor meter operating conditions, e.g. temperature variations, hydraulic disturbances, or lack of particles or particle size variations affecting Doppler instruments, that may be transient or persistent, or
- declining meter performance due to poor water quality, e.g. chemical properties or suspended sediment and grit causing wear, clogging, and/or corrosion.

Commissioning tests followed by installation verifications at intervals of no more than five years are intended to minimise these problems.

Quality code of the data is QC 200 or at least QC 400 depending on the outcome of these verifications (see Section F 2.3.1).

An Operational Comment that describes extent and cause of calibration loss must be filed for periods assessed as affected, which may be a more general statement for the site if all data are potentially affected.

Adjusting data to compensate for loss of calibration is not permitted.

Affected data must be assessed for representativeness. What constitutes representative in this context must be determined by the recording agency on a site-by-site basis. If not adequately representative of the actual volumes of water through the meter, affected period(s) should be removed from the record and treated as missing (see Section F 3.8).

Table F 4 – Guidance for data affected by loss of calibration

Guidance for data affected by loss of calibration		see Section(s)
Issue(s)	Inaccurate measurement of volumes and rates of abstraction.	F 3.5
Evidence	Results of commissioning tests and periodic verifications of the installation.	F 3.5 F 2.3.1
Solution(s)	Remove data that are not representative and mark as a gap. Apply missing data processes to the resulting gaps.	F 3.5 F 3.8
Metadata	Quality code as determined from results of verifications. Operational Comment(s) describing extent and cause. Revise quality code and comments for gaps subsequently infilled. Refer to missing data guidance as applicable.	F 3.5 F 2.3.1 6.2.3 F 5.2.3 6.2.4.5 F 3.8

3.6 Incorrect scaling

Incorrect scaling means volume increments stored are wrong by some factor. The problem may arise from:

- wrong measurement units, including a misplaced decimal point
- incorrect logger configuration, e.g. a wrong multiplier, or
- a mismatch between totaliser and pulse count increments.

The problem is detected by verifications and/or pulse output tests (see Section F 2.3) and may be identified by apparent non-compliance with consent limits if the error results in increments that are too large.

For affected data to be rescaled, cause must be traceable to an error during set-up from which the adjustment(s) needed are obtained by calculation. It may be necessary to reverse the applied configuration then apply the correct configuration.

Assign a quality code of QC 400 to rescaled data and explain the adjustment in a Transformation Comment.

Rescaled data must only be stored in the fully processed time series (see Section F 6).

Table F 5 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale of the stored data is wrong.	F 3.6
Evidence	Results of periodic verifications and/or pulse output tests. Apparent non-compliance with consent limits.	F 2.3
Solution(s)	In the fully processed series, apply linear transformations to change the data increments to their correct volume.	F 3.6 4.8 F 6
Metadata	QC 400 for rescaled data. Transformation Comment(s) explaining the adjustment(s).	F 3.6 F 2.3.1 6.2.3 F 5.2.6 6.2.4.8

3.7 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section F 3.8).

A time drift adjustment alters the accumulation interval of each volume increment and therefore changes the apparent rate of take calculated from these data. Determining whether a clock drifted or stopped is therefore important (see Figure F 7).

Data logging may also have stopped when the clock stopped, or all subsequent pulses may be tallied into a single stored value at clock restart, depending on how data collection is configured. A period of missing record is a consequence of either, but a pulse tally captures all volume since the clock stopped allowing the gap to be infilled (see Appendix F.1 Section 2.1).

Time-series processing software often combines data adjustment tools so that it is possible to unintentionally alter time and introduce time errors. Errors in fixed interval data can be identified by analysing the timesteps or inspecting the timestamps but can only be detected in 'on-event' data by comparing the processed data with the original as in Figures F 4 and F 5.

3.7.1 Supervisory Control and Data Acquisition (SCADA) systems

Clock drift

Clocks in SCADA system remote devices (i.e. the programmable logic controllers or PLCs) often drift. To minimise the drift, some SCADA systems synchronise all PLCs with the base clock once per day, usually at midnight. The PLCs may have drifted enough over the preceding day that they are pulled forward or pushed back by more than the data logging interval, so they may skip an interval or overwrite data previously collected. Under-reporting results if the data overwritten were not zero values.

Daily tallies

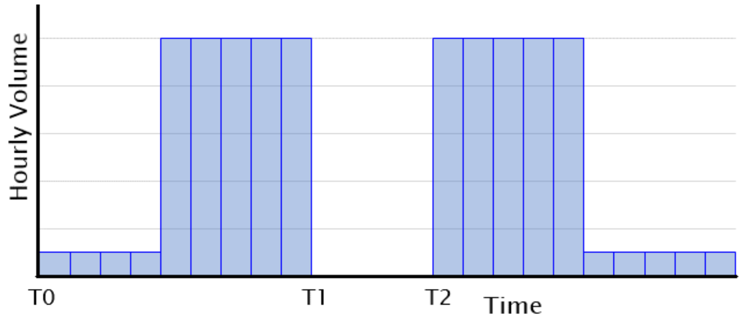
Daily tallies are usually logged at a SCADA base at midnight then the tally register cleared for the new day. If the PLC and base clocks are not synchronised:

- counts may be assigned to the wrong day, or
- 'late' counts may be wiped when the register is cleared without being included in the day's tally but no longer exist to be included in the next day's tally either, leading to under-reporting.

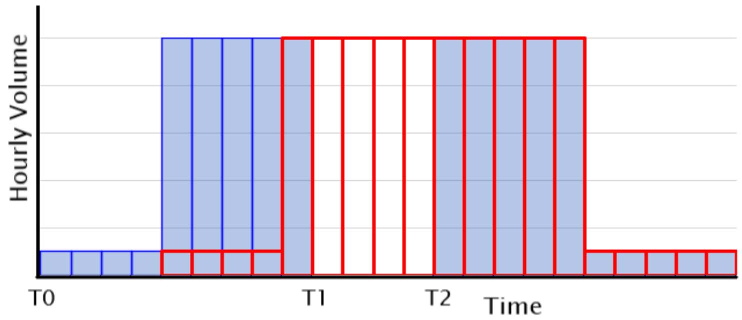
Under-reporting from these systems is not recoverable other than by comparing with an independent non-resetting meter reading.

The remedy for both situations is a combination of:

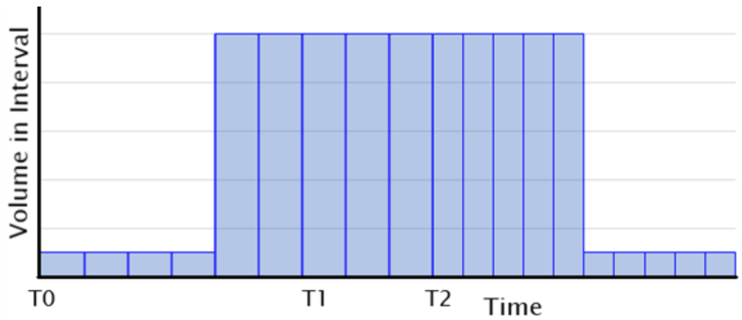
- reconciling with independent non-resetting meter readings
- intimate knowledge of the SCADA system's data collection methods and clock operations
- tedious and meticulous inspection of the data either side of the time the system performs synchronisation and/or resets its tallies
- repair of the data where possible or marking as a gap if not.



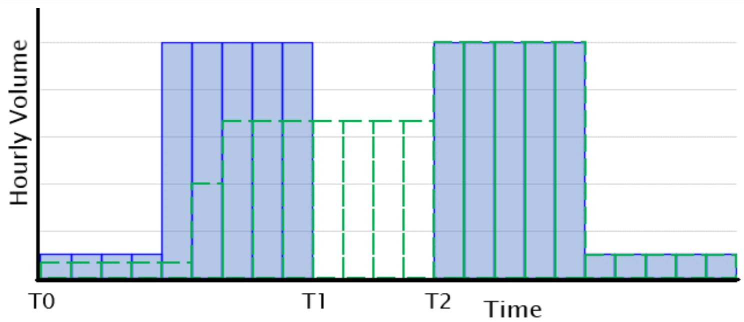
A record of hourly volumes with a gap of 4 hours between T1 and T2.



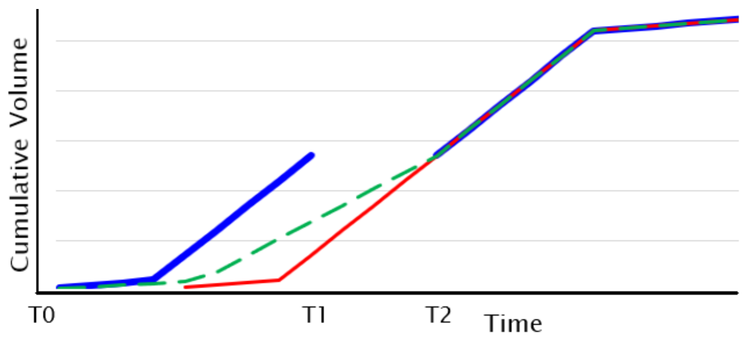
Example 1: At T2, start time T0 is found wrongly set 4 hours back. Data from T0 to T1 is shifted forward 4 hours, closing the gap between T1 and T2.



Example 2: At T2, logger time is T1, 4 hours slow. Hourly timesteps between T0 and T1 are 'stretched' to compensate for the drift, closing the gap between T1 and T2.



The 'stretched' data reapportioned to hourly intervals.



Example 3: Cumulative plot showing original data (blue) with the time shifted (red) and the time drift adjusted (green dashed). Slope of each line indicates apparent flow rate.

Figure F 7 – A comparison between time shift and time drift adjustments in a period of hourly water meter data stored as an interpolating incremental data type.

Table F 6 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Timing and/or temporal distribution of recorded data is wrong, and/or data are missing.	F 3.7
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with other available and relevant data.	F 3.7 Fig. F 7 F 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If clock is slow or fast apply time drift adjustment. If a clock fault and/or has stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. F 7 and/or F 3.8
Metadata	If a time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	F 5.2.5 6.2.4.7 F 5.2.4 6.2.4.6 6.2.3

3.8 Missing data

When data are stored as incremental totals of interpolating data type, a gap created by missing data must either be closed, infilled, or marked to prevent interpolation through the period of the gap.

The clean data series is stored with all verified gaps marked but not filled. Gaps in the fully processed time series must be filled wherever possible (see Section F 6). This series is more useful for scientific analysis over long time periods, for which gaps in the record are problematic.

When considering the treatment and associated metadata requirements for missing water meter data the following broad descriptions are helpful:

- a brief period is a few recording intervals, but never more than a day
- a short duration is no more than 3 days
- a longer period may be up to two weeks
- an extended period is two weeks or more.

On power loss, no data are logged but the meter totaliser should continue to register water use and can be read at intervals to provide a substitute record. However, certain meters can get stuck such that the meter totaliser also fails to register.

If pulse generation fails, depending on the measurement system, values of zero may be logged when water may have been abstracted, e.g. status checks (see Section F 2.3.4). Verification of data collection (see Section F 2.3.2) and pulse output tests (see Section F 2.3.3) identify and confirm the problem. Unless zero take can be corroborated by other data and observations the zero values must be stripped from the record and the period(s) marked and treated as a gap.

3.8.1 Seasonal recording

Water meter data may be seasonal. Some consenting authorities allow data logging to be switched off with the pump in the off-season, creating annual gaps of several months duration in the record.

- If the meter reading at the start of the next season matches the reading at the end of the previous season the off-season gap may be infilled with nil take (see Appendix F.1 Section 2.4).
- If the meter has incremented between seasons the volume recorded must be added to the record as off-season take using the method described in Appendix F.1 Section 2.2.
- If the meter was not read at either of the end of the previous or start of the current season the off-season period must be marked as a gap and treated accordingly.

Note: It should not be assumed that because there is no irrigation there is no water take in the off-season. Land occupiers may use the water for a variety of purposes. Some knowledge of these other purposes is helpful when verifying the recorded data.

Data may be missed at season start if the measurement and recording devices can be isolated from the pump (and therefore do not meet COP section B1.1.4) and the recording equipment is not powered up when the pump is turned back on.

- A data collection verification should detect the problem if not noted sooner (see Section F 2.3.2.).
- A pulse output test confirms that otherwise, pulse recording is reliable (see Section F 2.3.3).
- Comparison with pump run time records confirms when the pump was switched on (see Section F 2.2.3).
- The off-season, and the period up to data collection resuming, are marked as gaps to subsequently be infilled where possible (refer to Appendix F.1).

3.8.2 Closing gaps in incremental interpolating data

Closing a gap by removing the gap marker or flag in an incremental interpolating data series results in the next stored total being spread at a constant rate through what was the duration of the gap (see Section F 1.3).

Where this is not a reasonable representation of the actual water use, the temporal distribution of the data can be altered by inserting additional data elements to redefine the interval(s) associated with the value(s), in the same way that status checks (see Section F 2.3.2) create a problem.

3.8.3 Methods for infilling gaps

For details on specific methods for infilling gaps in water meter data, see Appendix F.1 of this Annex.

Table F 7 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing, or values of zero are generated and logged in place of actual measurements.	F 3.8
Evidence	Expected timestamps are not present in raw fixed interval data. A gap marker may or may not be present depending on data collection method. Logged volume is short compared with totaliser. Cumulative plot shows unexpected flat periods of trace. Comparison plots show expected event(s) and/or volume missing. Investigation confirms data were not logged and/or not collected.	F 3.8 4.16 F 2 3.6
Solution(s)	Mark the gap in the clean data series. In the fully processed series apply one or more methods from Appendix F.1 as appropriate to the available supporting data.	4.16 to 4.20 incl. App. F.1 5.4 & 5.5
Metadata	QC 300 if infilled with synthetic data or an accumulated total. QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including the resolution and expected reliability of any synthesised infill.	F 5.1 6.2.3 F 5.2.4 6.2.4.6

3.9 Data transfer

Operational systems such as SCADA that collect then transfer water use data may log service meter reading, independent pulse count, or volume in interval calculated from either, or a measured flow rate. These consent holders and third-party providers may, by agreement, provide a different measurement or data in a different form to that stored by the recording agency.

What is being sent must be agreed and fully documented to ensure data are received, stored, and ultimately interpreted appropriately. Record of the site setup(s) and data transfer protocols must be collated and maintained and provided to the recording agency to incorporate in their site/station history/file and summarise in the site metadata.

Procedure must be developed, documented, and implemented to ensure:

- data transfer between agencies is controlled and traceable, and
- data types are aligned, or suitable tested, controlled, and traceable transformations are applied, and
- data subsequently changed are reported back to the collector.

4 Adjusting Data to Verification Results

Installation verifications provide independent measurements of volume through the meter. The verification device must have the same or better accuracy than the meter being verified.

If a verification does not unequivocally confirm compliance with the accuracy requirement of the Regulations (see Section F 2.4.1) the recorded data may be adjusted to compensate for the identified bias, but only if the origin of the bias is traceable to a configuration error.

The adjustment is implemented retrospectively by rescaling the data (see Section F 3.6). For data captured by pulse count this means changing the volume increment of each pulse and therefore changing the apparent resolution of the data (see Section 4.8).

The adjustment is applied after all other data processing has been completed, including any infilling of missing record. Adjusted data are therefore only to be stored in the fully processed time series (see Section F 6).

5 Metadata

5.1 Quality coding

Quality code for water meter data is set by the performance objectives in the quality coding flowchart in NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)*. The flowchart is also available in NEMS *National Quality Code Schema*.

5.1.1 Data processing actions and adjustments

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Minor modifications reduce quality code to QC 500.

Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section F 3 of this Annex.

5.2 Example water meter data comments

The following are templated examples of comments for water metering sites.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water use) via some form of 'Site' and 'Measurement' key combination. These 'database keys' are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

Type: Site
Measurement: Water Take
Initial comment for the water meter *<meter-ID> (*at *<site, property, or locality name>)*
Located at *<map co-ordinates and type[17]>* drawing water from the *<river name>* River, river number *<river number>[18] (or <aquifer name>* aquifer, *or <name of water body> as applicable)* under resource consent *<auth_number> (or* permitted use) for *<intended use e.g. pasture irrigation>*
Data is recorded as *<x>*m^3 *(or* L) pulses logged as they occur *(or* total volume (m^3) *(or* L*)* in *<x>* minute intervals*)* *(*by *<name of supplier>)* *(*transferred *<time interval e.g. daily, weekly, annually, or periodically* to the recording authority by *<method of data transfer>*
Additional information: *<site purpose, anything relevant to general interpretation of the record e.g. seasonal recording, additional location information if part of a distribution network, abstraction scheme or allocation plan, water source properties that may affect meter performance, verification frequency>* <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.
The following data is also measured at this site: *<list variables, including any backup record or supplementary data, whether permanently stored or not>*
The local recording authority is: *<name of recording and/or archiving agency(ies)>*

5.2.2 Equipment Comment examples

Type: Equipment
Measurement: Water Take
Meter *<make, model and serial number>* installed on *<dd-mm-yyyy hhmmss>* is a *<state type (see Table 2 of the COP)>* meter with accuracy *<state accuracy and/or standard and accuracy class and date of wet lab certification>*, display resolution of *<increment and units>* and dials range of *<maximum dials reading and units>*. The meter is installed in

[17] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

[18] from *Catchments of New Zealand* (SCRCC, 1956).

<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs> (or* is portable). Meter calibration is valid for *<calibration period>*. The meter and installation is independently verified every *<installation verification frequency>.* Data *(*and location*)* is logged to a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. each increment of volume as it occurs, or, total volume in fixed intervals of x-minutes>*. Data is collected by *<whom, and method and frequency e.g. twice daily telemetry polling and occasional manual download>*, verified *<data collection verification frequency>* by *<whom and method e.g. recording authority inspection or consent holder submission>.*

5.2.3 Operational Comment examples

Type: Operational
Measurement: Water Take
Pipework reconfigured on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>.* The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>.*

Type: Operational
Measurement: Water Take
Meter *<serial no.>* replaced on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>*. Installation is otherwise unchanged *(or* Installation was also modified to/because of *<provide reason>.* The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>).* Refer to the associated Equipment Comment for details of the new meter.

When a meter is replaced, a corresponding Equipment Comment is required (see Section F 5.2.2) for the new meter. If the installation is also modified a Stationarity Comment alerting and explaining the change is also required (see Section F 5.2.7).

Type: Operational
Measurement: Water Take
Installation verification on *<dd-mm-yyyy hhmmss>* was inconclusive with deviation of meter from reference of *<(-) or (+) x %>*. Reference uncertainty was +/-*<x %>*.

Type: Operational
Measurement: Water Take
Installation verification passed on *<dd-mm-yyyy hhmmss>* with deviation of meter from reference of *<(-) or (+) x %>*. Reference uncertainty was +/-*<x %>*.

Type: Operational
Measurement: Water Take
Installation verification failed on <*dd-mm-yyyy hhmmss*> with deviation of meter from reference of <*(-) or (+) x %*> because of <*provide reason*>. Reference uncertainty was +/-<*x %*>. Raw readings from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> are considered to under *(or* over*)* register water use by <*verification difference*>. Meter was repaired (*or* replaced) on <*dd-mm-yyyy hhmmss*> *(*with same type *(or* a <*state type*> *if different).* Refer to the associated Equipment Comment for details of the new meter*)*.

Routine comment of all verification results is recommended for water meter data because assignment of a lower quality code is not exclusive to evidence of bias in the record, and data are not routinely rescaled to the results of verifications to mitigate the bias. If the data are rescaled there must be a corresponding Transformation Comment (see Section F 5.2.6).

5.2.4 Data Comment examples

Type: Data
Measurement: Water Take
Missing record from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> due to <*identified cause of recording failure*>. The gap is not filled because <*state reason(s)*>.

Type: Data
Measurement: Water Take
Gap from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> due to <*identified cause of recording failure*> filled with zero water use verified by pump run time *(or* electricity*)* records.

Type: Data
Measurement: Water Take
Gap from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> due to <*identified cause of recording failure*> filled with zero water use inferred from no movement in the totaliser over the period as evidenced by <*type of evidence e.g. timestamped photos supplied by the consent holder*>.

Type: Data
Measurement: Water Take
Data capture method changed on <*dd-mm-yyyy hhmmss*> to <*describe new method e.g. event data, where each volume increment generates a pulse that is timestamped as it occurs*>. (A zero-value status check is also generated on the logger every <*describe frequency e.g. hour, or day at a certain time*>.) Data was previously logged as <*describe previous method e.g. total volume in fixed intervals of x-minutes*>.

Type: Data
Measurement: Water Take
Data may be compromised by <*reason e.g. sediments, temperature, air entrapment*> from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*>. Record is not adjusted.

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Totaliser readings are not available. Record was generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression or rainfall-runoff model algorithm, etc.>* with input data of *<list measurements and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. daily values only, or not recommended for daily water balances, irrigation application analysis etc.>*

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record was calculated as the sum of *(*difference of*)* meters *<meterID-1>* and *<meterID-2>* on the same distribution network. Calculated total in the period is *x* m^3. Corresponding volume by totaliser is *y* m^3.

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Total take in the period is filed as a single value at *<dd-mm-yyyy hhmmss>* being the recorded backup pulse tally *(or* assessed as *<x>* m^3 from a reading of *<y>* m^3 for the period *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>). (*Record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is filled with zero water use verified by *<method>).*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Take
Values deleted (*or* edited to zero) from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove false (*or* test) data due to *<identified cause e.g. interference or verification check>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
Data filtered from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove zero values generated as *<frequency e.g. hourly, or daily (at hhmmss)>* site status checks. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by (*or* for) *<method and parameters e.g. time drift (or shift) of x (hours, minutes etc.)>* to compensate for *<identified cause e.g. clock running slow (or fast), or wrong logger time at setup etc.>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: negative volumes removed and gapped; Over-range Test: Values exceeding pump capacity of x* m^3*/hr not accepted; Gap Test: error flagged if timestep > 24 hrs; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

Type: Transformation
Measurement: Water Take
Data and totaliser readings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are rescaled by *<factor applied>* to compensate for the under *(or* over*)* registering of water use identified by verification on *<date of installation verification>*. Edited by *<name>* on *<date of processing>*.

5.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Water Take
Meter replaced by *<new type>* (*and/or* relocated to *<new location> and/or* reinstalled at/in *<new pipe configuration>*) on *<dd-mm-yyyy hhmmss>. <Add relevant before and after details and reason for change>.*

Type: Stationarity
Measurement: Water Take
Pipework reconfigured on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>.* The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>.*

Stationarity Comments can also be used to capture and collate information about historical methods and data. A common change to be identified in a Stationarity Comment is date and time of a change in data recording method, e.g. from fixed interval to 'on-event' logging (see Section F 1.3).

Type: Stationarity
Measurement: Water Take
Data capture method changed on *<dd-mm-yyyy hhmmss>* to *<describe new method e.g. event data, where each volume increment generates a pulse that is timestamped as it occurs>*. (A zero-value status check is also generated on the logger every *<describe frequency e.g. hour, or day at a certain time>.*) Data was previously logged as *<describe previous method e.g. total volume in fixed intervals of x-minutes>*.

6 Preservation of Record

For water meter data, in addition to the requirements of Sections 6 and 8 of this Standard, the recording agency must store and retain indefinitely and, if electronic, back up regularly:

- all verification reports, totaliser readings, and results
- all site inspection observations and notes
- the raw recorded data
- the verified edited and quality coded record with all gaps marked, i.e. the clean data
- the fully processed time series, i.e. the clean data, rescaled to the installation verification results if required, and with any missing record filled wherever possible, and quality codes revised as applicable, and
- all required associated metadata for each of the above.

Appendix F.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the duration requiring infilling
- the likelihood of no water use during the period missing
- the likelihood of variable water use during the period missing
- whether other meters in the same distribution network also measure the take in part, or in combination with other metered use
- availability of supplementary data and supporting observations such as:
  - totaliser readings
  - pump on/off and/or run time records
  - records of pump electricity use
  - observations of abstraction occurring, including anecdotal, or a nearby downstream stream flow record or water levels recorded in an affected well
- prior knowledge of the likely pattern of abstraction
- the existence of models that can predict likely abstraction.

2 Recommended Methods

The following methods are candidates for infilling gaps in water metering records:

- inserting all, or an assessed part, of a totaliser reading
- inserting values of zero for known and verified periods of no water use
- calculating by sum and/or difference from records obtained from other meters in the same distribution network that measure some or all of the same take
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- apportioning all or part of a totaliser reading to the temporal distribution of available supplementary data
- regression with available supplementary data
- estimates generated by models.

A combination of the above methods may improve results. For example, modifying a regression or model to account for known and verified periods of no water use.

Infilling of missing data is only required to be attempted for the fully processed time series (see Section F 6).

If reliable totaliser and/or independent reference readings exist, the corresponding record period(s) that include synthetic data generated by any method must sum to the relevant totaliser or independent reading.

2.1 Using a pulse tally or totaliser readings to infill a gap

When data logging has failed a pulse tally may be maintained that is recorded when data logging resumes.

When pulse generation and/or data logging fails, totaliser readings may still be available from the meter display. The consent holder may be required to supply regular readings until data logging resumes, or the volume difference since the totaliser was last read may pertain to a longer interval, in which case the portion relevant to the missing period must be assessed (see Appendix F.1 Section 2.2).

Manual readings supplied by the consent holder that are used to infill missing data are quality coded QC 300 to allow all periods of filled missing record to be identified and separated on the basis of quality code if desired. (A record of self-monitored water meter data would otherwise be quality coded QC 200 'not verified').

Totaliser readings may need to be interpreted before they can be manually entered into the record at the date and time of the reading. For example, they may be:

- converted between volume in interval and cumulative volume or pulse count and vice versa, and/or
- rescaled as described in Appendix F.1 Section 2.2 if the average of prior relevant data collection verifications shows consistent bias > ±1% between logged and totaliser volumes.

With the gap marker removed the interpolation engine spreads the tallied or derived volume evenly through the interval from the previous data element in the series, except if the data are stored using Hilltop Software's 'Thirty minute Rainfall' data type where it is spread only through the previous thirty minutes.

Temporal distribution of the infilled record may be improved by combining with infilling periods of no water use (see Appendix F.1 Section 2.4).

2.2 Assessing a totaliser reading to infill a gap

If a totaliser reading relates to a period longer than the period of missing data, the portion applicable to the period missing must be assessed.

If the clean recorded data are otherwise reliable and have been in good agreement with the totaliser (deviation ≤ ±1%), determine the total volume logged in the interval of the totaliser reading then deduct it from the volume obtained from the totaliser reading. The remainder is the assessed portion of the totaliser reading to be used to infill the gap.

If there has not been good agreement with the totaliser (i.e. deviations > ±1%) the assessed portion must be rescaled by the average of deviations observed for the same meter and installation configuration.

For example:

- *Totaliser on 1-Mar-2020 12:00:00 reads 13000 m^3 and on 1-Apr-2020 12:00:00 reads 14000 m^3.*
- *Period of record missing is 20-Mar-2020 12:00:00 to 1-Apr-2020 12:00:00.*
- *Recorded volume from 1-Mar-2020 12:00:00 to 20-Mar-2020 12:00:00 is 653 m^3.*
- *Average of all data collection verifications for same meter and installation to date of gap is -1.8% (i.e. logged volumes are less than those from the totaliser).*
- *Total volume expected to have been logged between 1-Mar-2020 12:00:00 and 1-Apr-2020 12:00:00 is (1+(-1.8/100)) * (14000-13000) = 982 m^3*
- *Volume estimated would have been logged between 20-Mar-2020 12:00:00 and 1-Apr-2020 12:00:00 is 982 – 653 = 329 m^3 to be applied to infill the gap*

2.3 Estimating a totaliser reading to infill a gap

If the meter itself has failed, temporal distribution and estimates of volumes of water abstracted can be obtained from pump and/or electricity records and the pump specification.

Appropriate relations to estimate volumes of water used may be developed:

- directly from the pump specification and run hours, and/or
- by regression analysis with simultaneous good quality logged record from the water meter, and the pump and/or electricity records (see Appendix F.1 Section 2.6).

2.4 Infilling periods of no water take

A gap in the record may not have missed any water take. Periods of no water use may be:

- known from documented independent observation at site
- inferred from no movement in the totaliser, or
- deduced by calculation from other meters on the same distribution network if they measure all or part of the same take (see Appendix F.1 Section 2.5).

Deleting the gap marker is not sufficient on its own to substitute a period of no water take because the system will then interpolate between the adjacent values, which may be non-zero.

A record of nil take can be created in the time series by deleting the gap marker (if any) and entering values of zero at the start and end of the nil take period. However, because of the incremental interpolating data type the effective period of no take begins from the last non-zero value stored prior to the zero now filed at the start of the infill period.

If the period of nil take is known, or inferred from totaliser readings, quality code may be carried forward from the adjacent series, but a Data Comment is required to explain that there was a gap in the record, no take occurred, and how this is known or was inferred (see Section F 5.2.4).

If the period of nil take is deduced from other records it is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

2.5 Calculating infill record from other meters

In some cases, the meter may be one of two or more in a water distribution network supplied from the same abstraction point or be one party to a shared allocation from an aquifer or catchment. It may be possible to calculate infill record for the meter of interest from the records of other meters in the network or scheme (the 'donor' sites).

Before 'donor' site data are used in the calculation of infill record:

- they must be verified as free of error
- some repacking of the data may be needed to align data intervals (see Section 4.13), depending on recording method at the 'donor' site(s).
  Note: Repacking incremental data alters its resolution.

The infilled record should be checked against a subsequent totaliser reading.

The infilled record is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

A diagram, plan or map of the distribution network or scheme that identifies each meter used in the calculation and its relation to the others must be stored with the data processing records and referred to from the Data Comment.

2.6 Infilling by regression analysis

Regression analysis can be used to estimate water use if there is no record of water use available or able to be calculated (see Appendix F.1 Section 2.5) but records of pump operation such as run time and/or electricity usage, are available.

- General procedure is described in Appendix 2 to the main document.
- Analyse as long a period as possible within the period of the same meter and installation configuration and installation verification interval.
- Decide a suitable data interval for analysis and acceptable timestep of the infill, taking into account the extent of the gap and the quality of the relationship(s) (see Section F 3.8 and 6.2.5).

The derived relation may introduce a constant that predicts negative values or water use when the pump is not operating unless one of the following options is utilised:

- Calculate the regression equation only when the pump is operating and apply it only to those times to generate the infill record.
- Force the regression through the origin (0,0). This tends to inflate R^2.

The infilled record is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

2.7 Infilling from models

Choice, availability, and degree of sophistication of a suitable predictive model depends on what the abstracted water is used for, and the availability and reliability of the necessary input data. For example:

- models that predict daily irrigation requirements from climate, soil and crop factors are reasonably common but will not necessarily reflect actual application of water
- simple but coarse models to estimate water take for public supply are easily constructed from population or connections data
- simple routing models or relatively complex rainfall–runoff models might be used to estimate natural stream flow from which a water take may be estimated by difference from actual recorded stream flow, but timing issues usually limit estimates to daily averages at best.

If a model already exists or is simple to create then it may be a viable source of infill data; however, if time consuming to set up, difficult to replicate, and/or accuracy and/or resolution is poor, models may be difficult to justify for the sole purpose of generating infill record.

Infill from this source is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

3 Other Considerations

Infilled record is not intended, and must not be used, for assessment of compliance with any legal obligation of the consent holder. Its purpose is to facilitate water balance calculations and the naturalising of stream flows for scientific and water management planning activities.

Annex G Soil Moisture Data Processing

1 General Overview

1.1 Normative references

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

- NEMS *Soil Moisture Measurement (Measurement of water held within soils)*

Where reference is made from this Annex to specific sections of the above NEMS document, the title is abbreviated, and version stated, i.e. 'NEMS *Soil Moisture* v2.0.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

Note: At date of publication of this Annex, NEMS Soil Moisture Measurement *is undergoing review, with some changes to verification and validation requirements expected. This Annex will be revised to align with the updated NEMS soon after its release.*

1.2 Scope of this Annex

NEMS *Soil Moisture Measurement (Measurement of water held within soils)* includes, and references, information about measuring soil water potential but excludes doing so from scope. This Annex therefore does not address data measured by tensiometers, resistance blocks, or psychrometers. Also excluded from scope is the sampling of random sites using handheld or portable sensors, as is used to assess areal variations in soil moisture.

While focus of this Annex is on continuously sensed data logged to a device, manual measurements are used to verify the in-situ measurement system, and the processing guidance contained in this Annex is applicable to a continuous or quasi-continuous time series of at-point soil moisture, regardless of whether measurements are manual or automatic.

1.3 Units of measurement

The terms soil moisture and soil water (content) are used interchangeably in NEMS *Soil Moisture* v2.0.0 and in this Annex to refer to the amount of water in a soil, either as a mass (i.e. gravimetric measure) or a volume. Neither should be confused with soil water potential, which is the force (tension) holding water in a soil that a plant must overcome to extract that water, usually expressed in kilopascals (kPa).

Water content expressed as a proportion or percentage is not dimensionless because the ratio is of water to soil. This is important if solving mass balance or continuity equations for water.

NEMS *Soil Moisture Measurement (Measurement of water held within soils)* requires time-series measurements as % volume of water per unit volume of soil, and/or as mm of water per unit depth of soil. However, primary reference measurements are recommended to be gravimetric water content unless impractical. In any case, primary reference measurements used for calibration and validation must be in the same units as the sensor delivers, and for data verification must be in the units of the logged data and the consequent time series.

The following example illustrates the relationship between the various units.

An 80 cm^3 sample of soil, of surface area 16 cm^2 and depth 5 cm, is weighed (m_{wet}), dried, then weighed again (m_{dry}).

The gravimetric water content, θ_g, is given by:

$$\theta_{\mathrm{g}} = \frac{m_{\mathrm{water}}}{m_{\mathrm{dry\ soil}}} = \frac{m_{\mathrm{wet}} - m_{\mathrm{dry}}}{m_{\mathrm{dry}}} = \frac{105-93}{93} = 0.129\ \mathrm{g\ g^{-1}}\ \text{or}\ 12.9\%$$

The bulk density of the soil, ρ_b, is given by:

$$\rho_{\mathrm{b}} = \frac{m_{\mathrm{dry}}}{V_{\mathrm{sample}}} = \frac{93}{80} = 1.1625\ \mathrm{g\ cm^{-3}}$$

The volumetric water content, θ_v, is given by:

$$\theta_{\mathrm{v}} = \theta_{\mathrm{g}} \times \frac{\rho_{\mathrm{b}}}{\rho_{\mathrm{w}}} = 0.129 \times 1.1625 = 0.15\ \text{or}\ 15\%$$

where ρ_w is the density of water, close to 1 g cm^{-3}, and is usually ignored.

The volumetric water content, θ_v, is also given by:

$$\theta_{\mathrm{v}} = \frac{V_{\mathrm{water}}}{V_{\mathrm{sample}}}\quad \textit{rearranged}\ V_{\mathrm{water}} = \theta_v \times V_{\mathrm{sample}} = 0.15 \times 80 = 12\ \mathrm{cm^3}$$

where V_{sample} is the total volume of dry soil + air + water in the sample.

The equivalent depth of water is therefore $12 \div 16 = 0.75$ cm in 5 cm, or 150 mm per metre of soil, i.e. 15% of the unit depth of soil.

Note: 1 cm^3 = 1 mL and 1 g cm^{-3} = 1000 kg m^{-3}

1.4 Supplementary variables

Dielectric sensors are sensitive to soil temperature and conductivity. If soil moisture is measured using a dielectric sensor that is susceptible to these effects but lacks on-board compensation, concurrent measurement as supplementary data, and subsequent compensation during data processing for the following, is required:

- soil temperature (see Sections 2.1.1.1 and 3.4 of NEMS *Soil Moisture v2.0.0*),
- conductivity if a significantly saline soil, which may be encountered in areas of low rainfall, e.g. central Otago, or that receive wastewater (see Section 3.5 of NEMS *Soil Moisture v2.0.0*).

Organisations may choose to permanently store supplementary data as a supplementary rather than primary time series and therefore not apply all procedures in this Standard to those data.

However, as a minimum, supplementary data must be:

- inspected and edited for gross errors
- quality coded QC 200 (not assigned a final quality code)
- identified in the Soil Moisture Site/Initial Comment (see Sections 6.2.4.3 & G 5.2.1), and
- described in the archived soil moisture time-series Data Comments (see Section 6.2.4.6 & G 5.2.4).

Soil moisture data cannot attain a quality code higher than that achieved by any fully processed supplementary record used for compensation of dependent soil moisture values.

If the supplementary data are not fully processed and are assigned QC 200, the lesser of QC 500 or the relevant quality code matrix score (see Section 4.2 of NEMS *Soil Moisture v2.0.0*) applies to the processed and compensated soil moisture record.

Note: At date of publication of this Annex there are no NEMS Standards for the processing of soil temperature or conductivity data, and therefore no mechanism to assign a quality code higher than QC 200 to these supplementary data.

If supplementary data are edited it may change dependent soil moisture values, therefore:

- processing inter-dependent time series together is strongly recommended
- the impact on the soil moisture record of editing necessary supplementary data must be assessed, which will normally require the supplementary data to be reviewed and/or processed first
- inconsistent adjustments between supplementary data and dependent soil moisture record must be avoided
- editing of necessary supplementary data must be described and explained in a Data Processing Comment attached to the soil moisture time series.

1.5 Complementary measurements

Measurements listed in Section 2.1.1. of NEMS *Soil Moisture v2.0.0*, other than soil temperature, are not required supplementary data (see Section G 1.4) but are useful metadata and records for comparison with soil moisture data for quality control.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site, instrument(s), and deployment, are required to be available when verifying soil moisture data:

- site and location details, including:
    - purpose of the monitoring and consequent specification or expectations of accuracy and precision of the data
    - description of the local topography, including slope, aspect, and presence of any humps and hollows near the sensor(s) and/or access tubes (see Section 1.3.2 of NEMS *Soil Moisture v2.0.0*)
    - presence of any natural and man-made features in proximity and clearances from any larger obstacles (see Section 1.3.3 of NEMS *Soil Moisture v2.0.0*)
    - information about the soil type(s), soil profile, and bulk densities if available (see Section 1.3.1 of NEMS *Soil Moisture v2.0.0*)
    - details of land cover, land use, irrigation applied, and any other on-farm activities that influence soil moisture, including any changes noted within the record period (see Sections 1.3 and 2.1.1 of NEMS *Soil Moisture v2.0.0*)
    - information about presence of and changes to relevant drainage features that influence sub-surface hydraulic gradient at and around the sensor, e.g. seasonal water table variations, depth of any sub-surface drains, proximity and invert level of nearby surface drains, drainage pump activity, bed level and associated elevation of the water surface in nearby water bodies
    - estimates of field capacity and permanent wilting point for the soil and ground cover, pasture, or crop present in the record period
- sensor and deployment details, including:
    - descriptions of all sensors installed, including on-board soil temperature and conductivity compensation capability, range of measurement, and their replacement history (see Section 4.1.3 of NEMS *Soil Moisture v2.0.0*)
    - details of the instrument(s) and methods used, and facilities provided for obtaining field calibration and verification measurements
    - GPS location data, plans, and photographs of the site and soil pit showing the soil horizons and relative (x,y,z) locations of the in-situ sensor(s) and access tubes (see Section 4.1.2 of NEMS *Soil*

Moisture v2.0.0) and any identification markers (see Section 2.1 of NEMS *Soil Moisture v2.0.0*)
    - calibration and validation records for all instruments used at site (see NEMS *Soil Moisture v2.0.0*: Sections 4.1.4 and 4.1.5).
- Site visit information, including:
    - observations of settling around the sensor(s) and any remediation
    - observations of other changes to the sensor environs (ground cover, crop type and stage, obstructions, irrigation activity, land clearance, construction, stock movements etc.)
    - details of neutron probe readings (e.g. locations, depths, measurement times, calibrations, uncertainties)
    - verification results, and
    - relevant completed quality coding matrix assessments.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by site remediation, or replacing or reconfiguring the sensor, data logger, and/or altering the installation.
- Check for inconsistencies or trends in the values of significant thresholds deduced from the data such as field capacity and stress point.
- Identify any loss of expected patterns in the data such as the daily steps associated with plant transpiration and surface evaporation (see Figure G 1).

2.2.1 Comparisons

- Use comparisons to:
    - cross-check data for anomalies, and
    - confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
    - record collected from other sensors at different depths, or within the same site, if any, provided they are not affected by the same data quality issue
    - other associated variables recorded at the site, e.g. relevant supplementary variables (see Section G 1.4), and complementary measurements (see Section G 1.5), especially rainfall and/or irrigation depths as applicable
    - verification measurements, and validation results, if any.

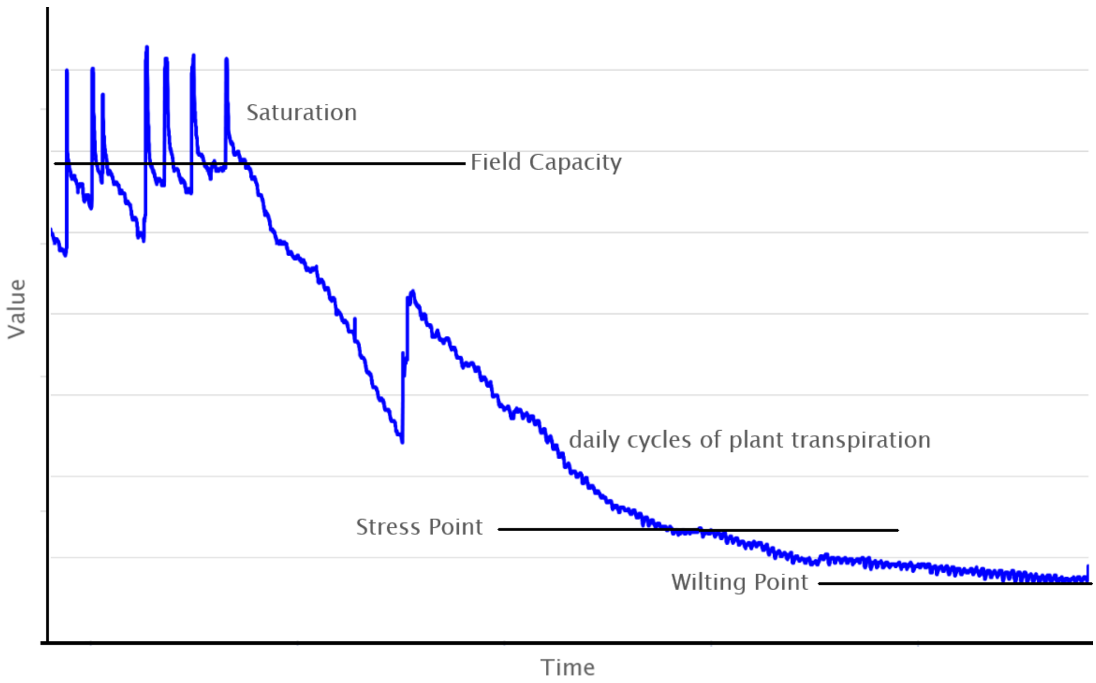


Figure G 1 – An example of a period of soil moisture data showing the typical features of saturation, field capacity (below which daily transpiration is apparent), stress point (where the trace levels out), and wilting point (where daily transpiration ceases).

2.2.2 Between-station comparisons

In areas where soils and catchment characteristics are reasonably homogenous and irrigation is not taking place there may be a consistent relationship between sites that are up to a few kilometres apart, sufficient to verify pattern and range of the data.

Records of rainfall at a nearby location may be used to confirm occurrence and timing of increases and decreases in soil moisture.

Other climate variables may help distinguish the effects of evaporation and transpiration from discontinuities or noise caused by recording faults.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons, to identify:

- possible failure of on-board temperature and/or conductivity compensation in dielectric sensors
- trend indicative of in-situ sensor calibration drift
- change in and/or disruption of:
    - diel and seasonal patterns
    - shape and pattern of response to rainfall, dry spells, and/or growth stage of ground cover
    - relative timing of daily maxima and minima
    - inferred values of field capacity and stress point
    - the annual range of the recorded data, which may be indicative of a calibration shift or loss of sensor span.

Note: The above may be difficult to distinguish from effects of hydraulic gradient change without additional verification measurements and knowledge of surrounding drainage systems.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Calibration, validation and verification

2.3.1 Field calibration and verification of in-situ dielectric sensors

While most in-situ dielectric sensors are capable of precise measurement provided compensation for soil temperature and conductivity is functional or not required (see Section G 1.4 and Sections 3.4 and 3.5 of NEMS *Soil Moisture v2.0.0*), they must be field calibrated to provide accurate values of soil moisture so that installation effects, and soil type and organic matter content, may be accounted for.

Note: Some brands of dielectric sensor may give repeatable but implausible readings for the soil type unless field calibrated.

Reference values are used to establish and maintain the field calibration of the in-situ sensor (see Section G 4) and to verify that the measurement system in general is operating correctly, but they are not used directly to adjust for sensor drift (see Section G 3.3).

Ideally, the reference values, i.e. independent readings of soil moisture, are obtained by taking soil samples near the sensor and analysing them gravimetrically in a laboratory, but collection of the samples disturbs the sensor environment so use of a calibrated and validated neutron probe (see Section G 2.3.2) is preferred (see Section 3.3 of NEMS *Soil Moisture v2.0.0*).

- The neutron probe is deployed via suitably located permanently installed access tubes at depths consistent with depth(s) of the in-situ sensor(s).
- For strip (ribbon or tape) sensors a reference value is the average of a minimum of two near-simultaneous independent readings, one at each end of the strip.
- Reference values obtained at site over a relatively short timeframe are used for field calibration of the in-situ sensor (see Section G 4).
- Reference values obtained at site at least every six months (see Section G 2.3.3) are used to verify system performance in general and detect drift from an established field calibration.
- Verification tolerance is ± 1%. If the checks from two consecutive visits differ beyond tolerance from the current field calibration, drift is a possible cause (see Sections G 3.3 and G 4).

Soil matric potential and water retention curves

Tensiometer readings in conjunction with water retention (pF) curves (soil matric potential vs %w/w or %v/v soil moisture for various soil types) may be useful to:

- extend field calibration relationships to field capacity and wilting point (which is difficult to measure under irrigation), or
- act as a sanity check on soil moisture values obtained by measurement.

However, they cannot be considered verification reference readings when assessing quality code using the quality coding matrix, either with respect to the range of the field calibration obtained, or the elapsed time between reference readings.

2.3.2 Calibration and validation of reference neutron probes

For a neutron probe to be used as a reference instrument it must be calibrated to gravimetrically determined values, i.e. results of samples analysed in a laboratory. A minmum of fifty samples is recommended. Linear relationships with residuals of < 2% are achievable.

The soil samples for calibration can be drawn from a variety of locations, including various sections of a sample core, and therefore include a range of soil types and soil moisture values; however, samples must be obtained from each site and soil horizon for which bulk density is required to be known.

Annual validation of neutron probes is by way of stable reference standards, i.e. sealed drums of various materials of known water contents. The known water content in each drum is established using a calibrated neutron probe. It does not matter what the drum water content values are provided the annual validation readings remain within ± 0.5% of those values.

2.3.3 Reliability of reference values

When using reference values, the following should be considered and assessed:

- the units of measurement of the in-situ and reference sensors, and the supplementary measurements and conversions necessary to achieve compatibility (see Section 3.1 of NEMS *Soil Moisture v2.0.0* and Section G 1.3)
- the need for compensation for soil temperature and/or conductivity (see Sections 3.4 and 3.5 of NEMS *Soil Moisture v2.0.0* and Section G 1.4)
- timing of the reference measurement or collection of each sample with respect to in-situ sensor readings

  Note: The data-logger reading immediately before any disturbance caused by sampling should be used.

- reference measurement stability and location, or sample location(s) relative to the sensor (see Sections 3.3.1.1 and 3.3.1.2 of NEMS *Soil Moisture v2.0.0*)

  Note: Location includes depth in the soil profile. Reference readings are taken near each end of a ribbon sensor then averaged. If cable stops are used to position a neutron probe, its depth is sensitive to elevation of the top of the access tube. If a neutron probe is used too close to the surface it will underread because neutrons escape from the soil and are not reflected back to the probe's detector. Neutron probe sampling radius decreases with increasing soil moisture.

- records of calibration and validation of the neutron probe(s) used (see Section G 2.3.2)

  Note: Laboratory instruments are subject to the calibration and validation requirements of the laboratory method of analysis.

- integrity of sample(s) collected (see Annex C of NEMS *Soil Moisture v2.0.0*)
- precision and accuracy of the reference readings or sample results

  Note: Sample drying temperature may result in loss of organic matter as well as water content (Birendra et al, 2016). Results for stony soils may need adjusting for stone content.

- stability of the in-situ sensor electronically, and with respect to settling after installation (see Section 2.2.9 of NEMS *Soil Moisture v2.0.0*).

  Note: Buried sensors may take up to two years to settle.

A reference reading is unreliable, and must be identified as such in any field calibration analysis if:

- its uncertainty exceeds verification tolerance (see Section G 2.3.1)
- it is outside the calibrated range of the reference probe (see Section G 2.3.2), or
- the reference probe fails its next validation check (see Section G 2.3.2).

The field calibration relationship of the in-situ sensor must not be changed solely on the basis of an unreliable reference reading.

If there is more than six (6) months between verification visits (i.e. site inspections that include obtaining one or more reference readings), data within that period cannot be quality coded QC 600. If more than nine (9) months has elapsed, the intervening data cannot be quality coded higher than QC 400. If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and
- date of the disregarded visit cannot be used to determine the verification frequency for quality coding purposes.

Note: At date of publication of this Annex, NEMS Soil Moisture v2.0.0 *is inconsistent with respect to frequency of reference readings between the requirements for QC 600 as stated in 'The Standard' table, and Section 3.3 to which the quality coding matrix at Section 4.2 refers. The working group for NEMS* Soil Moisture v2.0.0 *has subsequently recommended reference readings are obtained every six months. The nine-month threshold between QC 500 and QC 400 introduced here ensures that to achieve 'fair' data quality, checks on field calibration and site performance are not confined to the same season.*

2.3.4 Laboratory results

Laboratory results must be supplied as the raw unrounded measurement value with its associated uncertainty of measurement (UoM) to be useful for:

- field calibration of instruments, and
- verifying the continuous data collected.

Note: For laboratories this may be a departure from their standard practice and will require prior arrangement.

Laboratory results are subject to extensive quality processes but errors, usually of human origin, may still arise. Agencies making use of laboratory results must ensure procedures exist and are implemented to ensure any error found is identified, and corrected wherever possible, at every instance of the result being stored, including at the source laboratory, to prevent future transfers of results reintroducing the error.

2.4 Deviation tests

Monitoring deviations over time, e.g. by control or run charts or similar, is largely redundant for quality control of soil moisture data. The information provided can be incorporated into the field calibration analysis (see Section G 4).

Deviation with range (see Section 3.6.4.5, Figure 13) may also be useful to investigate any non-linearity of the field calibration relation but may be indistinguishable from calibration drift until the installation has fully settled.

3 Potential Errors and Recommended Editing

This section describes common problems specific to soil moisture data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The site environs, with respect to undocumented and/or unknown variations and/or changes in:
  - drainage, and associated depth to the water table
  - land use
  - irrigation practice, application and/or methods

- crop type and stage and/or other ground cover, and
  - proximity to undesirable features (see Section 1.3.3 of NEMS *Soil Moisture v2.0.0*).
- Site factors:
  - variations in soil type through the profile (see Sections 2.2.3.1 and 2.2.3.2 of NEMS *Soil Moisture v2.0.0*), and
  - relative locations of the sensor and gravimetric sampling locations and/or reference probe access tubes.
- Instrument deployment:
  - orientation of the sensor (see NEMS *Soil Moisture v2.0.0*: Sections 2.2.4, 2.2.5 and 2.2.7)
  - degree of disturbance of the soil profile (see Section 2.2.9 of NEMS *Soil Moisture v2.0.0*), and
  - voids around the sensor and/or access tubes.

    Note: Stony and shrink-swell clay soils are prone to this problem (Birendra et al, 2016).

- Interference, deterioration, and damage caused by:
  - installation (sensor prongs bent and/or not parallel)
  - stock and/or machinery (e.g. trampled, mowed, ploughed etc.)
  - unintentional wetting of and/or ponding over the sensor
  - soil compaction (e.g. from human, animal, or irrigator traffic)
  - excavation
  - vandalism
  - static discharges to the wave guides, and
  - nearby electrical or radio equipment (e.g. electric fences),

    Note: TDR and some TDT sensors are not subject to electrical errors because they use time and not current or voltage to measure the soil dielectric, while capacitance sensors are very susceptible (Birendra et al, 2016).

- Instrument performance:
  - maintenance of calibration
  - over-ranging
  - electronic transients. and
  - sensitivity to soil temperature and/or conductivity (see Sections 3.4 and 3.5 of NEMS *Soil Moisture v2.0.0*).

3.2 Steps in the data

Steps in soil moisture data may be real, in response to plant transpiration, or erroneous due to recording problems.

Daily cycles associated with plant transpiration may appear as steps if recording resolution is close to the range of the cycle (see Figure G 1). They will be apparent when soil moisture is between field capacity and permanent wilting point and plants are present and growing. Values step down around the middle of the day from a daily maximum in the very early morning.

Erroneous steps may result from:

- sensor replacement (soil moisture and/or supplementary variables) (see Sections G 3.2.1 and G 1.4)
- disturbance around the sensor, e.g. the taking of reference samples (see Section G 2.3.1)
- a sensor and/or logger configuration error (usually confined to analogue sensors outputting current or voltage) (see Sections G 3.2.2 & G 3.9)
- a fault with the sensor(s), including those measuring the supplementary data used for temperature and/or conductivity compensation (see Sections G 3.2.2 and G 1.4).

Cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

3.2.1 Instrument replacement and disturbance

Describe an instrument replacement and/or relocation in an Operational Comment (see Section G 5.2.3). If the replacement instrument is a different type, brand, or model, include its details in a corresponding Equipment Comment (see Section G 5.2.2).

Record when and where soil samples are taken from near the sensor in an Operational Comment (see Section G 5.2.3).

A new field calibration relation is required for a new soil moisture sensor and/or installation (see Section G 4). The new relation applies from the time of the instrument replacement or relocation without any gradual transition. Another period of settling is likely during which field calibration may drift, so subsequent revisions to the field calibration must be made until it is again stable.

If the data collected after replacement, relocation, or sampling remains offset from data previously collected despite reliable and stable field calibrations, leave the bias in the data, but identify and explain it in a Stationarity Comment (see Section G 5.2.7) filed at the time of the instrument replacement or disturbance that initiated the change.

3.2.2 Offset errors

Offset errors may be due to sensor and/or logger configuration errors or to unexplained electronic glitches. Offset errors in soil moisture data must be identified and the bias removed before field calibration is attempted. Offset errors in required supplementary data must be identified where possible and the bias removed then compensation revised if the bias has affected recorded soil moisture values (see Section G 1.4).

Note: It is possible for the offset error to occur when supplementary values are logged rather than measured, in which case, depending on the recording system, compensation may be unaffected by the error.

A configuration error will be coincident with a site visit or remote update of a logger program. Remove the incorrect offset from the affected data then reapply the correct one (see section G 3.9.2).

Electronic glitches may occur at any time and may remedy themselves, reversing the initial step. They can be difficult to detect. Visible bias such as a shift in the value of a key threshold, e.g. field capacity, and/or recession discontinuity in a plot of the data may be the only clue (see Figure G 2). Comparison plots, and reference readings if available, help confirm which period either side of a step is correct, and which is offset and requires adjustment to remove the bias.

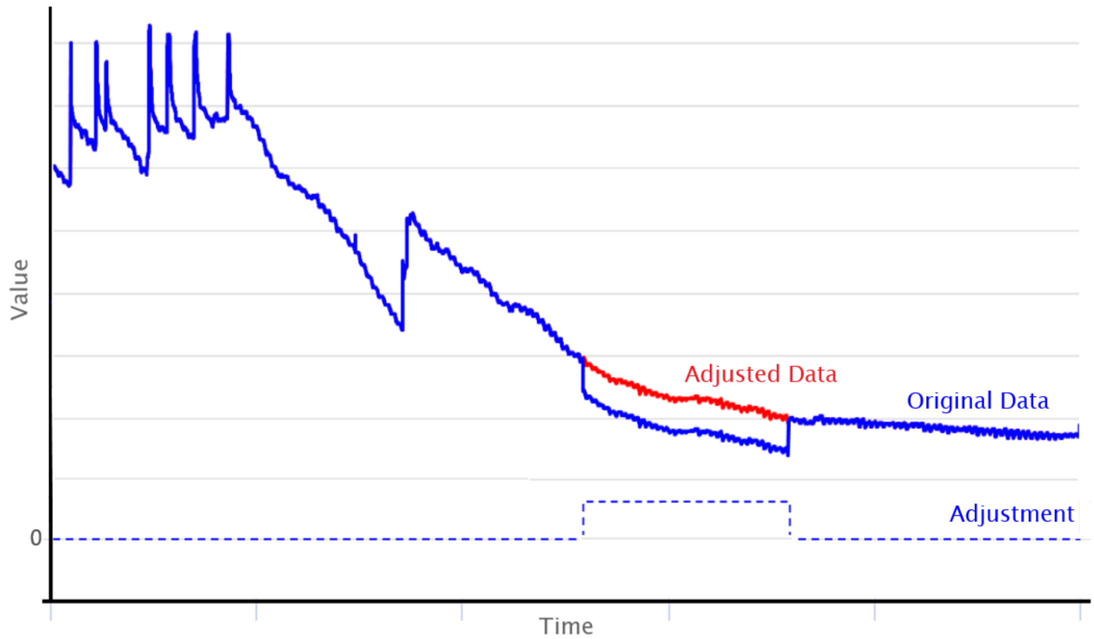


Figure G 2 – An example of part of a recession offset by a constant or near-constant amount (blue line) with the adjusted data (red line) and showing the offset shift adjustment applied (blue dotted line).

Table G 1 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in soil moisture between successive readings that disrupts continuity of pattern in the data, especially of a recession or values of key thresholds, e.g. field capacity.	G 3.2
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps unexpectedly up (and/or down). May be other evidence of bias (reference values and comparison plots).	Fig. G 2 G 2 3.6

Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Apply an offset shift to the biased period if an offset error.	G 3.2.1 G 3.9 G 3.2.2 4.2
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. If offset shift or rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the adjustment(s) applied (amount, type, and period of adjustment) is required.	G 5.2.3 G 5.2.2 G 5.2.7 G 3.2.2 G 3.9 & G 5.2.6 G 5.1 6.2.3 G 5.2.5 6.2.4

3.3 Drift

Drift apparent in soil moisture data from in-situ instruments is most likely associated with calibration drift as the installation settles or is a consequence of drift in the supplementary sensor(s), which, unless those measurements are logged separately and field checked, may be extremely difficult to detect.

In any case, elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift.

Drift in soil moisture data is recommended to be addressed as part of the maintenance of the field calibration (see Section G 4). Drift adjustment as described in Sections 4.4 and 4.5 should not be used.

3.4 Spikes

Soil moisture measurements may spike to higher or lower values depending on the instrument and cause. Spikes in a record from a sensor below the root zone may be real and indicate a drainage event.

Spiking to spurious values must be edited. In many cases they are due to electronic transients and may become more frequent prior to a sensor failing completely. Spurious values may also be due to electrical interference, or surface water entering voids around the sensor.

Isolated spurious values may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required.

Intermittent spurious values may be deleted manually or discarded using a numerical filter. A track minimum or maximum (as applicable) or a rate of change filter may be more successful than a threshold filter if there is frequent spiking to values within the range of the reliable data.

If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.19, and G 3.11).

If spurious values are frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section G 3.5).

Table G 2 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	G 3.4
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by comparison plots and field investigation, and elimination of cause if possible.	Fig. 30 G 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spurious values are frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or G 3.11 or G 3.5
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	G 5.1 6.2.3 G 5.2.5 6.2.4.7 or G 3.11 or G 3.5

3.5 Noisy data

Noise in soil moisture data may be due to:

- frequent persistent interference
- loss or lack of on-board soil temperature and/or conductivity compensation
- imminent failure of the sensor electronics
- erratic measurements due to the presence of air gaps around sensors and access tubes.

Noise within expected precision of the sensor need not be edited. Excessive noise may be filtered out manually or by machine algorithm.

If the noise appears to be randomly distributed about the expected true value an averaging, moving mean, or median of values filter may be used. The averaging window should not be so long as to induce hysteresis in the data.

If the noise appears biased toward higher (or lower) values, use a track minimum (or track maximum) filter. Carefully assess the edited data to confirm that the values retained are not also biased.

If insufficient values are retained to reliably represent the measured soil moisture, treat the period as missing data (see Section G 3.11).

Table G 3 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations compromises precision.	G 3.5
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. 7 Fig. 31 G 2 3.6
Solution(s)	Resample, or 'smooth' manually or by applying a statistical filter. Filter choice is determined by whether noise is apparently random or biased. Some cautions apply.	G 3.5 Fig. 31 4.12
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' data modification, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	G 5.1 6.2.3 G 5.2.5 6.2.4.7 or G 3.11

3.6 Over-ranging

Over-ranging occurs when measurements exceed the manufacturer's stated range for the sensor, including range for supplementary measurements made by the sensor that are used for on-board compensation. Values returned when a range is exceeded are brand dependent and may be an error code.

Data loggers and some sensors may prevent recording of values and create a gap or a flag when measurement range is exceeded. Others may continue to output values. If not flagged by the instrument, over-ranging of measurements used for on-board compensation may be difficult to detect unless the supplementary measurements are also logged and reviewed.

When processing soil moisture data it is important to identify when over-ranging may be an issue and be alert to the possibility of consequent false values or data loss.

False values must be removed from the record, then treat as for missing data.

Table G 4 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	No data, or false values may be recorded.	G 3.6
Evidence	Gaps or error flags in the record when adjacent values are near the limits of manufacturer's stated range. Recorded values exceed manufacturer's stated range for the variable (primary and/or supplementary measurements affecting primary values).	4.16 G 3.6 G 2 3.6 G 1.4
Solution(s)	Remove false values and error flags. Treat all consequent gaps as missing data. Some infilling of gaps may be feasible, but cautions apply.	G 3.6 4.16 to 4.19 incl.
Metadata	Refer to missing data guidance.	G 3.11

3.7 Saturation bias

For soil moisture, saturation is a real phenomenon that occurs when water content exceeds field capacity of the soil. If surface ponding occurs over the sensor due to surface depressions, the measured soil moisture will be elevated and misrepresent the site.

Surface depressions over the sensor may form as the installation settles or the area is traversed, and their presence should be monitored. Any depression found should be noted and remedied (see Section 2.2.10 of NEMS *Soil Moisture v2.0.0*).

If a surface depression over the sensor is observed, review the prior data for possible bias. Comparison with rainfall and/or irrigation records may reveal more frequent and/or prolonged periods of saturation. Suspected periods of bias may be retained in the record but must be quality coded as QC 400 (compromised) and a Data Comment filed alerting to the possibility of bias, the reason for the bias, and the date and time of site remediation.

Table G 5 – Guidance for resolving saturation bias

Guidance for resolving saturation bias		see Section(s)
Issue(s)	Periods of high moisture content and saturation may be over-represented.	G 3.7
Evidence	Surface depressions noted over the sensor. Comparison plots may indicate more frequent and/or prolonged saturation events compared to rainfall and/or irrigation depth.	G 3.7 G 2.2 3.6
Solution(s)	Downgrade the quality code of periods suspected to be biased.	G 3.7 6.2.3
Metadata	QC 400 and a Data Comment explaining the downgraded quality code.	G 3.7 G 5.1 6.2.3 G 5.2.4 6.2.4.6

3.8 Sensor exposure

A sensor may become exposed inadvertently if the soil around it falls away due to erosion, slumping or pit wall collapse, or by deliberate removal, legitimate or otherwise. Cause should be evident from site inspection or may be advised by the land occupier.

Measurements after exposure will not be representative, may be offset, and possibly erratic.

Remove affected data from the record and treat the period as missing data (see Section G 3.11).

Table G 6 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	False values are recorded.	G 3.8
Evidence	Physical cause is known or identified (observed or verified at site, or consequence of an event known to have occurred). Recorded values are not representative and may be erratic.	G 3.8 G 2 3.6
Solution(s)	Remove false data and treat as missing.	4.16 to 4.19 incl. G 3.11

Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	G 5.1 6.2.3 G 5.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is wrong by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor and/or logger configuration.

3.9.1 Wrong measurement units

Data in the wrong measurement units are recoverable without impacting data quality if all necessary information is available to explicitly convert values (see Section G 1.3).

- Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different (see Sections G 5.2.2 and G 5.2.6).
- Any change to the density values used to convert between units (see Section G 1.3) must be noted in a Stationarity Comment (see Section G 5.2.7).
- Verification data must be in the same measurement units as the continuous data collected to be directly comparable.
- Field calibration relations should be derived in the units required for archiving the data, so associated uncertainty and goodness of fit relates to the data in its final form.

3.9.2 Wrong instrument configuration

Analogue sensors that output a current or voltage require a multiplier and offset to be applied by the data logger to convert sensor signal to measurement units. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent verification checks that vary in proportion to the logged value and/or unrealistic values for the soil type and conditions. If the configuration was changed part way through a continuous record, there may be a step in the data at the time of the change.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable and do not compromise precision, there is no effect on quality code.

Table G 7 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	G 3.9
Evidence	Differences between reference and logged values are variable and often large. Data inconsistent with expected range. A step-change occurs at time of configuration change.	G 3.9 G 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	G 3.9.1 G 1.3 G 3.9.2 4.7
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	G 3.9 G 5.2.6 G 5.1 6.2.3 G 5.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section G 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table G 8 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong and/or data are missing.	G 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal anomalies are apparent when compared with data from a nearby rain gauge or similar soil moisture site.	Fig. 18 Fig. 26 G 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or G 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 G 5.2.5 6.2.4.7 G 5.1 6.2.3 G 5.2.4 G 5.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous soil moisture data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel transpiration cycle, or of runoff events, i.e. within the rising or falling side of the cycle or event, but not over the peak or trough
- a longer period may be one or more days up to one week
- an extended period may be a week or more.

Soil moisture can be strongly influenced by local factors and large seasonal differences in variability, so similarity between nearby sites is rarely adequate to synthesise data to infill a gap from record at a donor site.

Backup instrumentation is not usually installed at soil moisture sites but there may be multiple sensors installed through the soil profile. Depending on the fault that has caused the missing data, record from a sensor at another depth may be available to assist with filling a gap at another, by confirming the presence or absence, and pattern and timing, of features and events in the data.

- A brief gap may usually be closed and left to interpolate (see Section 4.17).

  Note: Slight truncation of a runoff peak may result but is of minimal consequence for most users of soil moisture data.

- Fill a short period with reference readings if available (see Section 4.18) or by manually adding values to complete the curve (see Section 4.19).
  - Adjust the reference readings by the inverse of the field calibration relation before adding into the in-situ record if the gap is infilled before the field calibration is applied.
- A longer period may be filled if soil moisture is in recession and no rainfall or irrigation occurred during the gap.
  - Copy in a piece of similar record from another time period, but preferably the same season, at the same site, or from a nearby site that shows similar daily patterns within a similar recession.
  - Some offset adjustment, or slight drift adjustment at start and/or end of the infill, may be needed to avoid creating a step in the recipient data.
  - The end result must reflect the range and timing of the adjacent recorded diel cycles if present and not create a discontinuity in the overall recession of the recipient data.
- Infill of an extended period is not recommended.

Table G 9 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	G 3.11
Evidence	Expected timestamps are not present in the raw data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire, or parts of cycles or events are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 G 2 3.6
Solution(s)	Use verification readings where available, and/or: a) if brief, interpolate across gap b) if short period, interpolate across gap, or manually infill with a curve, but not over a peak or trough c) for longer periods, in recessions only, copy in a piece of similar trace from same or nearby similar site d) otherwise mark the gap or note a temporary site closure.	G.3.11 4.16 to 4.19 incl. 5.4 & 5.5

Metadata	QC 500 if brief and interpolated. Otherwise, QC 300, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, and reliability of the infill.	G 5.1 6.2.3 G 5.2.4 6.2.4.6

4 Field Calibration

4.1 Field calibration data

Field calibration requires clean continuous in-situ data (see Section G 3) and reliable reference values (see Section G 2.3.3).

Reference values collected over as wide a range of moisture content as possible in a relatively narrow timeframe are preferred to avoid the influence of calibration drift.

Ideally, the reference values are obtained by taking samples of the soil near the sensor and analysing them gravimetrically in a laboratory, but collection of the samples disturbs the sensor environment we are attempting to calibrate, so use of a suitably calibrated and validated neutron probe (see Section G 2.3.2) is preferred.

Reference values are obtained with the neutron probe via suitably located permanently installed access tubes at depths consistent with depth(s) of the in-situ sensor(s) or, in the case of strip (ribbon or tape) sensors, from the average of the probe readings at both ends of the strip.

A minimum of three, and ideally up to seven, calibration points over a wide range of values between field capacity and wilting point are required to confirm linearity of the relation.

4.2 Deriving the field calibration relation

Deriving the field calibration relation is a modelling exercise. As such it requires:

- analysis of the available data, and
- consideration of alternatives within the context of:
    - robustness of the relation
    - linearity of the relation
    - likelihood that the relation slope and constant differ significantly from 1 and 0 respectively (i.e. sensor scale and offset are significantly different from 1:1 and zero)
    - the possibility of calibration drift
    - the nature of the drift (e.g. linear or non-linear, episodic or gradual, range of values affected etc.), and
    - overall reliability of the result of calibration as reflected in the quality code(s) assigned to the calibrated time series.

Use one or more scatter plots (see Section 3.6.4.1, Figure 10) to develop and maintain the field calibration relationship(s).

- Reference readings must be the y-values in the scatterplot if fitting trendlines to obtain a regression equation(s) that describes and will apply the calibration (see Appendix 2).
- Label each x-y pair in the scatter plot chronologically to assist assessment of any calibration drift with time.
- If using a time-series manager rating development toolbox:
  - reference readings and calibrated values are the 'rated' data and the uncalibrated in-situ sensor values are the 'unrated'
  - gap ratings may be used to halt application of any calibration relationship for a specified period
  - synthetic ratings are not acceptable.

The field calibration relationship may change over time as soil profile disturbance from installation, and initial sampling to calibrate the neutron probe, settles (see Section G 2.3.2).

As new calibration points (i.e. verification data) are collected, assess whether their deviation from the current relation is outside the verification tolerance of ± 1% (see Section G 2.3.1).

- If not, revisit the quality code matrix assessment if the new data extend the calibrated range.
- If so, consider whether the existing relation should be modified, or a new relation developed.
- If the checks from two consecutive visits differ beyond tolerance from the current field calibration, drift is a possible cause.
- If a new relation is decided, additional calibration points will be required to support it (see Section G 4.1).
- If deviation exceeds tolerance but a new relation cannot be justified, the period of data verified by that check must be quality coded no higher than QC 500, and no higher than QC 400 if the deviation is twice the tolerance.

4.2.1 Example

Figures G 3, G 4, and G 5 show three interpretations of the same field calibration data.

In Figure G 3, beginning with the blue data, a new relation is derived when two consecutive checks are outside tolerance of the existing relation. The red relation technically has sufficient calibration points but two are close together, so linearity of that relation is inconclusive. The other two relations have one or two calibration points that participate in determining the trendline but are outside tolerance of the relation derived. Both these relations also have slope and constant significantly different from 1 and 0.

In Figure G 4 the red data from Figure G 3 are used to modify the initial blue relation resulting in a slope and constant much closer to 1 and 0, but two calibration points that participate in determining the trendline are outside tolerance of the relation derived.

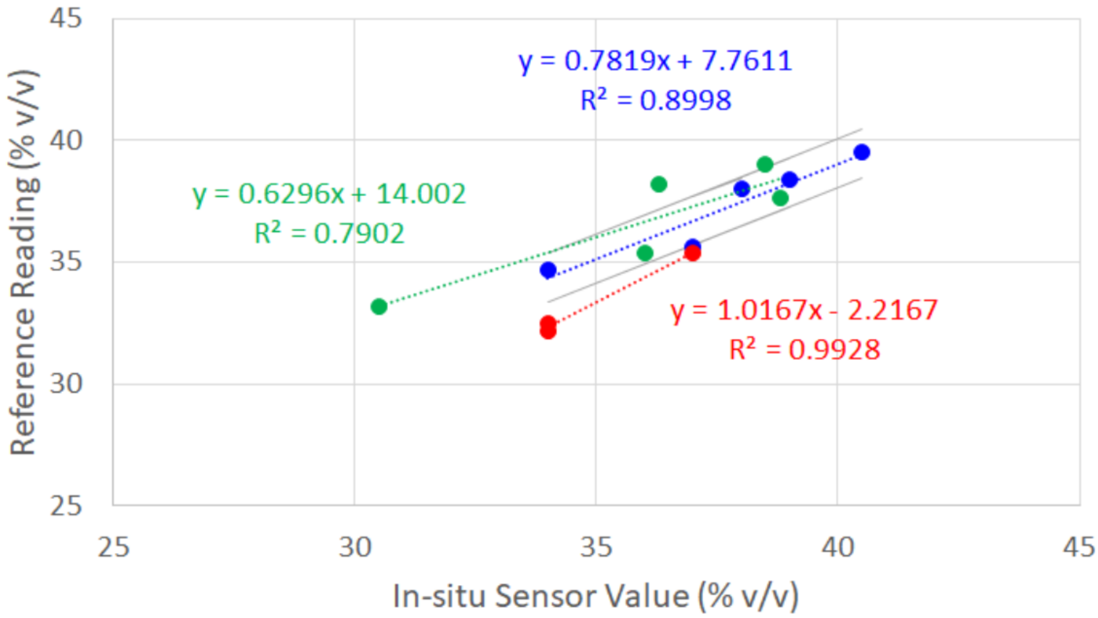


Figure G 3 – An example of a soil moisture sensor field calibration where dots are the calibration data, dotted lines are the trendlines for each of the three derived relations over time (blue, red, and green) with their corresponding linear equations shown similarly colour coded. The grey lines are the tolerance of ± 1% v/v for the blue relation.

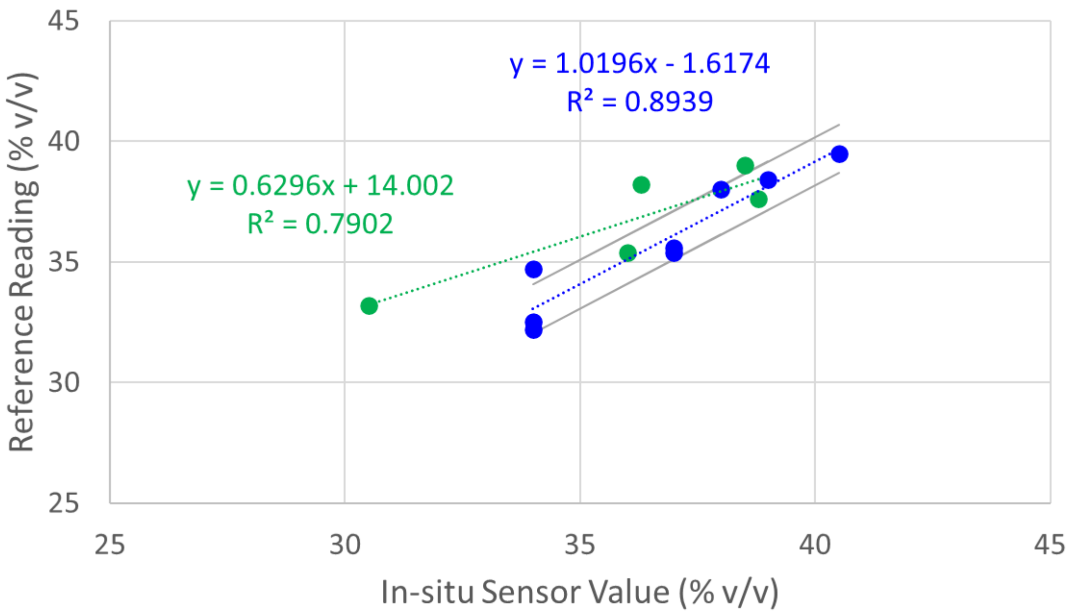


Figure G 4 – An example of a soil moisture sensor field calibration where dots are the calibration data, dotted lines are the trendlines for each of the two derived relations over time (blue and green) with their corresponding linear equations shown similarly colour coded. The grey lines are the tolerance of ±1% v/v for the blue relation.

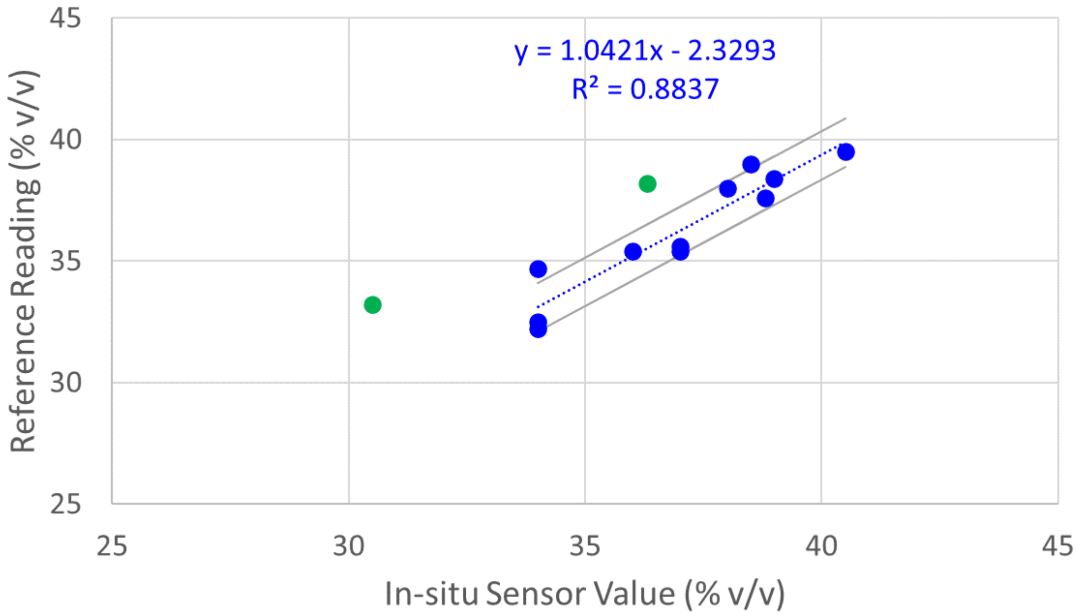


Figure G 5 – An example of a soil moisture sensor field calibration where dots are the calibration data, the dotted line is the trendline fitted to the blue data with its corresponding linear equation shown. Green dots are outliers not used to derive the trendline. The grey lines are the tolerance of ± 1% v/v for the blue relation.

In Figure G 5 the later green data from Figure G 4 are noted as being close to the initial blue relation so the first two green calibration points have been set aside as outliers and the blue relation revised using all other data. The change to the relation from that shown in Figure G 4 is of little real consequence in terms of accuracy of the data and the occurrence of outliers so revising the relation as in Figure G 5, and regenerating the derived calibrated data, is probably not justified.

For this example, regardless of the chosen interpretation of the calibration data, the calibrated range is too small (< 70% of the range between field capacity and permanent wilting point) for the resulting field calibrated time series to achieve QC 600. Other factors in the quality coding matrix determine whether each field-calibrated period can achieve QC 500.

4.3 Field calibration metadata

Where field calibration is undertaken, a field calibration history must be maintained, preserved, and be accessible. The history must contain the following:

- the definition of each relation (e.g. the equation, lookup function, or rating point pairs)
- range and period of applicability of each calibration
- the calibration data, including their uncertainties and provenance (method of reference measurement, validation etc.)
- the method used to develop the relation(s)
- explanation of assumptions
- assessment of outliers

- observations and descriptions of any unusual or exceptional conditions impacting the relation(s)
- explanation of extrapolations beyond the calibrated range, if any
- the method used to apply the relation(s)
- the method used to transition between successive relations
- assessment of uncertainty of the relation(s) (see Section G 4.5)
- any other known or suspected limitations of the relation(s) that may affect use of the calibrated soil moisture data.

A Data Comment must be filed for any period of final record that is not field calibrated, explaining why a field calibration has not been applied.

4.4 Applying the field calibration

Apply the field calibration relation(s) to clean soil moisture data, after all other data processing operations have been completed.

Field calibration relations may be applied by one of the following methods:

- explicit transformation processes that write the transformed data to a new time series
- via the time-series manager's rating engine (transformed data are virtual; calculated as and when the data are accessed and not written to file), or
- using modelling facilities (transformed data may be 'virtual' or written to file depending on the facility).

Different methods may be used for different sites, but method must be the same for the duration of any individual time series.

Unless there is an associated step in the uncalibrated data, transitions between successive field calibration relations must be gradual, pro-rated with time over the period of suspected calibration drift between each relation.

Retrospectively modifying field calibration relations (see Section G 4.2), maintaining their history (see Section G 4.3), and transitioning between successive relations is easier to implement using rating facilities; however, there are risks when exchanging or migrating rating definitions between time-series management systems (see Section 4.10.2).

4.5 Uncertainty of the field calibration relation

Uncertainty of a field calibration relation may be difficult to quantify; however, its component uncertainties must be described, either in the Transformation Comment (see Section G 5.2.6) or Rating Model Comment (see NEMS *Rating Curves* Section 1.2.2) as applicable, as follows:

- number of calibration points supporting the relation
- range of the calibration points

- time period over which the calibration points were collected
- uncertainties associated with the calibration points, if known
- range of the data calibrated by the relation
- tolerances applied when developing the relation (e.g. maximum acceptable deviation, number of permissible outliers etc.)
- outliers to the relation, their inclusion or exclusion when developing the relation, and their deviation from the adopted relation
- goodness of fit statistics, if obtainable (e.g. R^2 if the relation was derived by regression).

  Note: Quality codes for soil moisture data include assessment against some of the above criteria but are affected by a range of other factors. The quality code ultimately assigned to the data is an indicator of its reliability and usability but does not directly quantify or convey its expected uncertainty.

5 Metadata

5.1 Quality coding

Quality code for soil moisture data is set by four different but related sets of criteria:

- the quality coding flowchart
- the quality coding matrix
- blanket provisions, and
- data editing actions and adjustments.

The quality coding flowchart and quality coding matrix may be found in NEMS *Soil Moisture Measurement (Measurement of water held within soils)* version 2.0.0.

Note: At date of publication of this Annex the quality coding flowchart available in NEMS National Quality Code Schema *is the previous version 1.0.*

5.1.1 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, installation, instruments, and field calibration range to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the period of data to which each field calibration relation applies.

- Quality codes above QC 400 cannot be assigned before the field calibration relation is determined.
- Quality code may change retrospectively as new field calibration data are obtained.

Compensation for soil temperature and/or conductivity are not regarded as data editing but are included in the Quality Coding Matrix assessment.

5.1.2 Blanket provisions

The following provisions apply to soil moisture data in addition to the generic application of quality codes QC 100, QC 200, and QC 300 as set out in the quality coding flowchart descriptions:

- data suspected of saturation bias are limited to a quality code of QC 400 (see section G 3.5)
- supplementary data required to be permanently stored (see Section G 6) must be assigned QC 200 if:
    - not processed and verified according to their relevant NEMS, or
    - no NEMS Standard exists for that variable (see Section G 1.4)
- maximum possible quality code of soil moisture values that are compensated for soil temperature, and/or conductivity using supplementary data during soil moisture data processing is:
    - the lesser of the soil moisture quality coding matrix result or the final quality code assigned to the supplementary data if processed to NEMS, or
    - the lesser of QC 500 or the soil moisture quality coding matrix result if the supplementary data is reviewed, possibly edited, but not fully processed and is assigned QC 200 (not assigned a final quality code)
- maximum possible quality code of soil moisture values that require compensation for soil temperature and/or conductivity but are not compensated is QC 400
- a period of record overdue its six-monthly verification cannot be quality coded QC 600. If verification is more than three months overdue the data since last verification cannot be quality coded higher than QC 400 (see Section G 2.3.3).

5.1.3 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Compensation for soil temperature and conductivity, conversion between units of measurement, and application of the field calibration, has no additional effect on the quality code, i.e. these actions are effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section G 3 of this Annex.

5.2 Example soil moisture comments

The following are templated examples of comments for soil moisture stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of soil moisture measurements) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

Type: Site
Measurement: Soil Moisture
Initial comment for soil moisture at *<site, property, or locality name>*
Site number *<network number, ID or code>* located at *<map co-ordinates and type*[19]>
In the catchment of the *<river name>* River, *<river number>*[20] (*or <name of water body> as applicable*) and is monitored for *<site purpose and target characteristics>.*
Soil type is *<provide brief description>* and land use is *<state predominant use>.*
Water content is monitored at *<depth(s) & units>* and <not> field calibrated.
Site plan and evaluation, and soil profile are available from *<reference>.*
Additional information: *<anything relevant to general interpretation of the record e.g. seasonal recording, compensation for conductivity, presence of obstructions, stock, artificial drainage and/or irrigation, verification frequency and method, adjacent sites>.*
<Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments>.
The following data is also measured at this site: *<list variables, including any sensors at other depths, and supplementary data, whether permanently stored or not>.*
The local recording authority is: *<name of recording and/or archiving agency>*

5.2.2 Equipment Comment examples

Type: Equipment
Measurement: Soil Moisture
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), on-board, multi- or single input, programmable etc.>* data logger recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The sensor is a *<type and form e.g. dielectric TDR ribbon, TDT or capacitance probe, etc.>*, *<brief description of deployment method e.g. driven from the surface, inserted in a pit wall, laid in a backfilled trench, via access tube etc.>* and measures *<list relevant on-board measurements & their units, including any supplementary variables>* in the *<zone or layer description e.g. near-surface, root zone, topsoil, subsoil etc.>* at *<depth & units>* below ground surface.

[19] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

[20] from *Catchments of New Zealand* (SCRCC, 1956).

Sensor range is <*range and units*> with resolution of <*resolution*> and nominal accuracy of <*accuracy specification*>*.* (Sensor output is converted to logged % water content by <*details of any transformation applied at the time of data capture or collection e.g. scaling multiplier and/or offset for an analogue sensor*>). Site is inspected <*verification frequency*>*.* Data is collected by <*method e.g. telemetry or manual download*>. Logged values are <not> field calibrated <by *method and frequency e.g. biannual neutron probe measurement or gravimetric sampling*>*.*

Explanation of sensor types, including abbreviations used, may be found in Annex B of NEMS *Soil Moisture v2.0.0*.

Type: Equipment
Measurement: Soil Moisture
Verification (and field calibration) reference data is obtained <*state frequency*> by <*describe method(s) and instrument(s) used e.g. gravimetric analysis of individual samples or sections of a core extracted from locations x to y metres from the sensor, and/or manual readings from a field calibrated neutron probe via access tube(s) placed x metres from the sensor etc.*>*.* <*Add other relevant information such as range, units, serial number, calibrated range, and validation frequency of the neutron probe, bulk density, and/or cross-reference to laboratory results and sample metadata; how the reference data is supplied (e.g. collected at each agency site visit, or via paper, email, or electronic transfer from the land occupier or a third party); and where the reference data is stored*>*.*

To avoid comments becoming too long and complex, create similar but separate comments for:

- each sensor at the site if multiple sensors are deployed at different depths, and/or
- sensor replacements if previously described details change as a consequence. Include confirmation that all other details have not changed. For example:

Type: Equipment
Measurement: Soil Moisture
Replacement soil moisture sensor is a <*type and form e.g. dielectric TDR ribbon, TDT or capacitance probe etc.*> installed on <*dd-mm-yyyy hhmmss*> at <*describe where in relation to replaced sensor*>. New sensor range is <*range and units*> with resolution of <*resolution*> and nominal accuracy of <*accuracy specification*> and is <not> field calibrated*.* Sensor output, calibration frequency and method, site visit frequency, and data collection method are unchanged.

5.2.3 Operational Comment examples

Type: Operational
Measurement: Soil Moisture
Sensor replaced on <*dd-mm-yyyy hhmmss*> because <*provide reason*>. <Replacement sensor is a different type (*or* model) (*or* range) (*or* deployment). Refer to the associated Equipment Comment for sensor specification and/or deployment details.>

Type: Operational
Measurement: Soil Moisture
Sensor relocated on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. instrument replaced, to avoid interference or obstruction, land use change etc.>*. New location is *<describe new environment>*. New sensor position is in the *<zone or layer description e.g. near-surface, root zone, topsoil, subsoil etc.>* at *<depth & units>* below ground surface.

If a sensor is relocated a Stationarity Comment is also required (see Section G 5.2.7). If a sensor is replaced and relocated, the above two comments can be combined.

Type: Operational
Measurement: Soil Moisture
Soil sample for gravimetric analysis collected on *<dd-mm-yyyy hhmmss>* at depth *<depth from ground surface>* from *<distance and compass direction or bearing>* of the sensor for the purpose of verification (*and* and field calibration) of the sensor (*and/or* the reference neutron probe).

Type: Operational
Measurement: Soil Moisture
Verification reference reading on *<dd-mm-yyyy hhmmss>* is unreliable because *<give reason>* <and is excluded from field calibration of the sensor>.

A comment for every verification reference reading assessed as unreliable is recommended in a soil moisture record because reference readings are infrequent but crucial to field calibrating the sensor and identifying and quantifying sensor drift. There is no other way to calibrate a soil moisture record for site variations and installation effects, or to validate the performance of an in-situ sensor while it is installed.

5.2.4 Data Comment examples

Type: Data
Measurement: Soil Moisture
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (*or* values removed because of *<describe recording fault>*). <Gap is for an extended period so is not filled.> *<Add any other relevant information such as why the gap has not been filled if not an extended period>.*

Type: Data
Measurement: Soil Moisture
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are measurements obtained by *<method>* that replace record affected by *<identified cause of recording fault or failure>. <Add any other relevant information e.g. who took the measurements, instrument or sample ID details etc.>.*

Type: Data
Measurement: Soil Moisture
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (*or* replaces data affected by *<describe recording fault>*). Record generated by inserting points to complete the curve (*or* inserting record from *<site, sensor depth, and date/time range>* <adjusted by *<method>* to merge with adjacent record>). *<Add description of any limitations on reliability or usefulness>.*

Type: Data
Measurement: Soil Moisture
Soil temperature from the soil moisture sensor (*or* an independent sensor at site) is logged at *<state recording interval>* intervals. Refer to the relevant Equipment Comment for sensor details. The data is used to compensate soil moisture readings on-board the sensor (*or* on the logger) (*or* during soil moisture data processing). The soil temperature data is reviewed and edited for gross errors but not verified prior to use and is archived as supplementary data (*or* is verified, processed, and archived as primary data at *<relevant site, time-series and metadata identifiers>*).

Type: Data
Measurement: Soil Moisture
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Soil Moisture
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. suspected or known interference or disturbance, sensor exposure, ponding in surface depressions over sensor, low power, suspected calibration drift, possible failure or range exceedance of supplementary sensor etc.>. <Add any other relevant information such as corroborating evidence, cautions on use of the data, and any mitigation subsequently applied such as a new field calibration or installation of an independent supplementary variable sensor including the date/time it is effective from>*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Soil Moisture
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Time shift of -1 hour is applied to convert period logged in NZDT from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to NZST. Error due to *<give reason e.g. incorrect clock reset at logger restart>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x % (or mm)>* to compensate for *<identified cause e.g. configuration error>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Data smoothed using a *<time interval or number of values>* centred moving mean from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to minimise random noise caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x mm or > x' mm not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

Transformations applied prior to archiving a soil moisture record are included here. Transformations of archived records to other forms of the variable, or to other variables of interest, for analysis or modelling are outside scope (see Section 6.2.4.8).

Field calibration transformations developed and applied using a TSM's rating engine must be commented as for rating curves. Refer to NEMS *Rating Curves* (Sections 1.2.1 to 1.2.5 inclusive and Annex L) for requirements, substituting uncalibrated soil moisture for 'recorded stage', reference values for 'gauged flows' or 'gaugings', field calibrated soil moisture for 'rated', 'derived' or 'recorded' flows, and ± 1% for the deviation tolerance.

The first example needs only to be filed once at the start of the relevant archive record, not repeated for each period of data processed.

Type: Transformation
Measurement: Soil Moisture
Soil moisture is archived in millimetres of water per metre of soil transformed from sensor readings in % volumetric water content using the relation, depth = % v/v x10.

Type: Transformation
Measurement: Soil Moisture
Archived soil moisture is field calibrated from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by transformation using the linear (*or* nonlinear) relation *<provide equation>* derived by *<method>.* The calibration data comprises *<x>* samples (*or* neutron probe readings) obtained between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>* with range *<range & units of reference values>* and maximum deviation from the derived relation of *<deviation & units>*. Range of the calibrated data is *<range & units>*. *<Add other goodness of fit statistics as applicable e.g. regression coefficient R^2>.* <A gradual transition pro-rated with time is applied from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* being the period of suspected drift between the previous and this field calibration>. Applied by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Soil Moisture
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>.* Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Soil Moisture
Compensation for soil conductivity is applied from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<describe method, including equations or reference to them e.g. a manufacturer's manual>* using *<frequency e.g. hourly or daily or simultaneous etc.>* soil conductivity readings (*or* estimates) from *<source of conductivity data or estimates>*. *<Add other relevant information e.g. description and limitations of assumptions, if any>*

5.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Soil Moisture
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. instrument replaced, to avoid interference or obstruction, land use change etc.>*. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment. <A new field calibration is effective from this date>.

Type: Stationarity
Measurement: Soil Moisture
Step-change in data from *<dd-mm-yyyy hhmmss>* is coincident with change of sensor type *(or* location*)*, *(and/or* deployment*)*. Sensor and deployment details are available from the relevant Equipment Comments. Location details are available from the relevant Operational Comments. <A new field calibration is effective from this date>.

Type: Stationarity
Measurement: Soil Moisture
A change in land use *(or* irrigation practice*) (or* drainage*)* from *<description of previous>* to *<description of new>* effective from *<dd-mm-yyyy hhmmss>* at *(or* within*)* *<location relative to sensor e.g. x m (or km) upslope (or radius) etc.>* may affect soil moisture values recorded at this site after this date. *<Add references to other relevant information such as maps, farm plans, water use records, drainage plans etc.>*

Type: Stationarity
Measurement: Soil Moisture
Method to field calibrate the in-situ sensor is changed from *<dd-mm-yyyy hhmmss>*. Refer to the relevant Transformation Comments for method details.

Type: Stationarity
Measurement: Soil Moisture
Bulk density was resampled on *<dd-mm-yyyy hhmmss>* and the new value of 1.1832 g/m^3 applies from that date when calculating reference values of volumetric water content from the gravimetric water content results of gravimetric analysis.

Stationarity Comments can also be used to capture and collate information about historical methods and data.

6 Preservation of Record

For soil moisture sites, in addition to the requirements of Section 6 and 8 of this Standard, the recording agency must store and retain indefinitely, and, if electronic, back up regularly:

- the raw unprocessed data as collected (i.e. the original data), which may include on-board (the instrument) compensation for soil temperature and/or conductivity
- as supplementary data, soil temperature and/or conductivity that are not compensated for in the original soil moisture data collected, but for which compensation is necessary
- the time series of clean (compensated, verified and edited) uncalibrated soil moisture data
- if applicable:
    - the field calibration history (see Section G 4.3), and
    - the field calibration relations stored and implemented via the TSM's rating engine, or
    - the field-calibrated time series as transformed by applying the field calibration relations to the clean data series, and
    - the field calibration metadata.

7 References

Birendra KC, Breneger S, Curtis A. 2016. *Soil Moisture Monitoring – Book 11.* Irrigation New Zealand. Christchurch, New Zealand. Retrieved from https://www.irrigationnz.co.nz/Members%20Only/good%20management%20practice/Book11-SoilMM.pdf (21 April 2021).

Annex H Dissolved Oxygen Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous dissolved oxygen (DO) data measured using in-situ sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of dissolved oxygen (DO) compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held device.

1.1 Normative references

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

- NEMS *Dissolved Oxygen (Measurement, Processing and Archiving of Dissolved Oxygen Data)*
- NEMS *Water Quality Parts 1 to 4: Sampling, Measuring, Processing and Archiving of Discrete Groundwater (River Water, Lake Water, Coastal Water) Quality Data*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Dissolved Oxygen* v2.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

1.2 Units of measurement

The dissolved oxygen (DO) concentration at which water is fully saturated varies with water temperature, salinity, and barometric pressure. Barometric pressure varies with altitude and the passage of weather systems.

Almost all DO sensors and meters measure the partial pressure of oxygen so the raw sensor values are DO% saturation, from which DO concentration may be calculated.

When measuring DO% saturation it may be:

- referenced to equilibrium 100% saturation at standard atmospheric pressure of one atmosphere at sea level (1013.25 hPa), known as DO% raw, uncorrected DO%, or DO% reference (DO% ref), or
- in terms of equilibrium 100% saturation for the barometric pressure at the site at the time of the measurement, known as corrected DO% or DO% local.

Both normative references (see Section H 1.1) allow measurements of DO as concentrations (mg/L) or as % saturation but require the time-series data to be archived as corrected DO% saturation.

The following example illustrates the relationship between DO concentration, and uncorrected and corrected DO% saturation:

A DO sensor is calibrated in a fully saturated solution when barometric pressure is 987 hPa. The sensor should read 987/1013.25 x100 = 97.4% (DO% uncorrected).

DO concentration of the fully saturated solution is 97.4% of the solubility of oxygen in water at standard atmospheric pressure for the current temperature and salinity of the solution. If salinity is zero and temperature is 15°C, then the DO concentration of the calibration solution is

10.084 x 0.974 = 9.82 mg/L (see Table 10 of NEMS Dissolved Oxygen *v3.0.0).*

The sensor is then used to measure a fully saturated solution at a site at 880 m altitude. The barometric pressure reduces as a result of the altitude difference to

$(1 - 2.25577 \times 10^{-5} \times 880)^{5.25588} \times 987 = 0.90 \times 987 = 888.3$ *hPa (see Tables 7 and 9 of NEMS* Dissolved Oxygen *v3.0.0).*

The sensor will read 888.3/1013.25 x100 = 87.7% (DO% uncorrected) i.e. 0.90 x 97.4%. DO concentration, if no salinity and temperature is 15°C, is 10.084 x 0.877 = 8.84 mg/L.

If barometric pressure is measured at site, the uncorrected DO% saturation reading can be corrected so that 8.84 mg/L registers as 100% saturation, i.e. 1013.25/888.3 x 0.877 = 100% (DO% corrected, also known as DO% local).

1.3 Supplementary variables

Measurement of dissolved oxygen (DO) requires concurrent measurement of:

- water temperature at all times
- salinity when eight parts per thousand or more, or varying
- local true barometric pressure, when at-site atmospheric pressure must be known (see Section 2.2 of NEMS *Dissolved Oxygen* v2.0)
- altitude, if not at sea level and local true barometric pressure is unknown.

A record of stage and/or flow may be needed if DO measurements are significantly affected by variation in either, for example, in estuaries, or where there is risk of sensor exposure.

Local true barometric pressure must be known:

- when calibrating a DO sensor, and
- if measuring DO% local

(see Section H 1.2, and Section 2.3 of NEMS *Dissolved Oxygen* v2.0).

Organisations may choose to permanently store supplementary data as a supplementary rather than primary time series and therefore not apply all procedures in this Standard to that data. However, as a minimum, supplementary data must be:

- inspected and edited for gross errors

- quality coded QC 200 (not assigned a final quality code)
- identified in the DO Site/Initial Comment (see Section 6.2.4.3 & H 4.2.1), and
- described in the archived DO time-series Data Comments (see Section 6.2.4.6 & H 4.2.4).

DO data cannot attain a quality code higher than that achieved by any fully processed supplementary record used for compensation of dependent DO values during DO data processing.

Note: The above requirement is transferred from Section 3.4.1 of NEMS Dissolved Oxygen *v3.0.0 and overrides the DO matrix score. There are no current NEMS Standards for continuous records of salinity, specific conductivity, or barometric pressure.*

However, where QC 200 has been assigned as described above to supplementary data used for compensation of dependent DO values during DO data processing, the lesser of QC 500 or the relevant DO matrix score applies to the processed DO record.

Note: The above requirement means that in effect, corrected DO% saturation data (DO% local) cannot be QC 600 unless barometric compensation is carried out on the sensor, i.e. prior to data collection. Most in-situ DO sensors are deployed fully immersed and therefore cannot measure barometric pressure. The DO quality code matrix also determines that uncorrected DO% saturation (DO% reference) cannot be higher than QC 400, regardless of its accuracy or verification results.

If supplementary data are edited it may change dependent DO values, therefore:

- processing inter-dependent time series together is strongly recommended
- the impact on a DO record of editing one or more supplementary data series must be assessed, which will normally require the supplementary data be reviewed and/or processed first
- inconsistent adjustments between supplementary data and dependent DO record must be avoided
- editing of necessary supplementary data must be described and explained in a Data Processing Comment attached to the DO time series.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying dissolved oxygen (DO) data:

- site details:
    - type of environment (river, lake, wetland, coastal water, or groundwater (see Section 1.1.1 of NEMS *Dissolved Oxygen* v2.0))

  - the site purpose, measurement objective(s), and target characteristic(s) to be measured
  - a record documenting the site selection process and its evaluation (see Sections 1.3 to 1.6 inclusive of NEMS *Dissolved Oxygen* v2.0)
  - location (in GPS co-ordinates and WGS84 datum), and altitude (in MASL) if not at sea level (see Sections 1.3 to 1.6 inclusive of NEMS *Dissolved Oxygen* v2.0)
  - location (in GPS co-ordinates and WGS84 datum), and altitude (in MASL) if not at sea level, of any supplementary measurements not co-located (e.g. barometric pressure), and
  - bore details as applicable (see Section 1.6.2 of NEMS *Dissolved Oxygen* v2.0)
- instrument details (in-situ sensor and reference instrument):
  - sensor type, model, manufacturer, and serial number
  - sensor accuracy, resolution, and response time, as specified by the manufacturer
  - the units of primary measurement, and other units available (concentration (mg/L) and/or % saturation, and if % saturation, DO% reference and/or DO% local)
  - the sensor range, as deployed in the units of primary measurement
  - details of any on-board compensation for temperature, salinity, and/or barometric pressure
  - characteristics of any on-board anti-fouling mechanism
  - date, laboratory, and identifier for each calibration
  - the calibration relation(s), if and when supplied; these are essential if applied on the data logger by the user
  - date and results of any validations (i.e. checks on the calibration of the sensor other than by verification during field visits), and
  - date and time of each deployment
- sensor deployment details as applicable to the water body:
  - sampling method and data-logging interval
  - details of data logged as backup, secondary, and/or supplementary
  - method(s) used for verification of sensor readings
  - photos of the deployment showing mounting/housing detail and location context, including distance from margins and presence of structures or machinery that may aerate the water
  - characteristics of the water environment and installation that may impact data quality (see NEMS *Dissolved Oxygen* v2.0: Sections 1.3.4, 1.4.3, 1.5.3, and 1.6.3)

    - any other known influences on DO at the site (e.g. potential for super-saturation due to algal blooms)
    - the level of the sensor(s) with respect to:
        - the water level gauge, where co-located
        - the water surface
        - the riverbed or lakebed
        - screen depths and water level range in bores
        - likely temperature and/or salinity gradients or stratification
    - date, time, and reason(s) for any relocation of the sensor
    - any changes over time in the measurement environment
- reference readings, including:
    - instrument used
    - uncertainty in the result, and/or
    - information about when, where, and how each reading was obtained (e.g. proximity to the in-situ sensor).

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by cleaning, or replacing or reconfiguring the sensor, data logger, and/or the installation.
- Check continuity of the daily sine curve and that each daily maximum and minimum occurs at a plausible time.

2.2.1 Comparisons

- Use comparisons to:
    - cross-check data for anomalies, and
    - confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
    - Other associated variables recorded at the site, e.g. relevant supplementary variables, and water level or flow
    - a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)
    - an auxiliary instrument at the same site, e.g. a multi-parameter instrument that may be recording over a different range, accuracy and/or resolution, provided it is not also affected by the same data quality issue(s)
    - verification measurements, and validation results, if any.

2.2.2 Between-station comparisons

Unless there are substantially different inputs there can be good agreement between dissolved oxygen (DO) recorded at quite distant sites within the same river system, and between nearby sites in adjacent rivers of similar physical character, sufficient to verify diel variation and weekly cycles.

Records of flow or water level at sites either upstream or downstream are useful to confirm occurrence and timing of relatively sudden reductions in the daily range of DO.

For example, a fresh may slough algae from a riverbed that was causing large diel variations due to photosynthesis and respiration. Diel variation may gradually increase again after the event as the algae re-establishes.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons, to identify:

- sensor exposure due to low water levels or dry channel or bed, and
- change in and/or disruption of:
  - diel and seasonal patterns
  - expected correspondence with supplementary variables (water temperature, salinity and/or barometric pressure as applicable)
  - shape and pattern of response to level and/or flow variations
  - relative timing of daily maxima and minima
  - daily DO range, especially possible gradual loss of span.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

Reference values used to verify a dissolved oxygen (DO) record from an in-situ device are obtained directly using an independent reference sensor (see Section 2.4.1 of NEMS *Dissolved Oxygen* v2.0).

When using reference values to verify or to adjust recorded DO the following should be considered and assessed:

- the units of measurement of the in-situ and reference sensors, and the supplementary measurements and conversions necessary to achieve compatibility (see Section 2.4 of NEMS *Dissolved Oxygen* v2.0 and Section H 3.9)
- calibration records and validation results for the reference sensor (see Section H 2.3.1) and the in-situ sensor (see Section H 2.3.2)
- measurement stability and location relative to the in-situ sensor (see NEMS *Dissolved Oxygen* v2.0: Sections 2.2.5 to 2.2.8 inclusive and Sections 2.4.1.2 and 2.4.1.3)

- timing of the reference measurement with respect to in-situ sensor readings (see Section 2.4.1.4 of NEMS *Dissolved Oxygen* v2.0)

  Note: Simultaneous readings are the most reliable for data verification, especially when conditions are changing rapidly.

- precision and accuracy of the reference reading (see Sections 2.2.9 and 2.4.5 of NEMS *Dissolved Oxygen* v2.0).

A reference reading is unreliable, and must be identified as such on quality plots, if:

- it is outside the calibrated range of the reference sensor, or
- its uncertainty exceeds the verification tolerance, or
- the reference sensor fails its end-of-day validation (see Section H 2.3.1).

DO record should not be adjusted to any unreliable reference value unless there is other corroborating evidence of faulty recording. If adjusted, the adjustment(s) should be reviewed when reliable reference readings resume. In any case the period of data associated with the unreliable reference cannot be quality coded higher than QC 400.

If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and
- date of the disregarded visit cannot be used to determine the verification frequency for quality coding purposes, i.e.:
  - if a disregarded check results in an interval between accepted verifications that exceeds two months the intervening data cannot be assigned QC 600
  - if a disregarded check results in an interval between accepted verifications that exceeds four months the intervening data cannot be assigned higher than QC 400.

  Note: NEMS Dissolved Oxygen *v3.0.0 sets a minimum verification frequency of two months for QC 600 but does not assess verification frequency in its quality coding matrix.*

2.3.1 Calibration and validation of reference sensors

Reference sensors and meters should be validated in 100% saturated air or water on each day of use, preferably before departure, but at least at the end of each day. Validation fails if the result is not within ± 0.5% and may be presumed to be due to sensor calibration drift (see Section 1.7.1 of NEMS *Water Quality Parts 1 to 4* v1.0.0).

If a reference sensor or meter fails a validation, review all reference readings with that instrument since its last successful validation, and add the apparent calibration drift to the uncertainty of those readings.

Calibration of these instruments involves adjusting the sensor or meter settings to known values. Methods of calibrating DO sensors are described in Section 2.3 of NEMS *Dissolved Oxygen* v2.0, and Table 1 and Annex E (or F, or G) of NEMS *Water Quality Parts 1 to 4* v1.0.0.

Calibration may be 1-point (100% saturated air or water) or 2-point (100% saturated air or water then zero DO). There is no method to check linearity through the sensor range to 100% saturation other than by Winkler titration, which is not preferred (see Section 2.3.7.1 of NEMS *Dissolved Oxygen* v2.0). Calibration beyond 100% saturation is complicated (Wilcock et al, 2011) and therefore impractical, and linearity of response is assumed to continue up to the sensor's nominal range (see Section 2.2.9 of NEMS *Dissolved Oxygen* v2.0).

A 1-point calibration follows any failed validation, before the instrument is used again. A 2-point calibration is expected:

- after replacing a sensor cap (usually 2-yearly), or
- after changing a membrane (3-6 monthly), or
- when consistently low DO concentrations are expected, and
- as a minimum, every 6 months

(see Tables 1 and 2 of NEMS *Water Quality Parts 1 to 4* v1.0.0).

A calibration and validation history must be maintained and be accessible (see Section 2.4.1.1 of NEMS *Dissolved Oxygen* v2.0).

Manufacturer-stated accuracy required of a reference DO sensor or meter is:

- ± 3% in the 0 to 200% saturation range, and
- ± 0.3 mg/L in the 0 to 20 mg/L concentration range.

(see Section 3.1.2 of NEMS *Water Quality Parts 1 to 4* v1.0.0)

2.3.2 Calibration and validation of in-situ sensors

In-situ sensors are required to be calibrated:

- prior to deployment, and
- at least annually thereafter, and
- after replacing a sensor cap (usually annually) or after changing a membrane, and
- when sensor drift is suspected, and
- when verification confirms deviation of the in-situ value from the primary reference exceeds tolerance.

  Note: Confirmation implies a second check that should be done as soon as possible to minimise the period of possibly compromised data.

(see Sections 2.2.8 and 2.3.6 of NEMS *Dissolved Oxygen* v2.0).

In-situ sensor performance over time is checked by routine two-monthly verifications, plus additional visits as needed to confirm any non-conformances and prevent data loss.

Note: Section 2.4 Validation in NEMS Dissolved Oxygen *v3.0.0 describes verification in the context of the NEMS* Glossary *definitions.*

2.4 Deviation tests

NEMS *Dissolved Oxygen (Measurement, Processing and Archiving of Dissolved Oxygen Data)* tolerances vary with the reference value. Performance can still be monitored graphically using a control chart or deviation with time plot, but the tolerance thresholds must be calculated from each reference value at the same time as each deviation (Figure H 1).

Verification tolerances for corrected DO% are one and two times either of the following as applicable:

- ± (3% + 5% of reference value) for DO% saturation, or
- ± (0.3 mg/L + 5% of reference value) for DO concentration

(see Section 2.4.5 of NEMS *Dissolved Oxygen* v2.0).

The tolerance band each deviation falls in determines how many points (together with points for other criteria) contribute to a quality code matrix score that sets maximum possible quality code of the data.

Because of the conversions required (see Section H 1.2), separate charts or plots are needed for uncorrected and corrected DO% saturation, and DO concentration, with the tolerances also converted to align with the units of the data.

Analysis of deviation with range (Figure 12) is also strongly recommended to monitor for loss of linearity, especially in the super-saturated range (DO% > 100%) (see Section D 2.3.1). Note that loss of linearity may affect the in-situ or reference sensor, or both.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

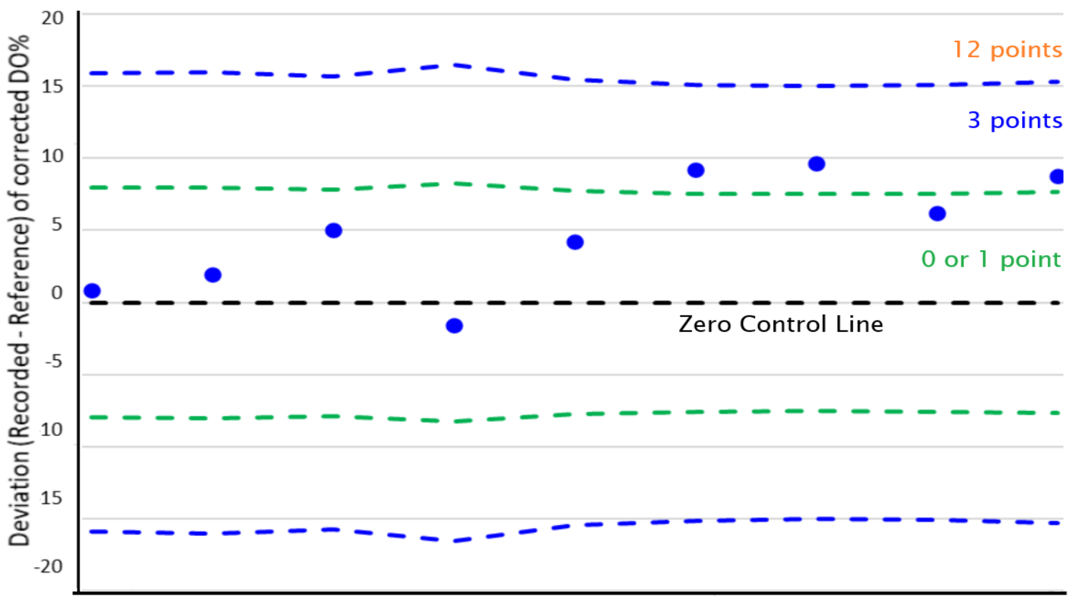


Figure H 1 – An example of a control chart used to track verification deviations and consequent quality coding matrix points for corrected DO% (DO% local) saturation data.

3 Potential Errors and Recommended Editing

This section describes common problems specific to dissolved oxygen (DO) data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Environmental conditions, such as:
    - changes in the light regime that affects instream photosynthesis, due to:
        - intermittent cloud cover
        - periodic shading, and/or
        - variations in turbidity
    - atypical inflows (e.g. an unauthorised discharge)
    - stratification
    - tidal influence.
- Instrument deployment and operation, and conditions that adversely affect them (see NEMS *Dissolved Oxygen* v2.0: Sections 1.3.4, 1.4.3, 1.5.3, and 1.6.3), including:
    - proximity of the sensor to the water surface
    - response times, including lag between changes in one or more supplementary variables and the reported DO value
    - insufficient water velocity (electrochemical sensors) (see Section 1.7 of NEMS *Dissolved Oxygen* v2.0),
    - unintended aeration (e.g. due to pumping)
    - the relative locations of the sensor and point of collection of reference measurements at various flows (see Section H 2.3).
- Interference and/or damage from:
    - human activities
    - debris
    - biofouling
    - chemical interference (gas-permeable membranes only)
    - sensor exposure (including desiccation during storage), and
    - flood damage

  (see NEMS *Dissolved Oxygen* v2.0: Sections 1.3.4, 1.4.3, 1.5.3, 1.6.3 and 2.5).
- Instrument performance, including:
    - maintenance of calibration (see Section 2 of NEMS *Dissolved Oxygen* v2.0), that may be compromised by one or more of:
        - baseline drift
        - loss of span or range

- loss or gain of amplitude
- loss of linearity
- poor signal to noise ratio (luminescent sensors at high DO concentrations)
- delayed replacement of sensor caps or membranes
- mistakes loading cap or membrane coefficients
- inaccurate, or no compensation for temperature, salinity and/or barometric pressure

- electronic transients
- over-ranging.

The effects of environmental conditions are measured as part of the target characteristic(s) and may or may not be regarded as errors depending on the purpose of the monitoring. If they are retained in the data, the causative factors and influences must be described in the Site/Initial Comment (see Section H 4.2.1).

3.2 Data offset

If a persistent constant or near-constant bias is evident from successive verifications (as depicted in a control chart or other quality control deviation test presentation) an offset adjustment can be applied to remove the bias.

Investigate probable cause and confirm the period of data that is affected. It may be apparent from a visible corresponding step in the data, in which case the adjustment is a constant applied that minimises the step, and the bias, without creating a step in the edited data.

A linear (baseline) drift adjustment (see Figure H 2 and Section H 3.4) may be required leading into and/or out of the offset adjustment to avoid creating a step in the edited data.

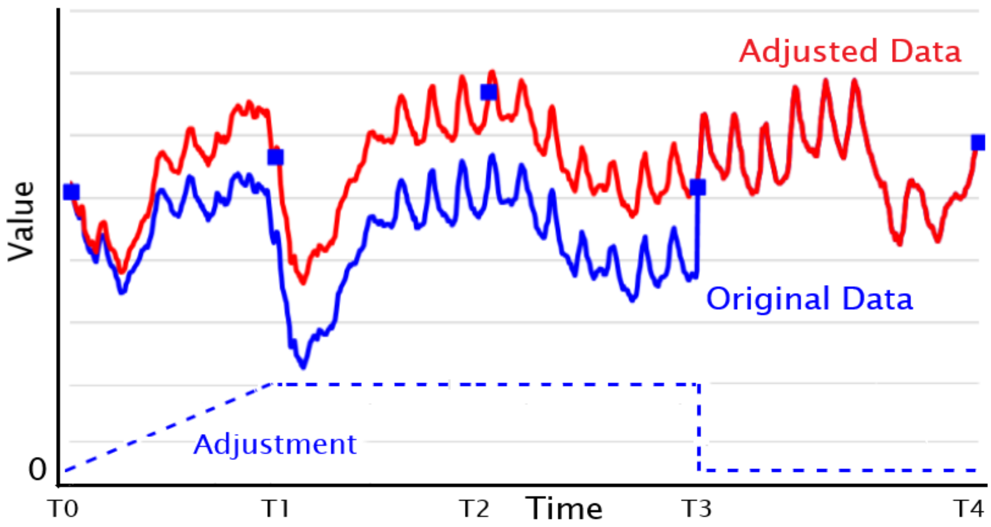


Figure H 2 - An example of dissolved oxygen data offset by a constant amount between T1 and T3 (blue trace), the reference readings (blue squares), adjusted data (red trace), and the adjustment applied (dotted line), which includes a baseline drift adjustment up to T1.

Table H 1 – Guidance for resolving data offset

Guidance for resolving data offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	H 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and a corresponding step in the data may be apparent.	H 3.2 Fig. H 2 H 2.2 Fig. H 1 H 2.4
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	The lower of the matrix quality code, or 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	H 4.1 6.2.3 H 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- replacement of the dissolved oxygen (DO) sensor
- change of DO sensor caps, membranes and/or their coefficients
- DO sensor recalibration
- a fault with, recalibration, or replacement of a supplementary measurement sensor
- moving the DO and/or supplementary measurement sensor(s) to a different location (vertical or horizontal)
- interference or disturbance around the DO and/or supplementary measurement sensor(s)
- clearing or cleaning the DO and/or supplementary measurement sensor(s)
- change in the environment, e.g. shading at certain times of the day.

Cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

In most cases the appropriate adjustment is a simple special case of linear (baseline) drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a specified non-zero value at the end of the affected period, or vice versa (see Figure H 2).

3.3.1 Instrument servicing and replacements

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, describe the change in an Operational Comment (see Section H 4.2.3) that references relevant Equipment Comment(s) (see Section H 4.2.2) as needed. If the data subsequently collected are offset from data previously collected as a result of the change, leave the step-change in the data but identify and explain it in a Stationarity Comment (see Section H 4.2.7).

If the step coincides with a change of DO sensor cap or membrane, and the sensor calibration coefficients must be manually entered, the problem may be due to a data entry mistake. In some cases, it is possible to recover the correct data (see Section H 3.9), which should eliminate the step. If there is no mistake with the meter coefficients, assume some form of drift in the prior data and address it (see Section H 3.4).

If the step is attributable to an issue with necessary supplementary data (temperature, salinity and/or barometric pressure) it should be addressed in the supplementary data and dependent DO values recalculated (see Section H 1.3). If recalculating DO values is not possible, the recorded DO data may be adjusted directly, assuming an offset (see Section H 3.1) or some form of drift (see Section H 3.4), but quality code cannot be higher than QC 400 (compromised).

If none of the above situations apply and calibration of the replacement instrument is confirmed pre-deployment, assume some form of drift in the replaced instrument and adjust the data accordingly (see Section H 3.4).

3.3.2 Interference or disturbance

Physical interference may be due to the actions of people or animals on or about the sensor. Site maintenance, self-cleaning mechanisms, and water sampling activities may also disturb ambient conditions.

If the interference rapidly warms, cools, aerates, or suddenly increases turbidity near the sensor, the dissolved oxygen record may step up or down over one or two recording intervals, then recover when the interference moves or dissipates, or conditions equilibrate. Normal conditions are expected to resume within a few hours.

Data may be offset for the duration of the interference. If bubbles are able to form on the sensor, periods of elevated readings may be prolonged.

The effects of short-duration interference or disturbance may be treated as spikes (see Section H 3.5). Otherwise, adjust for offset as shown in Figure H 2 but with the baseline drift adjustment following the offset shift.

Disturbance may change position or location of the sensor. Data recorded in these cases may be valid but not fit for purpose and therefore require, as a minimum, an appropriate lesser quality code and a Data Comment (see Section H 4.2.4). If the change is made permanent, treat the step as in Section H 3.3.1.

If the sensor is exposed, or buried (e.g. by accumulation of debris, bed movement, or a relatively sudden event such as bank collapse), the subsequent data may include spurious values and are likely not representative and should be deleted then treated as missing record (see Section H 3.11).

Membrane electrode sensors are subject to gaseous interferences (mainly hydrogen sulphide and ammonia present in anaerobic situations) (see Section 2.5.7 of NEMS *Dissolved Oxygen* v2.0). Affected data are likely not representative and should be deleted then treated as missing record (see Section H 3.11).

Dissolved oxygen variation due to periodic shading, tidal influence, salinity and water temperature variations, geothermal effects, groundwater interactions, runoff inputs, and passage of floods are part of the target characteristics to be measured and not considered interference or disturbance that requires editing or impacts data quality.

3.3.3 Sensor clearance or cleaning

Clearing or cleaning the sensor may result in a step in the recorded data.

Note: Partial clearing and/or cleaning may occur naturally during floods because of drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment. However, abrasion may damage optode sensors leading to noisy data (Wilcock et al, 2011).

If the sensor was buried by sediment or debris, treat as in Section H 3.3.2.

Biofouling (algal film growing on the sensor, compounded by fine sediment settling in the algae) and chemical fouling (a chemical film, e.g. from tannins or salts in the water) are gradual accumulations that may progressively affect readings.

Fouling behaviour and the corresponding evidence in the data is dependent on cause, and sensor cleaning frequency and method (e.g. wiper or brush, ultrasound, or pumped air or water). Fouling may affect sensor readings non-linearly with time, especially if the cause is biological accumulation. However, if magnitude of the error is small, a linear drift adjustment to eliminate any step introduced by cleaning is an acceptable solution (see Section H 3.4).

Fouling may also cause noisy data, which should be smoothed or resampled (see Section H 3.6) before any drift or offset adjustment is applied to eliminate a step.

Table H 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in DO between successive readings that disrupts continuity of the usual pattern. Prior data are often biased.	H 3.3

Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down). May be evidence of increasing bias in prior data (e.g. control chart or other deviation test presentation).	Fig. H 1 H 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted).	H 3.3.1
	Transform if instrument configuration was wrong.	H 3.9
	Adjust or remove values affected by interference or fouling. Treat any gaps created as missing data.	H 3.3.2 H 3.5
	Drift adjustment with maximum adjustment at the step in the trace and no (i.e. zero) adjustment at onset (or resolution) of problem (depending on cause).	H 3.4 4.4 & 4.5
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step.	H 4.2.3 H 4.2.2 H 4.2.7
	If transforms are fully traceable, quality code is unaffected, but a Transformation Comment is required.	H 3.9 & H 4.2.6
	Quality code of adjusted data is lesser of matrix, 'minor' or 'significant' modification criteria, or as determined by quality and application of required supplementary data.	H 4.1 6.2.3 H 3.3.1 H 1.3
	Data Processing Comment explaining identified cause and details of adjustment(s) applied (amount, type, and period of adjustment) required, OR	H 4.2.5 6.2.4
	Refer to missing data guidance as applicable.	H 3.11

3.4 Drift

Instances of noise (see Section H 3.6), over-ranging (see Section H 3.7), or sensor exposure (see Section H 3.3.2) must be isolated from analysis of drift and treated beforehand.

Elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift. Duration of drift is dependent on frequency of instrument cleaning, servicing, and calibration.

Note: Sensor validation in the field is often impractical so the in-situ sensor will usually be replaced if cleaning and servicing do not return readings to within verification tolerance. Verification checks may not be available for the lower end of the DO range because DO minima tend to occur at night.

Proper adjustment of the affected data should eliminate any step-change resulting from instrument cleaning, servicing, calibration, or replacement (see Section H 3.3). If affected data cannot be reliably adjusted, delete it from the record and treat the period as missing data (see Section H 3.11).

3.4.1 Baseline drift

Baseline drift may arise from fouling, general degradation of membranes and foils, or delamination of optode sensor foils under harsh conditions (high sediment loads or significant depth) often accompanied by increasing noise.

Apply a linear drift adjustment (see Section 4.4) to the affected period unless the diel DO range is large. If the diel range is large treat as for amplitude drift (see Section H 3.4.2).

3.4.2 Amplitude drift

Luminescent sensors are prone to larger errors at higher DO concentrations. If the range of DO values is large, assume widening amplitude of diel DO fluctuations occurs with baseline drift (Wagner et al, 2006). In these cases, a % of value linear adjustment (see Section 4.5) is more appropriate (see Figure H 3).

This adjustment is also applicable to suspected loss of sensor span arising from calibration drift (see Figure H 4).

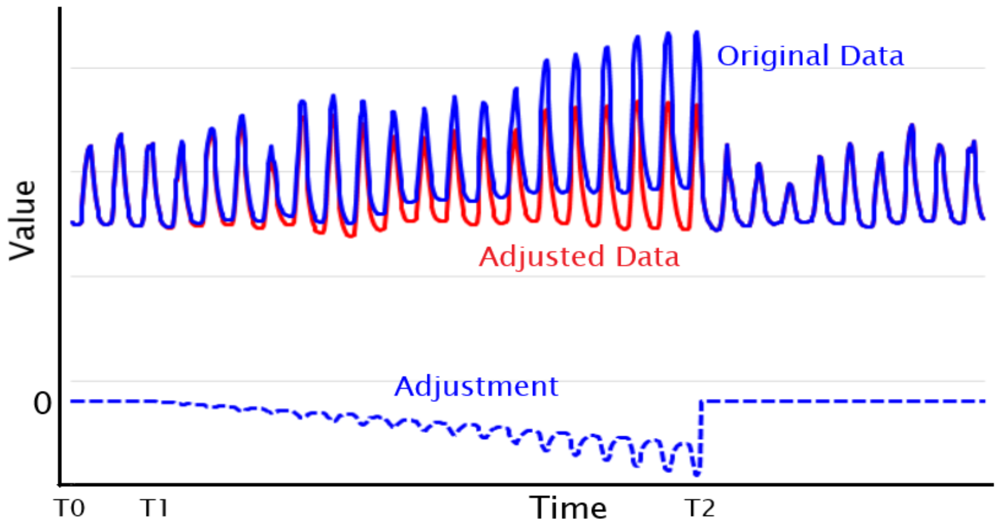


Figure H 3 - An example of a one-tailed % of value linear drift adjustment for amplitude drift between T1 and T2 (blue trace), with the adjusted data (red trace), and the adjustment (dotted trace) shown as the absolute values obtained from 0% of raw value at T1, incrementing linearly with time to -20% of raw value at T2.

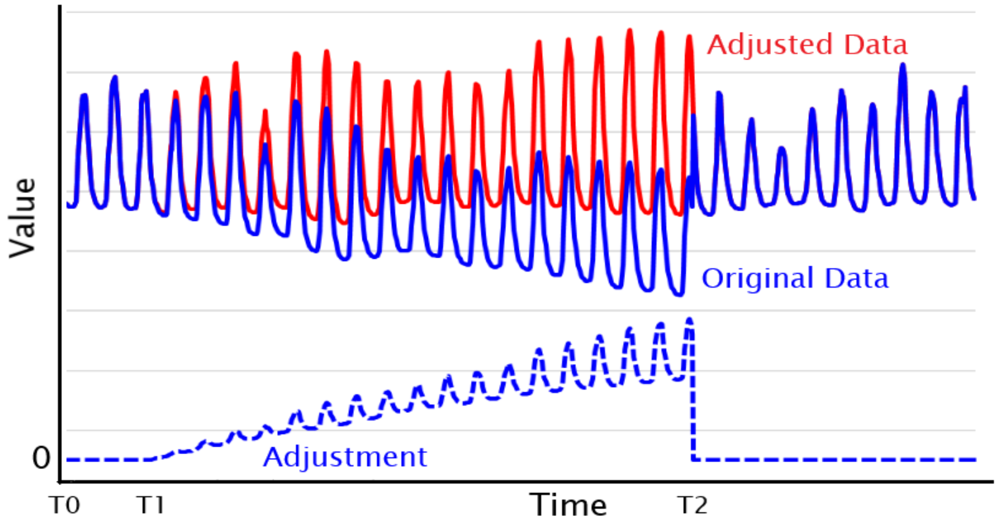


Figure H 4 - An example of a one-tailed % of value linear drift adjustment for loss of sensor span between T1 and T2 (blue trace), with the adjusted data (red trace), and the adjustment (dotted trace) shown as the absolute values obtained from 0% of raw value at T1, incrementing linearly with time to +50% of raw value at T2.

3.4.3 Loss of linearity

Linearity of DO sensors is assured by manufacturers up to 100% saturation and assumed up to 500% saturation in some cases.

Winkler titration is the only method capable of validating a DO sensor at a range of values to confirm linearity of response. Even so, the method cannot be used beyond 100% saturation. Accurate Winkler titration is difficult to achieve in the field.

Loss of linearity is therefore practically only detectable as trend or cycle in a deviation with range plot (see Section 3.6.4.5 and Figure 13). If the deviation with range plot is sufficiently robust (several verifications over as wide a range of values as possible with minimal scatter and unaffected by baseline drift) it may be used to derive a non-linear transformation to adjust the data for the calibration error (see Section H 3.9).

Table H 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount or % of value over time.	H 3.4
Evidence	Deviation of recorded from reference increases with time and/or value. Physical cause may be identifiable, such as biofouling or sensor degradation. Drift may be evident in a data plot as trending baseline and/or widening range.	H 3.4 H 2 3.6

Solution(s)	Apply linear drift adjustment for baseline drift unless diel range is large. Apply % of value linear drift adjustment for amplitude drift, baseline drift when diel range is large, and loss of span. Apply a transformation derived from verification results if loss of linearity is detected.	H 3.4 4.4 Fig. H 3 Fig. H 4 4.5 4.9
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each drift adjustment applied (type, amount, and period of adjustment). QC 400 and Data Comment if loss of linearity is detected but transformation is not possible.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 H 4.2.4 6.2.4.6

3.5 Spikes

Spikes may be due to short-term interference or disturbance (see Section H 3.3.2) or data transmission interruptions, power supply problems, or electronic transients.

Isolated spikes may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required.

Intermittent spikes may be deleted manually or discarded using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data is required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20, and H 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section H 3.6).

Table H 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	H 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	H 2 3.6

Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or H 3.11 or H 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 or H 3.11 or H 3.6

3.6 Noisy data

Noise in dissolved oxygen (DO) data may be real in response to environmental conditions such as intermittent cloud cover or turbidity, or erroneous due to instrument malfunction or floating algae or small debris obstructing the sensor.

3.6.1 Real noise

Noise that is real retains a pattern consistent with how ambient light regime affects photosynthesis by in-stream algae. Real noise will:

- not be present on a clear day, or at night
- be less in the mornings and evenings
- never exceed the clear day maximum
- have variable periods of high DO in bright sunshine with lag in DO reduction as cloud cover reduces photosynthesis
- be more or less random.

If real noise is excessive with respect to expected precision (see Section 2.2.9 of NEMS *Dissolved Oxygen* v2.0), reduce the random variation to acceptable variance by:

- manual editing (e.g. 'freehand draw')
- resampling, or
- filtering using a fixed or moving interval mean or median.

Avoid:

- disrupting expected range, timing, and legitimate features of diel cycles (e.g. avoid inducing lag and/or attenuation, or eliminating rapid change in DO due to bank shading or change in flow), or
- creating a step at the boundary with adjacent unedited data.

3.6.2 Erroneous noise

Erroneous noise can have rapid swings between high and low around the diel light cycle and at night (Wilcock et al, 2011). Faulting electronics may be due to poor connections or imminent failure of the sensor, requiring replacement, and effect on the data may be erratic.

Erroneous data is unusable. Delete the affected period and treat as missing record (see Section H 3.11).

Table H 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Fluctuations are high frequency and exceed expected sensor precision. Range of fluctuation compromises use of data in ecosystem models.	H 3.6
Evidence	Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Real noise varies with ambient light. Erroneous noise is not seen in independent observations.	H 2 3.6
Solution(s)	Method choice is determined by identified cause. Manually edit or resample, or 'smooth' with a statistical filter, if 'real' random noise. Delete affected period and treat as missing if erroneous noise.	H 3.6 H 3.6.1 4.12 H 3.6.2
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 or H 3.11

3.7 Over-ranging

Over-ranging occurs when measured values are beyond a sensor's calibrated range. For DO, this is any value that exceeds 100% saturation (see Sections H 2.3.1 and H 2.3.2).

Values above 100% saturation are routinely encountered. Values exceeding 200% saturation are rare (unless erroneous). Extreme diel variation in DO is more likely during low flows and warm weather, coinciding with maximum occurrence of algal blooms. Super-saturation generally occurs at very low flows and calm conditions when exchange of DO with the atmosphere is weak. Daily minimum DO% saturation exceeding 100% indicates a sensor needs maintenance and possible replacement

(Wilcock et al, 2011). Amplitude drift (see Section H 3.4.2) may also produce values above 100% saturation.

Maximum quality code for saturation measurements exceeding 100% is QC 400, and concentrations derived from these measurements cannot be assigned a higher code.

Depending on the sensor and logger configuration, peak clipping may occur, where over-range values are not stored or are set to the nominated maximum value (see Figure H 5). Datasets that include periods of clipped over-ranging may be filed as a censored time-series with appropriate metadata (see Sections 1.1.5 and H 4); however, treating affected periods as missing data is preferred (see Section H 3.11). A change of over-range (clipping) threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section E 5.2.7).

Clipped values are not recoverable by adjustment. After adjustment the diel maxima will not conform to the original censoring threshold (see Figure H 5) so affected periods must instead be gapped and treated as missing.

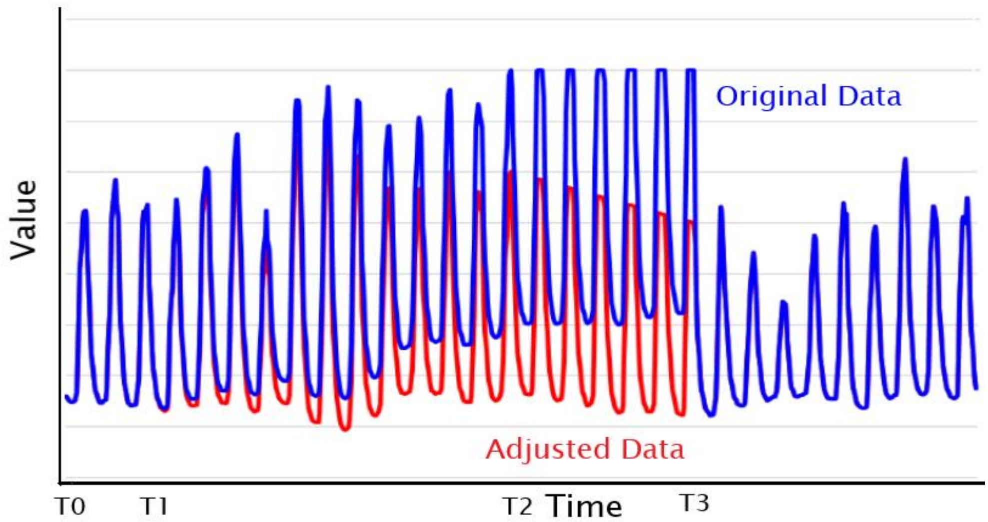


Figure H 5 - An example of clipped over-range DO values between T2 and T3 within a period of amplitude drift from T1 (blue trace), with the adjusted data (red trace), and showing the diel range of the adjusted data from T2 to T3 remains compromised and does not conform to the original over-range threshold.

Table H 6 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	Measured values are outside calibration range of the sensor, or full range of DO is not recorded.	H 3.7

Evidence	Values exceed known calibrated range of the sensor or over-ranged record flatlines or has gaps when DO is at or near a constant high value or known threshold. May be verified by independent measurements.	Fig. H 5 H 2 3.6
Solution(s)	Apply drift adjustments as needed. If peaks are clipped, store as censored data, or gap and treat as missing data.	H 3.4 4.4 & 4.5 H 3.7 1.1.5 4.16 H 3.11
Metadata	QC 400 all saturation values exceeding 100%, corresponding derived concentrations, and censored data. QC 100 if left missing. Data Comments are required identifying and explaining treatment of periods of clipped over-ranging. A Stationarity Comment is required if threshold and/or treatment is changed.	H 4.1 6.2.3 H 4.2.4 6.2.4.6 E 4.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently because of bed scour, channel migration, channel works, or by deliberate interference, or when removed for cleaning. Measurements while exposed are not representative and may be spurious.

Exposure may lead to sensor membrane or foil damage that continues to affect measurements after re-immersion.

If the level of the sensor is known relative to water level datum a water level threshold can be determined below which the corresponding dissolved oxygen data collected must be regarded as unreliable.

Remove data affected by sensor exposure from the record and treat the period as missing data (see Section H 3.11).

Table H 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	Measurements in air are not representative and may be spurious. Exposure may damage sensor membranes and foils.	H 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels of sensor and water, or consequence of an event known to have occurred).	H 3.8 H 2 3.6

Solution(s)	Remove affected data and treat as missing.	4.16 to 4.20 incl. H 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	H 4.1 6.2.3 H 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor and/or logger configuration.

3.9.1 Wrong measurement units

DO data collected in the wrong measurement units are usually recoverable if the necessary supplementary data have been recorded. Explicit conversion by mathematical relation between different units of DO measurement, e.g. % saturation to concentration, is possible.

- Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different (see Sections H 4.2.2 and H 4.2.6).
- Any change to the conversion methods and/or equations applied must be noted in a Stationarity Comment (see Section H 4.2.7).

  Note: Conversion equations are empirically derived, and the equations and methods of application vary.

- Verification data must be in the same measurement units as the continuous data collected to be directly comparable.

Note: The DO quality code matrix allows QC 600 to be assigned to DO% saturation data that is compensated during processing for at-site (or nearby) barometric pressure, but because there are no NEMS Standards for barometric pressure or salinity, the effect of assimilating supplementary variable quality codes into DO quality code (see Section H 1.3) is that corrected DO% saturation data (DO% local) can only be QC 600 if barometric compensation is carried out on the sensor, i.e. prior to data collection. Most in-situ DO sensors are deployed fully immersed and therefore cannot measure barometric pressure. The DO quality code matrix determines that uncorrected DO% saturation (DO% reference) cannot be higher than QC 400, regardless of its accuracy or verification results. NEMS Dissolved Oxygen (Measurement, Processing and Archiving of Dissolved Oxygen Data) *allows measurement of DO as concentrations, but quality coding scores are biased* *toward corrected DO% saturation due to the barometric pressure criteria, such that DO concentrations cannot be a higher quality than QC 400 either.*

3.9.2 Wrong instrument configuration

Replacement DO membranes and sensor caps may be supplied with new coefficients requiring upload by the user. If a mistake is made when entering one or more coefficients, DO data are recorded using an incorrect calibration relation between the sensor output and DO value.

If the calibration equations are published by the manufacturer, the necessary supplementary measurements are available, and the incorrect and correct coefficients are known, the instrument output can be calculated and the correct calibration then applied to obtain the correct DO values.

If the transformations are fully traceable to preserved calibration records, quality code is unaffected, but a Transformation Comment is required.

Some manufacturers provide proprietary software that allows coefficients to be edited, then revises the DO measurement values if the raw sensor output stored in temporary memory has not been overwritten. DO data recovered in this way may be regarded as replacement original record.

If transformation or recovery is not possible but the calibration equations are known, assess the recorded data for impact of the incorrect coefficient(s). If the impact is not significant and the data are not misleading they may be retained, quality coded as QC 400 (compromised) and explained with a Data Comment.

If the affected data cannot be assessed, or are assessed as unreliable and not representative, they must be deleted and the period treated as missing record.

Table H 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	H 3.9
Evidence	Differences between reference and logged values are variable and often large. Data inconsistent with expected range. A step-change occurs at time of configuration change.	H 3.9 H 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal, OR Assess impact of configuration error(s) and if not significant or misleading, file data with lower quality code and comment, OR	H 3.9.1 H 3.9.2 4.7

	Delete affected data and treat as missing.	H 3.11
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. QC 400 and Data Comment detailing assessment if configuration error is assessed as not significant, OR Refer to missing data guidance as applicable.	H 3.9 H 4.2.6 H 4.1 H 4.2.5 6.2.4 H 3.11

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section H 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table H 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong and/or data are missing.	H 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal distribution anomalies are apparent when compared with data from a similar nearby site.	Fig. 18 Fig. 26 H 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or H 3.11

Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 H 4.2.5 H 4.1 H 4.2.4 6.2.3 H 4.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous dissolved oxygen (DO) data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel cycle, i.e. within the rising or falling side of the sine curve, but not over the peak or trough
- a longer period may be one or more days up to one week
- an extended period may be a week or more.

DO is influenced by local factors such as:

- position of the sensor in the depth profile
- nature of the surrounds above and below water (e.g. shading, wind, and presence of algae and/or macrophytes)
- the degree of mixing brought about by velocity distribution.

When selecting and applying an appropriate method for resolving missing DO record, take account of the:

- likely variation at the sensor location
- possibility of extreme highs or lows having occurred in the period, and
- duration of the missing data (see Appendix H.1).

A maximum duration of fourteen (14) days for any period of synthetic infill is recommended, dependent on:

- the typical and expected variation in DO at the sensor location during the period
- the possibility of one or more significant events having occurred that may have altered the sensor environment (e.g. floods and/or algal blooms), and
- reliability of the relationship(s) used to generate the synthetic record.

For DO, provided it is collected near the primary sensor or in a well-mixed environment, backup data include:

- data obtained from another continuous sensor at site of a different type and/or standard, and
- manual observations using a reference meter that are intended to fill a period of missing data, i.e. measured at a frequency that captures the full range and rate of change of DO in the period.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in DO series, see Appendix H.1 to this Annex.

Table H 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	H 3.11
Evidence	Expected timestamps are not present in the raw data. A gap marker may or may not be present depending on data collection method. Data plot shows entire, or parts of cycles are missing. Investigation confirms data were not logged and/or not collected, OR data have been intentionally removed.	4.16 Fig. 9 H 2 3.6
Solution(s)	Use at-site backup data, and manual observations including verification readings where available, OR a) if brief, interpolate across gap, except if a peak or a trough b) if short period, interpolate across gap, or infill with a curve, but not over a peak or trough c) reinstate a clipped peak by substitution d) for longer and extended periods, apply methods to infill with synthetic data, or mark the gap e) if more than 14 days are missing, mark the gap, or note a temporary site closure.	App. H.1 H 3.11 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record or QC 300 if infrequent manual observations or synthetic infill, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	H 4.1 6.2.3 H 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

Quality code for DO data is set by four different but related sets of criteria:

- the quality coding flowchart
- the Quality Coding Matrix
- blanket provisions, and
- data editing actions and adjustments.

The quality coding flowchart and Quality Coding Matrix may be found in NEMS *Dissolved Oxygen (Measurement, Processing and Archiving of Dissolved Oxygen Data)* version 3.0.0. The flowchart is also available in NEMS *National Quality Code Schema*.

4.1.1 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, instruments, records, and results of each verification to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the data collected between each inspection. This assessment should, for quality assurance preventive action purposes, be completed before departing the site, but if not, becomes the first step of quality control during data processing.

By applying the Quality Coding Matrix at the time of data collection it is possible to assign quality codes other than QC 200 to unprocessed data, but this may be misleading because data editing actions may result in periods of data acquiring a different code (see Section H 4.1.2).

Compensation for water temperature, salinity, and/or barometric pressure are not regarded as data editing and are included in the Quality Coding Matrix assessment.

4.1.2 Blanket provisions

The following provisions apply to DO data in addition to the generic application of quality codes QC 100, QC 200, and QC 300 as set out in the quality coding flowchart descriptions:

- DO% saturation measurements greater than 100% and their corresponding concentration values are limited to a maximum quality code of QC 400 (see Section H 2.3)
- periods of censored (over-ranged) data are limited to a maximum quality code of QC 400 (see Section H 3.7)
- supplementary data required to be permanently stored (see Section H 5) must be assigned QC 200 if:
    - not processed and verified according to their relevant NEMS, or
    - no NEMS Standard exists for that variable (see Section H 1.3)

- maximum possible quality code of DO values that are compensated for water temperature, salinity, and/or barometric pressure using supplementary data during DO data processing is:
    - the lesser of the DO quality coding matrix result or the final quality code assigned to the supplementary data if processed to NEMS, or
    - the lesser of QC 500 or the DO quality coding matrix result if the supplementary data are reviewed but not processed and are assigned QC 200 (not assigned a final quality code)
- a period of record that would otherwise be verified by a disregarded check cannot be quality coded higher than QC 200 (see Section H 2.3)
- a period of record retained uncorrected after assessment, despite known incorrect calibration coefficient(s), cannot be quality coded higher than QC 400 (see Section H 3.9.2).

4.1.3 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Compensation for water temperature, salinity, and/or barometric pressure, and conversion between DO units of measurement, have no additional effect on the quality code, i.e. these actions are effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section H 3 of this Annex.

4.2 Example dissolved oxygen comments

The following are templated examples of comments for dissolved oxygen stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of dissolved oxygen measurements) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for *<river name>* River dissolved oxygen <saturation *or* concentration> at *<site name>*

Site number <*network number, ID or code*> on river <*river number*>[21]
The site is situated <*distance to coast*> km from the mouth at grid reference <*map co-ordinates and type*[22]>, <*altitude*> masl. Drains <*catchment area to site*> km^2 and is monitored for <*site purpose and target characteristics*>.
Additional information: Site is affected by <*persistent adverse conditions at site (e.g. biofouling, discharges, low velocity, bed movement)*>. Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <Saturation values are corrected to local barometric pressure (*or* referenced to 1 atmosphere)>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured at this site: <*list variables, including any backup DO recorder and separately logged supplementary data*>*;* <This record is used to derive <*list variables e.g. DO concentration from DO% saturation (reference)*>>.
The local recording authority is: <*name of recording/archiving agency*>

Lake station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for <*name of water body*> dissolved oxygen <saturation *or* concentration> at <*site name*>
Site number <*network number, ID or code*> on river <*river number*>[10]
The site is situated <*distance to outlet*> km from the outlet at grid reference <*map co-ordinates and type*[11]>, <*altitude*> masl. Drains <*catchment area*>km^2 of <*river name*> River catchment and is monitored for <*site purpose and target characteristics*>. Lake area is <*surface area*>km^2 and level is controlled by <*describe features e.g. natural outlet, dam, weir etc.*>
Additional information: Site is affected by <*persistent adverse conditions at site (e.g. biofouling, some form of regular disturbance, etc.)*>. Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <Saturation values are corrected to local barometric pressure (*or* referenced to 1 atmosphere)>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured at this site: <*list variables, including any backup DO recorder and separately logged supplementary data*>*;* <This record is used to derive <*list variables e.g. DO concentration from DO% saturation (reference)*>>.
The local recording authority is: <*name of recording/archiving agency*>

[21] from *Catchments of New Zealand* (SCRCC, 1956).

[22] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Coastal station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for <*name of water body*> dissolved oxygen <saturation *or* concentration> at <*site name*>
Site number <*network number, ID or code*> at grid reference <*map co-ordinates and type*[11]> Situated <*brief location description*> and is monitored for <*site purpose and target characteristics*>.
Additional information: Site is affected by <*persistent adverse conditions at site (e.g. biofouling, some form of regular disturbance, etc.)*>. Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics*>. Site evaluation is available from <*reference*>. <Saturation values are corrected to local barometric pressure (*or* referenced to 1 atmosphere)>. <Some (*or* All) quality control (*and/or* data editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured at this site: <*list variables, including any backup DO recorder and separately logged supplementary data*>*;* <This record is used to derive <*list variables e.g. DO concentration from DO% saturation (reference)*>>.
The local recording authority is: <*name of recording/archiving agency*>

Groundwater level station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for <*name, ID, or bore number*> Groundwater dissolved oxygen <saturation *or* concentration>.
Located at <*map co-ordinates and type*[11]> and monitored for <*site purpose and target characteristics*>.
Drilled on <*dd-mm-yyyy hhmmss*> to depth of <*depth of well*>m >. Well construction: from <*depth*> to <*depth*>m diameter <*bore dia.*>mm and is <*cased, uncased, or screened*>
Well type <*type*>[23] for <*purpose*>[24] Aquifer type <*type*>[25] depth <*depth*>m
Aquifer lithology <*brief description*>. Log available from <*name and contact details*>
Consent <*number or* permitted use>
Ground elevation <*level and datum*>m, Static water level <*level and datum*>m
Additional information: Sensor is located <*brief description of sensor placement and environment*>. Data is affected by <*influences incorporated in target characteristics e.g. salinity, tide, pumping etc.*>. Site evaluation is available from <*reference*>. <Saturation values are corrected to local barometric pressure (*or* referenced to 1 atmosphere)>.
<*Additional bore location information if more than one bore in vicinity, and aquifer properties, water quality grade if available*>. <Some (*or* All) quality control (*and/or* data

[23] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring

[24] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused

[25] confined, unconfined, perched, or fissure

editing) is automated; refer to the relevant Data Processing Comments.> <Data is stored as a censored series.>
The following data is also measured at this site: *<list variables, including any backup DO recorder and separately logged supplementary data>;* <This record is used to derive *<list variables e.g. DO concentration from DO% saturation (reference)>*>.
The local recording authority is: *<name of recording/archiving agency>*

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Dissolved Oxygen
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), on-board, multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The DO sensor is a *<type and platform e.g. electrochemical probe or optode sonde>* measuring *<list relevant on-board measurements, including supplementary variables, e.g. uncorrected DO% saturation, water temperature, salinity (or conductivity), etc.>* installed in (*or* on) *<brief description e.g. weighted cable x-m down well, or below moored buoy, plastic conduit attached to timber pier, steel box section secured on piles etc.>* positioned at *<reduced level and datum, or equivalent stage, or depth from water surface, or other (briefly describe)>*.
Sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* calibrated on *<calibration date>*. Sensor output is converted to logged values of <<(uncorrected *or* corrected)> % saturation *or* concentration> by *<briefly describe the calibration equation(s) e.g. "by a modified Stern-Volmer equation with <x> calibration coefficients">*. Sensor calibration is valid for *<calibration period>*.
Site is visited *<verification frequency>.* Data is collected by *<method e.g. telemetry and occasional manual download>*.

Create a similar but separate comment for any:

- backup sensor or secondary source of DO data at the site, to avoid the comments becoming too long and complex
- replacement sensor if any of the previously described details change as a consequence. Include confirmation that all other details have not changed, for example:

Type: Equipment
Measurement: Dissolved Oxygen
Replacement DO sensor is a *<type and platform e.g. electrochemical probe or optode sonde>* installed on *<dd-mm-yyyy hhmmss>* in the existing installation. New sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* calibrated on *<calibration date>*. Sensor output, calibration frequency, site visit frequency, and data collection method are unchanged.

Type: Equipment
Measurement: Dissolved Oxygen
Verification data is obtained <*state frequency*> by <*describe method and instrument(s) used e.g. manual readings from a calibrated reference sonde (or handheld instrument ABC), positioned as close to the sensor as possible, etc.*> <*Add other relevant information such as range, units, serial number, and calibration frequency of the reference sonde or handheld*>.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Dissolved Oxygen
Sensor moved on <*dd-mm-yyyy hhmmss*> to <*where in relation to previous*> because <*provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor velocity etc.*>. New location is <*describe new environment*>. New sensor position is <*reduced level and datum, or equivalent stage, or depth below surface, or briefly describe*>.

Type: Operational
Measurement: Dissolved Oxygen
Sensor cleaned on <*dd-mm-yyyy* from *hhmmss* to *hhmmss*>. Data between these times is not representative of in-stream DO and has been <*describe action e.g. deleted from the record or replaced with manual readings from the reference meter*>.

Type: Operational
Measurement: Dissolved Oxygen
Verification reference reading on <*dd-mm-yyyy hhmmss*> was collected <*distance vertical and/or horizontal*> from the sensor due to <*provide reason e.g. high flood preventing access*>. Some deviation from recorded value is expected.

Type: Operational
Measurement: Dissolved Oxygen
Verification reference reading on <*dd-mm-yyyy hhmmss*> is unreliable because <*give reason*>. <Recorded data is not adjusted to this check.>

Type: Operational
Measurement: Dissolved Oxygen
Sensor replaced on <*dd-mm-yyyy hhmmss*> because <*provide reason*>. <Replacement sensor is a different type (*or* model) (*or* range). Refer to the associated Equipment Comment for its specifications.>

4.2.4 Data Comment examples

Type: Data
Measurement: Dissolved Oxygen
Backup record used from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> due to <*identified cause of primary recording failure*>.

Type: Data

Measurement: Dissolved Oxygen

Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (*or* values removed because of *<describe recording fault>*). *<Add any other relevant information such as why the gap has not been filled>.*

Type: Data

Measurement: Dissolved Oxygen

Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (*or* replaces data affected by *<describe recording fault>*). Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression, etc.>* with input data *<list sites, variables, and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. not recommended as supplementary data or for model calibration etc.>*

Type: Data

Measurement: Dissolved Oxygen

Barometric pressure is recorded *<state interval>* by (*and/or* obtained *<state frequency>* from) a barometer at site (*or* at *<site name>*, site number *<network number, ID or code>*, grid reference *<map co-ordinates and type[11]>*, *<altitude>* masl, operated by *<recording agency>*). *<Add other relevant information such as barometer type, range, units, precision, and accuracy>.* The data is supplementary; <reviewed and edited for gross errors but not verified prior to use (*or* applied as received from the recording agency)>.

Type: Data

Measurement: Dissolved Oxygen

Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. low velocity, suspected interference or disturbance, intermittent flow, fouling, low power, pumping, suspected calibration error or loss of linearity, etc.>. <Add any other relevant information such as corroborating evidence, limitations on usefulness, or possible reasons for data being reliable.>*

Type: Data

Measurement: Dissolved Oxygen

DO exceeds maximum recording range *<indicate frequency e.g. continuously, occasionally, or each day>* between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>*. Affected periods are deleted and marked as gaps (*or* censored at *<maximum stored value and units>*).

Type: Data
Measurement: Dissolved Oxygen
Change of datalogging interval on <*dd-mm-yyyy hhmmss*> from <*previous interval*> to <*new interval*>.

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Dissolved Oxygen
Values deleted and record interpolates from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> to remove spikes caused by <*identified cause*>. Edited by <*name*> on <*date of processing*>.

Type: Data Processing
Measurement: Dissolved Oxygen
Time shift of -1 hour is applied to convert period logged in NZDT from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> to NZST. Error due to <*give reason e.g. incorrect clock reset at logger restart*>. Edited by <*name*> on <*date of processing*>.

Type: Data Processing
Measurement: Dissolved Oxygen
Values replaced from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> to remove spikes caused by <*identified cause*>. Edited by <*name*> on <*date of processing*>.

Type: Data Processing
Measurement: Dissolved Oxygen
Data smoothed using a <*time interval or number of values*> centred moving mean from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*> to minimise random noise caused by <*identified cause*>. Edited by <*name*> on <*date of processing*>.

Type: Data Processing
Measurement: Dissolved Oxygen
From <*dd-mm-yyyy hhmmss*> (to <*dd-mm-yyyy hhmmss*>) automated quality control (*and/or* editing) is applied to this data. Actions include: <*briefly describe each action in specific terms e.g. Range Test: values < x %Sat or > x' %Sat not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.*> (*or* Actions are documented in <*provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.*>*)*, applied <*describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data has been preserved but before near real-time web publication etc.*>, using <*provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar*>.

Type: Data Processing
Measurement: Dissolved Oxygen
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x %saturation (or mg/L), linear drift adjustment of* x_0 *%saturation (or mg/L) to* x_1 *%saturation (or mg/L) etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the original measurements (see Sections 3.1.1 and 8.2).

4.2.6 Transformation Comment examples

Transformations applied prior to archiving a dissolved oxygen record are included here. Transformations of archived records to other forms of the variable, or to other variables of interest, for analysis or modelling are outside scope (see Section 6.2.4.8).

Type: Transformation
Measurement: Dissolved Oxygen
Archived DO% saturation values are corrected to local barometric pressure recorded at site (*or* at *<site name>*, *<x>* km from site, with altitude correction) by applying the barometric correction function from Table 7 Annex D NEMS Dissolved Oxygen v2.0 to logged values of DO% saturation (referenced to standard atmospheric pressure). Barometer details are available from the relevant Equipment Comment.

Type: Transformation
Measurement: Dissolved Oxygen
DO concentration values archived in mg/L are transformed from logged values of DO% saturation (referenced to standard atmospheric pressure) and water temperature in degrees C, using the relation C = Cs x (DO%/100) rounded to nearest 0.1 mg/L, where Cs is solubility of oxygen in water at equilibrium under 1 atm of pressure obtained from the APHA 23rd edition equation provided in Annex G of NEMS Dissolved Oxygen v2.0.

The above two examples need only be filed once at the start of the relevant archive record, not repeated for each period of data processed.

Type: Transformation
Measurement: Dissolved Oxygen
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by a correlation rating to adjust for suspected loss of calibration linearity. Rating points are (original, adjusted) *<list the rating point pairs>*. Sensor was replaced on *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Dissolved Oxygen
A calibration coefficient was incorrect from <*dd-mm-yyyy hhmmss*> to <*dd-mm-yyyy hhmmss*>. The error was in coefficient <*name, e.g. C0*>; value applied was <*value*>, correct value is <*value*>. Affected data has been corrected by applying transformations to recover raw DO sensor signal, then applying the correct calibration equations and parameters, as provided in the manufacturer's calibration certificate <*calibration certificate reference and/or date*>, to the recovered raw signal. Edited by <*name*> on <*date of processing*>.

4.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Dissolved Oxygen
Sensor moved on <*dd-mm-yyyy hhmmss*> to <*where in relation to previous*> because <*provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.*>. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment.

Type: Stationarity
Measurement: Dissolved Oxygen
Step-change in data from <*dd-mm-yyyy hhmmss*> is coincident with change of sensor type and installation. Data has not been adjusted because all verification checks are within tolerance and a slight shift in stationarity is suspected. Sensor details are available from the relevant Equipment Comments. Location and position details are available from the relevant Operational Comments.

Type: Stationarity
Measurement: Dissolved Oxygen
New effluent discharge consent <*provide consent number and consenting agency*> operative from <*dd-mm-yyyy hhmmss*> at <*location relative to sensor e.g. x m (or km) upstream*> on <*name of stream, or unnamed tributary*> may affect DO values recorded at this site after this date.

Type: Stationarity
Measurement: Dissolved Oxygen
Method to convert from measured uncorrected DO% saturation to archived DO concentration (mg/L) is changed from <*dd-mm-yyyy hhmmss*>. Refer to the relevant Transformation Comments for method details.

Type: Stationarity
Measurement: Dissolved Oxygen
Data is a censored series. Maximum accepted value and therefore censoring threshold was changed on <*dd-mm-yyyy hhmmss*> from <*x %Sat*> to <*x' %Sat*>. Refer to the corresponding Equipment Comment for logger reprogramming details.

Stationarity Comments can also be used to capture and collate information about historical methods and data.

5 Preservation of Record

Requirements in this section are additional to Section 8 of this Standard for dissolved oxygen (DO) sites.

End users must have access to verified DO record in the following forms, either directly or by subsequent calculation:

- DO% saturation:
  - referenced to standard atmospheric pressure (uncorrected, DO% reference), and
  - corrected to local at-site barometric pressures (DO% local), and
- DO concentration (mg/L).

Recording agencies must therefore permanently archive and back up regularly:

- the original DO data as collected, which may include on-board (the instrument) corrections for water temperature, salinity, barometric pressure and/or altitude
- the verified and edited series of DO, which may be a different form from the original, and
- as supplementary data, any of water temperature, salinity, barometric pressure, or altitude that:
  - have not been compensated for in the original DO data as collected, and/or
  - are needed in combination with the verified and edited DO record to derive the other forms of DO data.

For example: The processed and permanently archived record of DO at a freshwater site may be of uncorrected DO% saturation provided continuous records of water temperature and local barometric pressure are also permanently archived to enable corrected DO% saturation (DO% local) and DO concentration to be derived from the archived series at any time in the future.

6 References

Wagner RJ, Boulger RW, Oblinger CJ, Smith BA. 2006. *Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting.* U.S. Geological Survey Techniques and Methods 1–D3. Retrieved from https://pubs.usgs.gov/tm/2006/tm1D3 (31 May 2021)

Wilcock B, Gibbs M, McBride G, Young R. 2011. *Continuous measurement and interpretation of dissolved oxygen data in rivers.* NIWA Client Report HAM2011-010, prepared for Horizons Regional Council. NIWA, Wellington.

YSI. 2009. *The dissolved oxygen handbook: A practical guide to dissolved oxygen measurements* (76 pp.). Yellow Springs, OH: Yellow Springs Instruments Inc. (www.ysi.com).

Appendix H.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, estuarine, sea, or groundwater)
- location of the sensor in the depth profile
- the nature of the surrounds above and below water (e.g. shading, wind, presence of algae and/or macrophytes)
- the duration requiring infilling
- the degree of mixing at-site during the period missing
- availability of other relevant at-site time-series, such as:
    - backup dissolved oxygen data (see Section H 3.11)
    - water temperature data
    - flow or water level data
- likelihood during the period missing of:
    - extreme DO highs or lows having occurred
    - an event causing disturbance or alteration of the sensing environment (e.g. floods and/or algal blooms), or
    - local inputs that may affect DO, e.g. a nearby upstream discharge
- availability of supporting observations and other evidence such as:
    - verification readings
    - manual observations using the reference meter, intended as infill, and
    - other readings, e.g. observations during other sampling at-site or nearby in the period, including those measured using an instrument other than the usual reference meter.

2 Recommended Methods

The following methods are candidates for infilling gaps in dissolved oxygen (DO) records:

- inserting one or more of:
    - at-site backup DO data (see Section H 3.11)
    - at-site verification readings
    - other at-site readings obtained using the reference meter
    - at-site manual readings from other instruments
    - readings obtained nearby in the same water body
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for brief and short periods (see Appendix H.1 Section 2.3 and Section H 3.11)
- mathematical calculation of the sine curve or copying from a reference trace recorded at the same site for short periods (see Appendix H.1 Section 2.4 and Section H 3.11)
- superimposing a recorded peak from the same site to reinstate a clipped peak (see Appendix H.1 Section 2.5 and Section H 3.7)
- generating a record from results of a linear or curvilinear regression with one or more suitable donor sites (see Appendix H.1 Section 2.6).

Manual readings can be incorporated into all the above methods to improve confidence in the synthesised data.

Periods of fourteen (14) days or more should not be filled with synthetic data.

2.1 Infilling with backup dissolved oxygen data

Backup DO data (see Section H 3.11) must be compensated, verified, edited, and quality coded as for the primary record for the period it is needed, including assessing for recording problems that would preclude its use.

If the backup data are manual readings from an instrument other than the primary in-situ sensor, note their source and uncertainty in the Data Comment and select a quality code for the period by following the schema.

Local effects and differences in instrument design and calibration make it unlikely the backup and primary records will directly overlap if not from the same instrument. Small drift adjustments (see Section H 3.4) may be needed to eliminate steps at the junction of the primary and infill backup series.

2.2 Infilling with observations

Verification readings and other manual observations at-site or nearby may be used to assist with infilling a gap.

If a logger and/or sensor is disconnected for a period during a site visit and there is no backup in-situ sensor, manual observations from the primary in-situ sensor and/or reference meter should be collected so they can be inserted into the record as backup data to avoid a gap (see Appendix H.1 Section 2.1).

If the manual readings are not of sufficient frequency or reliability to be backup data, the period infilled by them is an estimate from limited measurements and therefore must be quality coded QC 300.

2.3 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section H 3.11) is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or fall within a diel cycle. If a straight line is a good approximation, deleting the gap marker may be all that is required to close the gap.

2.4 Infilling the curve between adjacent peaks and troughs

It may be sufficient to copy values from a similar period of record at the same site.

Note: Seasonal variation in diel cycles may need to be taken into account.

An unbroken curve can be estimated by connecting the adjacent periods of good DO record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the curve may be calculated from the sine curve formula $y = a \sin(bx + c)$ where a is the amplitude, b is the period, and c is the phase shift of the sine curve.

2.5 Reinstating a clipped peak

A recorded peak may be superimposed onto a diel cycle to reinstate a clipped peak. The superimposed peak can be offset to merge with the clipped diel cycle but must not be 'stretched' or 'contracted' over its range or with time in order to fit.

This option should be used with caution for lengthy periods of DO% saturation clipped at 120% or less, because while high DO values are less certain and of less ecological concern if occasional, prolonged exposure to DO above 120% may adversely affect fish and other stream life (Wilcock et al, 2011).

2.6 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Do not use equations forced to zero for regression of DO data. If low DO is predicted, its significance and likelihood at the recipient site must be assessed. If periods of low DO are not plausible the analysis should be discarded.

For river sites, regression analysis should only be used when flow is in recession at the donor and recipient sites and at least five days has elapsed since the most recent fresh at either site(s).

Apply the regression equation intended to generate the synthetic record to another period of record of similar duration, season, and flow conditions, where recipient site data exist and compare actual and predicted maximum and minimum DO values. If the difference between actual and predicted for either extreme exceeds ± 10% of the actual value, the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.6.1 Selecting suitable donor sites

One or more donor sites should be selected from other DO recording sites with similar physical characteristics in the same water body. For rivers, donor and recipient sites may be some distance apart provided they are physically similar.

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contributions of each donor site. Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

Compare an extended period of record from all candidate sites. Assess whether lag is needed on any input.

Note: Lag may be observed if thermal lag and/or shading is a factor at any of the sites. Lag due to relative timing of flow variations should not be a significant feature of DO data between sites under the flow conditions recommended for regression analysis.

2.6.2 Time resolution of the synthetic record

Time resolution of the synthetic record should match the primary recording interval.

Note: Although a longer interval average may improve the correlation, incorporating average in preceding or succeeding interval data into an instantaneous series with diel cycles distorts the timing of those cycles unless the time-series manager permits mixing of average in interval and instantaneous data in the same series.

The filed comment(s) must make clear how the synthetic infill was derived and then incorporated into the record.

2.6.3 Seasonality of relationships

Seasonal variation in DO is typical for most water bodies except deep groundwater. The effect of seasonality on the relationship used to derive a synthetic record should be explored, especially if potentially influenced by factors such as high temperatures, algal blooms, and stratification. If significant, relationships may be required for each season.

3 References

Joenssen D, Bankhofer U. 2012. *Hot Deck Methods for Imputing Missing Data*. In: International Workshop on Machine Learning and Data Mining in Pattern Recognition. Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).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