National Environmental Monitoring Standards

Water Temperature

Continuous Measurement of Water Temperature for Environmental Monitoring Purposes

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Disclaimer

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Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.0	June 2013			Initial release
2.0	April 2017			
3.0.0	February 2026	Reviewed, and new document format applied, with content restructured and edited throughout. All previous content has moved and is modified to include additional guidance and/or clarification or to make minor corrections. Significant content changes from the previous version are detailed below.		
		Title		Altered to better reflect content.
		The National Environmental Monitoring Standards		Updated to standardised text.
		About this Standard		Updated commentary.
		The Standard – Continuous Water Temperature		Updated and restructured. New tables clarify requirements for QC 600 vs lower quality codes. New quality coding flowchart adds QC 0.
		2.2.1.2	Resolution	Updated specifications.
		2.8	Reference method	Clarified calibration of primary references are independently certified, and reference sensors are validated rather than calibrated.
		3.3	Installation and commissioning	Expanded commentary.
		4.3 & 5.3	Reference instruments	Clarified reference sensors are supplied pre-calibrated and are only required to be validated.
		5.4	In-situ sensors	Added examples where validating an in-situ sensor is recommended.
		7.2	Measurement	Added complementary measurements.
		7.5	Verification	Clarified method requirements. Reduced minimum verification frequency.
		8.2	Managing method changes	Included guidance on site relocation and sensor replacement.
		9.4	Quality coding	New to include use of quality coding matrices.
		10	Data Management and Preservation	Renamed, refocused on field records and data acquisition. Refers to NEMS *Data Processing* for office processes.
		Various	Required records	New sections within sections 1 to 10. Collates record keeping requirements under each main topic.
		References		Was previously Annex A. Updated.
		Annex A	Quality Coding Matrices	New.

		Annex B	Sensor Deployment Field Form Checklist	New.
		Annex C	Validation a Reference Sensor	Was previously Annex B. Minor revisions.
		Annex D	Site Visit Form Checklist	New.

Table of Contents

The National Environmental Monitoring Standards

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

Development

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

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

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

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

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

Implementation

Stationarity

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

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

Data fit for purpose

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

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

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

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

Health and safety

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

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

Limitations

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

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

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

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Funding

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

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

Review

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

Feedback

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

About This Standard

Introduction

Water temperature is commonly included in environmental monitoring programmes as it influences most physical and biological processes in natural waters and is a major driver of ecosystem processes. Many other water quality variables, including dissolved oxygen, pH and salinity, are also affected by water temperature, as is the toxicity of some contaminants. Water temperature is not only important to aquatic life, but also to recreational users (e.g. swimmers and fishers) and industry.

Water temperature is subject to many influences, including heat gains from solar radiation, inflows of groundwater, tributaries or contaminant discharges, and losses of heat from evaporation or radiation to the atmosphere. Changes in water flow, depth and shading, and other factors can significantly influence water temperatures. Changes in rainfall patterns, decreasing snow cover and glaciers, and warming air temperatures, among other factors, have led to concerns about warming temperatures in natural waters.

High frequency (i.e. continuous) measurements of water temperature using in-situ sensors have been collected in New Zealand for decades. However, the number and type of sensor deployments have increased in the last 10 or so years, reflecting improved availability of low-cost temperature sensors as well as reliable multi-variable sensors that measure variables such as dissolved oxygen, pH, conductivity and salinity alongside water temperature.

High frequency monitoring of water temperature is essential for continuous dissolved oxygen monitoring programmes and calculation of ecosystem metabolism. In lakes and some coastal waters, continuous measurements of water temperature, when linked with a real-time monitoring system, also provide early warning of thermal stratification and the potential for associated water quality issues.

Each monitoring situation provides its own challenges and it is important that the measured data are fit for purpose. Key to continuous monitoring of water temperature is understanding and catering for stationarity.

This version of this Standard is the culmination of a review in 2024/25 by Juliet Milne (Traverse Environmental Ltd), David Brown (Horizons Regional Council), Hamish Carrad (Environmental Canterbury) and Chris Jenkins (Environment Southland), with technical support from Marianne Watson (Hydronet Ltd). It includes the application of a new, more standardised format for NEMS Standards adopted in 2024 and incorporates quality coding matrices for the first time. Reference is also included to recent temperature sensor selection guidance developed by NIWA (McKergow 2025).

Objective

The objective of this Standard is to ensure that continuous water temperature data measured in rivers, groundwater, lakes and coastal waters are obtained, quality assured, and preserved in a verifiable, consistent, and documented manner to a known standard over time throughout New Zealand, and are therefore suitable for:

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

Scope

This Standard covers all requirements and processes associated with continuous in-situ measurements of water temperature in rivers, groundwater, lakes and coastal waters. This includes both permanent and short-term (e.g. seasonal) in-situ sensor deployments.

Exclusions

This Standard does not apply to the monitoring of water temperature for industrial applications. It also does not apply to any discrete or vertical profile-based water temperature measurements.

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.

The meaning of terms such as sensor calibration, validation and verification varies across manufacturer specifications for temperature sensors. Ensure that you understand the meaning of these terms as they apply to this Standard.

Normative references

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

- NEMS *Data Processing – Processing of Environmental Time-series Data*
- NEMS *Glossary – Terms, Definitions and Symbols*
- NEMS *National Quality Code Schema*
- NEMS *Safe Acquisition of Field Data in and Around Fresh Water – Code of Practice*

The Standard – Water Temperature

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

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

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

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

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

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

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

Minimum requirements for the application of all Standards

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

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

Requirements for water temperature data irrespective of quality

Table 2 – Requirements for continuous water temperature data irrespective of quality.

Measurement	Units (7.2.1)	Degrees Celsius (°C)
	Minimum resolution (2.2.1.2)	0.02°C
	Method (2.2)	Temperature sensor deployed in situ.
	Reference method (2.8.2)	Independent, portable temperature sensor or field thermometer validated against a certified primary reference thermometer. *Note: Sensor may be built-in to a multi-variable and/or handheld instrument.*
	Reference sensor accuracy (2.2.1.1)	Manufacturer's stated accuracy of ±0.3°C or better.
Timing of measurements	Sampling method (7.2.2)	Point sample stored as an instantaneous value. *Note: A representative value average of a burst of measurements may be used but must result in a point sample.*
	Resolution (7.2.3)	1 second
Certified primary reference thermometers	Certification method (4.2)	Accredited laboratory
	Certification frequency (4.2)	Once every 12 months
Reference sensor validation	Method (5.4.2)	Water bath using two certified primary reference thermometers and at least 5 different temperature points.
Maintenance	In-situ sensor (6.2)	Guided by manufacturer's instructions and/or recommendations.

<table>
<tr><td>Verification</td><td>Method
(7.5.4)</td><td>• Reference measurements shall be made using an independent reference sensor as close to the time and place of in-situ measurement as possible.
• Calculate difference between reference measurement and simultaneous logged value from in-situ sensor (ensuring the same form and units of measurement).
• Compare difference to verification tolerance.</td></tr>
<tr><td rowspan="4">Metadata</td><td>Site records
(1.4, 3.4, 6.3 & 10.1.2)</td><td>• All stations shall have a unique identifier.
• A Station History (or site file) shall be established and maintained, including a bore log at groundwater stations.
• Remote telemetry station configuration changes shall be controlled and recorded.
• Significant site and station maintenance shall be recorded in the Station History. Records of those activities with bearing on data quality shall be retained indefinitely.
• All photos and video retained as metadata shall be date-stamped, indexed to the site, and named and/or annotated with the orientation and subject.</td></tr>
<tr><td>Site visit records
(6.3 & 7.2.7)</td><td>• A record of every site visit shall be made, including routine cleaning and maintenance and verification details.
• The records shall be accessible when data are processed and retained indefinitely as original data.</td></tr>
<tr><td>Instrument records
(2.9, 3.3.2, 4.5, 5.5 & 6.3)</td><td>• All specification, configuration, calibration and validation records shall be retained indefinitely.
Note: Include timing method used if part of instrument specification.
• Logger software history (version and code) shall be maintained and preserved.</td></tr>
<tr><td>Change of method
(8.2)</td><td>Every method change shall be:
• noted in the site visit records at the time,
• added to the relevant history, and
• summarised in a filed comment (and in a Stationarity Comment if significant change).</td></tr>
</table>

	Processing of data (7.7)	• Incoming data shall be tracked, and records of quality checks maintained and available. • All changes from raw data shall be documented. • Automated facilities shall be controlled, documented, and regularly evaluated. • Time-series comments shall be timestamped at the start of the applicable record period or gap.
	Derived values (10.2)	Any derived values shall be: • fully traceable back to the sensor or logger output • labelled, and kept separate from measured data, and • summarised in the time-series metadata.
Quality assurance	Field and office manual (8.1.1 & 8.1.2)	• Monitoring agency shall develop SOP(s) or equivalent. • Monitoring personnel shall be conversant with the SOP(s) and competent to perform required tasks.

Additional requirements for water temperature data of good quality

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

Table 3 – Additional requirements for continuous water temperature data of good quality.

Site selection	Location (1.3.2 & 3.3.3)	• Representative of the target characteristics of the water body or location to be measured. • Not influenced by radiant heat sources and/or obvious heat sinks. *Note: In most cases, this will also require a well-mixed location.*
In-situ sensor	Accuracy (2.2.1.1)	Manufacturer's stated accuracy of ±0.5°C or better.
	Operation and maintenance (3.3.4 & 6.2)	Sensor and shroud/casing are not obstructed, buried, exposed to the air, or damaged.

Instrumentation	External data logger (2.4.2)	Stores the data without compromising the accuracy, resolution, and recording interval also required for QC 600.
Reference sensor validation	Frequency (5.3.1)	At least every 12 months.
	Acceptance criteria (5.3.3)	Reference sensor and average of certified primary reference thermometers readings agree within ±0.3°C across all water temperature measurement points.
Timing of measurements	Maximum recording interval (for continuous data) (7.2.2)	• 5 minutes (estuarine). • 15 minutes (rivers, groundwater, lakes and the open coast).
	Accuracy (clock drift) (7.2.3.1)	• Within ±90 s of actual NZST, and • Clock drift < ±90 s over 30 days.
Verification	Frequency (7.5.3)	Logged values shall be verified: • immediately after initial sensor deployment • during every verification visit • before and after sensor cleaning • prior to sensor replacement or retrieval, and • at least once every 90 days.
	Verification tolerance (7.5.5.1)	±0.5°C

Other requirements, guidelines, and recommendations

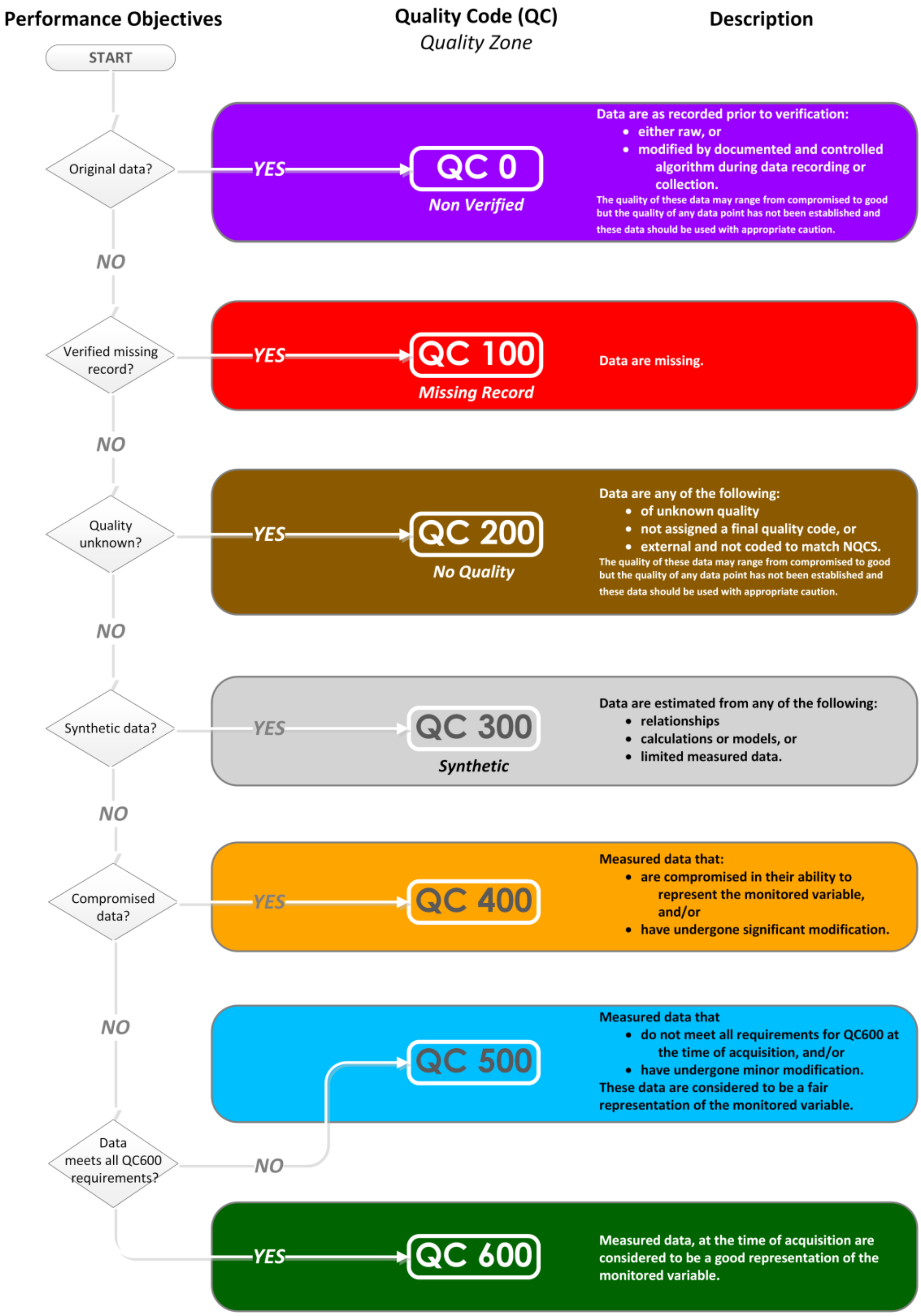
The following table summarises other requirements and guidelines (e.g. for quality assurance or lower quality codes), and additional recommended practices that are either not relevant to or not required for QC 600 but if implemented will enhance work practices and data quality.

Table 4 – Other requirements, guidelines, and recommendations.

Risk management	Scope (1.2 & 3.2)	• Secure and safe access. • Hazards identified (initial and on-going). • Compliance with regulations as required.
	Site access and security (1.2.1, 1.3.3 & 3.1)	• Permission required for all access. • Long-term access agreement recommended.
	Missing data (2.3.3 & 7.7.3)	Backup systems and equipment recommended at remote or isolated sites.
Site selection	Mixing considerations (1.3.2.1)	Horizontal (rivers) or vertical (lakes and estuaries) cross-section survey recommended.
Measurement	Measurement resolution (2.2.1.2)	0.01°C
Metadata	Instrument history (2.9)	Dedicated instrument database or asset management system recommended.
Verification	Pre-deployment verification (5.4)	Recommended for sensors deployed at depth (e.g. in lakes) and those that only have internal logging capacity.
	Verification frequency (7.5.3)	Recommended at least every 60 days during warmer months (e.g. for river deployments in summer low flows).
Complementary measurements	Water level (1.3.2.1, 1.3.5 & 7.2.4)	Can identify sensor dewatering events and track sensor depth or bed clearance when not reasonably static due to changing water levels.
	Air temperature (7.2.4)	May assist with infilling of missing data, identifying sensor dewatering, and/or interpretation of water temperature data.
	Salinity (7.2.4)	May assist with interpretation of water temperature data in coastal waters.

	Archiving (7.2.4)	If collected, complementary data shall be: • identified • available during data processing, and • stored indefinitely.
Quality assurance	Telemetered sites (7.7)	Recommended: • Daily check of data collection, at-site power status, and sensor function. • Use logs and alerts to help maintain data integrity.
	Station inspection (8.1.3)	Visual inspection of structures and all on-site equipment recommended at least once every 12 months at long-term or permanent stations.
	Field site audit (8.1.4)	Independent check of deployment and field activities at permanent stations.
Stationarity	Change of sensor location or method (8.2)	Recommended to co-locate new sensor type with existing for a period of overlap that captures typical range of measurement. Create a new site if: • change of location alters site factors (e.g. range or characteristics), or • analysis of co-located data identifies significant difference following the change of sensor technology.

Quality coding of water temperature data



Application

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

The quality coding flowchart as shown shall be used as the framework to assign quality codes to continuous water temperature data.

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

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

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

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

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

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

1 Site Location

In this section

This section covers the factors to consider when selecting a deployment site for continuous water temperature monitoring. By selecting the best available site, data quality will be maximised, and work minimised over the period of sensor deployment.

Note: This Standard does not address where within a larger river, aquifer, lake or coastal system the site should be located. That is a matter for consideration during the design of a monitoring programme and will depend on the programme's purpose.

1.1 Sources of information

The following sources of information, where available or reasonably obtainable, may help in deciding the most appropriate location within a river reach, lake or coastal embayment in which to locate the site:

- topographical maps
- aerial photographs and plans
- local advice on access, stability, and history
- land ownership
- consent information about local water takes and discharges, and
- cross-sections, long-sections, bathymetry, and/or LiDAR.

For groundwater deployments, information such as well (drilling) logs and pumping infrastructure may be useful.

1.2 Risk management

1.2.1 Site access

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

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

1.2.2 Safety

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

1.2.3 Hazard review

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

- NEMS *Safe Acquisition of Field Data in and Around Fresh Water*
- relevant legislation
- relevant WorkSafe guidelines, and
- the monitoring agency's organisational hazard management processes.

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

1.3 Site factors

1.3.1 Monitoring purpose

Water temperature is commonly measured at continuous intervals to characterise the thermal regime (e.g. the magnitude and duration of temperature maxima in the warmer months), and interactions with other variables (e.g. dissolved oxygen) and processes (e.g. ecosystem metabolism). It may also be measured for long term temporal trends (e.g. in relation to climate warming).

It is important to identify the target characteristics of the water body to be measured (e.g. average or maximum water temperature, vertical temperature profile) and express these in the form of data measurement objectives that will guide site and equipment selection and type of deployment. Include the identified objectives in the summary of monitoring purpose recorded in the site metadata (see section 1.4).

1.3.2 Location

For QC 600, as a minimum, all sites shall:

- be appropriate for the data measurement objectives (see section 1.3.1)
- be representative of the location being monitored, and
- be uninfluenced by radiant heat sources and/or obvious heat sinks.

In most cases, sites will also need to be well-mixed. A key exception is monitoring aimed at establishing horizontal or vertical mixing properties (e.g. to identify the thermocline in a lake).

Factors to consider include:

- the degree of cross-section variation and vertical stratification
- range of water levels (across seasons and from low to flood flows/tides)
- water velocity or circulation, tidal currents, wave height and the presence of turbulence that will affect measurements
- the need for protection from high-water debris, wave damage and vandalism, and
- other features that may pose unique constraints (e.g. river channel configuration or the presence of structures).

Note: Historically, pressure transducers capable of measuring water temperature have been installed at some water level stations. However, water level monitoring stations may not be the most appropriate location for monitoring water temperature.

Stationarity of record must be maintained wherever possible. Document in the site metadata (section 1.4) if any change occurs or is likely to occur. A significant change in water depth, salinity or circulation may trigger the need to create a new site.

1.3.2.1 Horizontal and vertical cross-section variability

Horizontal and/or vertical mixing at the monitoring site may need to be characterised by in-situ discrete measurements of water temperature to determine the most representative measurement point. Measurement profiles may not be required for sites that are well-mixed.

In all cases, the depth of the sensor shall be specified as metadata for sites in lakes and other impounded waters (dams and reservoirs) with relatively static water levels. If sensor depth is not relatively static because of changes in water level, complementary continuous measurement of water level may be needed (see section 1.3.5).

Note: Horizontal mixing is likely to be more important than vertical mixing in most rivers and streams. In lakes and coastal waters, vertical mixing is likely to be a greater consideration.

The easiest way to obtain information on mixing is through cross sectional and/or depth profiles using a reference sensor or multi-variable sonde. A multi-variable sonde or meter that also measures dissolved oxygen and conductivity can be useful as variability in either could indicate sources of thermal variation.

Note: The NEMS Discrete Water Quality: Part 3 (Lakes) *addresses vertical profile measurements.*

1.3.3 Access and legal requirements

Consider the following, in addition to section 1.2.1:

- accessibility of the site, including parking, groundwater well or boat access, and
- resource consents or other permits required before deployment can begin (e.g. for a bore or mooring), safe and
- adequate space to perform site and sensor maintenance.

1.3.4 Range of measurement

The site shall allow measurement during all seasons and water level conditions over which monitoring is targeting.

1.3.5 Installation

Consider the availability of an existing monitoring site, and whether it is possible to add a water temperature sensor to an existing water quality station or add a water quality station to an existing hydrological recording site, in which case a suitable structure for mounting and protection of the in-situ temperature sensor, and housing for the datalogger, power supply, and communications equipment, will likely already exist.

Consider the ability to measure water level as a complementary variable to enable change in sensor depth to be known for fixed in-situ installations and/or change in height above bed for buoy deployments, and to identify and alert to when the temperature sensor may be exposed.

If a new site is needed, consider the following, in addition to sections 1.2.1 and 1.31 to 1.3.3:

- how to ensure public safety and site security, during construction and ongoing operation of the station (e.g. navigation hazard to watercraft)
- availability or provision of a suitable structure or platform on which to mount the sensor
- the need to secure permissions from the relevant road or rail controlling authority to mount sensors and/or other infrastructure on a bridge
- protection from flood or storm damage
- an adequate power supply (e.g. solar, mains, or other power sources), and
- adequate data communication for telemetry.

Additional considerations for lakes and coastal waters, include:

- the depth of measurement with respect to possible stratification, and
- the influence of any saltwater-freshwater interface.

1.3.6 Other considerations

The following shall be considered:

- safe and adequate space to perform site and sensor maintenance, and
- accessibility and safety of the site during extreme conditions or events (e.g. floods, high winds).

1.4 Required records

The following site metadata shall be recorded:

- site identifier (see section 3.4.1) and past and present aliases
- monitoring purpose, including data measurement objectives
- recording agency/ies
- site location, in a coordinate system supported by Land Information NZ (LINZ), and preferably WGS84 coordinates recorded by GPS:
  - with the date of GPS survey noted, and

  - latitude/longitude expressed to at least six decimal places.
- sensor depth in lakes and impounded waters, if relatively static and water level is not continuously recorded
- names and/or indices of relevant environmental features (river, lake, coast, etc.)
- significant factors influencing site selection, including any local advice
- photographs, maps, plans, and imagery
- legal details (e.g. ownership of land and structures, access agreements, and regulatory requirements)
- hazard assessments
- site surveys
- requirement for, and method(s) of obtaining complementary data, and
- relevant water abstraction and/or discharge data.

For groundwater sites, a geological well log record shall be obtained that includes as a minimum:

- depths, type, and diameter(s) of casings
- screening type and depth
- well use (e.g. production or monitoring), and
- where available and/or practical, hydraulic properties (e.g. storativity and transmissivity) at the time of construction.

2 Method and Equipment Selection

In this section

This section contains information about methods and equipment for continuous measurement and recording of water temperature to guide their selection. It also includes information on reference methods.

2.1 Method principles

Continuous water temperature measurements are made through deployment of an in-situ water temperature sensor and use of:

- a data logger, either integrated with the sensor or external to it
- a connection and method of communication between the sensor and the data logger (if external, the connection is usually cabled and may also provide power to the sensor)
  Note: A wide range of communication protocols exist. Some sensors may offer several options. Some may require signal conversion at the logger.
- a means of uploading firmware, software, and/or configuration settings and downloading data from the data logger (may be via direct physical or wireless connection while at the site or remotely via telemetry).

2.2 Sensors

Numerous temperature sensors are available. The main types are:

- Thermistors
- Resistance Temperature Detectors (RTD)
- Thermocouples, and
- Semiconductor-based temperature sensors.

Of these, Negative Temperature Coefficient (NTC) thermistors and RTDs are most commonly used in continuous water monitoring. Thermistors are reliable, accurate, and durable temperature sensors that require little maintenance. They are also relatively inexpensive. RTD sensors are known for both their high accuracy and stability in measuring water temperature.

See McKergow (2025) for details on the types and selection of temperature sensors.

2.2.1 Principles of operation

Most temperature sensors are designed to generate an electrical signal output that is used to establish a temperature value. Thermistors make use of the change in electrical resistance that occurs with temperature to determine the water temperature; in an NTC thermistor, as temperature increases, resistance decreases. This relationship is highly sensitive and exponential. In contrast, RTDs make use of the change in the electrical resistance that occurs in a conductive material (e.g. metal) and the resistance versus temperature relationship is almost linear over a wide temperature range.

2.2.1.1 Accuracy and range

Water temperature sensors with accuracies of ±0.2°C are available. This Standard requires the use of:

- a reference water temperature sensor with a manufacturer's stated accuracy of ±0.3°C or better, and
- an in-situ water temperature sensor with a manufacturer's stated accuracy of ±0.5°C or better.

Accuracy varies depending on temperature range; make sure the sensor can accurately record measurements over the full range of expected temperatures.

2.2.1.2 Resolution

For both reference and in-situ temperature sensors, the minimum measurement resolution shall be 0.02°C. A resolution of 0.01°C should be achievable for most sensors and is a best practice recommendation.

2.2.1.3 Compatibility

Ensure that the data logger or data offload device and software are compatible with the make and model of the temperature sensor.

2.2.1.4 Other considerations

Water temperature is a supplementary measurement for continuous dissolved oxygen, electrical conductivity and pH monitoring. Sensors measuring these variables therefore also incorporate a water temperature sensor, commonly a thermistor. However, these sensors may not meet all of the specifications of this Standard to serve as a primary water temperature record.

Where dissolved oxygen monitoring is the primary focus, ensure that the specifications of the selected water temperature sensor also satisfy the requirements of the current version of NEMS *Continuous Dissolved Oxygen*.

Note: There are currently no NEMS for continuous monitoring of conductivity or pH.

2.3 Site characteristics

Consider the following when selecting an appropriate sensor and associated equipment:

- the established site factors (see section 1.3)
- measurement range
- seasonal and environmental conditions, and
- power requirements.

2.3.1 Power requirements

The sensor and logger combination shall be capable of measuring and recording the full range of expected water temperature values at the site to at least the minimum accuracy and resolution required by this Standard.

Note: In most natural waters, with the exception of geothermal waters, the temperature range will typically be between 0 and 35°C.

2.3.2 Seasonal and environmental conditions

Relevant conditions to consider include radiant heating, weed and biofouling, other water users' activities, and mobile substrates. Conditions, such as floods, debris build up, tidal range and waves can also influence or damage a sensor or associated equipment.

2.3.3 Power requirements

Calculate the power budget and maximum demand of the sensor and – where relevant – logger and telemetry system combination, to ensure that sufficient charge and battery capacity are installed. Power requirements for any pumps or winching systems also need to be determined.

Consider the battery capacity required to cover:

- mains power outages, if mains power is used
- low solar charge (e.g. during winter periods), and
- power requirements through the worst conditions.

At remote or isolated sites, also consider backup systems and equipment.

2.4 Recording equipment

Recording equipment requirements depend on the selected in-situ sensor.

2.4.1 Internal-logging, combined sensor and recording

Many water temperature sensors can be powered by conventional batteries in a sealed compartment and come equipped with internal memory and data logging capabilities. These features are particularly valuable for remote or hard-to-access sites as there is no need for an external power source. Some key disadvantages of this set-up are that the status of the equipment can only be checked, and the data accessed, during site visits (i.e. loss of data is unknown until a site visit).

2.4.2 Externally powered sensor and data logger

Under this configuration the temperature sensor is installed in situ at the measuring point and communication cables are run to an external data logger and power system located in a shelter protected from and/or above possible water ingress. In remote locations where AC power is not practically available, direct current, 12-volt batteries or a solar panel can be used to provide power.

A key advantage of this system over internally logged configurations is that they can be monitored remotely to provide early warning (e.g. onset of stratification in lakes, rising temperature of potential stress to aquatic life), and identify problems or service requirements.

For QC 600, the electronic data logger must be able to store data at, or better than, the minimum accuracy and resolution for QC 600 required of the sensor (see section 2.2.1), and the maximum recording interval (see section 7.2.2).

Other capabilities and factors to consider when choosing a data logger are:

- ability to interface to relevant sensors (e.g. dissolved oxygen)
- digital resolution (16 bits) and accuracy
- telemetry capability and compatibility
- adequacy of set-up and downloading software
- ability to calculate and record derived data (e.g. statistics such as averages and standard deviation of multiple measurements)
- capability to record data at some distance from the sensor
- reliability, compactness, and cost
- power requirement, which should be low
- media and storage capacity
- clock resolution and accuracy (see section 7.2.3), and
- scan rate, i.e. the frequency at which a data logger can measure and process signals.

2.5 Sampling equipment

This section is not relevant to the measurement of water temperature and has been deliberately omitted.

2.6 Ancillary equipment

Other equipment that may be needed at a continuous water temperature monitoring station includes:

- a pump (to convey water to the sensor)
- a wiper system (to reduce biofouling)
- a radiation shield (to minimise radiant heating/cooling of the temperature sensor) (see section 2.7)
- communications equipment (if short-haul and/or remote-access telemetry is required), and

- a winching system (to position the sensor at the desired depth below a floating platform and retrieve it as required).

2.7 Interferences

Exposure to direct solar radiation can bias temperature measurements. Depending on the site's characteristics, a radiation shield may be necessary to ensure that sunlight striking the sensor does not influence its measurements. A shield can also serve as protective housing and provide secure points of attachment for the sensor.

Radiation shields can be purchased from a manufacturer or constructed from polyvinyl chloride (PVC). Drilling holes into the housing will facilitate water circulation (Figure 1).

Note: Opaque rather than clear shields will help to avoid erroneously high temperature readings. If vandalism is a concern use radiation shields that are neutral in colour or paint them a neutral colour.

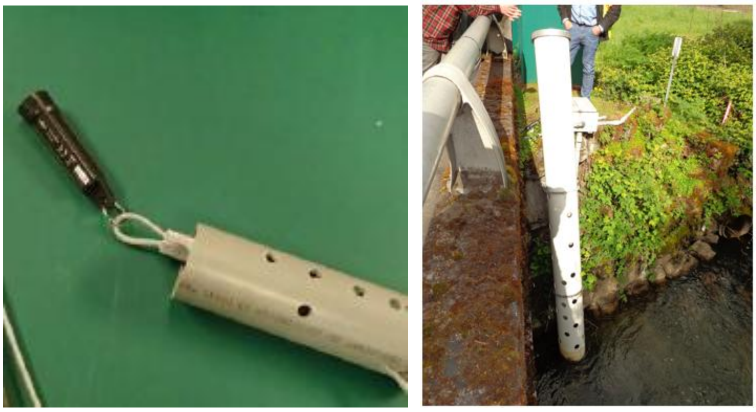


Figure 1 – Examples of a PVC housing. During field installation, the sensor is secured inside the PVC housing (e.g. through use of cable ties). The holes provide room for water mixing.

Rocks, steel or concrete structures, including stilling wells associated with water levels recording stations, can also radiate heat and deployment of sensors on these may bias temperature measurements. It is essential that there is good water circulation around the sensor to reduce any interference that may arise from attachment to its deployment structure (see section 3.3.4).

2.8 Reference method(s)

Two types of reference are required to check the performance of the in-situ temperature sensor.

2.8.1 Primary reference instrument

Under this Standard, the primary reference instrument is a traceable reference thermometer certified by an accredited laboratory. The monitoring agency shall operate or have access to a minimum of two traceable reference thermometers.

Traceable reference thermometers shall:

- have a unique identifier
- be certified by an accredited laboratory every 12 months, and
- always remain in the laboratory or safe indoor location as the primary reference standard.

2.8.2 Reference instrument

Under this Standard, an independent and portable temperature sensor shall be used as the reference method to verify the performance of the in-situ temperature sensor. The reference sensor shall be validated at least annually against the two primary reference thermometers (see section 5.3).

Note: A reference thermometer can also be used. The term reference sensor is used rather than thermometer to clearly distinguish it from the primary reference thermometer and to reflect the more common use of water temperature sensors (usually as part of a hand-held multi-variable field meter or sonde) as a field reference instrument.

The required accuracy and resolution of a reference temperature sensor are stated in sections 2.2.1.1 and 2.2.1.2.

2.9 Required records

Relevant site characteristics (see section 2.3) shall be recorded as part of the site metadata.

Details of instruments and equipment selected and installed at site shall be recorded and maintained in an instrument history. The instrument history may be part of the station history (see section 3.4.2) but should preferably be stored and managed in a dedicated instrument database or agency asset management system.

3 Deployment

In this section

This section addresses deployment of an in-situ water temperature sensor. It includes key considerations relating to planning and construction of the monitoring station, sensor installation and commissioning, and monitoring station documentation requirements.

3.1 Station planning

The degree of station planning required depends on:

- the water body
- the chosen site location (see section 1.3.2)
- associated site characteristics (see section 2.3)
- whether the temperature sensor is to be added to an existing station
- the type of temperature sensor selected (see section 2.2)
- the type of monitoring platform and/or housing required (external or internal/integrated datalogger and power supply)
- power and communications requirements (see sections 2.3.3 and 2.4)
- relevant regulations (see section 1.3.3), and
- the intended duration of continuous monitoring, i.e. how long the site is expected to be operative.

If adding water temperature (and potentially other water quality) monitoring at an existing hydrometric site, suitable structures will usually already exist, but possibly not a suitable monitoring platform for water quality instruments. Additional power supply may be needed and installation of comms if not already in place. Telemetry at longer-term water temperature monitoring sites allows data to be checked frequently without visiting the site.

If establishing a new site, the set-up required will depend on the intended duration and desired durability of the installation. For long-term sites it may be necessary to construct something from scratch to achieve the necessary access and resilience.

Note: The NEMS Water Level *v4.0.0 provides useful commentary on construction and durability considerations for long term monitoring stations.*

3.1.1 Access

Regardless of the water body and deployment duration, permission for land access and entry shall be obtained from the relevant owners, occupiers, or custodians.

Any regional plan, conservation land, or maritime requirements pertaining to installing equipment on riverbanks, lake shores, and/or in or on navigable waterways shall also be complied with.

Safe and convenient access to the station is crucial for continuity of record so the longer the station is required to operate, the greater attention and investment is needed toward establishing, securing, and maintaining access. For long-term sites, formal legal land access agreements are recommended.

Begin any construction work at the site with work on the access.

3.1.2 Design

3.1.2.1 Site survey

If any significant construction is needed for a new site a topographical site survey will probably be necessary. A topographical site survey is likely also to be a useful precursor to an installation plan and probably would also be needed if building consent or engineering design is required for housings or structures (for access and/or for instrument deployment).

Significant construction might include walk-in housings, catwalks, stairs and ladders, boardwalks, pontoons and jetties. Water depth, flow, wind and waves are important environmental characteristics that will influence design, construction and subsequent installation.

Note: Structures may need to be designed by a suitably qualified engineer.

The results of any preliminary assessments of the degree of cross-section variation and vertical stratification can also be considered part of a site survey (see section 1.3.2).

3.1.2.2 Signage and security

Provisions for signage and security (e.g. protective housing for loggers) may also be needed, particularly for long-term deployments. Signage should warn of any hazards (e.g. mains power, buried or overhead cables, or navigational hazards) and provide the monitoring agency's contact details. Security needs to protect installations from interference and damage (vandals, animals, and floods) and protect the public from injury.

3.1.2.3 Power and communications

Poles or masts may be needed, and cables run, for externally logged and powered monitoring installations. Cables should be trenched whenever possible, especially along riverbanks where they might otherwise catch debris. Overhead lines are preferable across paddocks that may be ploughed or drilled but may pose a hazard that should then be clearly marked. Masts may require engineering design for sufficient anchoring, and wind and/or snow loading.

Electricity regulations govern the installation of power supplies including low voltage systems. A registered electrician is required to install mains power (230/240V). Regulations also govern the use of radio communications.

3.1.2.4 Housings

External data loggers and power supplies, and pumped flow-through systems will require some form of protective housing. A secured electrical box or plastic drum may suffice for smaller installations. A walk-in shed may be needed for pumped flow-through systems and are more convenient and secure for permanent stations.

The recorder housing shall:

- fully protect the equipment from:
  - all inclement weather
  - spray
  - condensation
  - insects
  - vermin, and
  - the general public.
- provide sufficient room for:
  - equipment
  - field books
  - telemetry equipment (if applicable), and
  - downloading loggers.
- be clean and dry on the inside, and
- have an exterior appearance that blends with the landscape as much as possible.

  Note: The appearance can protect the recorder and associated equipment from the elements and from interference by the public and wildlife.

3.2 Monitoring platforms

Depending on the water body type, duration of monitoring, and what is available at the location in the way of existing structures (e.g. bridge pier, jetty), the temperature sensor may need to be mounted on a purpose-built platform, such as a bankside structure or monitoring buoy. The sensor is then anchored to, or fixed in place on (or under), the platform.

A purpose-built platform will likely require a design and installation plan (see section 3.1.2). This should incorporate details on how to avoid creating a potential navigation hazard.

The monitoring platform needs to allow for the sensor to be fitted inside a suitable protective housing (see section 3.1.2.4).

A winch may be needed to deploy and retrieve sensors for maintenance or replacement in some cases. A profiler system (e.g. in lakes) will require a winching system to lower the sensor up and down through the water column.

3.2.1 Materials

All materials used shall be of adequate strength, thickness, and durability (including UV stability) for the purpose. While PVC or stainless-steel materials are good for freshwater applications, titanium in brackish/ocean water will likely be needed to reduce corrosion (McKergow 2025).

Note: Fittings that corrode can be useful to secure items permanently in place but not for anything that must be undone regularly, e.g. to access equipment for maintenance.

Ensure:

- power and communication cables are of sufficient size and suitable length to not become stressed, tangled, or overheat, and
- power supplies and batteries charged on site are appropriately fused.

Materials used in walk-in housings, poles, masts, and access structures shall conform to:

- the New Zealand Building Code and Regulations, and
- NEMS *Guidelines for Hydrological and Meteorological Structures.*

Structures, poles, masts, and housings may need to be painted to minimise their visual impact.

3.3 Installation and commissioning

An overview of general requirements is provided here, including a pre-deployment check, sensor configuration, and sensor placement.

Detailed guidance on sensor installation and commissioning in river, lake and coastal environments is provided by McKergow (2025). Both the US EPA (2014) and the USGS (Heck et al., 2018) provide detailed guidance for installation of temperature sensors in rivers.

3.3.1 Pre-deployment check

This Standard does not require an accuracy check of the in-situ water temperature sensor prior to deployment. However, there are cases where such a check is useful (see section 5.4).

It is important to check:

- there is sufficient internal battery life remaining, where applicable, in the temperature sensor and/or the external data logger
- data logger storage has been cleared of unwanted data, and there is sufficient storage available for the intended download frequency to avoid data loss
- the sensor will launch and download correctly (if it is an integrated instrument with on-board data logging), and/or

- cable or wireless data transmission (e.g. to an external data logger or telemetry base) is correctly configured and will operate properly with no data corruption or loss.

3.3.2 Sensor and logger configuration

Configure the in-situ sensor and/or data logger as needed, and following manufacturer's instructions where applicable, to:

- measure and record
  - water temperature in degrees Celsius (see section 7.2.1), and
  - any complementary operational data, e.g. battery voltage.
- record complementary measurements that may be independently measured but logging to the same storage device, e.g. water level
- log data at the required intervals (see section 7.2.2), and
- apply any necessary on-board calculations to scale the output of an analogue sensor (i.e. convert a mV or mA signal to the required measurement units).

The sensor and/or logger can be programmed to start before or after the planned deployment time, or it can be launched on site. Record on a Sensor Deployment Field Form (Annex B) the period of any data logged when the sensor is not correctly positioned, so that those values can be removed later during data processing (section 7.7).

3.3.2.1 Sensor and logger configuration

Data logger programme code shall be controlled and documented. The code shall:

- be named informatively
- include creation and modification dates, and version number
- be tested to ensure it performs as expected and is free of errors, and
- be protected from inadvertent and unauthorised modification.

Note upload of a new programme in the site visit record, with a minimum of:

- the programme name and version
- date and time it is effective from, and
- brief description of reason for the change.

A copy of all logger code deployed, including versions, shall be stored indefinitely and be able to be retrieved in the future.

For logger providers that do not allow access to their code, a contract should be in place to ensure that they archive their code indefinitely, in a manner that can be retrieved in the future.

3.3.2.2 Telemetry

Remote station configurations may be changed via telemetry.

- New sampling programmes (including scaling and offset changes) may be uploaded to the remote data logger from the office.
- Sensor scaling and offsets may be applied at the telemetry base.
- Systems may have automatic update capabilities, e.g. remote clock synchronisation with base.

Ensure any change applied at base or made remotely initiated from base (e.g. changing a sampling method), is controlled and documented in a manner equivalent to making the change on site.

Note: An 'office' logbook, or electronic field form for the telemetry base, is useful for this purpose.

Automatic functions of telemetry systems can modify the data captured and/or collected from a station. If implemented, these automatic functions must:

- be described in the Station History, and summarised in the time-series metadata (see NEMS *Data Processing*)
- have changes to those functions controlled and tracked, and
- be regularly checked for performance and the outcome documented.

3.3.3 Sensor placement

Ensure that the point of sensor placement:

- is representative
- is not influenced by radiant heat sources and/or obvious heat sinks
- has sufficient water depth to keep the sensor submerged for the entire period of deployment
- is stable, accessible, and easy to relocate, and
- is protected from physical impacts associated with high water velocities, debris, waves, other water users, and/or vandalism.

In rivers and streams, placement in well-mixed water in a run (or pool) is preferable to a riffle. Care is also needed to ensure that the sensor is placed above the bed to reduce the potential for burial by moving substrate and influence from groundwater and subsurface flow.

The exact location of the sensor shall be accurately georeferenced and photographed.

3.3.4 Sensor installation

Site-specific conditions and the intended length of sensor deployment will dictate which installation technique is most appropriate.

For very short duration deployments in small rivers and streams, where flows are small, lightweight sensors (e.g. Onset Tidibit© sensor) or loggers may be able to be attached to the downstream side of a waratah driven into the bed. A waratah may also be suitable for deployments in shallow lakes and estuaries provided it does not pose a safety hazard to boats or other water users.

A more secure installation method for short-term deployments makes use of bent steel reinforcing bar driven into the bed where the sensor and its protective casing (or housing) are attached to the bar in two places using heavy duty cable ties or wire (Figure 2). This ‘bent rebar method’ is safer and more secure because it provides two anchoring points and ensures that no sharp points protrude up into the water column.

Note: Extreme care is needed with bed-based installations to avoid sensor burial or damage by sediment, debris or weed, sensor uprooting and loss during freshes, or temperature measurements being influenced by interflow through the bed. For this reason, these installations are generally only suitable for self-contained instruments deployed for short periods of time (e.g. a few weeks or months during summer).

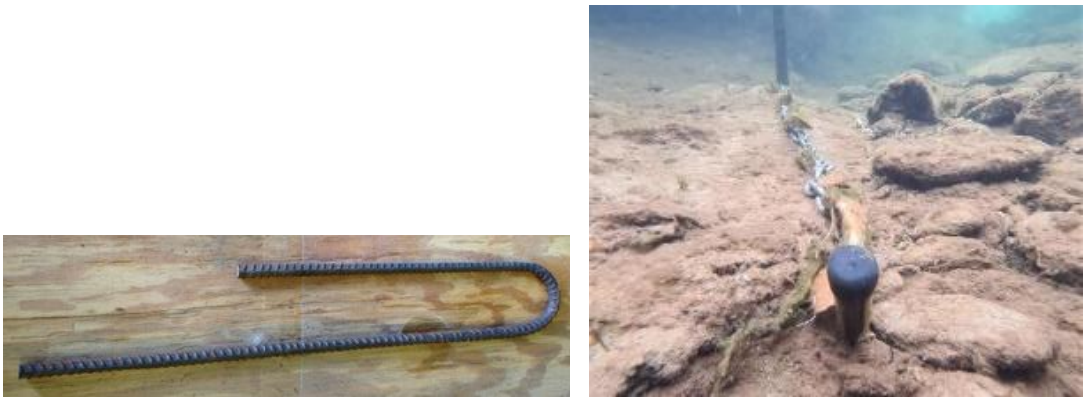


Figure 2 – Left: A piece of steel rebar. Right: Example of a Hobo water sensor deployed for monitoring during low river flows.

Photos: U.S. EPA (2014) and Otago Regional Council

For longer-term deployments and in larger rivers, bridge-based (Figure 3) or bankside (Figure 4) sensor installations are preferable, with the use of a PVC (or other impact resistant) housing to protect the sensor from damage including vandalism, excessive biofouling, debris and sedimentation. The best structures in rivers on which to mount a sensor are those that will remain immobile during floods and extend well above the low flow water surface to shield against moving rocks and debris.

It is easier to secure and protect a pump line bankside and all other equipment can be safely housed away from the water, above the maximum anticipated water level. The sensor should be secured within the housing and, where applicable, logger and power cables will also need to be secured and protected.

Mooring buoys or platforms are often used for deployment of temperature (and water quality) sensors in lakes and coastal areas, particularly offshore applications (Figure 5). Specialist advice is needed for design and installation, including buoyancy requirements, and mooring system type (e.g. surface, subsurface or stationary structure), length, material (e.g. synthetic rope, wire rope or chain) and anchor.

Figure 3 – Example of a bridge-based installation with PVC housing to protect a multi-variable water quality sonde. The sonde is secured inside the housing clear of the pipe wall. White pipe minimises radiant heating and the pier to which it is attached is also shaded from direct sunlight via the wide bridge above. This sensor was deployed to capture water quality during flood events so the installation has been secured to the downstream side of a bridge pier for added protection of the sensor from damage or loss. The housing includes a lockable cap for security.

Photos: NIWA

Figure 4 – Example of a bankside installation with PVC housing to protect a multi-variable water quality sonde. The sonde is secured inside the housing clear of the pipe wall, but retrievable for maintenance. White pipe minimises radiant heating while the holes allow unimpeded flow through the housing to minimise silting and fouling. The photo on the left shows the lockable cap for security, and a secured logger box alongside with power and communication cables all above flood level.

Photos: Hydronet Ltd

Figure 5 – Left: Example of a simple mooring system for a short-term sensor deployment. Right: a lake water quality monitoring buoy installed on Lake Tūtira, held in place on the lakebed by a weighted chain. The station includes a meteorological station and depth sensor.

Photos (left to right): Lucy McKergow and Hawke's Bay Regional Council

3.3.5 Sensor performance check

A verification check shall be performed on the in-situ sensor immediately following installation using a reference sensor (see section 7.5).

3.4 Station documentation

3.4.1 Site identifiers

All stations shall be allocated a unique identifier such as a site number or name.

It is the responsibility of the monitoring agency to allocate and catalogue their station identifiers.

3.4.2 Station history

A Station History record or site file shall be established for all continuous water temperature monitoring stations. This record or file collates and stores metadata about the site and station(s) including, but not limited to the:

- site identifier and/or name
- location
- intended purpose
- ownership of land
- installation(s) (e.g. structures)
- equipment types, including make and model
- variable(s) measured, and kinds of data collected, including any complementary variables

- method of data collection (e.g. logged internally within the sensor or telemetered)
- start (and end) date(s) of site and records
- records of pre- and any mid-deployment cross sectional and/or vertical water temperature profiles
- depth below water's surface of sensor suspension from buoys or platforms, and
- history of changes to the above over time.

Use a form to collate this information and include a detailed annotated map of the site showing landmarks, sensor locations and access points. See Annex B – Sensor Deployment Form. Completed forms must be retained indefinitely as an original record.

As a minimum, a station history record shall be:

- filled out for the site as soon as records begin
- checked and updated during the periodic site surveys and inspections
- updated whenever there are changes to:
  - the information recorded, and
  - what variables are measured.

Add a record to update existing items rather than over-writing, to preserve the history.

4 Equipment Calibration

In this section

This section addresses calibration and certification of primary reference thermometers, and calibration of reference sensors and in-situ sensors.

4.1 Purpose

Calibration is carried out to ensure that an instrument reads the correct value. This Standard does not require the monitoring agency to calibrate primary reference thermometers themselves, rather it requires the monitoring agency to have the calibration independently certified.

4.2 Primary traceable reference(s)

As outlined in section 2.8.1, the monitoring agency shall operate or have access to a minimum of two primary traceable reference thermometers. These thermometers must stay in the laboratory or a similar controlled space for use in validation checks of reference sensors.

Primary traceable reference thermometers shall be certified by an accredited instrument laboratory every 12 months. If certification fails, the primary traceable reference thermometer shall be replaced.

4.3 Reference instruments

Any independent and portable reference sensor shall be used as a reference instrument (see section 2.8.1). For convenience, this will usually be a handheld sensor (or thermometer).

Reference sensors are supplied pre-calibrated by the manufacturer. The monitoring agency is only required to *validate* the accuracy of these sensors against primary traceable reference thermometers (see section 5.3).

4.4 In-situ sensors

In-situ temperature sensors are pre-calibrated by the manufacturer; the accuracy of an in-situ temperature sensor is *verified* using a reference sensor (see section 5.4).

4.5 Required records

A record of the certification history for each primary reference thermometer shall be maintained and accessible. The record shall include:

- name of the person and organisation performing the certification
- date and time of the certification
- location and environment (e.g. laboratory)
- traceable reference used
- demonstrated relationship to the traceable reference, and
- outcome (e.g. serviceable, repaired, or for disposal).

5 Equipment Validation

In this section

This section sets out requirements for validation of reference and in-situ temperature sensors.

5.1 Purpose

Validation provides a check that temperature sensors (or thermometers) are performing to specification and their calibration is still valid. Routine checks can prevent loss of data by identifying faulty field equipment. Steps can then be taken to rectify the problem (e.g. calibrate the sensor or replace it).

Note: Some manufacturers of water quality sensors may refer to validation as verifying a sensor's calibration.

5.2 Primary traceable reference(s)

As per section 4.2.

5.3 Reference instruments

As per section 4.3.

5.3.1 When to validate

All reference sensors used to verify the accuracy of an in-situ temperature sensor shall be validated prior to first use and at least 12-monthly. If performed outside of this timeframe the reference sensor is considered to have not been validated and any reference measurements obtained are deemed unreliable.

5.3.2 Validation method

Validation of a reference sensor requires the use of a water bath and shall consist of at least a five-point temperature check against two primary traceable reference thermometers with current certification. The measurement points shall span the expected temperature range of the deployed in-situ sensor (Table 1).

See Annex C (Validating a Reference Sensor) for details on the validation procedure.

Table 1 – Defined temperature ranges for validation of a reference sensor

Temperature range (°C)	Notes
-5 (for cold regions) to 0	Required if in expected temperature range
0 to 5	Compulsory
5 to 10	Compulsory
10 to 15	Compulsory
15 to 20	Compulsory
20 to 25	Compulsory
25 to 30	Required if in expected temperature range
30 to 40	Required if in expected temperature range
40 to 50	Required if in expected temperature range
50 to 60	Required if in expected temperature range
60 to 70	Required if in expected temperature range
70 to 100	Required if in expected temperature range

5.3.3 Acceptance criteria

The reference sensor passes validation if it is within ±0.3°C of the mean temperature value of the two traceable reference thermometers across all five (or more) validation points.

A reference sensor that fails validation must not be used again until it is successfully repaired and/or recalibrated.

5.4 In-situ sensor

Validation of in-situ sensors is not required under this version of this Standard. The reference sensor is used to check the performance of the in-situ sensor as part of the at site verification process (see section 7.5).

However, there are instances where validating an in-situ sensor is recommended. These include:

- prior to deployment of sensors at depth (e.g. in lakes)
- where the sensor measurement timing can't be verified without retrieving the sensor (i.e. the sensor lacks external comms), and
- if the sensor fails a routine verification check and the monitoring agency wishes to investigate before sending it off for repair or disposing of it.

An in-situ sensor validation should follow the same procedure as that for a reference sensor (see Annex C).

Note: There may be other instances where a monitoring agency chooses to validate an in-situ sensor.

5.5 Required records

A record of the validation history for each reference and, if applicable, in-situ sensor shall be maintained and accessible. This shall include:

- site and variable identifiers
- sensor serial number
- name of the person performing the validation
- date and time of the validation
- location and environment (e.g. laboratory)
- method and reference(s) used
- the five or more target values for the validation and corresponding sensor readings, and
- outcome (e.g. serviceable, repaired, or for disposal).

6 Maintenance

In this section

This section deals with general and routine maintenance for water temperature monitoring stations and equipment.

6.1 Station maintenance

Specific maintenance requirements depend on the station configuration and equipment.

Site visit checks should include a check of the stability and integrity of any structure and associated cabling. Periodic cleaning may be required.

Maintain all stations in good order so that they are:

- reliable
- operate effectively
- safe
- accessible
- fit for carrying out their intended task
- sufficiently tidy for efficient work practice, and
- have minimal visual impact on the environment.

6.2 Equipment maintenance

The manufacturer's instructions must be followed for the maintenance of water temperature sensors. Maintenance checks during site visits shall include:

- ensuring the sensor is not obstructed, buried in bed sediment, or exposed to the air
- inspection of the sensor and other equipment for signs of physical damage, vandalism or disturbance
- cleaning of the sensor housing and sensor to remove any accumulation of biofilm or sediment
- battery or power check, and
- data download (where data are not telemetered) and clearance of the sensor memory as necessary to ensure sufficient capacity for continued data collection.

Where a sensor is cleaned, verify the data before and after (see section 7.5), and record the time of both the 'pre-cleaning' and first 'post-cleaning' water temperature measurements. This information is needed for data processing.

Note: Compared with other water quality sensors such as dissolved oxygen and turbidity, the performance of temperature sensors tends to be less affected by fouling. Sedimentation or sensor burial in aquatic plants may be a risk at some sites.

A site visit maintenance checklist is provided in Annex D.

Temperature sensors used for continuous monitoring should remain in the same location throughout their period of deployment. If removed for cleaning, calibration or other purposes, ensure that the sensor is returned to the same location as before.

Perform a verification check before and after any cleaning or other adjustment of the in-situ sensor (see section 7.5.4).

6.3 Required records

All maintenance activities shall be recorded as follows.

- routine maintenance, including sensor cleaning, in the site visit records (see section 7.2.7)
- sensor servicing, repair, reconfiguration or replacement in the instrument history record (see section 2.9), and
- significant site and/or station maintenance in the Station History record (see section 3.4.2).

All maintenance records must be accessible when data are processed. Retain indefinitely all maintenance records that have a bearing on data quality.

7 Data Acquisition

In this section

This section includes requirements and guidance for obtaining and verifying continuous water temperature measurements, what other measurements may be needed, and initial checks of the data collected.

7.1 On-site equipment set-up and checks

Set up handheld or portable reference instruments so they can measure as close to the in-situ temperature sensor as possible.

7.2 Measurement

7.2.1 Units of measurement

Units of measurement for recorded water temperature shall be degrees Celsius (°C).

7.2.2 Timing of measurements

All data shall be recorded in New Zealand Standard Time. To achieve QC 600, water temperature measurements shall be logged at intervals no greater than:

- every 5 minutes for estuarine waters, and
- every 15 minutes for rivers, lakes and the open coast.

For some monitoring purposes, a larger measurement interval may be sufficient. An interval of greater than 60 minutes is likely to increase the risk of missing daily minima and maxima in some water bodies.

Water temperature data shall be point samples archived as instantaneous continuous values timestamped at the end of each recording interval, whether obtained from:

- a single measurement at the end of each interval, or
- a median (preferred) or an average obtained from a burst of measurements within the interval.

Where timing is part of the instrument specification, the timing method used shall be included in the instrument history (see section 2.9) and clearly stated in the time-series metadata (see NEMS *Data Processing*).

7.2.3 Required accuracy, precision, and resolution

See sections 2.2.1.1 and 2.2.1.2 for temperature sensor accuracy and measurement resolution requirements.

7.2.3.1 Time

Time resolution for all logged data collected on site shall be 1 second.

Accuracy of timekeeping using digital timing devices can be affected by offset (e.g. from a clock reset) and/or drift. For QC 600, clock drift shall be less than ± 90 seconds over a month.

For 5-minute data (e.g. estuarine data), clock drift of ±90 seconds or more over 30 days shall receive an initial quality code no higher than:

- QC 500 – ±90 s and no more than ±120 s over 30 days
- QC 400 – greater than ±120 s but no more than ±180 s over 30 days
- QC 200 – greater than ±180 s over 30 days.

For 15-minute data, clock drift of 90 seconds or more over 30 days shall receive an initial quality code no higher than:

- QC 500 – ±90 s and no more than ±150 s over 30 days
- QC 400 – greater than ±150 s but no more than ±300 s over 30 days
- QC 200 – greater than ±300 s over 30 days.

7.2.4 Complementary measurements

It may be beneficial to record air temperature alongside water temperature. Air and water temperature are correlated and monitoring air temperature can provide a better understanding of the relationship between air and water temperature at a monitoring site. For streams in particular, this can provide important insights about the responsiveness of water temperatures to air temperatures and the differing vulnerabilities of streams to thermal change (US EPA 2014).

Air temperature measurements can also be used in the quality assurance process (e.g. as a quality control measure to help determine whether a water temperature sensor has been dewatered during deployment).

Note: US EPA (2014) provides guidance on robust measurement of streamside air temperature, including information on sensor installation and construction of suitable solar radiation shields.

Records from a nearby water level station could also be used to indicate if a sensor is out of the water.

Note: In lake and coastal waters, temperature sensors are often coupled with conductivity and pressure in sensor packages known as CTDs (conductivity-temperature-depth sensors).

If collected, complementary measurements shall be:

- identified
- available during data processing, and
- stored indefinitely.

7.2.5 Required calculations

Calculations may be required, as applicable to the site and instrument choice, and the instrument configuration, to convert raw sensor signal to measurement units (see section 3.3.2).

Calculations may be performed by the instrument, data logger, data collection system (e.g. telemetry) or during data processing.

Note: Data obtained from these calculations are not synthetic because they are directly calculated using other measurements as part of the method of measuring water temperature.

7.2.6 On-board processing (at site)

Modern data loggers are capable of more than storing data from sensors. They can also apply programmes and perform some processing of the data, for storage or for output to other devices.

On-board processing may be used:

- for quality control
- to convert raw signal to measurement units, or
- to create useful derived data, e.g. sub-interval averages, medians, and standard deviations.

All algorithms applied must be documented, tested, and controlled.

The definition of original time-series data must reflect any on-board processing and procedures for tracking the changes from raw data must be followed (see section 7.6.3).

7.2.7 Site visit records (visit metadata)

Record of every site visit shall be made and retained indefinitely as original data.

A site visit record shall include:

- the site identifier (i.e. name and/or number)
- the actual date and time of the visit (in NZST), and
- the name of the observer(s).

A site visit record may also include one or more of the following:

- the verification record(s) (see section 7.5.6)
- results of the monitoring platform, equipment and/or site inspections
- manual observations and measurements
- notes about maintenance performed (see section 6.3)
- details of software and/or configuration changes to instruments and/or the data logger (see section 8.3)

- status of power supply and communications
- general remarks about the site, station and/or activities, and
- photographs and/or video of the site environs, installation and/or instrumentation, as applicable.

A checklist for a site visit form is provided in Annex D.

7.3 Sample collection

This section is not relevant to the measurement of continuous water temperature and has been deliberately omitted.

7.4 Laboratory processing

This section is not relevant to the measurement of continuous water temperature and has been deliberately omitted.

7.5 Verification

7.5.1 Purpose

Verification assesses the performance of the installation and measurement system as a whole, to alert to possible sensor issues (e.g. drift), equipment problems (e.g. power supply), fouling, or physical damage or displacement that compromises the accuracy or prevents the collection of water temperature and any complementary measurements.

7.5.2 Factors to consider

The extent and impact of possible error and bias in water temperature data can depend on:

- the nature and resilience of the installation
- the season, e.g. summer weed growth
- whether data can be checked remotely, e.g. daily telemetry checks
- elapsed time between site visits
- occurrence of potentially damaging events, e.g. storms, floods, recreation events, and
- the presence of backup instruments.

7.5.3 Frequency

Resourcing must be adequate under normal circumstances to enable all in-situ instruments to be verified (and serviced) at intervals sufficient to ensure that the data collected are free of error and bias.

Visit monitoring sites according to the need for:

- instrument checks and calibration
- clearing of biological growth on and around the in-situ sensor and any associated structures
- observation of changes to the monitoring environment, e.g. riparian shading, weed growth, or bed movement
- maintenance of power supplies, communications, and access
- data recovery, and
- other servicing necessary to:
  - ensure complete data collection, and
  - keep the site in good operational order.

For QC 600 under this Standard, as a minimum, the logged water temperature values shall be verified:

- immediately following sensor deployment
- at least every 90 days during the period of deployment, and
- immediately prior to replacement or retrieval at the end of any monitoring period.

As best practice, in-situ sensor verification checks should be carried out at least every 60 days over the warmer months (e.g. December to March) because sensor operation during this period is critical for assessing thermal stress on aquatic ecosystems (e.g. summer low flows in rivers).

7.5.4 Method

An in-situ temperature sensor verification check shall be made using an independent reference temperature sensor that has passed the validation requirements set out in section 5.3.

A verification check must be made before conducting any in-situ sensor cleaning or other on-site maintenance. Repeat the verification check following cleaning and/or maintenance to confirm the in-situ sensor is operating to specification before leaving the site.

Take an instantaneous water temperature measurement with the reference sensor as close as possible to the in-situ sensor, allowing sufficient time for the reference sensor to stabilise. Once stable, read and record the reference measurement as close as possible to the time an in-situ sensor's measurement is being logged, but before noting the logged in-situ value to avoid potential confirmation bias.

Note: If the logger is capable of updating and displaying the current measured value at any time within a recording interval, verification can be carried out at any time. This is especially useful when data is noisy or if the logger only displays a value without an associated time.

Any relevant complementary variables should be measured when verifying the in-situ temperature data.

7.5.5 Assessment

Calculate the difference between the water temperature value from the reference sensor and the corresponding simultaneous value logged from the in-situ sensor.

7.5.5.1 Acceptance criteria

The verification tolerance for water temperature measurements is no more than ±0.5°C.

Note: Verification tolerance equates to observation accuracy in NEMS Water Temperature v2.0 and, when combined with a reference sensor accuracy of ±0.3°C, equates to an observation tolerance of ±0.8°C relative to the traceable reference sensor.

If differences are outside the verification tolerance, verification has failed, and the continuous data collected since the last verification and up to the date and time of the current verification cannot achieve QC 600 under this Standard.

The magnitude of the disagreement determines whether the maximum possible initial quality code for the in-situ data collected prior to the check is:

- QC 500 (greater than ±0.5°C but no more than ±0.8°C)
- QC 400 (greater than ±0.8°C but no more than ±1.0°C), or
- QC 200 (greater than ±1.0°C).

For example:

When the reference value is 21.4°C, any simultaneous logged in-situ sensor value within 20.9°C and 21.9°C is deemed to be within verification tolerance and has "passed" the check. A logged value less than 20.9°C or greater than 21.9°C is outside the tolerance, verification has failed, and the in-situ data collected prior cannot achieve QC 600. For this example, the simultaneous logged value can be any value from 20.4°C to 22.4°C before the initial quality code must be no higher than QC 200.

If the in-situ sensor fails verification, troubleshooting steps must be taken. If trouble shooting fails, the sensor must be replaced. A faulty sensor should be returned to the manufacturer for repair or replacement.

Note: Troubleshooting may, for example, include a second verification using a different reference sensor. QC 200 is a provisional code only and, as per Annex A, any data assigned an initial quality code of QC 200 need to be further evaluated in accordance with the NEMS Data Processing. *Data processing will determine whether the quality code can be elevated (e.g. to QC 400) or whether the data should instead be deleted and the affected time period coded as QC 100 – Missing Record.*

7.5.6 Required records

A record of the verification history shall be maintained and accessible. This shall include:

- site and variable identifiers
- sensor serial number
- name of the person(s) performing the verification

- date and time of the verification
- apparent date and time on the logger(s)
- conditions at the time of the verification (weather and reach environs)
- method and reference(s) used
- reference values and their corresponding logged values, and
- reference values (with uncertainties) and their corresponding logged values and any complementary measurements that are not logged
- results of visual inspections, and
- verification check outcomes (e.g. instrument serviceable, repaired, or for disposal).

Incorporate the verification record into its associated (parent) site visit record (see section 7.2.8).

The date and outcome of all verification checks, including a brief description of the nature of any failure, shall be noted in the time-series metadata by way of a filed comment (see section 9.5).

7.6 Data retrieval

The retrieval of water temperature data varies according to the type of recorder used and the urgency of acquiring the data. Many permanent water temperature sensor installations are collected through various telemetry systems, such as over radio, cell phone, internet connections, and satellite systems. Most other applications require data to be retrieved manually.

7.6.1 Telemetered systems

Telemetry is a means of communication with a remote field station for retrieval of data from the station data logger back to a base or office system.

It is good field practice to routinely, manually download logged water temperature (and any associated logged complementary) data from telemetered sites (see section 7.6.2).

7.6.2 Manual downloads

Manual download of data may occur:

- directly to a mobile device or laptop computer (either at the site or back in the office post-sensor retrieval), or
- by extracting a data card from the data logger and downloading from the card to a computer.

Data download may occur at the site or, in the case of short-term sensor deployments, back in the office post-deployment.

Downloaded data should be protected from loss or damage, including while in transit.

7.6.3 Original data

Original time-series data are defined as non-verified in the NEMS *National Quality Code Schema* until processed under the NEMS *Data Processing*. As such, original time-series data must be preserved indefinitely in case data processing errors are found in future.

The NEMS *Data Processing* requires that any modifications to raw measured values are controlled and fully traceable. In practice, for pre-processing performed on-board the data logger, or by the telemetry system, or a smart data importer, this means that:

- raw measured values must also be logged, collected, and retained indefinitely (see section 10.1.3), or
- sufficient documentation of the quality control actions and pre-processing is maintained and retained indefinitely so that any changes to data from raw measured values can be reversed in future, should the need arise.

For more information, refer to the 'original data' sections of the NEMS *Data Processing*.

7.7 Quality checks of incoming data

Checks of incoming data provide early detection of faults and failures, prior to formal data processing. Aspects to be checked include, but are not limited to:

- timeliness
- completeness (gaps and overwrites)
- transfer or transmission errors
- status and diagnostic data when available, and
- reconciliation of forms and paper records with data received and stored.

For sites equipped with telemetry, sensor function, battery/power and data download should be checked daily.

7.7.1 Telemetered systems

A telemetry system offers the opportunity to remotely check many functions of a water temperature monitoring station. It is possible to detect very quickly:

- instrument failures
- electrical problems, and
- when a sensor may be buried or out of the water.

The system should be used to its maximum capabilities to:

- avoid or reduce missing record (by prompting site visits as needed), and
- minimise expensive return trips to a site to replace faulty equipment (by identifying the fault before departing).

7.7.2 Manual downloads

Where possible, check manually downloaded data before departing the site.

7.7.3 Missing records

The goal is no missing record, particularly over the summer months where thermal stress on aquatic life is greatest. In practice, this can be difficult to achieve.

Having a backup sensor and, where needed, a backup logger, at a station can reduce the possibility of missing record.

Note: Flow recorder stations are often, or could easily be, fitted with a pressure transducer that can also measure water temperature. This may provide a back-up data record if a nearby primary in-situ sensor fails, or at least a source of data to support infilling of gaps in the record of the primary sensor during data processing.

Use of secondary (backup) sensor record does not count toward the missing record total, provided the backup sensor's performance has been validated and is reliable.

Data subsequently removed from the record because the data are faulty, and synthetic data infill (see NEMS *Data Processing*), do count toward the missing record total.

7.7.4 Required records

Data arriving at the office shall be tracked to avoid gaps, conflicts, corruption, and unnecessary duplication.

- Use an incoming data register, or similar, for manual downloads.
- Telemetry systems track data collection automatically and should be configured to log and/or alert if a problem is encountered.

Records of the quality checks shall be maintained and be available when the data are processed (see NEMS *Data Processing*).

8 Quality assurance

In this section

This section outlines quality assurance tools intended to prevent problems occurring, and guidance for method changes that may disrupt data stationarity.

8.1 Quality assurance tools

8.1.1 Field and office manual

A standard operating procedure (SOP) or equivalent shall be developed by the monitoring agency to support implementation of continuous temperature monitoring in accordance with this Standard.

8.1.2 Staff training/certification

Staff carrying out deployment, operation and maintenance of continuous water temperature sensors shall be conversant with the requirements of the SOP and competent to perform the tasks required.

8.1.3 Station inspection

For long-term (e.g. multi-year) or permanent deployments, a check of the integrity of all structures, and an inspection of the water temperature sensor and ancillary equipment should be carried out at least once every 12 months.

8.1.4 Field site audit

For permanent deployments, the monitoring agency may wish to engage a suitably experienced and independent person to check the integrity of the sensor deployment and/or observe sensor maintenance and verification activities being performed.

Note: An independent site audit is not a requirement of this Standard. However, depending on the monitoring purpose, site constraints and/or the monitoring agency's SOP requirements, this may be a useful exercise.

8.1.5 Laboratory checks and certification

Only a suitably accredited laboratory shall perform certification of the monitoring agency's primary reference thermometers (see section 4.2).

8.2 Managing method changes

Significant change to methods can disrupt stationarity of a continuous water temperature record. Examples include a change of:

- site and/or sensor location
- installation and/or instrumentation type, or
- the Standard(s) or version of a Standard used.

Relocating a site by a few metres can usually be regarded as the same site. The exceptions are groundwater (where a different bore is likely involved), if monitoring is conducted at a fixed depth in lake or other waters, and potentially some tidal margins of rivers.

Creating a new site is recommended if the change of location, irrespective of distance, alters site factors such as the:

- measurement range, and/or
- hydraulic or mixing characteristics.

8.2.1 Co-location

At long-term monitoring sites, if the type of water temperature sensor is to be changed (e.g. from a thermistor to a RTD), it is recommended that the new sensor is co-located with the existing sensor for a period of time that captures the typical range of measurements recorded at the site, and the data obtained be analysed for significant difference between the two records.

The analysis may be:

- statistical with significance determined at the 5% level, or
- a comparison of the frequency distributions of the two sets of data, with significance determined as one or more of the paired deciles differing by more than the combined uncertainty of the two sensors, and/or run statistics indicating a systematic trend in the differences.

Analysis results shall be stored in the Station History and summarised in a filed (i.e. with the time-series) Stationarity Comment (see section 9.5 and Annex H of NEMS *Data Processing*). If the two records are significantly different, the new sensor shall be deemed as a new site and the existing sensor's Station History updated to record its closure.

Note: Stationarity is critical for assessment of temporal trends.

8.3 Required records

Quality assurance records for continuous monitoring of water temperature include the following:

- all completed site or field audits,
- laboratory certification of the primary reference thermometers (see Section 4.5), and

- reference sensor validation and in-situ sensor verification check data (see Section 5.5).

Quality assurance reports may be stored with the Station History or in a suitably configured document management system and must be accessible when required.

Details of every change in method shall be:

- noted in the site visit records at the time of the change
- added to the relevant history (station and/or instrumentation) as soon as possible after the change, and
- summarised in a filed comment (see section 9.5) when the data are processed.
    - Significant change shall also be documented in a Stationarity Comment in the time-series metadata.

Where two sets of data exist due to co-location of new and existing in-situ water temperature sensors, both sets of data shall be retained (see section 10.1.5). The start of the new sensor record shall become the official measurement record.

9 Metadata

In this section

This section identifies the information required to be collected and preserved from the field (so that water temperature data collected can be verified and filed comments compiled) and provides requirements and guidance for assigning initial quality codes to the data.

Note: Final quality codes depend on full verification and possible subsequent modification of the data through the NEMS Data Processing.

9.1 Site details

Site metadata includes the following site details:

- the site identifier (see section 3.4.1)
- all records required from site selection (see section 1.4) and consideration of the selected site's characteristics (see section 2.3)
- the Station History (see section 3.4.2)
- the sensor history (see section 2.9), which includes the records of:
  - calibration (see section 4.5)
  - validation (see section 5.5), and
    verification (see section 7.5)
  - instrument servicing and maintenance (see section 6.3)
- assessment of the maximum quality code for water temperature measurements that the site and station are capable of achieving (see section 9.4).

9.2 Visit details

Visit details are captured and collated into site visit records (see section 7.2.7). Site visit records:

- are original records
- include verification checks if undertaken during the visit, and
- form part of the site metadata.

9.3 Other details

Time-series metadata (see NEMS *Data Processing*) includes:

- data acquisition records (see section 7.7.4)
- quality codes (see section 9.4)

- data processing records and filed comments (see section 9.5), and
- data access agreements and/or waivers.

9.4 Quality coding

All time-series data produced under NEMS shall be quality coded in accordance with the NEMS *National Quality Code Schema*. The overall schema and guidance on its application are presented after Table 4 at the front of this document.

All requirements of Tables 1 and 2 must be met to assign any quality code to continuous water temperature data (i.e. Tables 1 and 2 set out the minimum requirements for water temperature data to be considered as having been "produced under NEMS").

To achieve QC 600, requirements of Tables 1, 2 and 3 must be met.

This version of this Standard introduces quality coding matrices (see Annex A) to help decide an initial quality code for each period of data between verification checks. The matrices provide a framework for resolving between QC 400 and the higher codes.

An initial quality code of QC 400 or higher sets the maximum final quality code attainable for the period of measured data up to the time of the relevant verification check. Data subsequently modified during data processing may have their final quality code reduced from the initial code assigned.

All completed quality coding matrices shall be:

- annotated with the site identifier
- signed and dated by the person completing the assessment
- available when the data are processed (see NEMS *Data Processing*), and
- retained indefinitely as part of the site metadata.

9.4.1 Considerations

In most cases, water temperature data collected as part of long-term continuous monitoring programmes will achieve at least QC 400.

Quality codes lower than QC 400 are assigned directly from the flow chart.

Data obtained from co-located or back-up sensors are not synthetic data and should not be assigned QC 300. Apply the same method and criteria as used for the normal (primary) record to quality code backup data.

Note: Backup data may acquire a different quality code from the usual data source for the same period because of different instrument specifications and/or performance.

9.4.2 Data that do not meet QC 600

Data shall be quality coded QC 0 (non verified) until reviewed and/or verified by a suitably trained and experienced person. QC 0 indicates that the data are in their original form (see section 7.6.3).

Data may be quality coded QC 200 (not assigned a final quality code) if "provisional" but not original, i.e. data that are partially reviewed, verified, and/or processed.

Data processing may elevate an initial quality code in the following situations:

- from QC 0, i.e. original, to partially or fully verified and processed data
- from QC 100, i.e. missing, to infilled with synthetic data, or
- from QC 200, i.e. "provisional", to a final quality code once verification and processing are complete.

9.5 Comments

Comments may be one or more of:

- notes made in the field
- annotation and explanation during data processing, and
- filed comments timestamped and stored with the time-series data.

Field notes and data processing comments may be informal. They are mostly intended for use by the monitoring agency; however, they must be retained indefinitely as original records, and for quality assurance and traceability purposes, respectively.

Filed comments are intended for end users of the data. They have a formal structure and text format. They can include, but are not limited to:

- routine information about the site, station, and data characteristics
- unusual features or events that data users should be aware of
- summarised explanation of methods
- alerts and supporting information related to data quality
- brief explanation of quality control actions, including data editing, and
- aspects not easily quality coded or otherwise quantified in point detail.

Refer to NEMS *Data Processing* for requirements, procedures, guidance, templates, and examples for all aspects of filed comments.

Note: All comments are metadata but not all metadata are comments.

10 Data Management and Preservation

In this section

This section contains requirements and guidance for the management and preservation of water temperature data and metadata from the field, up to and including their storage in the office as original data and records.

Refer to NEMS *Data Processing* for the requirements, procedures, and guidance for processing and editing the time-series data, and final archiving of all data and metadata.

10.1 Original data

In general, original records comprise all information collected unaltered from the field. However, the original time-series data may not be unmodified, as described in section 7.6.3.

10.1.1 Field records

All forms completed in the field are original records and shall be secured and returned to the office in a timely manner. They include:

- site visit records
- verification records, and
- any field audit records.

10.1.2 Photos and video

Photos and video shall be curated to avoid overwhelming storage with unnecessary and/or unidentifiable content. All photos and video retained as metadata shall be:

- date-stamped
- indexed to the site
- informative, and
- named and/or annotated with the orientation and subject when not obvious (e.g. u/s of control, d/s of sensor, etc.).

Note: Audio can be used to 'annotate' video.

10.1.3 Raw data

Raw data may be acquired from primary and/or backup devices as needed (see section 7.6.3). Each raw data time-series shall be kept separate, with its source clearly identified.

10.1.4 Logged data

Any data recorded in different formats must be converted into a format that can be easily used by data-processing systems.

10.1.5 Duplicate data

Duplicate data arises when there are multiple sources of measurements of the same variable at the same site. Examples include:

- data from primary and backup sensors
- telemetered and manually downloaded versions from the same sensor, and
- overlapping data from an old and new location or method, collected concurrently for a period to assess stationarity.

Duplicate data shall be managed to ensure each original time-series is clearly identified and stored to prevent data becoming unintentionally combined, muddled, or corrupted.

If duplicate data are incorporated into a final record the period used and source must be identified in a filed comment (see section 9.5).

10.1.6 Data register(s)

An incoming data register (or similar) tracks manually downloaded data arriving at the office (see section 7.7.4). The register must be available until the data it includes are processed and permanently archived but need not be retained indefinitely.

10.1.7 Metadata

All required metadata (see section 9) must be collated, securely transferred, and stored as described in this Standard.

10.2 Derived data

10.2.1 Statistics

Time series of derived statistics must be:

- clearly identified and labelled to avoid confusion with other data
- kept separate from the measured data
- catalogued in the site and time-series metadata (see NEMS *Data Processing*), and
- used properly and appropriately.

10.2.2 Transformations

Transformations may be applied to:

- raw sensor signal before data are captured as raw water temperature in the required measurement units (see section 7.2.6)
- raw water temperature values prior to transfer to the data processing system as original data (see sections 7.2.6 and 7.6.3), and
- original data during data processing (see NEMS *Data Processing*).

All transformations shall be fully traceable back to the sensor output and summarised in the time-series metadata by way of filed comment(s) (see section 9.5).

10.3 Preservation of data and records

The following data and records shall be permanently stored and retained indefinitely by the recording agency:

- all required site and time-series metadata (see section 9)
- all other original records (see section 10.1)
- the original data, as defined by the recording agency (see section 7.6.3)
- records of changes to raw data as a result of automated quality control and/or pre-processing (see section 7.6.3)
- all other records needed to trace stored time-series data back to the initial sensor output (see section 10.2.2),
- quality assurance records (see section 8.3), and
- complementary data used in the production of the final verified and archived time series (see section 7.2.4).

10.3.1 Electronic

Electronic records required to be retained indefinitely shall be:

- clearly identified
- catalogued
- backed up regularly, and
- retrievable in perpetuity.

Retrievable in perpetuity requires:

- a storage facility that is:
  - known (i.e. whereabouts and custodian)
  - secure, and
  - accessible.
- records be stored in a format that is either:
  - universally readable (e.g. text)
  - migrated as systems change, or

  - stored with the software to open and read them.

10.3.2 Paper records

Paper records required to be retained indefinitely shall be:

- labelled
- indexed, and
- retrievable in perpetuity, i.e. stored in a facility that is:
  - known (i.e. whereabouts and custodian)
  - accessible, and
  - protects the records from damage and/or loss.

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Annex A – Quality Coding Matrices

Quality coding matrices determine an initial quality code for the data based on site factors and field visit actions, observations, and verification checks. As such, these matrices are best completed in the field.

If the initial quality code is QC 400 or above, it is then the maximum achievable final quality code for the data. The final quality code may subsequently be lowered from the maximum achievable by further data verification and subsequent actions during data processing, which are the subject of NEMS *Data Processing.*

For any quality code to be assigned, including QC 0, the requirements of Tables 1 and 2 of the Standard must also be met.

Use of the matrices follows the concept of hierarchy in the NEMS *National Quality Code Schema.* Tick one of the boxes in every row applicable to the type of site being assessed. Where different site types have different criteria, strikethrough those that do not apply. For each applicable row in each matrix:

- Start with the QC 600 column and if the performance threshold is achieved, put a tick.
- If not QC 600, then consider the QC 400 column:
  - If the QC 400 performance description applies, put a tick.
  - If performance is between the QC 600 and QC 400 thresholds, or there is no QC 400 performance description, tick QC 500.
  - If performance is below (poorer than) the lower bound of a QC 400 performance band, tick QC 200.

    Note: QC 200 may not be available if there is no sensible concept of "poorer than" the relevant QC 400 performance requirement.

  - Action may be required instead, either immediately or subsequently, to resolve the performance issue and/or recheck.

The initial quality code to be assigned to the data is the lowest of all the boxes ticked.

- Initial quality code cannot be higher than QC 500 if any one QC 600 performance threshold is not achieved, by definition of Table 3 of the Standard.
- Data are considered to be of compromised or poor quality if any one QC 400 performance description applies.
- QC 200 indicates data quality is unknown until the affected data are processed and fully verified. Data processing may elevate or reduce an initial quality code of QC 200, depending on additional tests, other available evidence, and subsequent editing actions.

Note: Original data may retain quality code QC 0 until they are altered or fully verified and processed. Initial data assigned QC 200 that are not elevated to QC 400 or higher as a result of data processing should be deleted.

Site matrix

Criteria	QC 600	QC 500	QC 400	QC 200
Site selection (1.3.2 & 3.3.3)	Representative of target characteristics and/or location being monitored. ☐	☐	Poorly representative. ☐	☐
	Not influenced by radiant heat sources or sinks. ☐		Influenced by radiant heat source or sink. ☐	
External data logger (2.4.2)	Retains required accuracy, resolution and recording interval required for QC 600.			☐ *Degree of compromise and further effect on DO quality code to be assessed during data processing.*
Sensor accuracy (2.2.1.1)	±0.5°C or better. ☐		Poorer than ±0.5°C. ☐	
Rivers and lakes				
Recording interval (7.2.2)	15 minutes ☐	☐	Greater than 30 but no more than 60 minutes. ☐	☐
Tidal river mouths and other estuaries				
Recording interval (7.2.2)	5 minutes ☐	☐	Greater than 10 but no more than 20 minutes. ☐	☐

Visit matrix

Criteria	QC 600	QC 500	QC 400	QC 200
Sensor operation (6.2)	Sensor not obstructed, buried, exposed to the air, disturbed or damaged.			*Extent of obstruction, burial, exposure, etc. and further effect on quality code to be assessed during data processing.*
Verification timing/frequency (7.5.3)	On sensor deployment, replacement, or retrieval AND before and after sensor cleaning AND otherwise within 90 days of the last check.		Between 120 and 180 days of last verification check.	
Verification – reference reading (5.3)	Reference sensor passed validationas required (against certified primary reference in last 12 months).			Reference reading is unreliable *Further effect on quality code to be assessed during data processing.*
Verification – logged data (7.5.5.2)	Logged value differs from reference sensor reading by no more than ±0.5°C.		Difference between logged value and reference sensor reading is between ±0.8°C and ±1.0°C.	
Rivers, groundwater, lakes and open coast				
Clock drift (7.2.3.1)	Less than ±90 s over 30 days, if any.		Greater than ±150 s and up to ±300 s (5 minutes) over 30 days.	
Tidal river mouths and other estuaries				
Clock drift (7.2.3.1)	Less than ±90 s over 30 days, if any.		Greater than ±120 s and up to ±180 s (3 minutes) over 30 days.	

Initial quality code assigned from both matrices Select the lowest quality code ticked across all boxes.	

Annex B – Sensor Deployment Field Form Checklist

The details below are intended solely to act as a checklist of the key fields for documentation of initial sensor deployments. Use of electronic field forms (e.g. in ArcGIS Survey123) is recommended.

- Station number
- Waterbody name
- Site name
- GPS coordinates
- Site altitude
- Deployment date and time (NZST)
- Field personnel
- In-situ temperature sensor details – make and model, serial number, measurement range, pre-deployment validation performed (Y/N)
- Sensor details for any complementary measurements
- Logger details (where applicable) – make and model, serial number, programme name and version
- Comms details
- Type of power supply, and voltage at deployment
- Configuration details – recording interval, start time
- Installation technique
- Description of location (e.g. type of structure sensor attached to, type of habitat installed in (e.g. run) and map
- Site photos
- Post-installation sensor verification details
  - reference sensor make, model and ID
  - date and time (in NZST)
  - reference temperature value (°C)
  - logged temperature value (°C)
  - difference between reference and logged values (°C)

Annex C – Validating a Reference Sensor

Validation of a reference sensor requires the use of a water bath and two traceable primary reference thermometers of certified accuracy. Traceable reference thermometers shall never be used in the field.

1. Identify a minimum of five temperature bands at which the reference sensor(s) will be validated in accordance with Table 1 in section 5.3.2.
2. Establish a water bath at the first temperature band and add the reference sensor(s) to the water bath.
3. Position the reference sensor(s) and wait at least 5 minutes for readings to stabilise.

   Note: Ensure the reference sensor(s) are properly immersed and positioned so that their displays can be read. Periodically stir the water.
4. Compare the temperature reading of the reference sensor(s) and that of each of the two traceable reference thermometers.

   Note: Without removing from the water bath, read the reference sensor(s) to the nearest 0.1°C and the traceable reference thermometers to at least 0.1°C.
5. Repeat steps 2 to 4 for each temperature band identified under step 1.

Validation passes if the reference sensor is within ±0.3°C of the mean temperature value of the two traceable reference thermometers across all validation points.

A reference sensor that fails validation shall not be used.

Annex D – Site Visit Form Checklist

The details below provide a checklist of key fields for documenting site visits and are not necessarily listed in the exact order that some fields may be completed. Additional fields will also be needed where a second in-situ sensor is installed or a second reference sensor is used, and for checks of supplementary sensors. Use of electronic site visit forms (e.g. in ArcGIS Survey123) is recommended.

- Station number
- Waterbody name
- Site name
- Date
- Site arrival and departure times (NZST)
- Field personnel
- Sensor condition check (prior to any remedial action)
  - Any signs of physical damage, vandalism or disturbance? Yes *(describe)* or No
  - Is the temperature sensor out of the water? Yes *(describe)* or No
  - Is the temperature sensor buried or partially buried in sediment? Yes *(describe)* or No
  - Is there evidence of sensor fouling (e.g. from algae, debris, vegetation, rubbish)? Yes *(describe)* or No
- Verification check (prior to any sensor cleaning or repositioning)
  - Reference sensor ID
  - Reference sensor validated today? Yes or No *(details)*
  - Time of check (NZST)
  - Logged temperature value (°C) and logger time (NZST)
  - Reference sensor temperature value (°C) and reference time (NZST)
  - Logged and reference sensor temperature values within verification tolerance?
    ☐ Yes – passed
    ☐ No – failed (recheck (validate/calibrate) and/or replace in-situ sensor)
  - Sensor removed for cleaning/inspection (e.g. after fouling)?
    ☐ Yes (repeat verification check)
    ☐ No
  - Sensor repositioned (e.g. after burial or exposure to air)?
    ☐ Yes (repeat verification check)
    ☐ No
  - Battery check – voltage, replaced Yes or No
  - Data offload – Yes or No
- Summary of any repairs and fixes made
  - photos/videos taken – Yes or No
- New/altered site hazards
- Other notes