National Environmental Monitoring Standard

Water Temperature

Measurement, Processing and Archiving of Water Temperature Data

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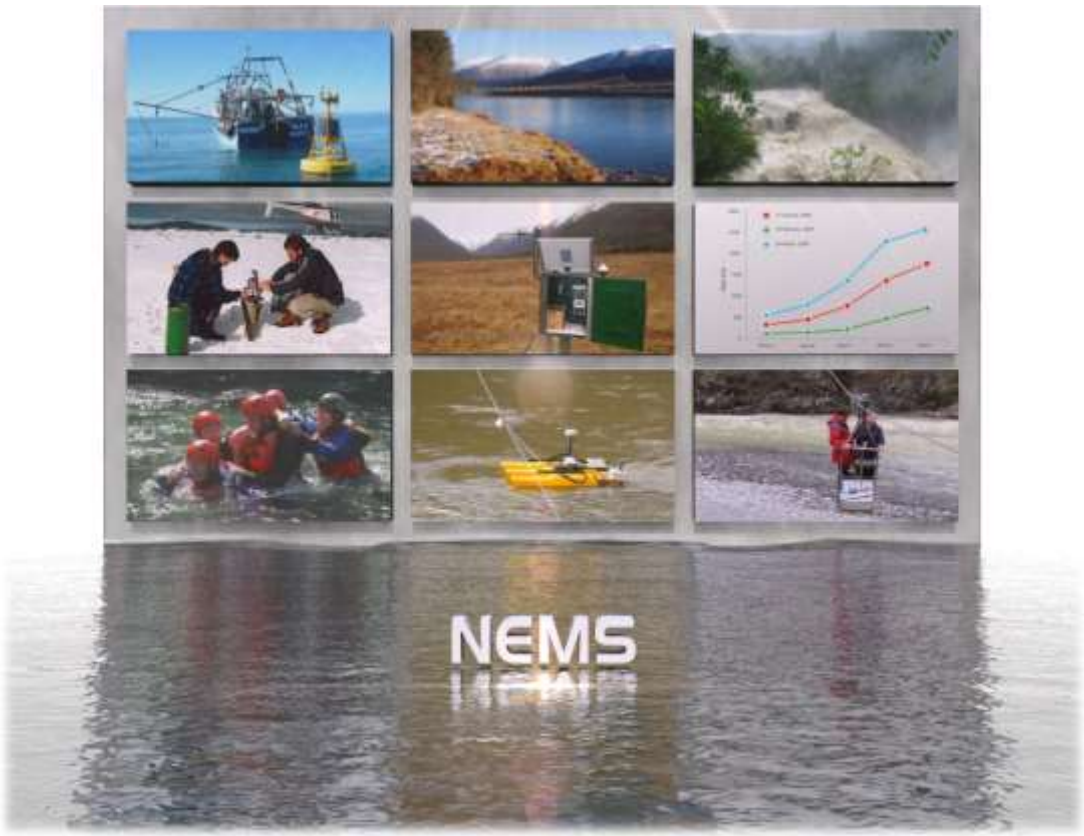

The National Environmental Monitoring Standards

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

Implementation

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

Limitations

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

The information contained in these NEMS documents relies upon material and data derived from a number of third-party sources.

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Development

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

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

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

The development of this Standard involved consultation with regional and unitary councils across New Zealand, industry representatives and the National Institute for Water and Atmospheric Research Ltd (NIWA). These agencies are responsible for the majority of hydrological and continuous environmental-related measurements within New Zealand. It is recommended that these Standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately to facilitate data sharing. The degree of rigour with which the Standards and associated best practice may be applied will depend on the quality of data sought.

This document has been prepared by Jochen Schmidt of NIWA, with workgroup members Chris Jenkins of Environment Southland and David Brown of Horizons Regional Council. The input of NEMS members into the development of this document is gratefully acknowledged; in particular, the review undertaken by the NEMS Steering Group.

Funding

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- Otago Regional Council
- Taranaki Regional Council
- Tasman District Council
- West Coast Regional Council
- Waikato Regional Council

Review

The NEMS Steering Group completed a review of this document in April 2017, and will be reviewed thereafter once every two years.

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Terms, Definitions and Symbols

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

Normative References

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

- NEMS *Glossary*
- NEMS *Quality Code Schema*

About this Standard

Introduction

Water temperature record often gives a measure of aquatic ecosystem health because it measures an important quality of the life-supporting capacity of natural waters. It is not only important to swimmers and fishers, but also to industry, fish and algae.

Water temperature is subject to many influences. These include wastewater discharges, plant (including algae) growth and respiration, and urban runoff. Water temperature data can provide information about organic inputs to water bodies and their capacity to cope with them. Water temperature is a key water quality descriptor that is included in most monitoring programmes. Many other water quality parameters, e.g. dissolved oxygen, pH, salinity and many nutrient tests, are affected by water temperature. Each monitoring situation provides its own challenges and it is important that the measured data is fit for purpose. Key to planning, maintaining and recording temperature measurement is the understanding of and catering for stationarity.

Objective

The objective of this Standard is to ensure water temperature is gathered, processed and archived consistently over time and across New Zealand and is suitable for 'at site' and comparative analysis.

Scope

The scope of the Standard covers all processes associated with:

- site selection
- deployment
- the acquisition of water temperature data from permanently installed sensors or instantaneous (ad hoc) measurements
- data processing, and
- quality assurance (QA) that is undertaken prior to archiving the data.

Exclusions

The Standard does not address industrial applications.

The Standard – Water Temperature

For data to meet the Standard, the following shall be achieved:

Sensor Accuracy	Water temperature	± 0.5°C
Stationarity	Stationarity of record shall be maintained.	

Requirements

As a means of achieving the Standard (QC 600), the following requirements apply:

Units of Measurement		Express units in degrees Celsius
Resolution		0.1°C
Timing of Measurements	Maximum recording interval *Estuarine*	5 minutes
	Maximum recording interval *Rivers, ocean, groundwater and lakes*	15 minutes
	Measurement	Instantaneous value *No greater than 20 s averaging*
	Resolution	1 second
	Accuracy	± 90 seconds/month
	Time zone	Express time as New Zealand Standard Time (NZST). *Do not use New Zealand Daylight Time (NZDT).*
Validation (In Situ Sensor)	Observation tolerance	0.8°C (sum of sensor accuracy and reference sensor accuracy)
	Frequency	At least once every 2 months
Reference Thermometer (Calibration)	Accuracy	± 0.3°C
	Frequency	Annually
	Method	Water bath using two traceable reference thermometers *See 'Annex B – Calibrating a Reference Thermometer'*

Continued on next page…

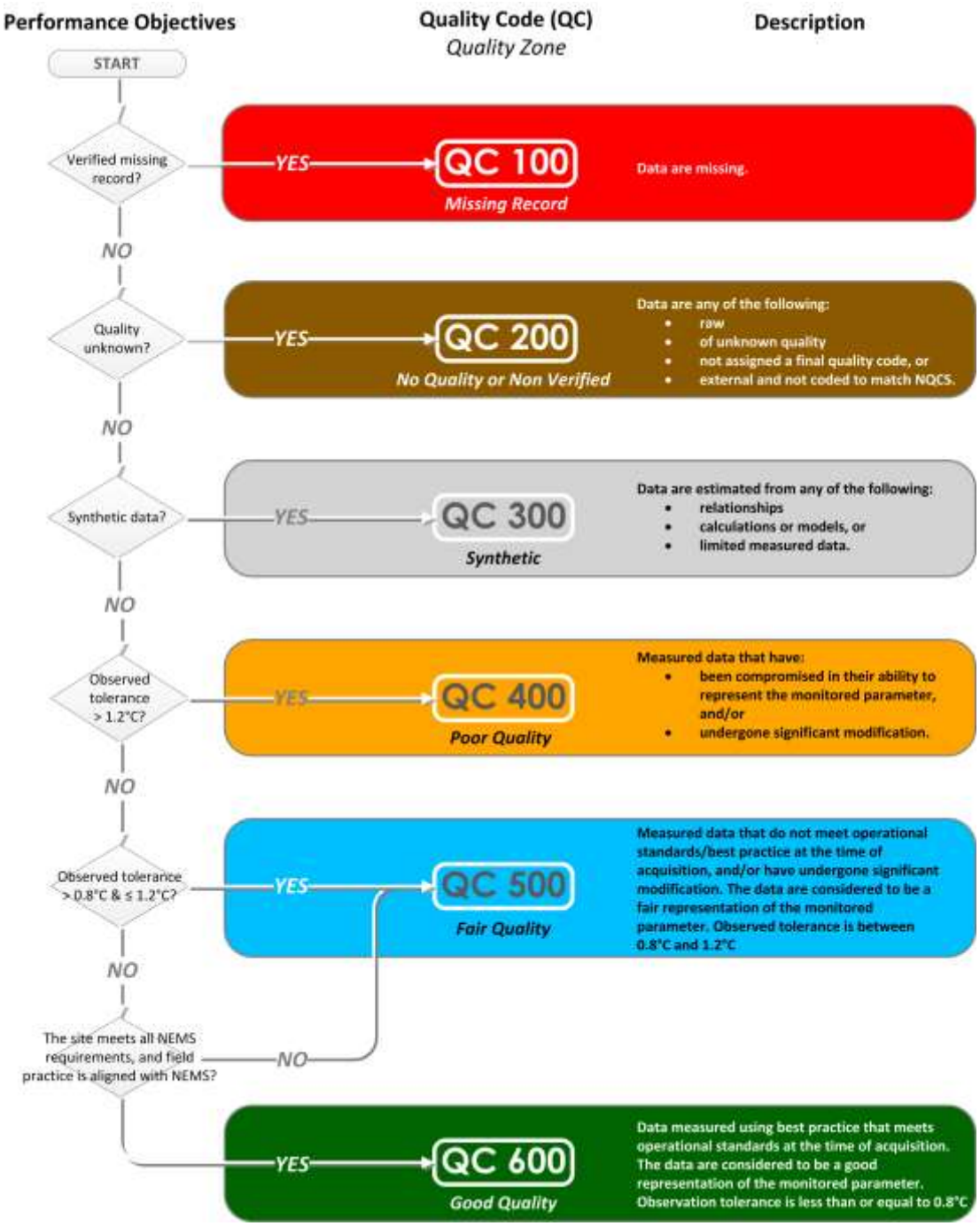
Calibration Traceable Reference Thermometer	Frequency	Once per year
	Method	Certification by an accredited laboratory
Metadata	Scope	Metadata shall be recorded for all measurements.
Quality Assurance		*Quality assurance requirements are under development.*
Processing of Data		All changes shall be documented. All data shall be quality coded as per the Quality Codes flowchart.

The following table summarises best practice and is not required for QC 600:

Validation Methods	Inspection of recording installations and reference sensor usage	Perform sufficient inspections to ensure the data collected are free from error and bias, both in temperature and time.
Archiving	Original and final records	File, archive indefinitely, and back up regularly: • raw and processed records • primary reference data • supplementary measurements • validation checks • calibration results, and • metadata.
Auditing		*Quality assurance requirements are under development.*

Quality Codes – Water Temperature

All data shall be quality coded in accordance with the NEMS *Quality Code Schema*. The schema permits valid comparisons within and across multiple data series. Use the following flowchart to assign quality codes to all water temperature data.



1 Site Selection and Deployment

This section contains information on the site-related variables to be considered when selecting a deployment site and positioning equipment on the selected site.

Selection of a site for field deployment of water temperature equipment depends on the:

- type of environment
- objective of the deployment, and
- equipment type.

1.1 Stationarity of Record

Stationarity of record:

- is maintained when variability of the parameter being measured is only caused by the natural processes associated with the parameter, and
- ceases when variability is caused or affected by other processes; for example, moving the location of the sensor within the site so that it may not characterise the same water as before.

Without stationarity, a data record cannot be analysed for changes over time (such as climate change). While the accuracy of collection processes may change, it is critical that the methods and instruments (both primary instrumentation and those for measuring supplemental data) used to continuously record water temperature remain without bias over the lifetime of the record. For example, if a water temperature sensor in the field is not calibrated against a reference thermometer, the measurements may give a false impression about trends in water temperature.

An external reference shall always be used, against which the continuous data can be checked. In the case of water temperature, the external reference is another device that has been calibrated or validated under ideal conditions as per the requirements outlined in this Standard.

1.2 Environmental Controls

Environmental and practical limitations, and equipment suitability shall be considered when selecting a site for:

- installing a water temperature sensor, or
- conducting water temperature instantaneous measurements.
  Note: Instantaneous measurments are used to optimise the accuracy of water temperature data.

1.2.1 Measurement Objectives

Measurement objectives shall be determined based on the:

- water body of interest to be observed, and
  For example, lake, river or aquifer.
- target characteristics (of the water body) to be measured.
  For example, average water body temperature, and vertical temperature profile.

1.2.2 Sensor Sites – General

1.2.2.1 Representativeness

Sensor sites shall be selected by considering the representativeness of the sample in the context of the:

- water body, and
- target characteristics.

1.2.2.2 Record

A record documenting the site-selection process and evaluation of the below considerations shall be kept.

1.2.2.3 Placement Criteria

When selecting a site, the sensor shall:

- be placed to achieve a representative sample of the target characteristic within the water body, and
- always be in contact with the water to be measured.

1.2.2.4 Sites to Avoid

Where practicable, the sensor shall not be placed where it will be influenced by the following factors:

- heat sinks and sources; for example, geothermal regions or industrial discharge
- water inflows or outflows
- vegetation (seasonal dynamics)
- human activities, or
- artificial structures.

Where these factors influence the sensor, the effects shall be measured as part of the target characteristic.

1.2.3 Sensor Sites – River Environments

When selecting a river site:

- the sensor shall always be submerged
- water mixing shall be adequate to achieve an unbiased measurement in the context of the water body and target characteristic, and
- substrate dynamics and bed mobility shall not influence the measurement.

Where relevant, the following conditions shall be considered:

- seasonality of flow
  For example, ephemeral reaches.
- tidal range, and
- floods.

1.2.4 Sensor Sites – Estuarine Environments

Where relevant, the following conditions shall be considered:

- tidal range
- the saltwater range
- flood inputs, and
- bio fouling.

Where these factors influence the sensor, the effects shall be measured as part of the target characteristics.

1.2.5 Sensor Sites – Groundwater Systems

Consideration shall be given to screen depth and sensor placement for measuring the appropriate aquifer characteristics.

To ensure that the sensor remains submerged, consideration shall be given to groundwater fluctuations.

Consideration shall also be given to potential geothermal impacts and other direct or indirect heat sources that can influence the measurement.

If the sensor is influenced by dryness, the effects shall be measured as part of the target characteristics.

1.2.6 Sensor Sites – Lakes and Lagoons

When selecting a lake site or lagoon, the sensor shall be placed to achieve a representative sample of the water body.

Note: Lakes can consist of many water bodies – horizontally and vertically.

Note: Where relevant, the following conditions shall be considered:

- *horizontal or vertical temperature gradients, or*
- *lake water mixing.*

Where these factors influence the sensor, the effects shall be measured as part of the target characteristics.

1.3 Practical Controls

1.3.1.1 Site Access

Site access shall be secure and safe for the complete period of deployment.

1.3.1.2 Safety

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

1.3.1.3 Hazard Review

On selection of a final site, a hazard review shall be carried out in accordance with relevant guidelines or best practice.

The potential for human activity affecting the measurement, e.g. vandalism, shall be minimised.

2 Equipment Selection and Preparation

This section contains information on selecting equipment in general, and in particular:

- traceable reference thermometers, and
- reference thermometers.

2.1 Equipment Selection Criteria

2.1.1 Sensor

The sensor, regardless of type, e.g. thermistor or resistance temperature detector (RTD), shall not affect the accuracy of the measurement.

2.1.1.1 Resolution

The resolution of all temperature sensors in use shall be at least 0.1°C.

2.1.1.2 Response Characteristics

The response characteristics of the thermometer used shall be as per the manufacturer's specification. The response characteristics shall be used to determine the minimum deployment time.

Note: This will assist with achieving measurement precision. The response characteristic is dependent on temperature.

2.1.2 Used Logger

The logger type (bandwidth of analogue input) shall not affect the accuracy of the measurement.

2.1.3 Transmission Type

The sensor-to-logger data transmission type, e.g. SDI-12 and 4 to 20 mA, shall not affect the measurement.

2.1.4 Thermometer Types

Three types of thermometer are required:

- traceable reference thermometers
- reference thermometers, and
- in situ thermometers.

Traceable Reference Thermometers

Traceable reference thermometers are certified by an accredited laboratory and shall always remain in the laboratory (not for use in the field) as the gold standard.

Reference Thermometers

Reference thermometers are calibrated against traceable reference thermometers and are used for checking in situ sensors or for instantaneous measurements.

In Situ Thermometers

In situ thermometers are used for continuous measurements in the field.

2.2 Traceable Reference Thermometers

2.2.1 Required Quantity

The recording agency shall operate or have access to two (minimum) traceable reference thermometers.

2.2.2 Certification

Only certified traceable reference thermometers shall be used.

The traceable reference thermometers shall be certified by an accredited laboratory once per year (minimum) (IANZ, 2008).

2.2.3 Identification

Traceable reference thermometers shall have a unique identifier.

2.2.4 Calibration History Record

A full formal record of the calibration history shall be permanently archived and accessible (Wilde, 2006).

Traceable reference thermometers shall always remain in the laboratory and shall not be used in the field.

2.3 Reference Thermometers

All thermometers used to perform field checks (reference thermometers) shall be calibrated at least annually against the two traceable reference thermometers. For more information, see Annex B – Calibrating a Reference Thermometer'.

2.3.1 Accuracy for Reference Thermometer Calibration

The accuracy for calibration shall be ± 0.3°C at all calibration points.

If a reference thermometer has failed the calibration at any point (outside ± 0.3°C range), it shall not be used any more.

2.3.2 Temperature Ranges for Thermometer Calibration

All reference thermometers used to perform field checks shall be calibrated for a temperature range consistent with the expected deployment temperature range.

Calibration shall be carried out with at least one value within each of the relevant (within expected range) bands. A sensor shall not be used beyond its calibrated range.

If the validation of the in situ sensor or the spot sampling sensor results in a value that falls outside the calibrated temperature range, the reference thermometer shall be calibrated retrospectively.

The required calibration bands are defined in Table 1 (below).

Table 1 – Defined temperature ranges for thermometer calibration

Range [degrees Celsius]	Notes
–5°C (for cold regions) to 0˚C	Required if in expected temperature range
0˚C to 5˚C	Compulsory
5˚C to 10˚C	Compulsory
10˚C to 15˚C	Compulsory
15˚C to 20˚C	Compulsory
20˚C to 25˚C	Compulsory
25˚C to 30˚C	Required if in expected temperature range
30˚C to 40˚C	Required if in expected temperature range
40˚C to 50˚C	Required if in expected temperature range
50˚C to 60˚C	Required if in expected temperature range
60˚C to 70˚C	Required if in expected temperature range
70˚C to 100˚C	Required if in expected temperature range

2.3.3 Stabilisation

Calibration shall be carried out in a laboratory water bath with at least 5 minutes temperature stabilisation for each measurement.

2.3.4 Calibration History

All reference thermometers used to perform field checks shall have a unique identifier.

A full formal record of the calibration history shall be permanently archived and accessible.

3 Data Acquisition

This section focuses on best practice associated with:

- precision and accuracy of measurement, and
- instrument validation and calibration.

3.1 Continuous Measurements

3.1.1 Temporal Logger Resolution

3.1.1.1 Rivers, Groundwater, Ocean and Lakes

Maximum recording interval of the logger shall be at least one reading every 15 minutes for rivers, groundwater, ocean and lakes.

3.1.1.2 Estuarine

Maximum recording interval of the logger shall be at least one reading every 5 minutes for estuarine areas.

3.1.2 Sensor Precision

The precision of all in situ temperature sensors shall be at least 0.1°C.

3.1.3 Observation Accuracy

The accuracy of all in situ temperature sensors shall be at least 0.5°C relative to the traceable reference thermometer.

3.1.4 Observation Tolerance

The observation tolerance of all in situ temperature sensors shall be at least 0.8°C relative to the reference thermometer.

3.2 Instantaneous Measurements

Typical applications of instantaneous temperature measurements are:

- SoE (state of environment) monitoring
- consent monitoring
- fish surveys
- gaugings, and
- pollution response.

3.2.1 Measurement Location and Time

Instantaneous measurements for purposes such as water quality (state of environment reporting) shall be taken at the location and time where the other water quality measurements have been taken wherever these sites have no in situ temperature sensor.

3.2.2 Criteria for Ideal Measurement

For the criteria required for obtaining ideal measurement, see Section 1: 'Site Selection and Deployment'.

3.2.3 Required Sensor

Measurements shall be taken with a reference temperature sensor.

3.3 Validation

In situ temperature sensors shall be checked against a reference thermometer that has current certification. For information on the required calibration process used to achieve certification, see Section 2: 'Equipment Selection and Preparation'.

3.3.1 Validation Frequency

Validation measurements shall be carried out at least once every 2 months.

3.3.2 Proximity to Sensor

Validation measurements shall be taken as near as practicable to the in situ sensor.

3.3.3 Observations

The reference thermometer shall be submerged until temperature readings have stabilised in accordance with the manufacturer's stated sensor response characteristics.

3.3.4 In Situ Sensor Validation Process

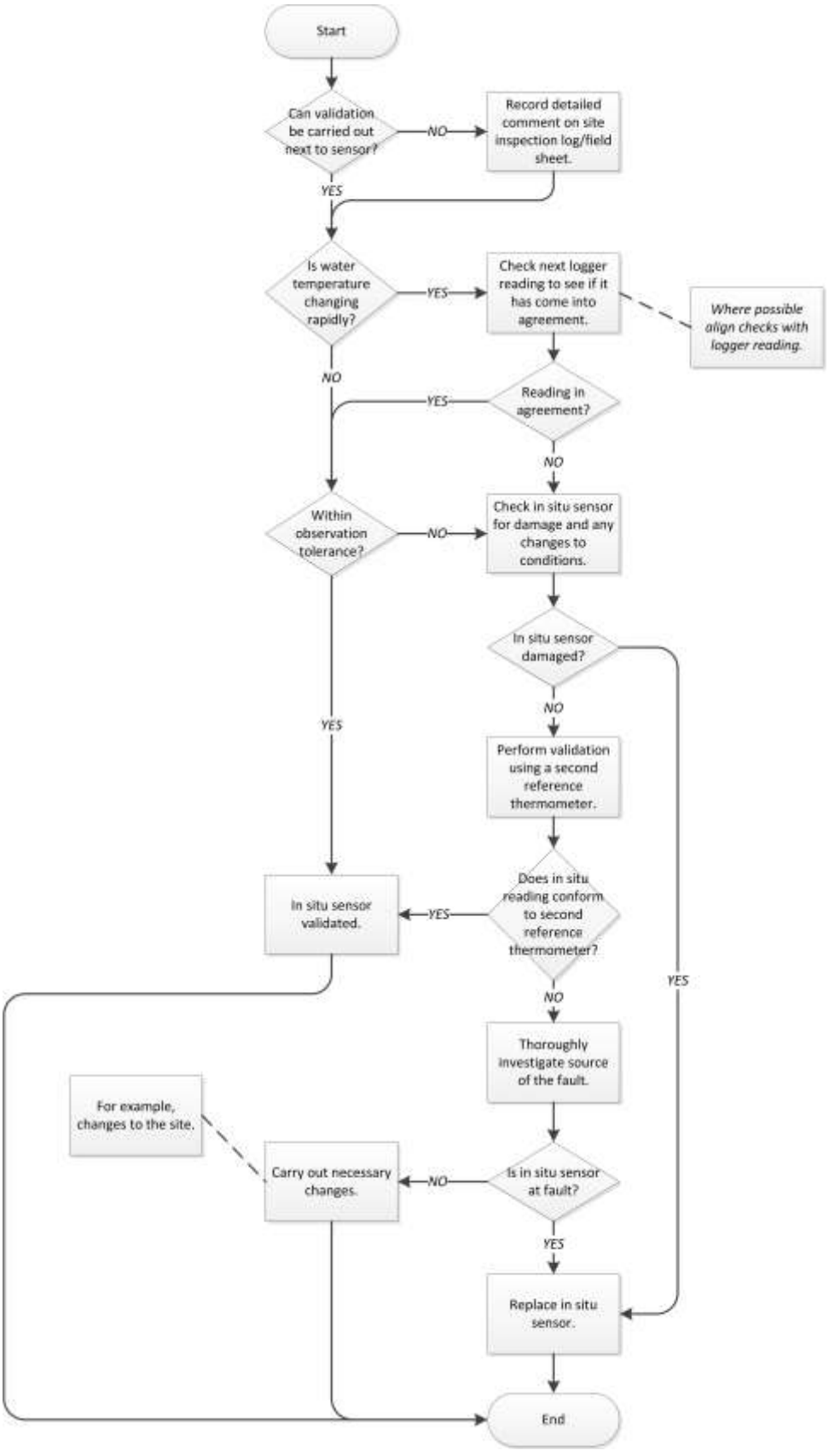


Figure 1 – In situ sensor validation process

4 Data Processing and Preservation

This section contains information on the handling of data from the field, in its original form, to data processing and editing, to final archiving.

4.1 Processing and Archiving

Processing and archiving of water temperature data shall be carried out in accordance with the relevant data management guidelines applied by each agency.

The processes utilised by each agency shall be documented.

4.2 Quality Coding

Water temperature data shall be assigned a quality code. This quality code shall be based on the qualitative and quantitative performance objectives outlined in the Quality Codes flowchart.

4.2.1 Considerations

The following points shall be considered when quality coding data:

- the resolution of the instrumentation at the time of data acquisition
- the instrument calibration status at the time of data acquisition, and
- the occurrence and quality of synthetic record.

4.2.2 Raw Data

Raw temperature data shall be archived.

Corrected data shall be traceable back to its corresponding raw data.

4.2.2.1 Data that Do Not Meet the Standard

Any data collected from an installation that do not meet this Standard shall be assigned quality code QC 500 or less.

4.2.2.2 Missing/Corrected Record

The methodology for filling any missing record or correcting the data shall be clearly recorded in the comment file.

4.2.2.3 Non-Submerged Sensor

In cases where the sensor is out of water and is recording air temperature, the air temperature data shall be deleted from the checked and final data record, and the resulting gap shall be assigned quality code QC 100.

4.2.2.4 Data Not Fit for Purpose

In cases where the sensor records data that are valid but not fit for purpose, e.g. through an event that will affect long-term statistics, appropriate quality codes shall be applied to the data and relevant comments recorded.

4.2.3 Missing Record

Any gaps that occur in a temperature record shall be filled to the best time resolution practical. The maximum time resolution shall be daily.

4.2.3.1 Acceptable Percentage of Missing Record

Note: Robust field procedures and good quality instrumentation should result in no more than 2% missing record occurring in any one site-year of record across an organisation's network. If there is more than 2% missing record occurring at a site over any rolling 12-month period, the underlying cause should be addressed.

4.2.3.2 Filling Missing Record

Where practicable, missing records may be filled by:

- using records from instantaneous measurements taken at the same site
- using records from calibrated and validated backup sensors at the same site
- assuming the linearity of record, or
- correlation with another site.

4.2.4 Data Corrections or Post Processing

Where water temperature data have deviated from the reference probe by a constant value, a linear correction shall be applied to bring the time series in line with the reference.

Before the validity transformation can be confirmed and applied, there shall be as a minimum:

- one year of record, and
- quarterly reference validation checks.

Corrected data shall be assigned a quality code QC 500 or lower.

4.3 Preservation of Record

4.3.1 Performance

The following data shall be archived and retained indefinitely:

- final checked and verified data – whether primary or backup
- unedited raw primary and backup data
- associated metadata, including;
  - data comments
  - site details
  - recording accuracy and resolution
  - site/station inspections
  - equipment calibration history, and
  - any other factors affecting data quality.

All original records shall be retained indefinitely by the recording agency.

Note: The original raw data may be required at a later date, should the archive data be:

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

4.3.2 Data Archiving

The archiving procedures, policies and systems of the archiving body shall consider:

- future data format changes
- off-site duplication of records, and
- disaster recovery.

4.3.3 Metadata – Site Details

Adequate mechanisms shall be put in place to store all relevant site-related metadata with the actual data records including, but not limited to:

- site purpose
- recording agency
- site location
  For example, GPS coordinates, spatial reference system (SRS) and triangulation information, as well as site name and past and present aliases.
- names and/or indices of relevant environmental features
  For example, river, lake or estuary.
- start and end date of site and record
  Recorded using New Zealand Standard Time (NZST).
- related sites and records, and
- reference to the standard used.

4.3.3.1 Metadata – Other Details

Adequate mechanisms shall be put in place to store all non-site-related metadata with the actual data records including, but not limited to:

- sensor details
  Preferably through an agency instrument management system.
- original format details
  For example, chart or digitised format details.
- logger and telemetry details
- calibration records
  Preferably through an agency instrument/asset management system.
- any relevant comments in document vocabularies that future users will understand, and
  For example, terms shall be defined and instrument types referred to (not brands).
- information about:
  - legal requirements
  - confidentiality agreements
  - intellectual property, and
  - any other restrictions related to data access.

4.4 Quality Assurance

All agencies shall implement a standard methodology for data audit and review. This methodology shall:

- ensure standardisation of data sets, and
- enable meaningful analyses and comparison of data:
  - within regions
  - across regions, and
  - nationally.

4.4.1 Audit Cycle

Quality assurance processes shall include an audit of the data:

- at a frequency appropriate to the organisation's and users' needs, or
- as defined by the organisation's quality management systems documentation or documented procedures.

This work shall be undertaken by a suitably qualified and experienced practitioner.

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

4.4.2 Minimum Audit Report Requirements

As a minimum, analyses and information required for an audit report for water temperature records shall cover:

- site and deployment metadata, including catchment (if applicable) and site details
- comments and quality coding attached to the records, and
- data tabulations.

4.4.2.1 Site and Deployment Metadata

The following shall be included in the audit report:

- deployment and site summary
- catchment details summary, and
- a location map.
  Sites shall be identified on the map.

The deployment and site summary shall:

- identify site purpose and any projects and stakeholders related to the record, and
- include information about sensor deployment.
  In particular, include limitations for data use.

The catchment details summary shall:

- identify the catchment or region, and
- include associated:
  - flow
  - water level, and
  - water quality records if available.

The catchment details summary shall also identify, for each water temperature record:

- the period of record covered
- the site name and number
- map reference
- altitude, and
- sensor (and logger) type.

4.4.2.2 Comments and Quality Coding

The following shall be included in the audit report:

- for each record being reviewed, a copy of the filed comments for the total record periods, and
- a copy of the quality codes that have been assigned to audited data.

4.4.2.3 Data Tabulations

For each record, tabulated record statistics that cover the reporting period, such as daily, monthly and annual maximum and minimum temperatures, shall be included in the audit report.

4.4.3 Other Requirements

4.4.3.1 Outputs

Any one of the following report outputs is acceptable:

- a hard copy report
- an electronic report
- an electronic document that only identifies which periods of record have passed audit.

4.4.3.2 Audit Certification

The completed audit shall contain the:

- name and signature of the auditor, and
- the date that the audit was completed.

Annex A – List of Referenced Documents

IANZ (2008). *Technical guide: Working thermometers calibration procedures.* Auckland, New Zealand: International Accreditation New Zealand (IANZ).

Wilde, F. D. (2006). Temperature (ver. 2.0). In *National field manual for the collection of water quality data* (TWRI Book 9, section 6.1). Washington DC: US Department of the Interior and US Geological Survey. Accessed 20 August 2012 at http://pubs.water.usgs.gov/twri9A6/

Annex B – Calibrating a Reference Thermometer

To calibrate a reference thermometer (field thermometer), instrument readings are checked across a range of temperatures against those of a thermometer of certified accuracy (a traceable reference thermometer).

Note: Traceable reference thermometers shall never be used in the field to ensure their integrity for the purpose of laboratory calibration.

To Calibrate a Laboratory Thermometer:

1. **Add the reference thermometer(s) to the water bath.**
2. **Position the sensor(s) and wait for readings to stabilise.**
   Note: Sensors must be properly immersed and so that their scales can be read. Periodically stir the water and allow at least 5 minutes for the thermometer readings to stabilise.
3. **Compare the temperature.**
   Note: Compare the reference thermometer with that of the two traceable reference thermometes..
   Without removing the sensors from the bath, read the test thermometers to the nearest graduation and the reference thermometer to at least 0.1°C.
4. **Take at least five readings for each thermometer.**
   The readings must be taken within the temperature bands as described in table 1 (2.3.2). Compare the thermometer with the mean value of the reference thermometers.

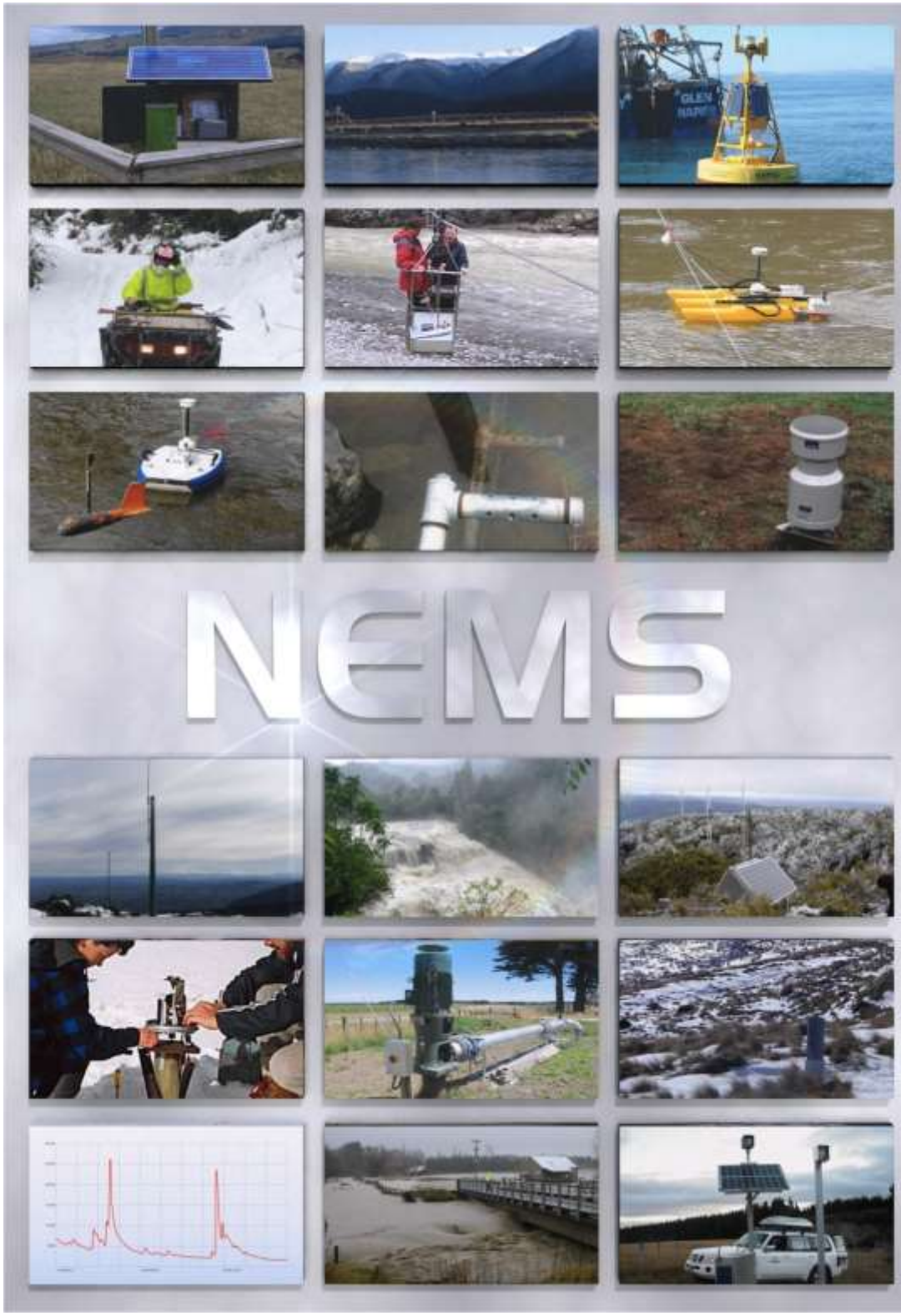
What's Next?

Calibration Passed

If the thermometer passes the test at all calibration points, it can be labelled as a reference thermometer and the calibration documented according to institutional procedures.

Calibration Failed

If the test thermometer is found not to be within ± 0.3°C of the reference thermometer at any point, the test thermometer shall not be used as a reference thermometer.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